GROWTH AND MORTALITY OF TWO GROUPS OF OYSTERS, (*Crassostrea virginica* GMELIN), MAINTAINED IN COOLING WATER AT AN ESTUARINE ELECTRIC POWER GENERATING STATION

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ABSTRACT

Growth and mortality of oysters with high and low levels of *Labyrinthomyxa marina* (L) infection were measured during 1972 in (1) 0.1 ha ponds receiving a continuous flow of heated water from an electric power plant, (2) the power plant intake canal, and (3) the power plant discharge canal. Pond oysters had less cumulative mortality than intake or discharge canal oysters, regardless of *Labyrinthomyxa* infection. Only pond oysters (high-L and low-L) gained in biomass (increasing 171 and 5,953 g or 2 and 25%, respectively) by the end of the study. In the intake canal low-L oysters decreased 6,293 g (27%) in the 10-month period prior to their disappearance while high-L oysters decreased 6,633 g (64%) by the end of the study. Oysters placed in the discharge canal during warm weather died within six weeks. Oysters held in the ponds grew as well or better than oysters from a natural reef in Galveston Bay.

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INTRODUCTION

Electrical power generation in the United States has doubled every 10 years since 1945 and is expected to increase at an even greater rate in each of the next few decades. Most of this electrical power is produced by steam-electric generating stations which are discharging large quantities of heated water into our rivers, lakes and estuaries. Krenkel and Parker (1969) predict that heated discharge water will increase from 50 trillion gallons per year in 1968 to 100 trillion gallons per year in 1980.

Numerous studies have been made to assess the biological effects of heated water at operating power stations but few have included oysters and only one of these took place on the Gulf of Mexico. Grimes (1971) studied trace metal accumulation in oysters collected from intake and discharge canals of the Crystal River steam-electric station located north of Tampa, Florida. Bimonthly collections of live oysters were made along the canal banks at the mouth of the intake canal, near the point of discharge and at the end of the discharge canal. Analyses of oyster tissue revealed that during summer, oysters collected near the point of discharge incurred higher concentrations of zinc (482 ppm) and copper (80 ppm) than did intake oysters (zinc 138 ppm and copper 9 ppm) collected at the same time. Increased concentrations of both zinc and copper in oyster meats were found through summer with peaks reached in October. Grimes says that increased metabolic rates due to elevated temperatures may have been responsible for the increased copper ion concentration found in the discharge canal oysters. He also stated that the zinc concentrations in the oyster may be explained by the fact that zinc ingots were placed on all metal structures in both intake and discharge canals to function as sacrificial metal (to retard electrolysis of other metals).

Roosenburg (1969) studied the effects of heated effluent from a steam-electric generating station on oysters in the Patuxent River, Maryland. Oysters were held in trays (about 210 oysters/tray) at several sites near the power plant. Monthly samples of 25 natural bar and 25 tray oysters were taken to determine oyster condition and heavy metals accumulation in the oysters. Greening and copper accumulation were greatest near the discharge outfall (0.89 mg copper/g dried meat). Oysters further removed from the discharge outfall contained lower concentrations of copper (0.12 mg copper/g dried meat). Copper concentration in oysters was highest in late summer and early fall (0.5 to 1.28 mg copper/g dried meat). The author found an inverse relationship between oyster copper concentration and oyster condition. Adams (1969) mentions an oyster study conducted at Humboldt Bay Nuclear Plant in California. Oysters (species not named) were held in baskets suspended in a warm-water discharge canal. When the oysters were first introduced into the discharge canal, they showed increased shell growth, and an initial debilitation, followed by a recovery period in which their growth exceeded the growth of the same brood year oysters in other parts of the bay. Adams does not explain how debilitation was determined. Spawning was apparently induced in experimental oysters, and natural setting of native oysters (*Ostrea lurida*) was observed.

Maurer and Tinsman (1971) reported on a study of the effect of a thermal effluent on the survival, growth, condition and reproductive behavior of *Crassostrea virginica* in Indian River Bay, Delaware. Young oysters were held at three stations including the intake of a power plant, the effluent site, and a site 2.5 kilometers from the effluent site. Highest mortality, heaviest fouling and lowest wet-meat weights occurred at the effluent site in the summer. Highest shell growth and wet-meat weights occurred at the effluent site in winter. The heated discharge waters also appeared to promote earlier maturation of oyster gonads.

The effects of temperature on oysters have been determined in several laboratory studies. Fingerman and Fairbanks (1957) determined the upper thermal limit for C. virginica and investigated loss of body fluid associated with heat death. They found that Louisiana oysters held at 17‰ salinity and 35°C showed no significant weight loss, but above 41°C appreciable weight loss and heat death occurred. Oysters can be killed by short exposures to high temperature or longer exposures to somewhat lower temperatures. A 29% mortality occurred in oysters subjected to 40°C water for 3 hours while 100% mortality occurred in oysters held in 45°C water for 35 minutes. No temperature preferences for oysters were given. Collier (1953) found that the optimum temperature range for C. virginica on the Gulf Coast is between 15 and 25°C. Quick (1971) in a symposium on the effects of elevated temperature on C. virginica concludes that at salinities of 15‰, a constant temperature of 35°C will not produce substantial deaths but will cause immediate responses such as altered gametogenesis, glycogen decreases and tissue damage. Oysters in good condition and/or in final stages of gametogenesis showed the most reaction to elevated temperatures. Oysters had a lower tolerance for elevated temperatures at salinities near 35‰. Oysters exposed to 15‰ salinity and 35°C showed slight edema and tissue damage. Andrews, Haven and Quayle (1959) found that oysters can be conditioned to endure prolonged situations of low salinity (below 5‰) and moderate temperatures (near 23°C).

Labyrinthomyxa marina (=Democystidium marinum) is an important fungal parasite of the American oyster. This parasite, which is widely distributed along the Gulf and South Atlantic coasts of the United States, has attracted much attention because of its close association with extensive warm-weather mortality of oysters (Mackin, 1953; Ray and Chandler, 1955). According to Ray and Chandler (1955), temperature and salinity appear to be the principal environmental factors controlling the incidence and intensity of L. marina in oysters. They say that Labyrinthomyxa infections and the associated oyster mortality rise during the warm months and decline during the cool ones. They point out that in Louisiana when water temperatures consistently exceed 20°C and salinities exceed about 18‰, the degree of infection and thus oyster mortality rises sharply. Thus it appears that Labyrinthomyxa infected oysters subjected to heated water from a generating station might be killed by an increase in Labyrinthomyxa infection. Quick (1971) found that constant 35°C temperature inhibited L. marina and says that in the field, such inhibitions may occur during highest summer temperatures.

Loosanoff (1958) studied oyster pumping rates in relation to water temperature and found that above 34.1°C, the pumping rate decreased and shell movements were erratic. Percy *et al.* (1971) found that the excised gill, mantle and adductor muscle of *C. virginica* exhibited an increase in oxygen consumption with rising temperature. Both mantle and adductor muscle had respiratory maxima at about 34°C, while gill respiration increased up to 40°C, with the rate of increase falling off considerably above 28°C.

Breese (1971) grew small Pacific oysters (*Crassostrea gigas*) in unheated (12.3°C) and heated (25.3°C) flowing seawater. Over a 5-month period (3 March to 4 August, 1970), a total of 90 spat were subjected to each of the two temperatures for 4-week intervals. Mortality of test oysters was 28% in heated water (25.3°C) and 18% in unheated water (12.3°C). Survivors in heated water averaged 14 times larger in surface area than those at 12.3°C.

Warm-water cultivation of shellfish has been suggested by several people (Gaucher, 1970a, 1970b; Bregman, 1968; Shelbourne, 1970; and Naylor, 1965). Gaucher (1970b) lists five ways biological activity is enhanced by increased temperature: (1) extended feeding activity during cold months; (2) increased food production; (3) more rapid reaeration in the winter time; (4) increased sedimentation; and

(5) enhanced removal of the biological oxygen demand. He does not explain how each way enhances biological activity.

According to Ryther and Bardach (1968) and Bardach et al. (1972), the G. Vanderborgh and Son Oyster Company is utilizing heated effluent from a Long Island Lighting Company generating station to grow young oysters during the winter. Preliminary tests during the summer of 1967 showed that oysters put on exceptional growth in heated water. According to the authors, the following factors may be partially responsible for the growth: (1) the generating station draws its cooling water from a deep, probably nutrient rich, section of the bay which can support a large growth of microscopic algae; (2) the volume of discharge water is such that strong currents pass through the area where the oysters are held; and (3) the water passes through the condenser in stainless steel cooling jackets which are non-toxic to young oysters. The feasibility of raising adult oysters to market size in the heated effluent was to have been investigated in 1968. In early 1973, a letter was written to Mr. Vanderborgh about the 1968 study but no reply has been received.

Personnel at the University of Southampton in Great Britain are using flue gas from an electric generating station as a source of carbon dioxide gas for mass culture of the alga, *Phaeodactylum tricornutum*. The alga in turn is used as food for the American quahog clam, Mercenaria mercenaria, growing in a harbor which receives warmed water from the power station (Gaucher, 1970b).

Numerous investigations into the feasibility of oyster pond culture have been conducted. Lunz (1955) cultivated oysters in 1-acre artificial ponds at the Bears Bluff Laboratory near Charleston, South Carolina. He found at lower salinities, oysters grew faster in the ponds than they did in nearby rivers and creeks. However, during a drought salinities climbed to 25-28‰ and a sudden mortality occurred, probably due to Labyrinthomyxa. Oysters spawned in ponds but set was negligible.

Carriker (1959) investigated the possibility of using Home Pond, a natural, shallow, 21-acre inlet on Gardiners Island, New York, for culture of oysters and quahogs. Both oysters and quahogs at the head of the pond retained large stores of glycogen throughout summer. Growth rate of both bivalves was excellent, probably due to the pond's good water circulation. Carriker concludes that cultivation of oysters in saltwater ponds is feasible.

Shaw (1968) reports on the attempted cultivation of oysters in four 0.25-acre artificial ponds into which water was pumped at a rate of 80 gallons per minute. Generally, the pond oysters grew less rapidly than control oysters in natural ponds.

Elam (1972) reported on studies which attempted to relate water depth, bottom substrate, and oyster position to growth and survival of oysters growing in artificial ponds near Palacios, Texas. Elam concludes that oysters cannot be grown with any dependable success below 2 feet from the surface in his ponds unless water is circulated in the ponds. He does not give any reasons for this conclusion, however, low dissolved oxygen concentrations (0.3 ppm) did occur.

The present study was initiated because few studies have been concerned with the biological effects of heated water from a power station on oysters, especially along the Gulf coast, and because we feel there is a potential for warm-water culture of oysters (C. virginica). Three major objectives of this study were to determine: (1) the effects of heated effluents on growth and mortality of oysters with high and low levels of L. marina infection; (2) the suitability of water passing through the Cedar Bayou generating station for growth of oysters; and (3) the feasibility of oyster pond culture utilizing heated effluents from a generating station.

STUDY AREA AND METHODS

Study Area

This 1-year study (December, 1971 - December, 1972), took place at Houston Lighting and Power Company's Cedar Bayou Generating Station situated at the head of Galveston Bay, Texas (Fig. 1). The Cedar Bayou generating station consisted of two 750-megawatt units (each with a circulating capacity of 786 cubic feet of water per second) with a third unit under construction. Unit No. 1 began circulating heated water in November, 1970, while unit No. 2 began circulating heated water in December, 1971. Periodically during the study, a unit of the generating station had to be shut down for maintenance or repair. Major (at least 3 day) periods in 1972 when at least one unit was shut down were: (1) 10 February to 16 February; (2) 24 February to 28 February; (3) 26 April to 30 April; (4) 11 May to 14 May; (5) 16 July to 19 July; (6) 14 August to 22 August; (7) 21 August to 25 August; (8) 13 September to 15 December; and (9) 19 December to 21 December.

