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A Comparative Study of a Salt Water Impoundment with Its Adjacent Tidal Creek Pertinent to Culture of *Crassostrea Virginica* (Gmelin)

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A COMPARATIVE STUDY OF A SALT WATER IMPOUNDMENT WITH ITS ADJACENT TIDAL CREEK PERTINENT TO CULTURE OF <u>CRASSOSTREA VIRGINICA</u> (GMELIN)

by

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ABSTRACT

A COMPARATIVE STUDY OF A SALT WATER IMPOUNDMENT WITH ITS ADJACENT TIDAL CREEK PERTINENT TO CULTURE OF *CRASSOSTREA VIRGINICA* (GMELIN)

William D. Anderson
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Certain physical, chemical and biological characteristics associated with the culture of subtidal *Crassostrea virginica* were assessed in a salt water impoundment and its adjacent tidal feeder creek. Large seed oysters (initial $\bar{y}$ = 57.3 mm) were transferred from a somewhat polluted estuary of Charleston Harbor to floating, mid-water, and bottom hardware cloth trays (200/tray) in a four hectare pond. Identical trays at comparable depths were placed in the tidal creek and each location was sampled monthly for growth and survival. Surface and bottom water samples were collected weekly throughout the study and hourly during four seasonal 25 hour stations. Standard hydrographic parameters (temperature, salinity, pH, dissolved oxygen, light penetration, and turbidity) were measured along with chlorophyll *a*, phytoplankton, dissolved and particulate carbohydrates, nutrients (nitrates, nitrites, orthophosphates and silicates), current velocities, and thioglycollate assays for *Labyrinthomyxa marina*.

Over a 12 month period, oyster growth was significantly ($\alpha = 0.01$) greater in the pond than the creek. Best growth in the impoundment occurred in floating trays; poorest in bottom trays. Growth and survival were higher in winter and lower in summer in both environments.

Higher levels of chlorophyll *a*, carbohydrates, pH, and dissolved oxygen were consistently observed in the impoundment. Lower comparative nutrient values in the pond together with higher biomass levels indicated a more favorable environment for autotrophic production. Greater oyster production in the pond was directly related to a higher instantaneous biomass maintained throughout the year. This relationship was supported by indications of an inverse correlation between nutrient concentrations and the instantaneous biomass. Nutrient and biomass data indicated an apparent NO_3^- limited system.

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"Indeed, I cannot think why the whole bed of the ocean is not one solid mass of oysters, so prolific the creatures seem...

"No doubt there are natural enemies which limit the increase of the creatures. You and I, Watson, we have done our part."

Sir Arthur Conan, Doyle, 1913

"The Adventure of the Dying Detective"

INTRODUCTION

Salt marsh estuaries are among the most productive natural ecosystems in the world (Odum, 1961; Schelske and Odum, 1961). In certain restricted estuarine areas, shellfish production is greater per unit of area than any form of animal protein (Ryther, 1969). Fifty-five percent of the world's commercial oyster harvest is produced from the 10% of the world's oyster beds which receive cultivation (Loosanoff, 1960, cited by Linton, 1968). Numerous processes contributing to the fertility of estuarine marshes have been suggested to explain this function of high productivity (Smalley, 1959; de la Cruz, 1965; Heald, 1969, Odum, 1970; and Kirby, 1971; Keefe, 1972; de la Cruz, 1973). Furthermore salt water impoundments appear to exceed even these high production rates (Lunz, 1958). Results of impounded water studies within the marsh-estuarine environment pertaining to oyster culture by Lunz (1951), Shaw (1965), May (1969), and current studies at this laboratory (Manzi & Burrell, 1976) indicate another level of higher ecosystem productivity.

Utilization of salt water ponds for the cultivation of oysters can be traced back to the Romans in the first century B.C., although the Chinese may have originated the practice even earlier (Yonge, 1960). Extensive reviews of early oyster culture and artificial propagation of larvae can be found in Dean (1892 and 1893), Baughman (1948), Loosanoff and Davis (1963), Galstoff (1964), and Joyce (1972).