Cooling water for the plant was drawn from the upper portion of Galveston Bay at a site about 3.7 km from the Houston Ship Channel, and from Cedar Bayou above the plant site. Many industrial plants discharge their waste material into the Houston Ship Channel and a

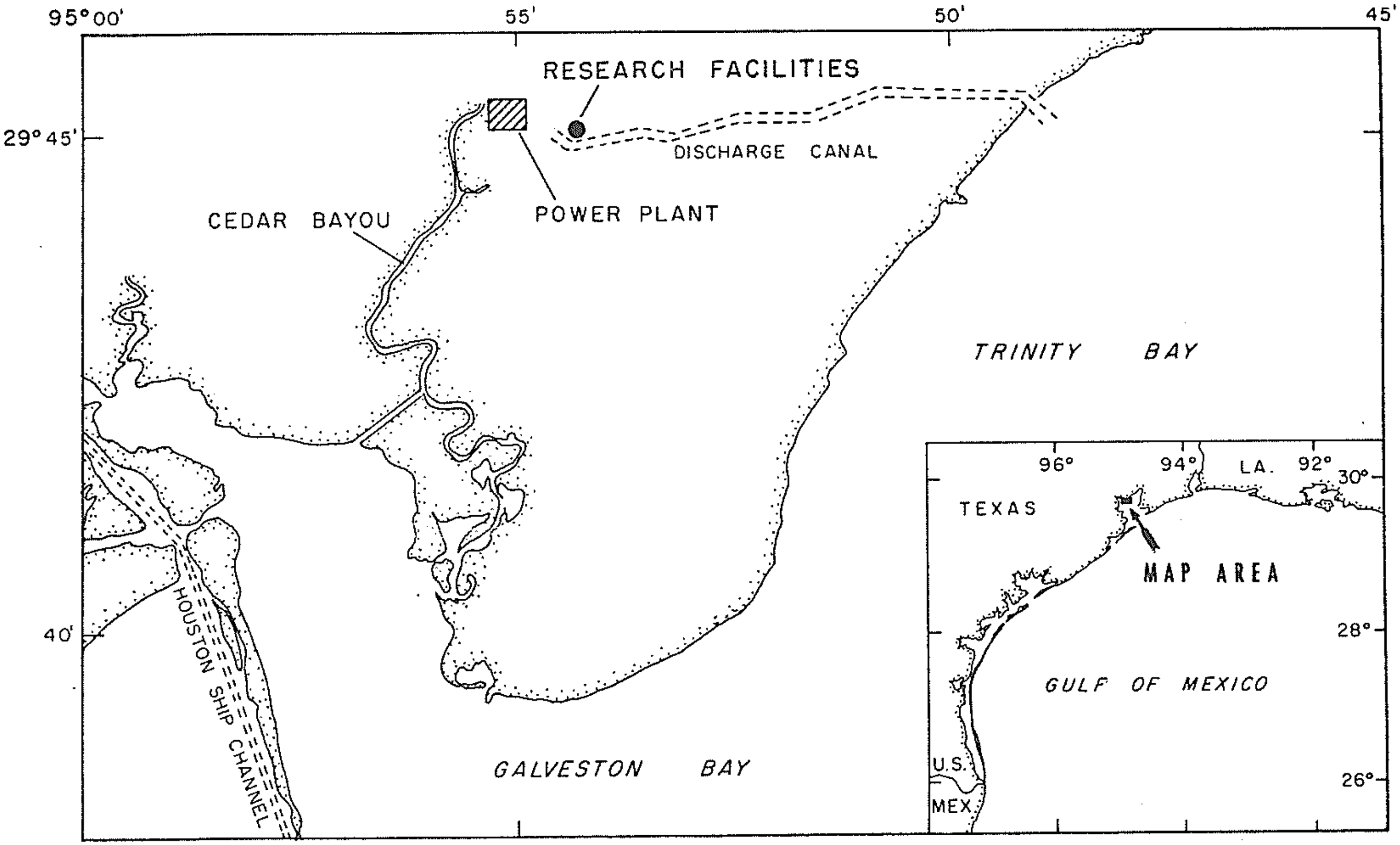

FIG. 1. Map showing location of power plant and research facilities. Insert shows Galveston Bay system on Texas Gulf Coast.

sewerage plant and a series of gas storage brine pits empty into Cedar Bayou above the power plant. These wastes passed through the Cedar Bayou power plant and may have had some affect on oysters. The intake canal consisted of Cedar Bayou, a short man-made canal connecting it to upper Galveston Bay and a dredged channel extending into upper Galveston Bay (Fig. 1). Heated water was discharged through a 9.8 km canal and 1053-ha (2600-acre) cooling pond before emptying into Trinity Bay.

Twenty-five ponds were located adjacent to the discharge canal about 200 m from its origin (Fig. 2). Each pond was about 0.1 ha (1/4 acre) in surface area, about 82 m long, about 12 m wide and varied in depth from about 0.9 m at the intake end to 1.5 m at the discharge end. A continuous supply of water (at least 113 l or 30 gal per minute) was pumped into each pond from the discharge canal and was discharged at the opposite end through a standpipe.

Methods

Growth and mortality were determined for oysters subjected to intake and discharge water. Since growth and mortality of Gulf Coast oysters are known to be related to *Labyrinthomyxa* infection, two groups of oysters, one with an initially low and the other with

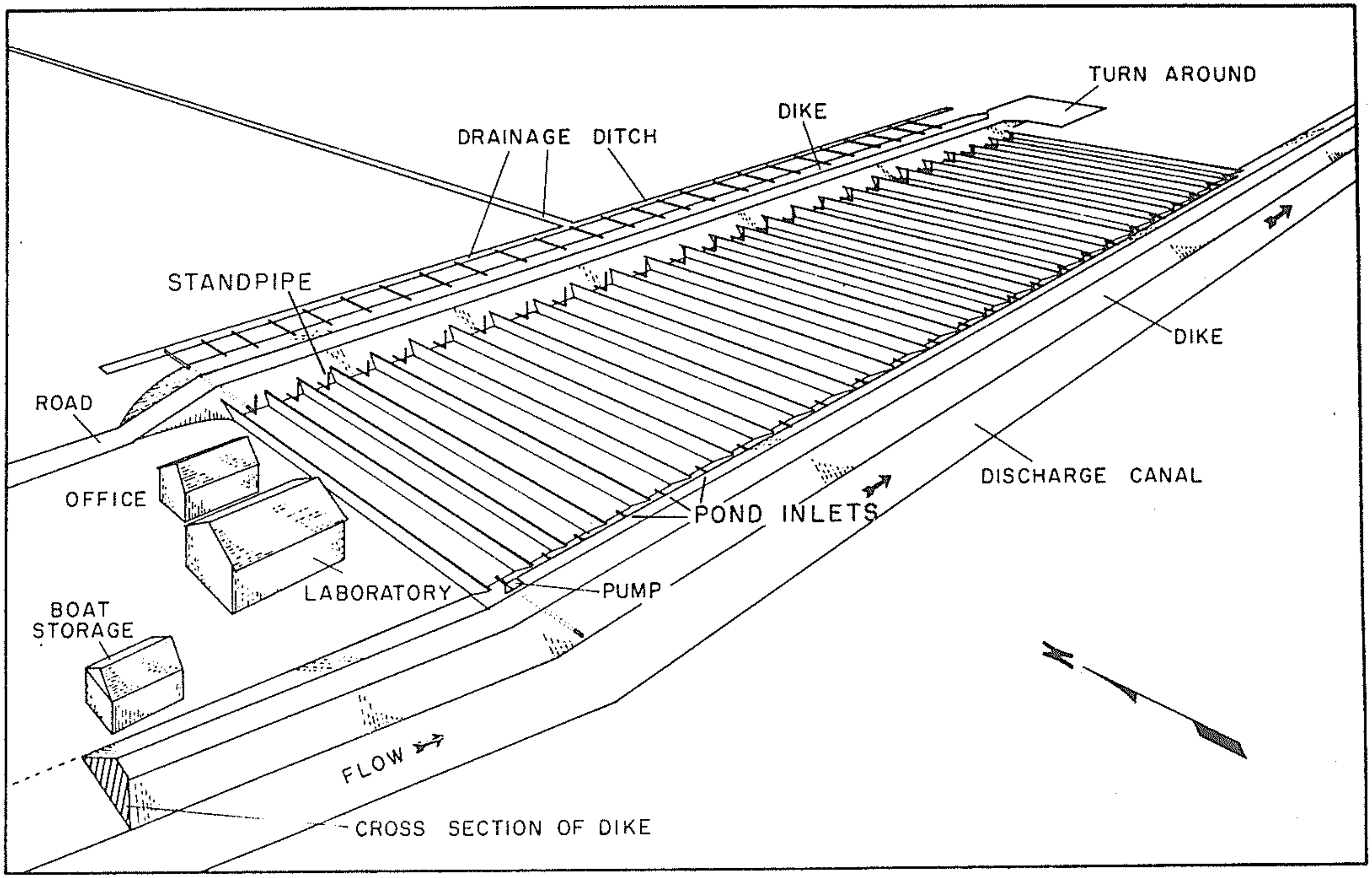

FIG. 2. Arrangement of ponds along the discharge canal at the Cedar Bayou Generating Station.

an initially high infection rate, were used in the experiment. To obtain high and low Labyrinthomyxa infected oysters for the study, oysters were collected from Dry Hole, Beasley's, Barts Pass, North Redfish and South Redfish reefs (all reefs were located in the Galveston Bay system). These reefs were chosen as collection sites because Mr. Robert Hofstetter (Texas Parks and Wildlife Department) indicated through personal communication that low and high Labyrinthomyxa oysters might be obtained from these reefs.

The thioglycolate method described by Ray (1966) was used to determine levels of Labyrinthomyxa infection in at least 25 oysters from each reef. Two pieces of tissue, each about 4 mm square, were removed from each oyster's mantle at the most anterior portion of this organ just lateral to the palps. This tissue from each oyster was cultured in 10 ml of fluid thioglycolate media fortified with 200 units of micostatin (nystatin) and 200 μg of chloromycetin (chloramphenicol). These cultures were incubated for 1 to 2 weeks at room temperature before the tissue was stained with iodine solution, thoroughly teased apart and examined for parasite cells with a light microscope. Infections were rated on a "0" to "5" scale (intensity rating) based on the number of parasite cells per 4 mm^2 of tissue (Table 1). Incidence of infection (proportion of infected oysters in any sample expressed as percent) and weighted incidence (average

TABLE 1. *Labyrinthomyxa* infection intensities rating key.

Intensity description	Letter code	Number code	Hypnospore concentration
Negative	N	0	None in sample
Very light	VL	0.5	1-10/sample
Light	L	1	11-100/sample
Light to moderate	LM	2	Intermediate between light infections and moderate infections
Moderate	M	3	Tissues are heavily infiltrated in some areas, but lightly infiltrated in others
Moderate to heavy	MH	4	Intermediate between moderate infections and obviously heavy infections
Heavy	H	5	Fungus cells concentrated in great numbers in all tissue samples

of intensity ratings of infected oysters) were calculated for each sample. Beasley's reef oysters appeared to have no initial *Labyrinthomyxa* infection and were used for the low infection group. South Redfish reef oysters had the highest initial *Labyrinthomyxa* infection (incidence = 76% and weighted incidence = 1.9) and were chosen for the high infection group. In the rest of this paper, Redfish reef oysters will be referred to as high *Labyrinthomyxa* (high-L) oysters and Beasley's reef oysters will be called low *Labyrinthomyxa* (low-L) oysters. The low-L oysters (mean length of 93 mm and mean weight of 225 g) were larger than the high-L oysters (mean length of 72 mm and mean weight of 102 g) but had to be used in the study because no smaller low-L oysters could be found (recruitment was low at Beasley's reef during the preceding year).

Five hundred or more oysters were dredged from each reef (South Redfish and Beasley's) on 28 October, 1971. Redfish (high-L) and Beasley's (low-L) oysters were culled, put into 81 x 46 x 10 cm polyvinyl-coated wire trays (approximately 100 oysters per tray) and held about 1 m underwater in ponds 2 and 3, respectively. On 8 December, 1971, high-L oysters (500) and low-L oysters (500) were removed from ponds 2 and 3 and put into ponds 6 and 7, respectively. Three hundred pond-6 (high-L) oysters and 300 pond-7 (low-L) oysters were placed into 36 x 30 cm labeled 2.5 cm square mesh DuPont polyethylene Vexar bags (10 oysters per bag) and held in trays (10 bags per tray) about 1 m underwater in ponds 6 and 7, respectively.

A tray of low-L oysters and a tray of high-L oysters were taken from the ponds and suspended 2 m underwater at the intake canal on 21 December, 1971. The intake canal high-L oysters were separated from the intake canal low-L oysters by a minimum of about 30 m. On 16 January, 1972, 10 Vexar bags of oysters were removed from trays in the intake canal and resuspended individually about 1 m apart and 2 m underwater from a walkway crossing the canal (high-L oysters were separated from low-L oysters by a minimum of about 20 m).

On 10 February, 1972, 10 Vexar bags (1 tray) of oysters in each pond were resuspended individually about 1 m apart and 1 m underwater from an aerial cable crossing the middle of each pond. Additional high-L and low-L oysters held in ponds 6 and 7, respectively, were used to determine Labyrinthomyxa infection and gonadal development periodically during the study. These additional oysters were held about 1 m underwater in trays (a maximum of 100 oysters per tray) supported by concrete blocks.

Another tray of low-L oysters and another tray of high-L oysters were removed from the ponds on 17 April, 1972 and suspended from a platform in the discharge canal about 200 m downstream from the discharge outfall. The high-L discharge canal oysters were suspended about 4 m downstream from the discharge canal low-L oysters to avoid possible contamination of low-L oysters with Labyrinthomyxa from high-L oysters.

All discharge canal oysters were dead by 24 May, 1972. A second group of oysters were collected from Beasley's reef on 8 June, 1972 by Mr. Robert Hofstetter. This population had a "0" Labyrinthomyxa infection rate based on a sample of 10 oysters. We culled the oysters and suspended 50 of them in the discharge canal in a manner similar to that indicated previously. These oysters were examined for mortality on a daily basis and some of the dead oysters were cultured for Labyrinthomyxa and sectioned for microscopic examination.

The length (to the nearest millimeter) of each oyster from the beak of the left valve to the bill of the right valve and the combined dry-air weight (to the nearest 1/8 lb $\sim$ 60 g) of each bag of oysters were determined monthly and mortality was determined semimonthly starting 20 December, 1971. The oysters were removed from the bag for dry-air weighing. Before the oysters were weighed, each oyster was scraped to remove fouling organisms (mostly barnacles and mussels, predominantly Congeria) so that the weight of the fouling organisms was not included in the weight of the oysters. The base plates of barnacles often remained on the oyster and sometimes a small piece of oyster shell was broken off during cleaning. We feel that the base plates did not add a significant amount of weight to the oysters and the few pieces of shell that were broken off did not decrease the weight significantly.

In order to monitor possible effects of Labyrinthomyxa and water quality on a short-term basis, the growth of individual oysters was measured by in-water weights following a modified Havinga method described by Andrews (1963). In-water weights of 10 low-L and 10 high-L oysters in each experimental area were measured semimonthly starting 19 January, 1972. These oysters were held in Vexar bags (10 oysters/bag) suspended in the same manner as those containing oysters for dry-air weight and length measurements. The same oysters were weighed each time. Each oyster was engraved with an identifying number with an engraving tool and the number was retraced with a black felt-tip pen for ease of reading. The oysters were taken from the water, placed into a bucket of water in which they were living and transported to the laboratory. At the laboratory, they were scraped clean of fouling organisms and were returned to the bucket of water. Individual oysters were out of the water only during weighing (to the nearest 0.01 g) with a Mettler balance type H23. Each time a group of oysters was weighed, one oyster from the group was weighed twice to determine the precision of the method. The precision was always better than ± 0.05 g.

Twenty-five low-L and 25 high-L oysters were removed from ponds 6 and 7 on each of the following dates: 3 March, 10 July, 9 November and 29 December, 1972. The remaining intake canal oysters (16 high-L individuals) were removed from the intake canal also on 29 December, 1972. *Labyrinthomyxa* infection was determined for each oyster by culturing a piece of the mantle. Subsequently each oyster was fixed, and oysters from March and July were sectioned and stained using methods described by Lillie (1965) for Harris' hematoxylin and eosin staining. Histological sections from the March and July oysters were examined to determined gonadal development.

A Hydrolab Model 6 Portable Surveyor Surface Unit (Hydrolab Corporation, Austin, Texas) was used on a daily basis, beginning 2 February, 1972, to measure water temperature (to the nearest 0.5°C), dissolved oxygen (to the nearest 0.1 ppm) and conductivity (to the nearest 100 micromhos/cm). The hydrographic readings were generally taken between 0800 and 1000 hrs; however, on several occasions they were taken after 1200 hrs. The Hydrolab dissolved oxygen (D.O.) module was temperature compensated but was not conductivity compensated. Due to the difference in solubility of oxygen in water at different conductivities, the readings were in slight error. Since the Hydrolab unit was calibrated for freshwater, all observed D.O. readings were slightly higher than actual values because oxygen solubility in water decreases with increasing conductivity, i.e., the error between observed and actual D.O. values increased with increasing salinity. Since the maximum error in the D.O. readings was less than 2 ppm, the D.O. values observed were not corrected. However, an oxygen solubility curve for seawater at 25°C using saturation values from Green and Carritt (1967) is included for consideration (Fig. 3).

The hydrological parameters were determined for approximately the midpoint (surface and bottom) of the intake canal and each pond while only mid-depth readings were taken from the platform in the discharge canal because water at the platform was turbulent enough to minimize stratification. In a preliminary study of the ponds and intake canal study area, little horizontal variation in the parameters was found. Bottom water temperatures (to the nearest 1°C) were recorded with Ryan 15-day recording thermometers for the middle of pond 6 and the intake canal. Water temperatures recorded by Ryan

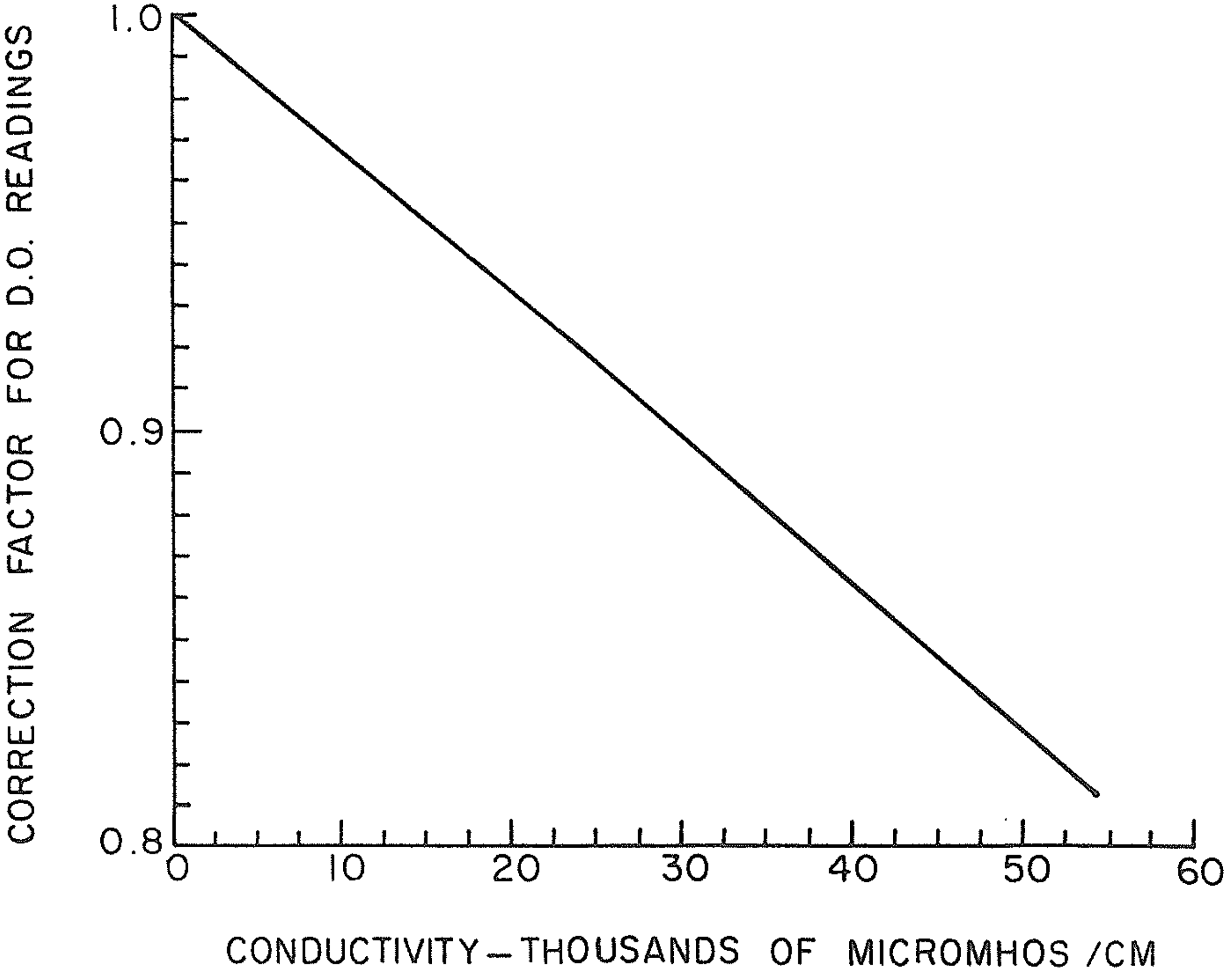

FIG. 3. Solubility curve at 25°C for oxygen in seawater of different conductivities.

thermometers were not used because temperatures taken simultaneously with a glass mercury thermometer indicated that the Ryan thermometers were off as much as 4°C.

Surface salinities (to the nearest 0.5‰) were taken semimonthly starting 6 January, 1972 for each area using a Goldberg T/S refractometer. These salinity values were compared to salinity values (to the nearest 0.1‰) obtained by converting conductivity readings taken simultaneously. Since these values were similar, all conductivities were converted to salinities (Fig. 4).

Hydrogen ion concentration (pH) and chlorophyll *a* values were determined semimonthly for each area. A Beckman model 76 pH meter was used to measure pH (to the nearest 0.01 standard unit) while chlorophyll *a* values (to the nearest 0.01 mg/m^3) were determined with a Turner model 111 Fluorometer using methods described by Strickland and Parsons (1968).

On 28 December, 1972, oysters from the intake canal and the ponds were frozen for heavy metals analysis. An atomic absorption method was used to analyze the tissue for arsenic, mercury, lead, copper, manganese, iron, cobalt and zinc by the Texas A&M University Agricultural Analytical Service on 20 February, 1973.

Oyster spat and/or fouling organisms were collected on experimental oysters, asbestos plates and cultch (dead oyster shell) set

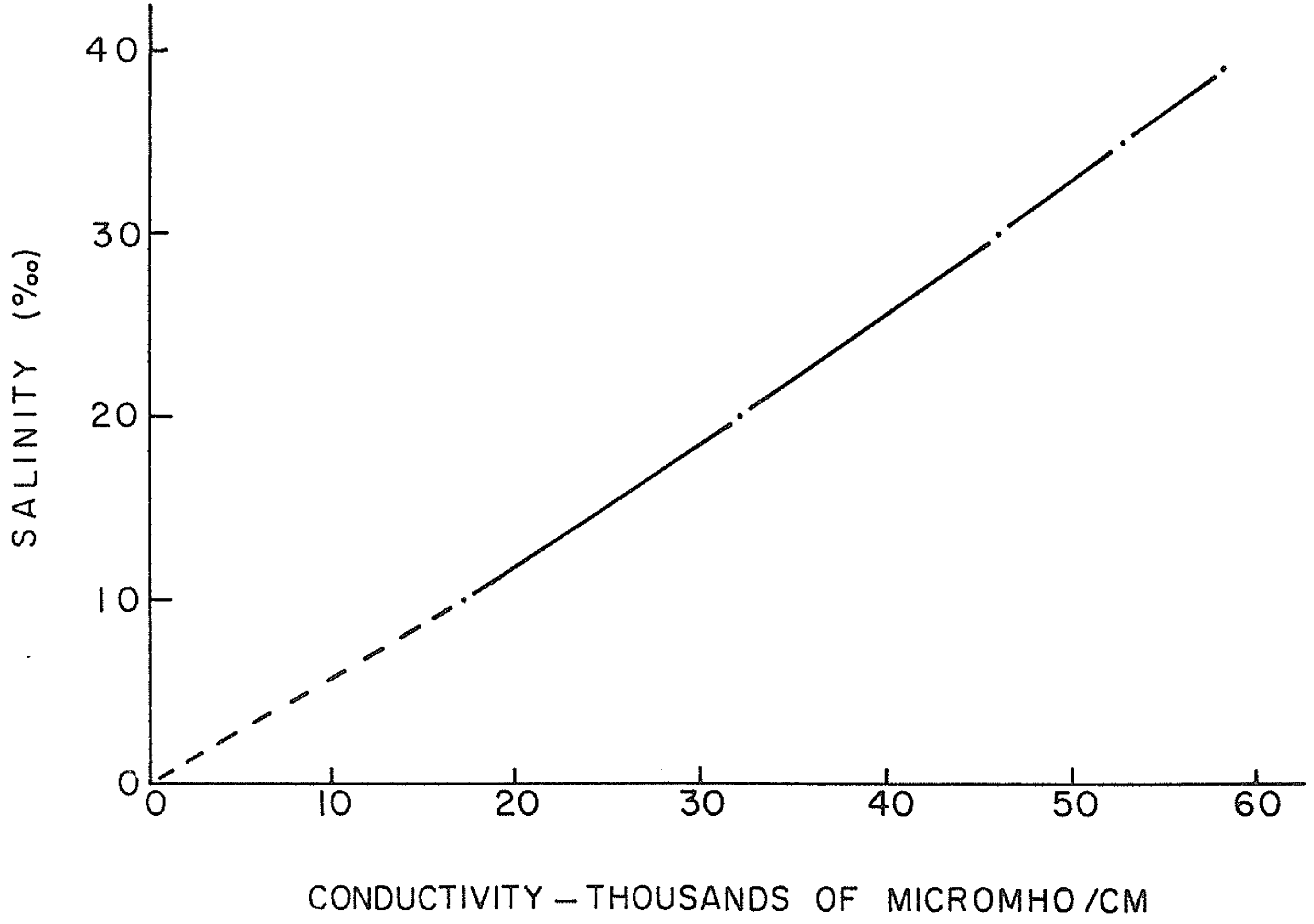

FIG. 4. Relationship between conductivity and salinity at 25°C.

out in ponds 6 and 7, the intake canal and the discharge canal. The experimental oysters were initially cleaned of spat and fouling organisms and from that time on were examined monthly for spat set. Two asbestos plates about 30 cm^2 were placed into each of four wooden frames so that one plate was vertical and the other would sit horizontally in the water column. Each wooden frame with its two plates was suspended about 0.5 m off bottom on 5 June, 1972. These plates were checked semimonthly for spat set and fouling organisms. All spat and fouling organisms were scraped from the plates before the plates were returned to the water. Spat set on the experimental oysters but did not set on the asbestos plates which were painted on one side. Since paint on the plates appeared to have been toxic to the oyster larvae, cultch of oyster shell were used subsequently to collect spat. Ten oyster shell halves were put into each of four 36 x 30 cm Vexar bags and on 11 August, 1972 one of these bags was placed in each of the four areas. The inner side of each shell in each bag was examined semimonthly for spat and fouling organisms. Spat and fouling organisms were scraped from the shells before returning them to the water.

As a matter of information, it should be noted that ponds 6 and 7 were not solely devoted to the oyster study. As part of another study, 500 striped mullet, Mugil cephalus, were raised in each pond from February, 1972 to December, 1972. A total of 263.3 kg of Purina Trout Chow was put into each pond during this period.

RESULTS

Hydrology

Water temperature.--Surface and bottom temperatures were similar in each pond; thus when stratification of temperature was present, it was slight (Figs. 5 and 6). Temperature stratification in the intake and discharge canals was not apparent. Mean water temperatures (ponds, intake canal and discharge canal) were similar, except for the discharge canal which averaged 6° to 6.9°C higher than the other areas (Table 2). Water temperatures ranged from 8.5°C in pond 7 on 4 February to 41.0°C in the discharge canal on 5 September, 1972. Seasonal trends for water temperature were similar in all areas (Figs. 5-8). Temperatures gradually increased from lows (about 9°C in the ponds and intake canal; 20°C in the discharge canal) in February to highs (about 30°C in the ponds and intake canal; 41°C in the discharge canal) in September. Temperatures then gradually decreased to near 11°C in the ponds and intake canal and near 18°C in the discharge canal in late November before leveling off (Figs. 5-8).