Oyster pond culture in enclosed tidal areas (Dean, 1892 and 1893) has been more extensively developed in France than in other European countries. Young spat are collected on roofing tiles and transplanted to tidal ponds. Prior to marketing they are again transplanted into claires, or deeper rectangular basins where the oysters may double their weight in six months (Yonge, 1960). Ponds were used in Holland primarily for growing seed oysters (Dean, 1893), and in Belgium to fatten the oysters for market (Yonge, 1960).

One of the first pond oyster culture experiments in the United States was conducted in an impoundment salt marsh adjacent to Chincoteague Bay, Maryland (Ryder, 1883; Shaw, 1965). Fertilized eggs were introduced into the artificial pond and newly set oysters were observed 46 days later. Ryder concluded that the experiment proved that impounded water areas could be utilized for oyster cultivation similar to methods practiced in Europe. He also observed abundant phytoplankton production in the pond, "greatly in excess of what may be found in the open bay." Perhaps the most comprehensive study of physical and biological factors in a salt water pond was a three year ecological investigation by Carriker (1959) in Home Pond, a tidal embayment on Gardiners Island, New York.

Salt water ponds for aquaculture have the following advantages over open estuarine areas: (1) protection from strong waves and adverse currents; (2) easier access to bottoms for planting and management; (3) predator control; (4) modification of tidal exchange; and (5) artificial fertilization (Bouchon-Bradley, 1882; Gaarder and Spärck, 1932; Turner, 1951; Lunz, 1955 and 1956; Koringa and Postuma, 1957; Carriker, 1956 and 1959; Loosanoff, 1964; Shaw, 1965; and Binmore, 1964. All salt water pond culture attempts have not necessarily been successful. Lunz (1955) reported a disastrous mortality resulting from what was later thought to be Labyrinthomyxa marina and possibly other predators. Evermann (1904), Lindsay (1947-1953) and others described unsuccessful attempts at pond cultivation, attributing failures to silting and high salinity predators.

Intertidal oysters predominate in South Carolina, Georgia and Northeastern Florida. Lunz (1958) and Smith (1949) thought subtidal oyster growth may be affected by silting and a relatively large tidal range in this region of approximately two meters. These conditions contrast to lower tidal amplitudes and less turbidity in the Mid-Atlantic and Gulf coasts where subtidal oysters predominate. Battle (1891) first proposed tidal pond cultivation in South Carolina in his investigation of the state's coastal waters for the U. S. Fishery Commission. However, cultivation of oysters and fish in marsh impoundments using an experimental approach was not initiated in South Carolina until 1943 (Lunz, 1967). Water was maintained in a one acre pond at approximately the spring tide height of the adjacent creek, and no attempt was made to "manage" the pond. In this study, Lunz (1956) observed faster growth of bottom oysters in the ponds than in nearby creeks and rivers. During subsequent harvests, gigantism was observed in blue crabs (Callinectes sapidus), many weighing up to 567 grams each (Lunz, 1951). An average weight for a matured male in this area is $\sim$ 180 grams. Further experimentation illustrated successful polyculture of fish, crabs, and oysters in the same pond. Oyster yield was 35.2 cubic meters of shell stock per 0.4 ha in one annual study (Lunz, 1967). Ponds dug in the marsh appeared to be less productive than impounded marshlands (Lunz, 1967).

Before pond culture can become a reasonably predictable process, specific knowledge of the impounded environment is required. Knowledge of the optimum growing periods, time of transplanting, along with survival and yield of oysters at various water levels during the year is necessary for successful cultivation.

Therefore, a program of environmental monitoring which assessed selected physical, chemical and biological characteristics of a salt water impoundment in comparison with its tidal feeder creek was conducted over a 12 month period to evaluate factors affecting the growth rate, meat production and survival of C. virginica.