Salinity.--Surface and bottom salinities were similar in each pond during most of the study (Figs. 5 and 6). However, on a few

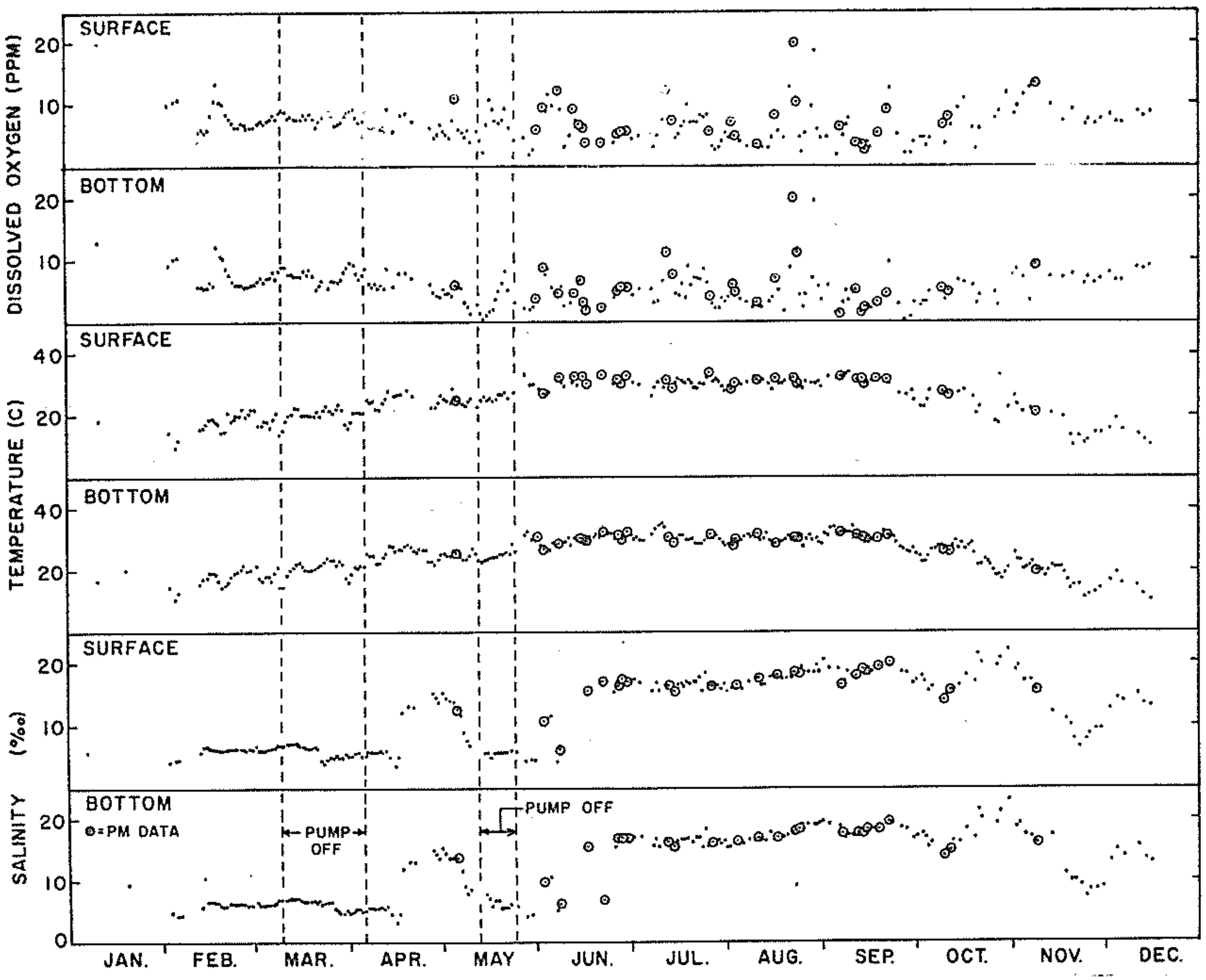

FIG. 5. Daily measurements of hydrological data taken from 6 January to 15 December, 1972 for pond 6, surface and bottom. Majority of measurements made between 8 and 11 AM. Measurements taken in the afternoon are encircled.

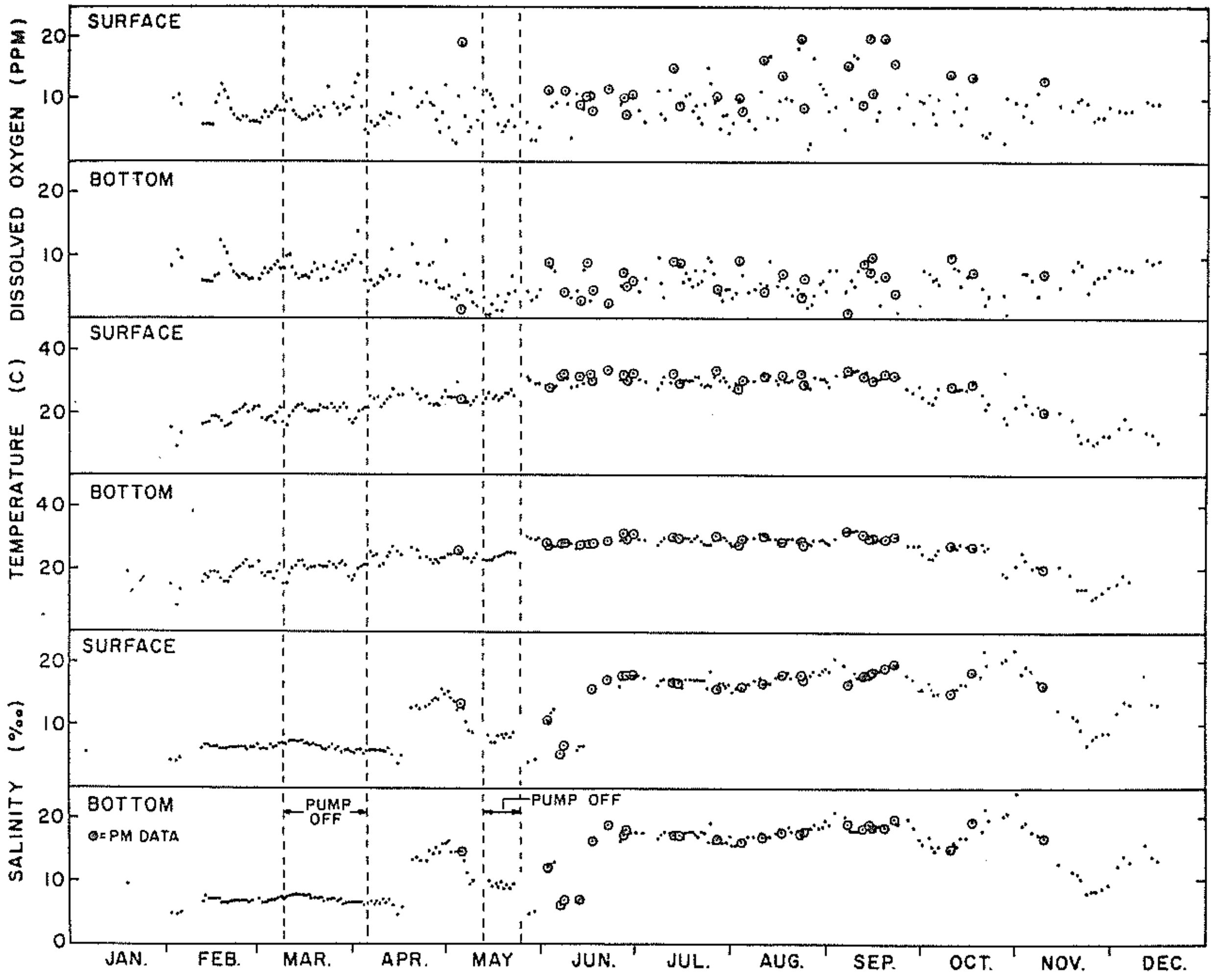

FIG. 6. Daily measurements of hydrological data taken from 6 January to 15 December, 1972 for pond 7, surface and bottom. Majority of measurements made between 8 and 11 AM. Measurements taken in the afternoon are encircled.

TABLE 2. Number of observations, average values and ranges for the five hydrological parameters by area for the total study period (20 December, 1971 to 28 December, 1972).

	Pond 7 (bottom)	Pond 6 (bottom)	Intake canal (surface)	Discharge canal (mid-depth)
Temperature (C)				
Number of observations	224	294	149	233
Average	24.4	25.3	24.5	31.3
Range	8.5-33.0	11.0-35.0	10.0-33.5	16.5-41.0
Salinity (‰)				
Number of observations	213	211	131	223
Average	12.3	12.2	12.8	12.2
Range	3.8-24.0	3.8-23.3	0.0-26.2	0.6-24.6
Dissolved oxygen (ppm)				
Number of observations	222	217	140	232
Average	6.1	5.5	6.2	6.7
Range	0.0-13.9	0.3-20+	0.0-14.4	0.0-11.7
pH				
Number of observations	23	23	24	24
Average	8.48	8.16	8.13	8.50
Range	7.88-9.15	7.51-9.07	7.66-8.66	7.74-8.65
Chlorophyll a (mg/m^3)				
Number of observations	24	24	25	25
Average	38.9	25.5	18.7	22.2
Range	12.0-188.6	0.6-100.0	5.0-45.5	3.7-75.8

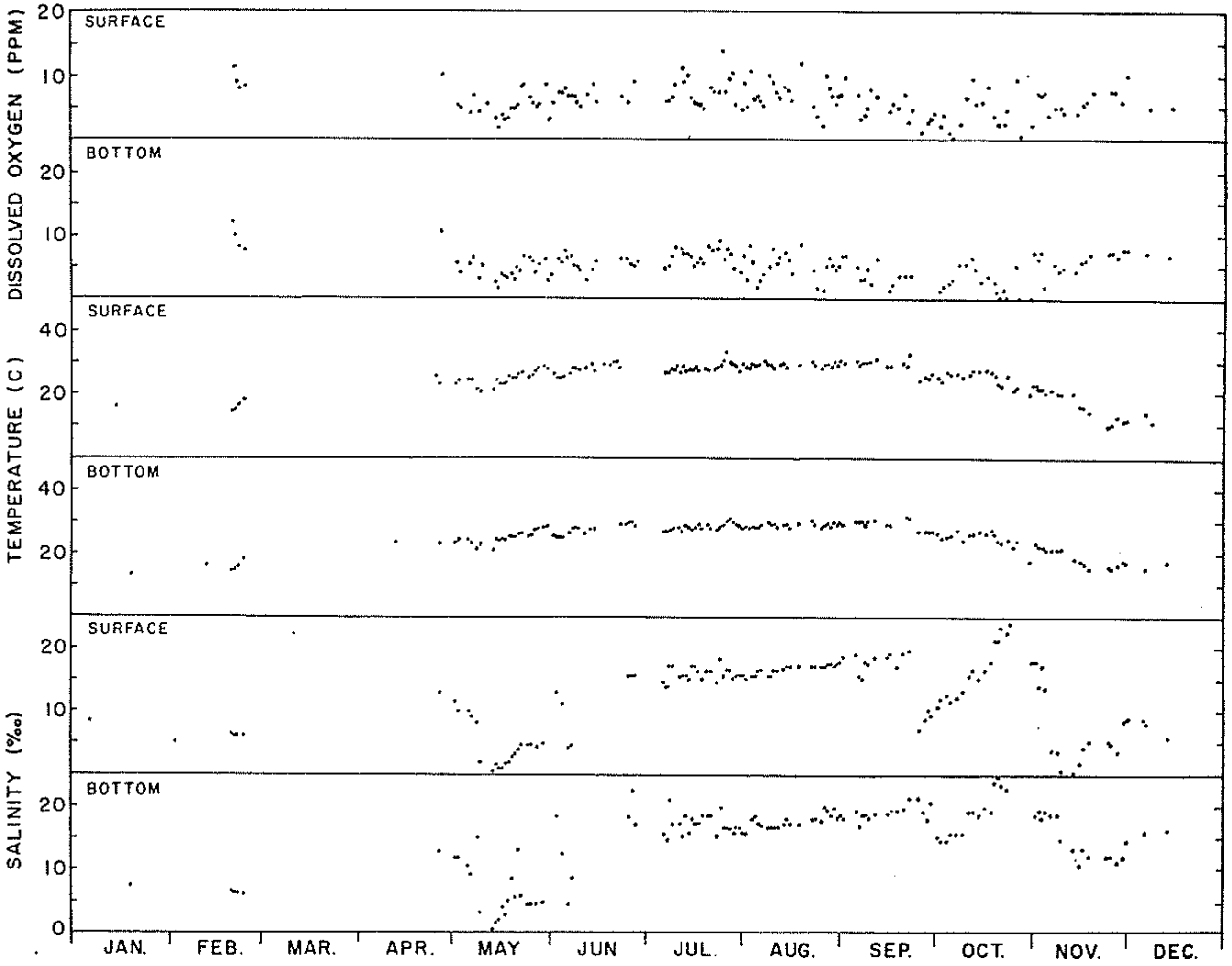

FIG. 7. Daily measurements of hydrological data taken from 6 January to 15 December, 1972 for the intake canal, surface and bottom.

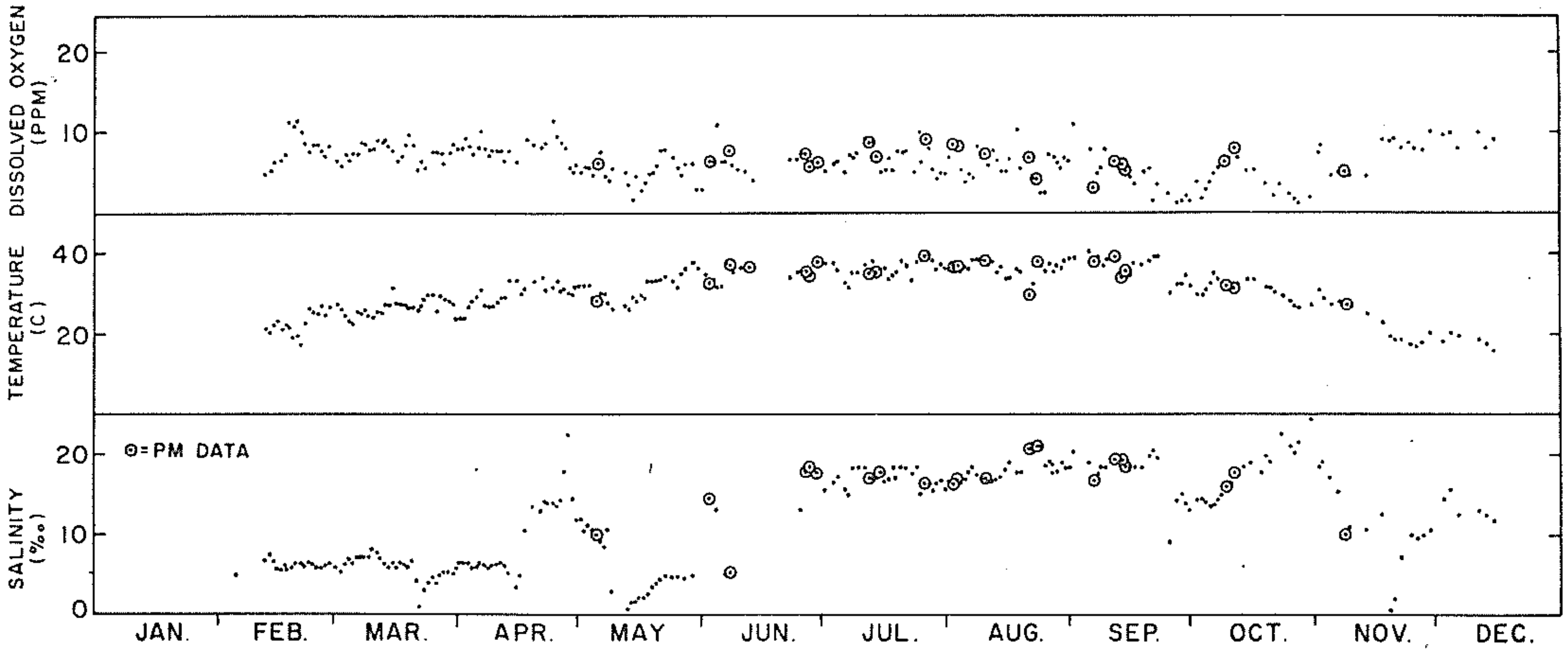

FIG. 8. Daily measurements of hydrological data taken from 5 February to 15 December, 1972 for the discharge canal, mid-depth. Majority of measurements made between 8 and 11 AM. Measurements taken in the afternoon are encircled.

occasions bottom salinities were slightly higher (1 to 2‰) than surface salinities. In the intake canal, salinity stratification occurred from late September to mid-December. During this period, bottom salinities were often 5‰ higher than surface salinities (Fig. 7). Salinity data for the intake canal (surface) were not collected on a regular basis from December, 1971 to May, 1972, a period of low salinity in the ponds and discharge canal. Average salinity values for the entire study period were near 12‰ for all areas, including the intake canal surface. Therefore, intake salinities were actually lower than the value indicates for the study period. The intake and discharge canals had lower minimum salinities (near 0‰) than the ponds (3.8‰) because, during a period of heavy rainfall, the pump that transferred discharge canal water to the ponds was shut down for 12 days (12 to 24 May). Thus, low salinity water in the discharge canal was transferred to the ponds by gravity flow at a reduced rate. Maximum salinities for all areas were near 25‰. Seasonal trends for salinity were similar in all areas (Figs. 5-8). Salinities were near 6‰ from February to mid-April at which time they rose sharply to about 15‰. Heavy rains in early May caused salinities to drop to mid-May lows (intake and discharge canals near 0‰ and ponds about 6‰). Following this period, salinities rose sharply to about 17‰ in June before leveling off at 15 to 20‰ in July and August. All areas reached maximums of about 25‰ in late

October before dropping rapidly in November due to heavy rains. In December they started increasing again.

Dissolved oxygen.--Dissolved oxygen stratification in ponds 6 and 7 was most apparent in mid-May and late September. At these times, bottom dissolved oxygen levels dropped to near 0 ppm while surface values remained about 6 ppm. Dissolved oxygen stratification was noted in the intake canal when salinity stratification was evident. This occurred periodically from August through October when dissolved oxygen levels were often 1 to 2 ppm lower on the bottom than at the surface (Fig. 7). Mean dissolved oxygen values for all areas were about 6 ppm and all areas had minimum dissolved oxygen readings near 0 ppm. Dissolved oxygen levels fluctuated daily. Most readings were made in the morning; however, on a few occasions readings were taken in the afternoon.

Hydrogen ion concentration and chlorophyll *a*.--Mean pH values were slightly higher in pond 6 (9.1) and pond 7 (9.2) than in the intake (8.7) or discharge (8.7) canal (Fig. 9). Mean chlorophyll *a* values were also higher for pond 6 (26 mg/m^3) and pond 7 (39 mg/m^3) than in the intake (19 mg/m^3) or discharge (22 mg/m^3) canals.

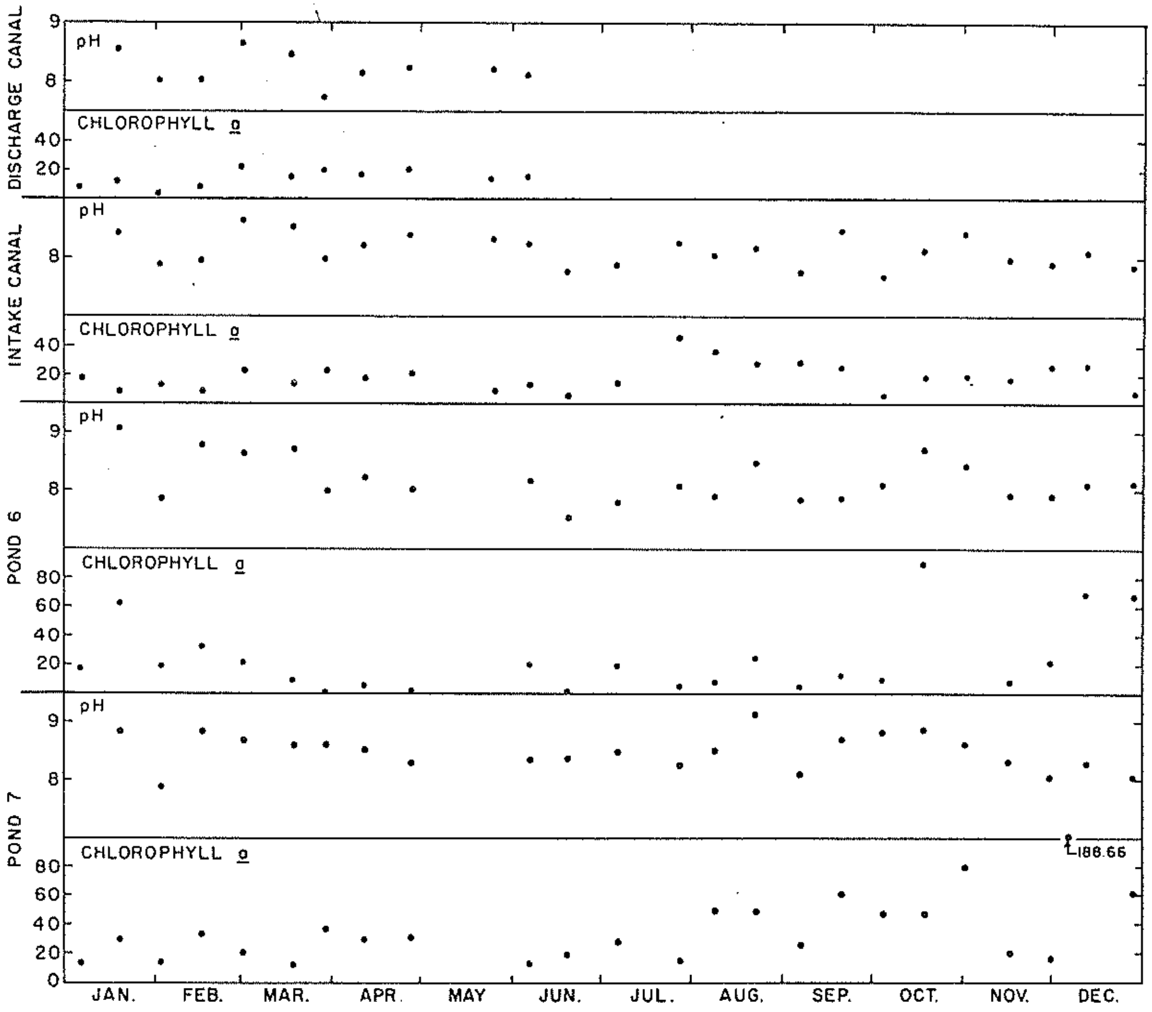

FIG. 9. Measurements of chlorophyll a (mg/m^3) and pH for ponds 6 and 7 and the intake and discharge canals at approximately semimonthly intervals during 1972.

Growth and Mortality

Long-term growth and mortality.--Accumulated mortality of oysters used for length and dry-air weight measurements was compared on a monthly basis among areas (Figs. 10 and 11, Tables 3, 4 and 5). These oysters generally showed greatest mortality during two periods, mid-May to late June and late August to early October. All the oysters (193) put into the discharge canal on 17 April were dead by 24 May, 1972. Low-L intake canal oysters disappeared sometime between 4 and 18 October, 1972; however, on 4 October they had an accumulated mortality of 51%. Low-L oysters in pond 7 had an accumulated mortality of 24% on 4 October and by the end of the study, this value had increased to 26%. High-L oysters in pond 6 and the intake canal had accumulated mortalities of 50% and 78%, respectively, by 4 October, 1972. By the end of the study, accumulated mortality had increased to 58% in pond 6 and 81% in the intake canal.

The total weight, total length, mean weight and mean length of surviving oysters were compared among areas for low-L and high-L oysters (Figs. 10-11, Tables 3-5). Total weights were computed for each measurement period by summing all the individual dry-air weights of surviving low-L or high-L oysters held in each area.

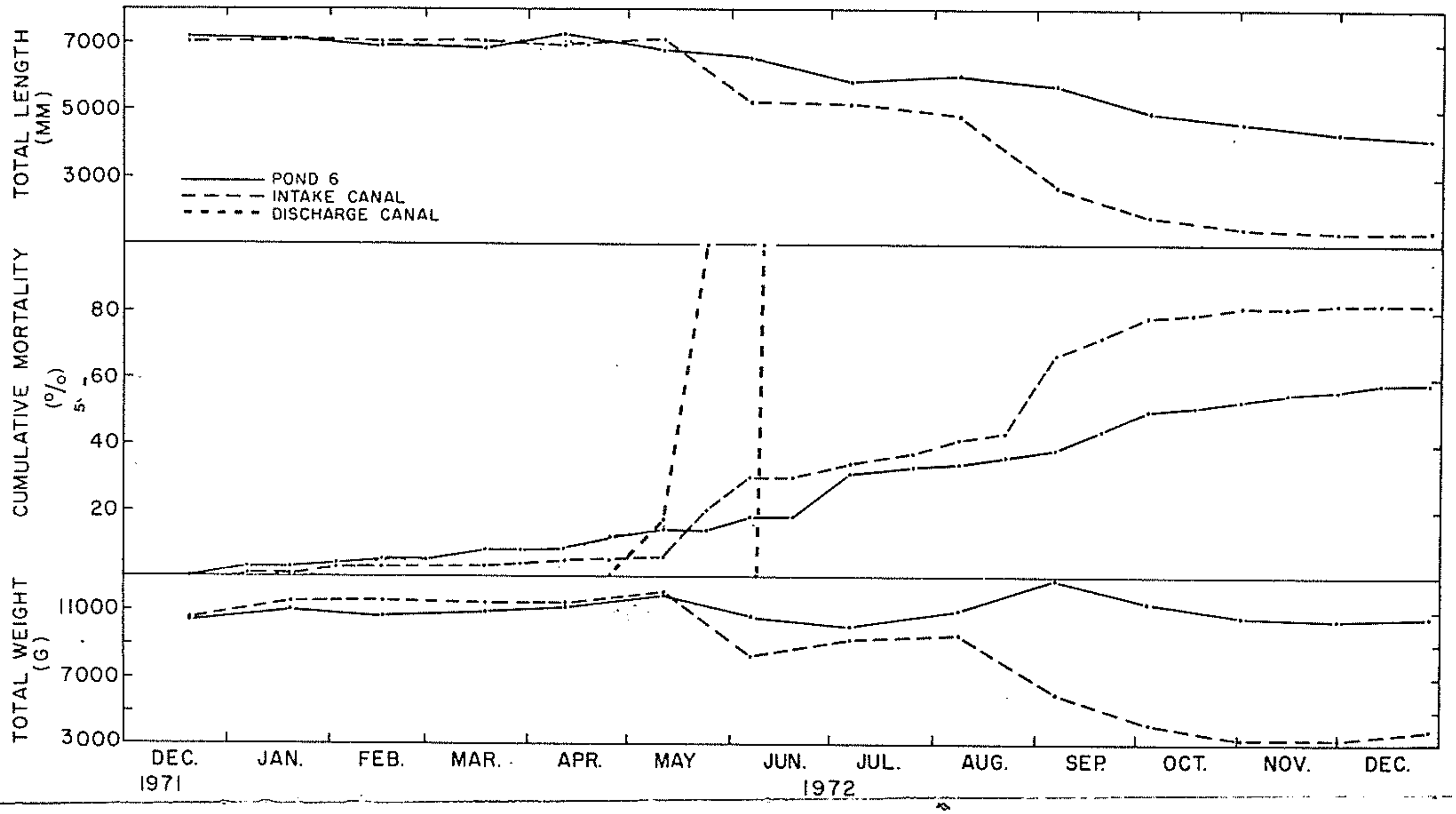

FIG. 10. Total length, total weight and cumulative mortality for high Labyrinthomyxa infected oysters held in pond 6, the intake canal and the discharge canal. Total lengths and weights represent summation of lengths and weights of individual oysters surviving at each measurement period.