The primary objectives of the study were (1) to determine whether oysters actually grew faster in an impounded environment compared to its adjacent tidal creek; (2) at what depth most favorable growth occurs, and (3) if greater production did occur in the impoundment, what were the parameters associated with accelerated growth.

Ancillary objectives included monitoring survival and determining periods of most favorable growth in each environment. The selected physical, chemical, and biological characteristics were to be compared in a qualitative analysis of each environment in regard to oyster dynamics.

METHODS

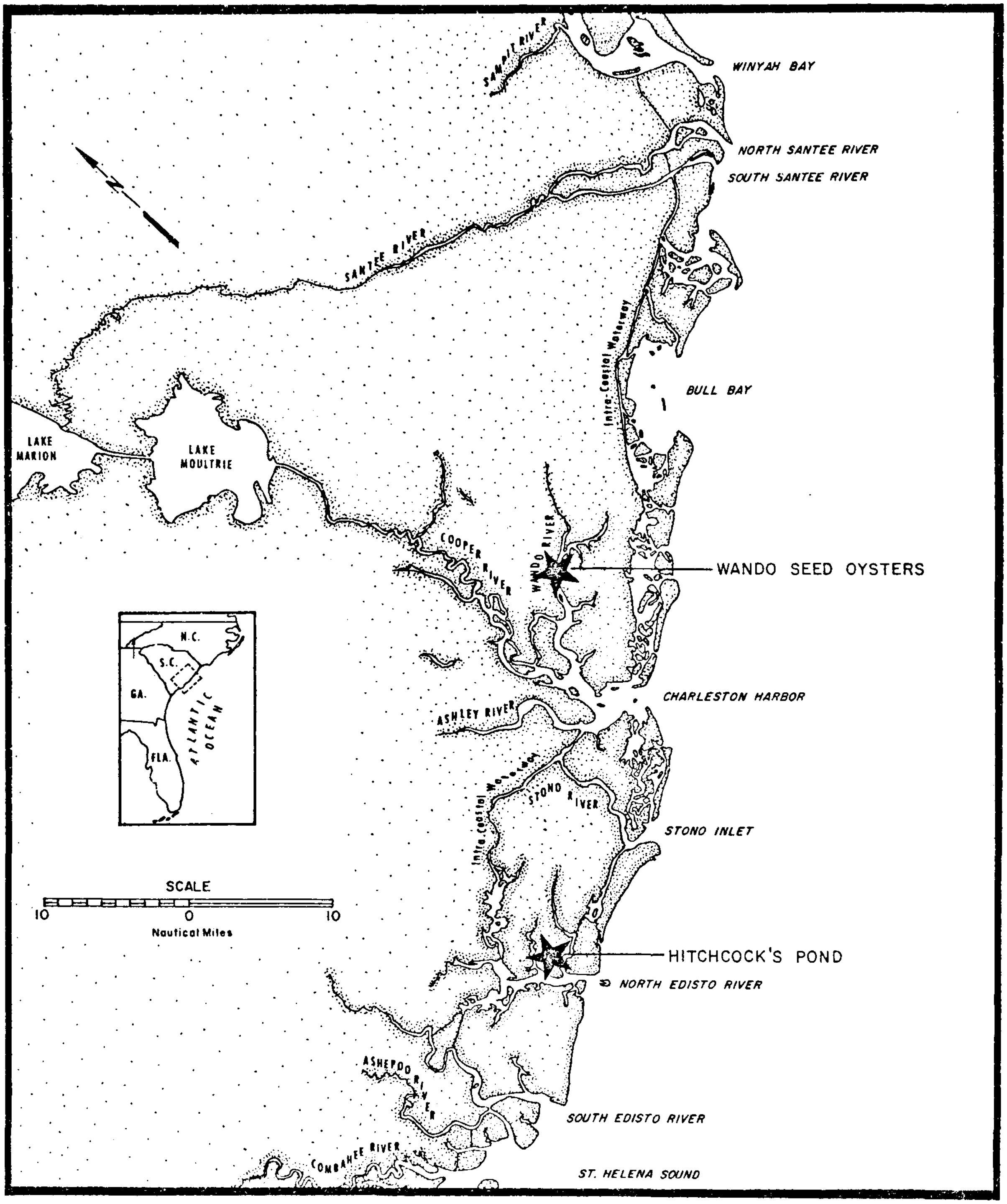
Two stations were selected for their relative seclusion from public interference and proximity to each other. The salt water impoundment (Hitchcock's Pond) is located on Wadmalaw Island, South Carolina, 800 meters west of the North Edisto River and 400 meters south of Leadenwah Creek. It was formed several years ago by damming Adams Creek, a small tidal creek that feeds into the North Edisto River through an extensive *Spartina* marsh (Figure 1). The four hectare pond is surrounded by maritime forest. Prior to transplanting the experimental oysters, the impoundment was subjected to tidal fishing from Adams Creek through a hinged floodgate.