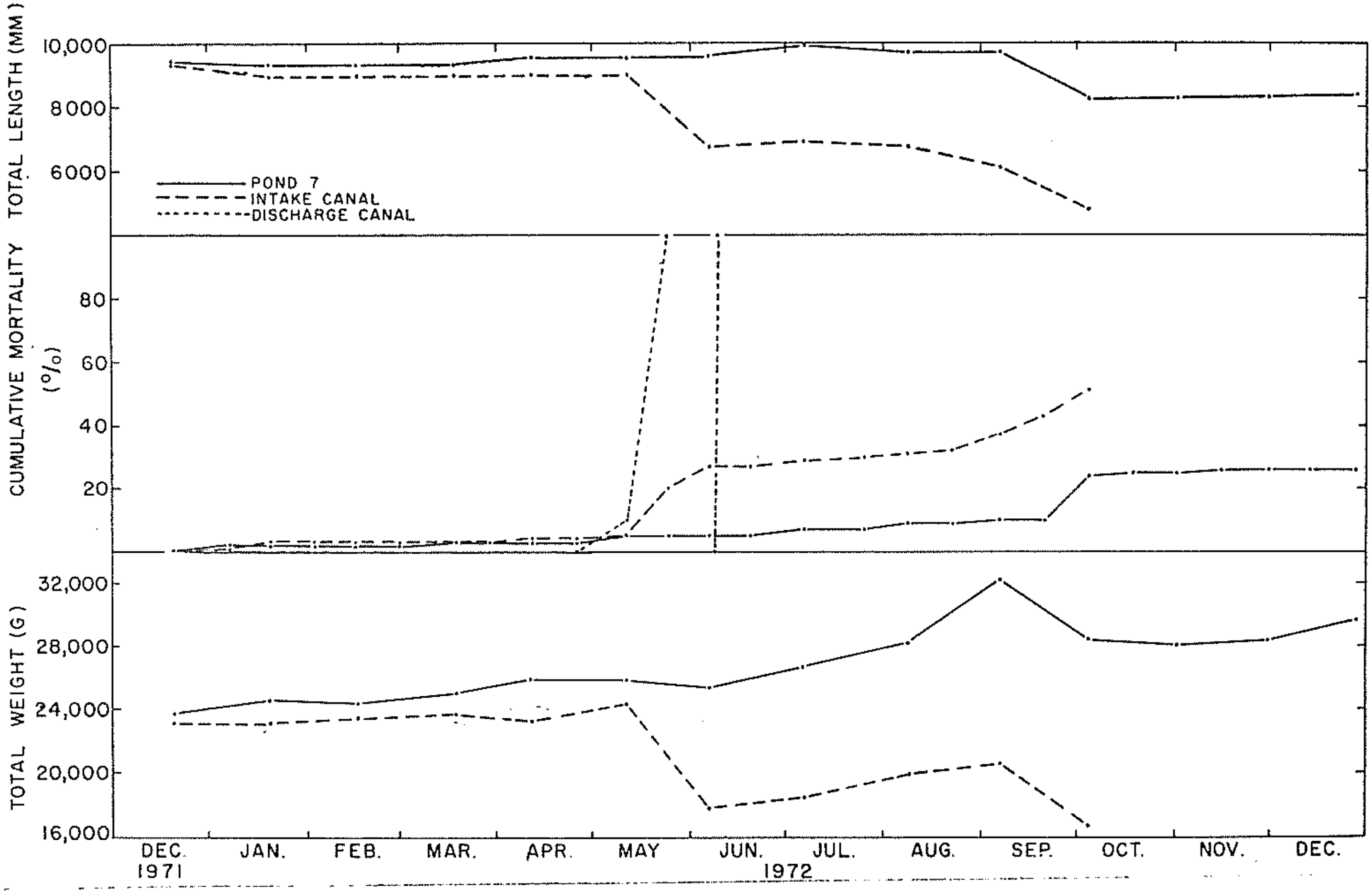

FIG. 11. Total length, total weight and cumulative mortality of low Labyrinthomyxa infected oysters held in pond 7, the intake canal and the discharge canal. Total lengths and weights represent summation of lengths and weights of individual oysters surviving at each measurement period.

TABLE 3. Number of surviving oysters and their total and mean lengths and weights through time for ponds 6 and 7.

Date	Pond 7 (low Labyrinthomyxa)					Pond 6 (high Labyrinthomyxa)				
	Total length (mm)	Mean length (mm)	Total weight (g)	Mean weight (g)	Number of live oysters	Total length (mm)	Mean length (mm)	Total weight (g)	Mean weight (g)	Number of live oysters
12-20-71	9443	94	23757	238	100	7182	72	10432	105	100
1-19-72	9383	96	24550	249	98	7136	74	11000	113	97
2-16-72	9375	96	24380	249	98	6928	73	10773	113	95
3-18-72	9397	97	25061	258	97	6864	74	10886	119	92
4-11-72	9546	98	25968	266	97	7023	76	11226	122	92
5-11-72	9559	100	25855	272	95	6768	79	11907	136	86
6-6-72	9607	101	25458	266	95	6560	80	10603	130	82
7-6-72	9991	107	26762	289	93	5794	84	10036	147	69
8-8-72	9768	107	28236	308	91	5996	91	11056	167	66
9-6-72	9763	108	32377	359	90	5715	92	12814	206	62
10-4-72	8317	109	28463	376	76	4857	98	11396	238	50
11-1-72	8299	110	28122	376	75	4626	99	10623	229	47
11-30-72	8322	112	28404	385	74	4319	99	10364	232	44
12-28-72	8465	114	29710	405	74	4145	99	10603	252	42

TABLE 4. Number of surviving oysters and their total and mean lengths and weights through time for the intake canal.

Date	Intake canal (low Labyrinthomyxa)					Intake canal (high Labyrinthomyxa)				
	Total length (mm)	Mean length (mm)	Total weight (g)	Mean weight (g)	Number of live oysters	Total length (mm)	Mean length (mm)	Total weight (g)	Mean weight (g)	Number of live oysters
12-20-71	9332	93	23076	229	100	7076	71	10432	105	100
1-19-72	8964	92	23076	238	97	7111	72	11510	116	99
2-16-72	9004	93	23473	240	97	7025	72	11623	119	97
3-18-72	9010	92	23643	243	97	7040	72	11453	119	97
4-11-72	9052	93	23303	240	96	6948	73	11453	119	95
5-11-72	9030	95	24437	260	95	7109	76	11963	127	94
6-6-72	6775	93	17803	240	73	5193	74	8335	119	70
7-6-72	6931	98	18540	266	71	5160	78	9242	144	66
8-8-72	6782	98	19958	289	69	4823	81	9469	161	59
9-6-72	6157	98	20638	325	63	2713	82	6067	187	33
10-4-72	4811	98	16783	342	49	1819	82	4196	184	22
11-1-72						1447	85	3284	192	20
11-30-72						1366	86	3288	204	19
12-28-72						1392	87	3799	235	19

TABLE 5. Number of surviving oysters and their total and mean lengths and weights through time for the discharge canal. Oysters held in ponds 6 and 7 until 17 April, 1972.

Mean	Discharge canal (low Labyrinthomyxa)					Discharge canal (high Labyrinthomyxa)				
	Total length (mm)	Mean length (mm)	Total weight (g)	Mean weight (g)	Number of live oysters	Total length (mm)	Mean length (mm)	Total weight (g)	Mean weight (g)	Number of live oysters
12-20-71	9070	91	21092	207	100	7180	72	9752	97	100
1-19-72	9135	92	22680	222	100	7199	73	10940	110	99
2-16-72	9165	92	22226	221	100	6930	73	10319	110	95
3-18-72	9395	94	23305	233	100	7050	75	10432	110	94
4-11-72	9486	95	24040	240	100	7065	77	10659	114	93
5-11-72	8598	96	22171	247	90	6423	78	10659	128	83

Total lengths were computed in a similar manner. Since low-L oysters were much larger (initial mean length and weight = 93 mm and 224 g, respectively) than high-L oysters (initial mean length and weight = 72 mm and 102 g, respectively), it is hard to compare growth between the two groups. Total lengths and dry-air weights are included because the true effect of mortality is shown in them while mean lengths and mean dry-air weights of live (surviving) oysters do not show the effect of mortality.

Only pond 6 (high-L) and pond 7 (low-L) oysters had gained in biomass (increasing 171 and 5,953 g or 2 and 25%, respectively) by the end of the study. Intake canal low-L oysters decreased 6,293 g (27%) in the 10-month period (December, 1971 to October, 1972) prior to disappearing. Intake canal high-L oysters decreased 6,236 g (60%) in the 10-month period and 6,633 g (64%) by the end of the study (Tables 3-5).

Mean lengths and mean weights of oysters in each area showed that the surviving individuals increased in size during the study. Percent change in mean length (PCML) and mean weight (PCMW) of the oysters in each area was calculated using the formula:

$$\text{percent change} = \frac{\text{final mean value} - \text{initial mean value}}{\text{initial mean value}} \text{ X } 100.$$

During the study, high-L oysters in pond 6 (PCML = 38% and PCMW = 140%) and the intake canal (PCML = 22% and PCMW = 124%) showed a greater percent change in mean length and mean weight than did the low-L oysters in pond 7 (PCML = 22% and PCMW = 70%). Low-L oysters in the intake canal had a PCML of 5% and PCMW of 49% in the 10-month period prior to disappearing. In comparison, during the same 10-month period, high-L oysters in the intake canal had a PCML of 15% and a PCMW of 75%. This was not unexpected since high-L oysters were initially smaller than low-L oysters and small specimens usually show greater growth rates than large ones.

<u>Short-term growth and mortality</u>.--Mortality also occurred among the oysters used for in-water weight measurements. Deaths were most frequent during the two periods noted above, mid-May to late June and late August to early October (Figs. 12, 13, 14, 15 and 16). All discharge canal (20) and 50% (5 of 10) of the intake canal low-L oysters died in late April or early May. These oysters did not show a decrease in growth rate before dying. Thirty percent (3 of 10) of the pond 6 high-L oysters died in late June, however, their weights started decreasing in May. Many pond 6 high-L (30%, 3 of 10) oysters and intake canal high-L (60%, 6 of 10) and low-L (30%, 3 of 10) oysters died during late August and early September. Generally, these oysters also decreased in growth rate before dying. Only one pond 7 (low-L)

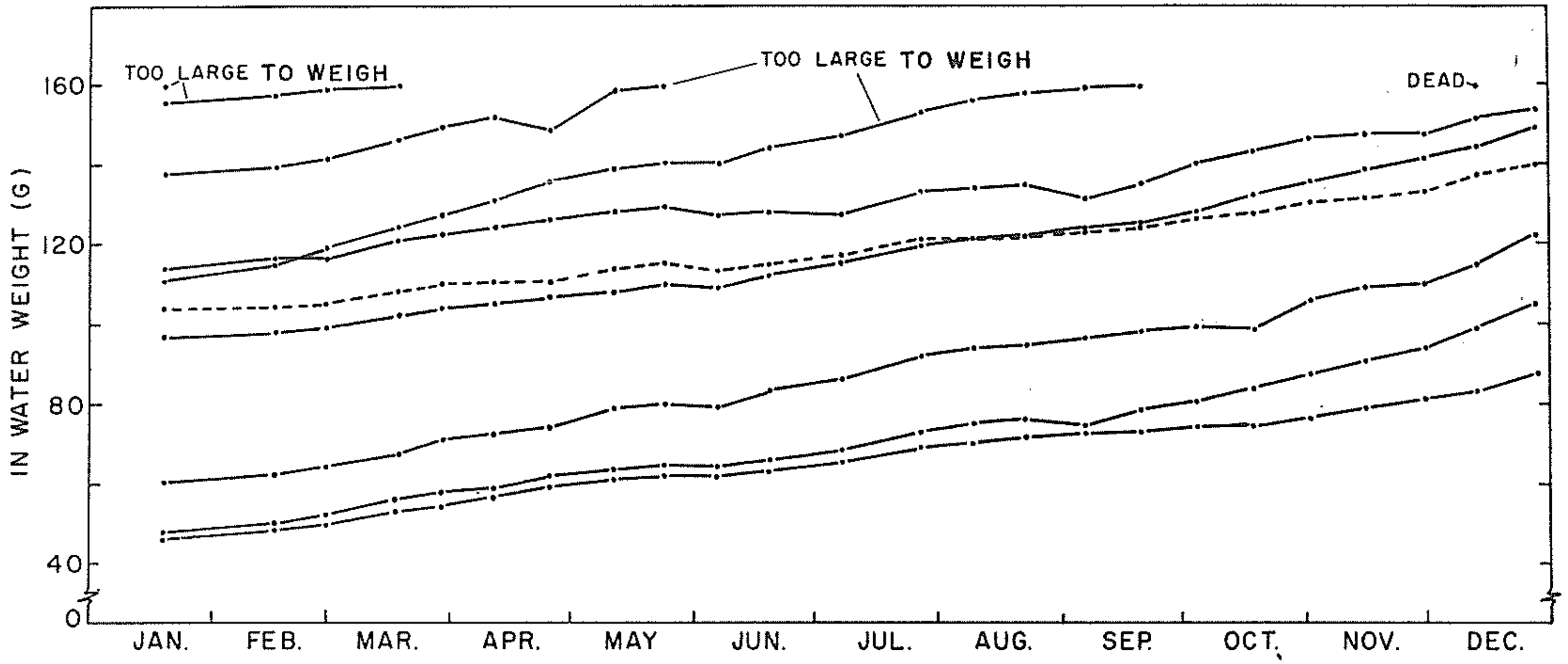

FIG. 12. In-water weights of 10 different oysters (low-*Labyrinthomyxa* infection) held in pond 7 during 1972. One oyster too large to weigh died in December.

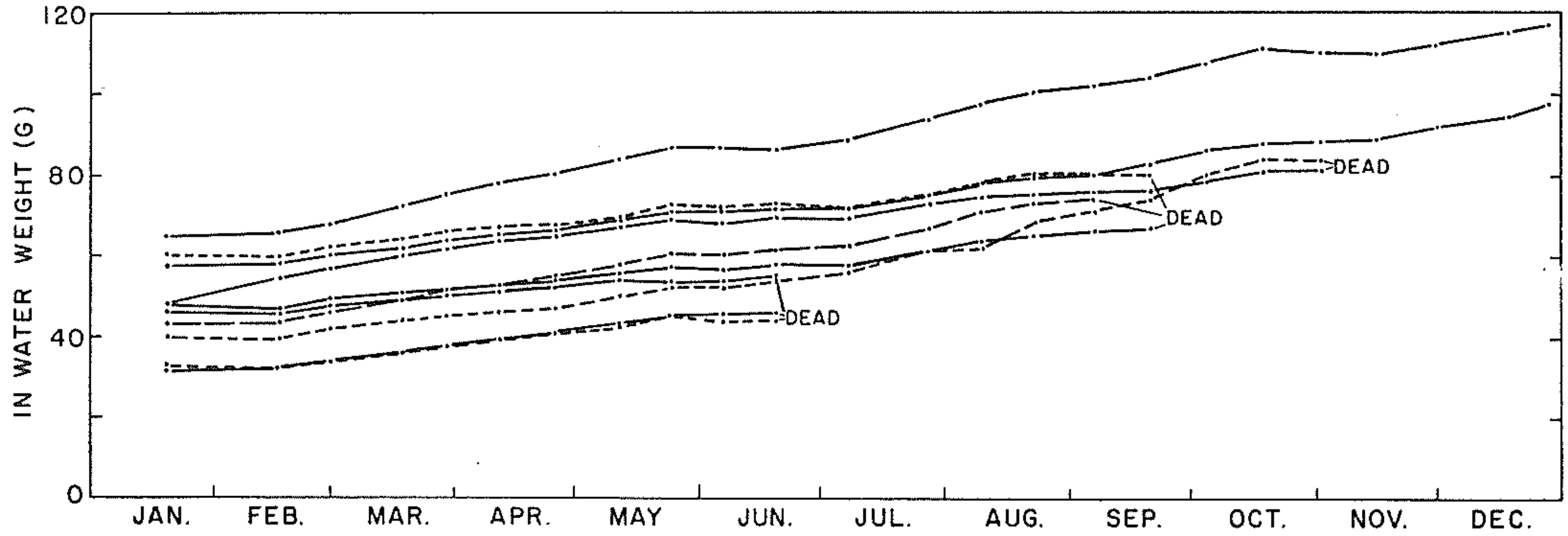

FIG. 13. In-water weights of 10 different oysters (high-*Labyrinthomyxa* infection) held in pond 6 during 1972.

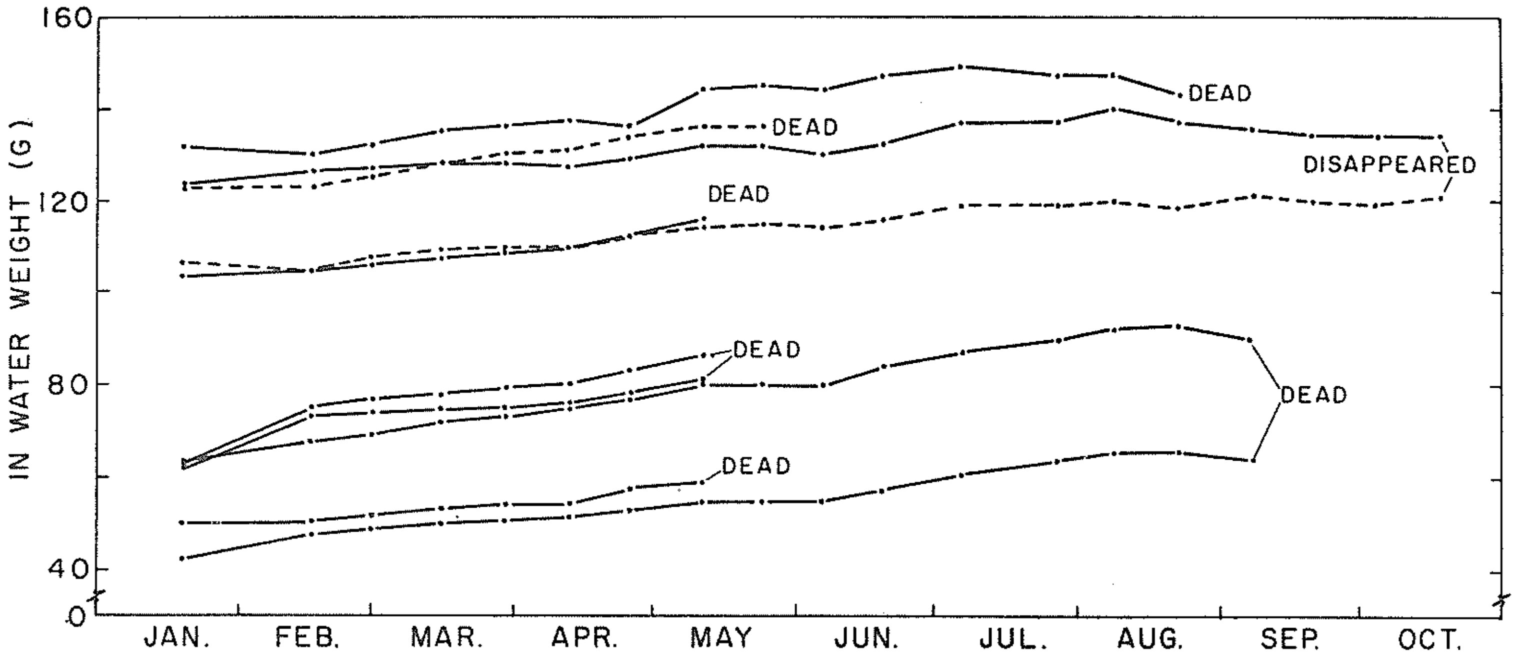

FIG. 14. In-water weights of 10 different oysters (high-*Labyrinthomyxa* infection) held in the intake canal during 1972.

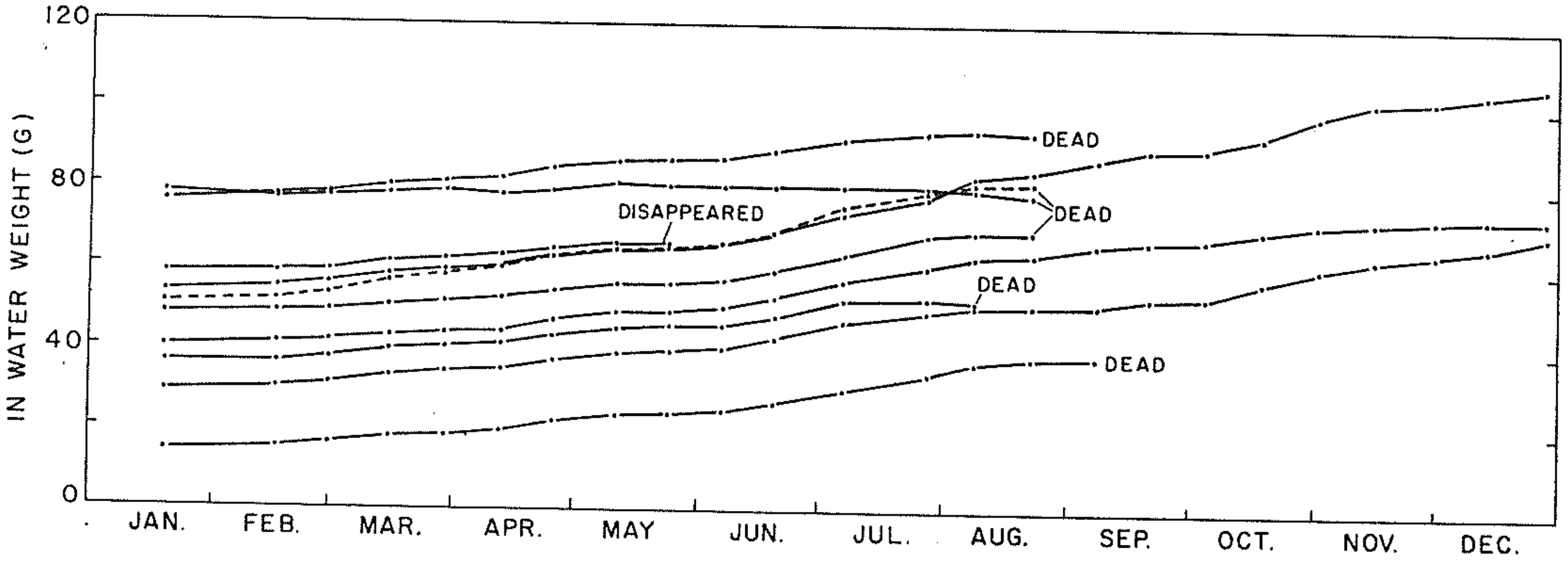

FIG. 15. In-water weights of 10 different oysters (low-*Labyrinthomyxa* infection) held in the intake canal during 1972.

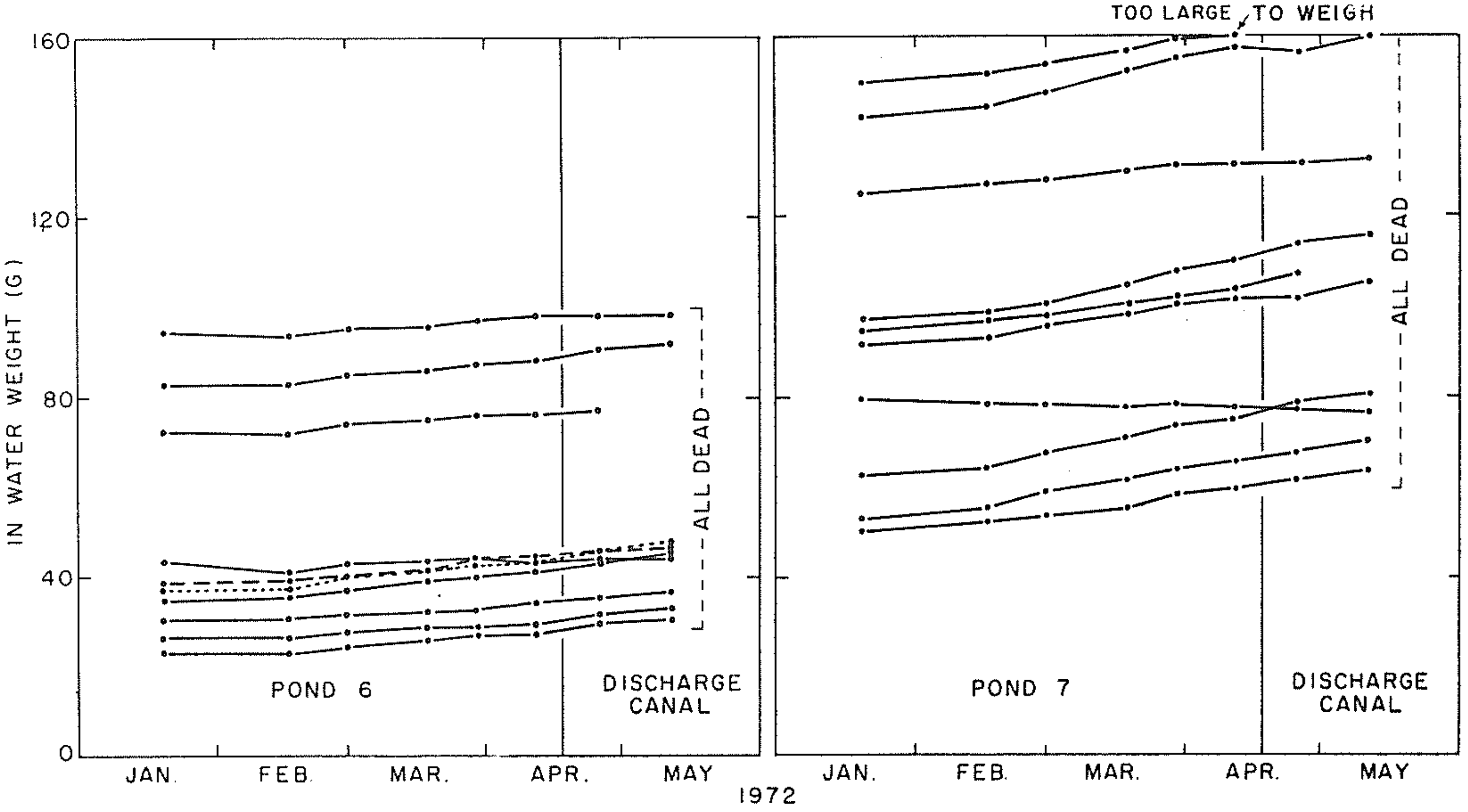

FIG. 16. In-water live weights of 10 different oysters held in each pond and then transferred to the discharge canal during 1972. Pond 7 oysters had low-Labyrinthomyxa infection rates while pond 6 oysters had high-Labyrinthomyxa infection rates.

oyster (10%) died during the study and it had become too large to weigh.