Adjacent to Hitchcock's Pond, Adams Creek constituted the tidally influenced experimental environment with a mean tidal amplitude of 1.8 meters.

Materials and Methods, Field

Large seed oysters ($\overline{y}$ = 57.3 mm) were dredged from subtidal seed beds in the Wando River ($\overline{x}$ salinity = 11.0 ^{o}/oo), a polluted estuary of Charleston Harbor (Figure 1). Oysters were culled and cleaned, then transferred (200 oysters per tray) to 18 1.5 m x 0.9 m x 0.1 m hardware cloth trays reinforced with 1.27 mm iron rods. Oysters were measured monthly from the umbo to a point tangent to the periphery of the lip using Vernier calipers to determine growth. Three trays were placed at each of three water levels in each environment: bottom, mid-water, and surface. Bottom trays in both the pond and creek were sunk to

Figure 1. Location of the experimental area. Seed oysters were dredged from the Wando River and transferred to Hitchcock's Pond and Adams Creek near the North Edisto River.



WINYAH BAY
SAMPIT RIVER
NORTH SANTEE RIVER
SOUTH SANTEE RIVER
N
SANTEE RIVER
Intra-Coastal Waterway
BULL BAY
LAKE MARION
LAKE MOULTRIE
COOPER RIVER
WANDO RIVER
WANDO SEED OYSTERS
N.C.
S.C.
GA.
FLA.
ATLANTIC OCEAN
CHARLESTON HARBOR
ASHLEY RIVER
STONO RIVER
STONO INLET
SCALE
10
0
10
Nautical Miles
HITCHCOCK'S POND
NORTH EDISTO RIVER
ASHEPOO RIVER
SOUTH EDISTO RIVER
COMBAHEE RIVER
ST. HELENA SOUND

approximately 15 cm above the bottom. Mid-water trays in the pond were supported on wooden stilts to an interval of one half the controlled pond depth of one meter. The three creek mid-water trays were supported in the same manner subject to the creek mean water depth ($\sim$ 0.9 meters above bottom). This resulted in oysters being exposed at low tide. Floating trays, consisting of regular trays with two styrofoam logs lashed on each side suspended oysters approximately 0.2 m below the surface in both environments. Floating trays in the pond were simply tied to stakes by nylon cord. However, metal rings were welded at each end of the creek floating trays and secured by vertically sunk galvanized pipes extending through the rings similar to a floating dock. Floating trays in the creek were subjected to an average 1.8 meter tidal amplitude. Spring and storm tides increased this excursion to nearly 2.1 meters. The two stations represented different physical habitats due to nearly total elimination of a tidal cycle in Hitchcock's Pond. The impoundment received salt water as overflow from Adams Creek only during spring and storm tides.