In-water weights of surviving pond oysters increased at a faster rate (about 1 g/week) than surviving intake canal oysters (slightly less than 1 g/week). Forty percent (4 of 10) of the pond 7 oysters became too large to weigh with available equipment. Discharge canal oysters used for in-water weight measurements did not show a distinct change in growth rate when transferred from the ponds to the discharge canal. Growth rates of oysters used for in-water measurements decreased in all areas in late May and early June.

Labyrinthomyxa Infection

Labyrinthomyxa infection remained low in pond 7 oysters (low-L) during the study with only one oyster (light infection) out of 100 (four samples of 25 oysters each) being infected. Infection in pond 6 oysters (high-L) increased from the initial infection (incidence = 76% and weighted incidence = 1.9) to a high (incidence = 100% and weighted incidence = 3.2) in early November. Subsequently, it decreased to a low (incidence = 56% and weighted incidence = 0.7) in late December, 1972. By this time the pond 6 oysters had accumulated a 58% mortality. Intake canal oysters (high-L) were only checked for *Labyrinthomyxa* infection twice during the study (Table 6). Initially they had a

TABLE 6. *Labyrinthomyxa* incidence and weighted incidence for surviving oysters by area during the period 19 October, 1971 to 29 December, 1972.

	19 Oct 1971*	3 Mar 1972	10 July 1972	9 Nov 1972	29 Dec 1972
Pond 7 (Beasley's Reef)					
Incidence	0	0	0	4 %	0
Weighted incidence	0	0	0	0.04	0
Pond 6 (Redfish Reef)					
Incidence	76%	86%	84%	100%	56%
Weighted incidence	1.9	1.5	1.8	3.2	0.7
Intake Canal (Redfish Reef)					
Incidence	76%	-	-	-	12.5%
Weighted incidence	1.9	-	-	-	0.06

- = no sample taken

* = initial sample taken from natural reef

low level of infection (incidence = 12.5% and a weighted incidence = 0.06). At this time, the number of intake canal oysters (high-L) had been drastically reduced by mortality (81%).

Heavy Metal Concentrations

Pond oysters and intake canal oysters contained similar concentrations of heavy metals except for zinc and iron (Table 7). Intake canal oysters had higher zinc concentrations (514 mg zinc/kg wet tissue = ppm) than pond oysters (332 ppm) while the pond oysters had higher iron concentrations (126 ppm) than the intake canal oysters (39 ppm). All values for heavy metals in Table 7 (page 52) are in ppm.

Gonadal Development

The four tissue examinations made during this study (March, July, November and December) revealed mature gonads in the majority of the oysters sampled only in July, at which time some oysters appeared partially spawned. A smaller proportion of the oysters examined in March had mature gonads. Oysters in the November sample had spawned or reabsorbed their gonadal tissue while oysters in the December sample had no developed gonadal tissue.

TABLE 7. A comparison of heavy metal concentrations found in oysters held at the Cedar Bayou Generating Station with oysters held at other areas

		Arsenic	Mercury	Lead	Copper	Manganese	Iron	Cobalt	Zinc
Cedar Bayou Power Plant									
Intake Canal	12-28-72	1.70	0.04	0.49	12.35	2.77	39.33	5.24	513.80
Ponds Along Discharge Canal	12-28-72	1.00	0.03	0.29	16.23	3.62	126.20	5.19	332.10
Crystal River Power Plant[a]									
Intake Canal	12-11-69	Nd[d]	Nd	1.75	8.00	Nd	33.00	Nd	200.00
Discharge Canal	12-11-69	Nd	Nd	1.90	35.00	Nd	33.00	Nd	475.00
End of Discharge Canal	12-11-69	Nd	Nd	2.00	15.00	Nd	38.00	Nd	250.00
Morgan's Point Reef (prohibited shellfishing area)[b]	12-8-70	Nd	0.05	1.30	42.00	6.00	Nd	Nd	1100.00
Dry Hole Reef (approved shellfishing area)[c]	11-12-70	< 0.30	0.04	< 0.30	4.79	0.70	7.34	< 0.15	26.12
Maximum Acceptable Levels in Shellfish[b]			0.20	0.20	100.00				1500.00

[a] Grimes (1971)

[b] Mr. Robert Hofstetter (Texas Parks and Wildlife Dept., Seabrook, Texas)

[c] Anonymous (1971)

[d] Nd = No data

Spat Set

Forty-three spat were collected on experimental oysters and cultch (oyster shell) from 7 July to 1 November, 1972. No spat were found on the asbestos plates. Thirty-eight spat were collected in the ponds, 5 in the intake canal and none in the discharge canal.

Fouling Organisms

Several species of fouling organisms were found on the oysters, asbestos plates and cultch (oyster shell) during this study. No fouling organisms were collected on the oysters, asbestos plates or cultch in the discharge canal. The intake canal and pond oysters had large concentrations of the ivory barnacle, *Balanus eburneus* (about 25 to 100 barnacles/oyster) set on them during most months of the study. There did not appear to be any seasonality to barnacle abundance. Large concentrations of the platform mussel, *Congeria leucopheata*, were found mainly on pond oysters and were most abundant in August.

DISCUSSION

According to Kinne (1967), available information indicates that biological methods of compensating for salinity changes are better developed than those for temperature among estuarine organisms. He also says that salinity is compensated for mainly by regulation (ion, volume osmoregulation) and reduction of contact (closure of shells) while adverse temperatures are tolerated rather than compensated for. Pearse and Gunter (1957) suggested that osmoregulation is facilitated by higher temperatures but Kinne (1963) believed that the osmoregulatory capacity of a given species is greatest at or just below optimum temperatures and decreases in supra-normal temperatures. Collier (1953) studied the pumping rates, growth rates and mortality rates of _C. virginica_ and concludes that their optimum temperature range lies between 15° and 25°C, even on the Gulf Coast. Galtsoff (1964) says that the maximum rate of ciliary activity responsible for the transport of water is at about 25° to 26°C; above 32°C ciliary movement rapidly declines. He also says that nearly all functions of the body cease or are reduced to a minimum at approximately 42°C. Galtsoff reports that the effect of salinity on growth of _C. virginica_ is minimal as long as it is maintained within a range of 10-34‰, but if salinity should become critically low (5‰), feeding and growth may become abnormal or cease altogether.

Andrews et al. (1959) have found that oysters are less tolerant of low salinities at higher temperatures. Loosanoff (1952) has shown that as temperatures rise oysters die at a more rapid rate from freshwater exposure.

Abbe et al. (unpublished report) investigated the growth and mortality of tray-held oysters in the vicinity of Potomac Electric Power Company's Chalk Point steam electric station in the Patuxent River, Maryland. They found heavy mortality in oysters held at low salinities (below 5‰) and warm water temperatures (near 28° C) and conclude that low salinity at a time of elevated ambient temperature was the main cause of the severe mortality.

Our oysters, subjected to discharge canal water, experienced a 100% mortality (172 oysters) within a 13-day period (11 to 24 May). During this period, water temperatures reached 34.5° C and salinities remained below 5‰. If oysters studied by Abbe et al. were killed by high temperatures and low salinities, then it would appear that our oysters, exposed to even higher temperatures, were also killed by a combination of these two parameters.

Pond oysters grew better and had less mortality than intake canal oysters during this study. At normal flow rates the pond waters had a long residence time (about 1 week); thus, phytoplankton had sufficient time to reach bloom proportions, as indicated by frequent high chlorophyll a and D.O. levels. Oysters feed on phytoplankton and probably had more such food available in the ponds, particularly pond 7, than in the intake canal. The presence of mullet and their food in these ponds may also have favored phytoplankton growth. In addition, particles of fish food and/or fecal material may have supplied food directly to the pond oysters. Oysters in the intake canal were also subjected to lower salinities than pond oysters. During the rainy period in May, when the pump that transferred water from the discharge canal to the ponds was shut off, pond oysters were not exposed to as low a salinity as were intake canal oysters.

Maurer and Tinsman (1971) studied the effect of a thermal effluent on the survival, growth, condition and reproductive behavior of C. virginica held at the intake canal, the effluent site and a site 2.5 kilometers from the effluent site of a power plant in Indian River Bay, Delaware. They found that highest mortality and heaviest fouling occurred in summer at the effluent site. In contrast, shell growth was highest in the winter at the effluent site.

It is of interest to compare the growth and mortality of oysters kept in power plant canals and ponds with oysters living under natural conditions in the same geographic area. Data on growth and mortality of oysters suspended on a natural reef in Galveston Bay, Hanna Reef, during 1972 were obtained from Mr. Robert Hofstetter (Texas Parks and Wildlife Department, Seabrook, Texas). Data from Hanna oysters of sizes nearest to ours were selected for comparisons. Oysters held in the ponds or intake canal grew as well, or better than the oysters on the natural reef. During the first 9 months of 1972, the low-L oysters in pond 7 and the intake canal increased in average length 14 and 5 mm, respectively, while large Hanna oysters showed no growth (Table 8). During 1972, the high-L oysters in ponds 6 and the intake canal increased in average length by 26 and 11 mm, respectively, while the small Hanna oysters increased about 26 mm in average length. The infection of pond 6 oysters with <u>Labyrinthomyxa</u> apparently prevented the increase in shellfish biomass noted in uninfected oysters held in pond 7.

Our low-L (large) oysters tended to have less mortality than the large Hanna oysters (Table 9). The small Hanna oysters had lower mortality than that of high-L (small) oysters in the intake canal. Mortality of small Hanna oysters was similar to that observed in high-L pond oysters.

Most heavy metal concentrations, found in oysters held for 1 year in the intake canal or in ponds receiving discharge canal water at the Cedar Bayou generating station, were below maximum acceptable levels

TABLE 8. A comparison of monthly average lengths (mm) of oysters from Redfish and Beasley's reefs held at the Cedar Bayou power plant to oysters collected and held on Hanna reef.

Month	Cedar Bayou Power Plant				Hanna Reef	
	Low fungal infection		High fungal infection		High fungal infection	
	Pond 7	Intake canal	Pond 6	Intake canal	Small	Large
January	96	92	74	72	47	103
March	97	93	74	72	53	106
July	107	98	84	78	57	99
August	108	98	92	82	61	101
September	110		99	85	62	103
December	114		99	87	72	

TABLE 9. A comparison of the monthly mortality rates (%) of oysters from Redfish (high-L) and Beasley's (low-L) reefs held at the Cedar Bayou power plant to oysters collected and held on Hanna reef (Galveston Bay).

Month	Cedar Bayou Power Plant				Hanna Reef	
	Low fungal infection		High fungal infection		High fungal infection	
	Pond 7	Intake canal	Pond 6	Intake canal	Small	Large
January	2	3	3	1	1	1
February	0	0	2	2	1	1
March	0	0	3	0	2	1
April	1	1	0	2	10	4
May	0	1	7	1	22	6
June	2	30	5	34	46	8
July	0	3	19	6	84	12
August	2	3	5	12	18	14

for shellfish (Table 7). Lead was somewhat above the maximum acceptable level but considerably below levels observed in oysters near the Crystal River power plant in Florida. Higher concentrations of heavy metals were found in Morgan's Point (a prohibited shellfishing area) oysters than in oysters held at the Cedar Bayou generating station. However, oysters from Dry Hole reef (an approved shellfishing area) had lower concentrations of all heavy metals except mercury than oysters from the generating station. Mercury concentrations found in oysters from these two areas were similar.

Spat set in the ponds was light in comparison to that found on many natural reefs, but it does indicate that pond water quality was suitable for larval oysters. As noted previously, no spat set in the discharge canal, probably due to high water temperatures and/or swift currents. Slow residence time of pond water may have permitted oysters in the ponds to produce the spat collected there. Two histological examinations of pond oysters, one in March and one in July, revealed developed gonads. Elam (1972) found that oysters in non-flowing ponds showed no evidence of spawning, apparently due to delayed gonadal development.

Fouling organisms must be considered when determining the feasibility of oyster pond culture at the Cedar Bayou power plant. Several hours each month were required to remove fouling organisms from pond and intake canal oysters. Engle and Chapman (1953) found that oysters covered with mussels, *Brachidontes recurvus*, had 27.5% less meat per animal than those free of mussels. Few *Brachidontes* were found on our oysters; however, high concentrations of *Congeria* and *Balanus* might also reduce the amount of meat per oyster.

CONCLUSIONS

It appears feasible to raise oysters in ponds receiving discharge canal water at the Cedar Bayou generating station if *Labyrinthomyxa* infection can be controlled. By regulating the amount of water going into each pond, water temperature and salinity can be controlled to some extent, thus providing a means for minimizing the effects of *Labyrinthomyxa* on oyster populations held in the ponds. Pond oysters may also have benefited from mullet culture activities which were carried on concurrently in the same ponds. Pond oysters grew better and had less mortality than intake canal oysters, regardless of *Labyrinthomyxa* infection. Highest mortality occurred at the head of the discharge canal during warm seasons. Oysters held in the ponds grew as well or better than oysters from a natural reef in Galveston Bay. Evidence of oyster reproduction was also noted in the ponds. Heavy metal concentrations both in pond and intake oysters were lower than those in oysters from a Galveston Bay reef (not approved for shellfishing) near the power plant intake canal. However, of the eight metals determined, all but mercury were higher in our experimental oysters than in oysters from an approved shellfishing reef in Galveston Bay.

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