Oyster growth was monitored monthly by measuring fifty oysters from each tray; mortalities were recorded and gapers (dying oysters with meats) examined histologically for Labyrinthomyxa marina. Trays and oysters were cleaned of accumulated algae, bryozoa, colonial hydrozoans, and curved mussels at this time. An August kill of all bottom oysters in each environment shortly after experimentation began necessitated another transplant of Wando seed in September. At the same time, previous mortalities in midwater and floating trays were replaced with

Wando transplants. At the end of a 16 month period, all surviving oysters were measured and shucked. Meat yield at each location was determined by measuring the total wet meat volume in graduated cylinders and comparing this with total shell volume.

Physical, chemical, and biological factors thought to influence oyster growth were assessed from water samples collected at weekly intervals throughout the year during daylight hours. These characteristics were observed hourly over a complete tidal cycle during four seasonal 25 hour stations.

Discrete surface and bottom water samples were obtained at very precise depths from specially constructed piers extending into the pond and creek on both sides of the dam. Bottom water samples were obtained 15 cm above the bottom, without disturbing the sediment, using L-shaped PVC tubing flushed by hand pumping. Surface water samples were obtained in the same manner utilizing a float attachment to gauge depth 15 cm below the surface.

The following _in situ_ methods were used to obtain data during each sampling period:

Water Temperature - stem thermometer in Kemmerer sampler

Air Temperature - stem thermometer

Light Penetration - Secchi disc

Turbidity - Hach Model 2100A turbidimeter; calibrated with formazin turbidity units

_pH_ - Instrumentation Laboratory, Inc. Porto-matic pH meter #175

Cloud Cover, Wind Direction and Windspeed - Visual estimations

Current Velocities - A savonius rotor current meter, Bendix ESD Model Q-9, was suspended in Adams Creek 15 cm above the bottom from a galvanized pipe tripod during the seasonal 25 hour stations. Current velocity was recorded hourly in meters/sec.

Hydrogen Sulfide - A Bausch and Lomb Mini Spec 20 Spectrophotometer measured absorbances of the standard and in situ samples. An Orion Model 94-16 silver sulfide ion electrode with an Orion Model 90-02 Double Junction Reference electrode was used with a Corning pH meter Model 10 to detect the endpoint in titration of sodium sulfide by silver nitrate (Barica, 1973).

Materials and Methods, Laboratory

Water samples were returned to the laboratory for the following analyses:

Salinity - Beckman Model RS7B induction salinometer

Dissolved Oxygen - collected with Kemmerer sampler and pickled at time of sampling; Winkler-Carpenter titration.

Chlorophyll *a* - spectrophotometric determination of chlorophyll *a* and its degradation products were determined by extraction (Richards and Thompson, 1952 as modified by Strickland and Parsons, 1972). SCOR/UNESCO equations (1966) were used to calculate total μg of chlorophyll *a*/liter. Samples were collected in 1 liter polyethylene dark bottles, and a few drops of 1% $MgCO_3$ were added during filtration to minimize degradation of chlorophyll to phaeo-pigments. Aliquot size varied at different times of the year, determined by the efficiency of filtration through Gelman

Type A/E glass fiber 47 mm filters. The filters were subsequently ground in a solution of 90% aqueous acetone with a 15 ml tissue grinder and rinsed into a 15 ml graduated centrifuge tube. A volume of 10 ml was preserved after 24 hours under refrigeration and in darkness. Following extraction, the tubes were allowed to reach room temperature and then centrifuged. The absorbances were read on a Shimandzu double-beam spectrophotometer UV-200.

Phytoplankton - half-liter phytoplankton samples were collected with a Kemmerer sampler and transferred to 500 ml polyethylene bottles during seasonal 25 hour stations and preserved for future identification with 20 ml of buffered formalin.

Dissolved Carbohydrates - phenol-sulfuric acid reaction (Strickland and Parsons, 1972). Whatman GF/C 4.25 cm glass fiber filters used prior to filtration were heated to 500°C for one hour in a muffle furnace to eliminate organics. Dissolved carbohydrates were sampled only on a weekly basis.

Particulate Carbohydrates - anthrone reaction (Strickland and Parsons, 1972) 2.5 cc of a 1% M_gCO_3 were added to 150 ml of distilled water in the filtering apparatus and agitated without suction. The vacuum pump was then applied, flushing the Millipore 47 mm HAWP filter while coating the surface with magnesium carbonate prior to filtration of the sample to facilitate later removal of the particulate with filtered sea water. The sample particulate was rinsed directly into a centrifuge tube, bypassing the 3 ml beaker suggested by Strickland and Parsons (1972). Filters were frozen and analyzed at a later time.

Nutrients - 50 ml aliquots were frozen in dry ice immediately after sampling; nitrates, nitrites, and silicates were analyzed with a Technicon Autoanalyzer II: orthophosphates were determined by the Ascorbic acid method (Standard Methods, 1971) using a Shimandzu double-beam spectrophotometer UV-200.

Histological Examinations - remaining tissues of gapers and live oysters were cultured periodically in fluid thioglycollate medium for ten days. After incubation, infections were exhibited in the cultured tissue by the presence of hypnospores stained with Lugol's aqueous iodine potassium iodide. The approximate number of hypnospore cells per unit volume of host tissue represented a quantative assay for monitoring the oyster pathogen, *Labyrinthomyxa marina* (Ray, 1952 and Quick, 1972).

RESULTS

Salinity

Salinities recorded in Adams Creek ranged from a high of 31.2 $^{o}/oo$ (Nov. 1975) to a low of 4.8 $^{o}/oo$ (April 1975) (Table 1). The range in Hitchcock's Pond was similar: 30 $^{o}/oo$ (July 1974) and 4.2 $^{o}/oo$ (April 1975). Both environments were influenced by a watershed area that produced lower surface salinities from freshwater runoff. Periodically heavy rainfall resulted in overflow from Hitchcock's Pond to Adams Creek. Figure 2 depicts monthly average salinities and water temperatures. Pond salinities throughout the year were lower than those of the creek. A surface to bottom salinity differential averaged 2.9 $^{o}/oo$ in the pond. Although a salinity gradient normally existed throughout the study, numerous weekly recordings showed no surface to bottom salinity differences. Three of the four 25 hour stations exhibited haloclines in the impoundment with only slight changes during the diurnal sampling period (Figure 3). Rainfall during the summer 25 hour station lowered surface salinity at one point from 22.6 $^{o}/oo$ to 12.9 $^{o}/oo$, while bottom salinities remained nearly constant. The single exception to diurnal salinity stratification in the pond was observed during the fall 25 hour station, as both surface and bottom salinities maintained a reading of 20 $^{o}/oo$ for fifty samples.

Adams Creek exhibited a similar, though weaker salinity gradient, as the stage of the tide influenced surface and bottom differences. As anticipated during the 25 hour stations, salinities were highest in the creek at high tide and lowest at low tide. Weaker gradients occurred

Table 1. Hydrographic Data

	Temperature (°C)				Salinity (o/oo)			
	Creek		Pond		Creek		Pond	
Date	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
24 June 74	28.1	27.8	28.3	28.3	28.5	29.4	28.8	28.8
1 July	29.5	29.0	32.5	32.3	27.4	27.4	26.4	26.8
8 July	26.8	27.5	31.4	33.2	26.5	27.3	19.4	24.1
16 July	32.0	31.8	33.3	32.4	27.3	27.8	23.8	24.2
24 July	29.0	28.6	30.5	29.8	12.6	30.7	29.6	30.0
30 July	27.9	27.8	29.5	29.5	29.2	29.5	28.1	28.2
7 August	27.1	26.9	26.4	27.0	26.6	26.9	16.8	26.0
13 August	28.8	28.6	28.0	29.5	23.1	24.5	7.9	13.4
20 August	27.9	27.9	27.9	27.6	22.8	23.9	12.0	22.9
27 August	28.5	28.5	30.4	30.5	22.2	23.3	16.3	16.4
3 September	29.2	29.8	30.9	30.7	24.4	25.7	16.2	16.2
10 September	28.2	26.8	27.0	26.8	22.3	25.2	12.5	13.2
17 September	31.8	31.5	30.2	30.1	24.6	24.7	9.3	23.8
23 September	23.7	23.8	23.0	23.2	25.2	26.4	11.7	18.6
30 September	23.9	23.9	24.8	24.6	25.7	27.8	12.0	12.0
8 October	20.2	20.1	20.8	20.7	18.6	22.6	12.8	13.2
16 October	22.0	21.9	24.3	22.9	27.1	29.5	27.9	16.4
21 October	15.7	15.1	15.9	16.5	28.4	29.0	17.2	22.1
30 October	22.6	22.6	23.8	23.8	22.0	23.8	20.0	20.0
6 November	21.7	21.6	22.4	22.4	29.0	28.4	20.5	20.5
13 November	14.5	14.5	13.8	14.8	30.5	31.2	26.2	27.4
20 November	17.8	17.0	19.4	19.6	28.9	29.8	27.4	27.6
25 November	17.0	17.0	16.3	16.2	28.0	28.2	26.4	27.9
2 December	10.1	9.6	8.8	8.8	28.5	29.2	27.4	27.4
9 December	11.4	—	11.1	11.0	27.1	--	27.2	27.2
16 December	12.1	11.7	12.4	12.1	27.7	29.1	24.6	27.3
23 December	16.2	16.0	12.6	14.2	25.0	25.1	8.0	24.9
2 January 75	14.4	13.4	12.5	14.9	26.6	27.6	16.1	22.2
7 January	10.2	10.4	10.5	12.5	22.4	22.4	16.2	21.6
14 January	12.8	12.4	10.6	14.4	24.0	26.5	13.5	17.5
21 January	13.7	13.2	11.2	13.0	16.0	19.3	10.5	13.8
28 January	13.0	12.8	14.2	13.8	23.2	25.5	21.7	23.5
4 February	11.9	11.7	9.2	10.2	24.3	24.9	12.7	22.7
12 February	12.9	12.6	17.2	19.3	24.3	--	7.6	15.5
19 February	17.6	15.8	19.6	19.0	22.9	24.0	8.6	12.6
26 February	13.4	13.2	13.9	13.7	20.3	23.8	11.2	20.6
4 March	15.6	15.2	10.0	10.4	16.4	16.4	11.2	15.7
10 March	13.1	12.5	13.5	12.2	20.8	22.4	10.4	17.8
18 March	14.9	14.1	15.1	15.3	22.8	23.9	9.7	9.7
24 March	19.1	19.1	21.1	21.1	17.0	17.1	9.4	17.1
1 April	16.9	16.3	17.9	17.9	18.9	22.0	10.7	11.8
7 April	16.5	15.9	16.3	16.1	17.8	24.0	8.8	8.8
15 April	18.2	18.2	20.2	18.4	18.2	20.7	5.6	8.8
21 April	20.7	20.7	22.3	21.6	4.8	4.8	4.2	4.2
29 April	23.7	23.0	25.9	25.8	24.2	24.4	24.3	24.4
6 May	23.4	23.4	24.5	24.7	24.2	24.2	24.0	24.2
12 May	23.4	22.6	24.9	24.7	24.0	24.0	23.9	24.0
19 May	27.8	27.8	28.5	28.6	20.3	20.5	20.6	20.8
27 May	27.6	27.0	29.0	29.0	22.4	24.9	12.8	12.6
2 June	26.6	26.5	28.0	28.2	20.7	22.0	14.0	14.3
16 June	28.7	28.7	31.9	31.3	24.5	25.2	17.3	17.3
23 June	26.4	26.3	26.8	26.8	25.3	25.7	20.0	20.0
$\bar{x}$	20.89	20.79	21.36	21.56	23.32	24.85	16.95	19.87
s	± 6.60	± 6.64	± 7.44	± 7.15	± 4.65	± 4.36	± 7.23	± 6.18

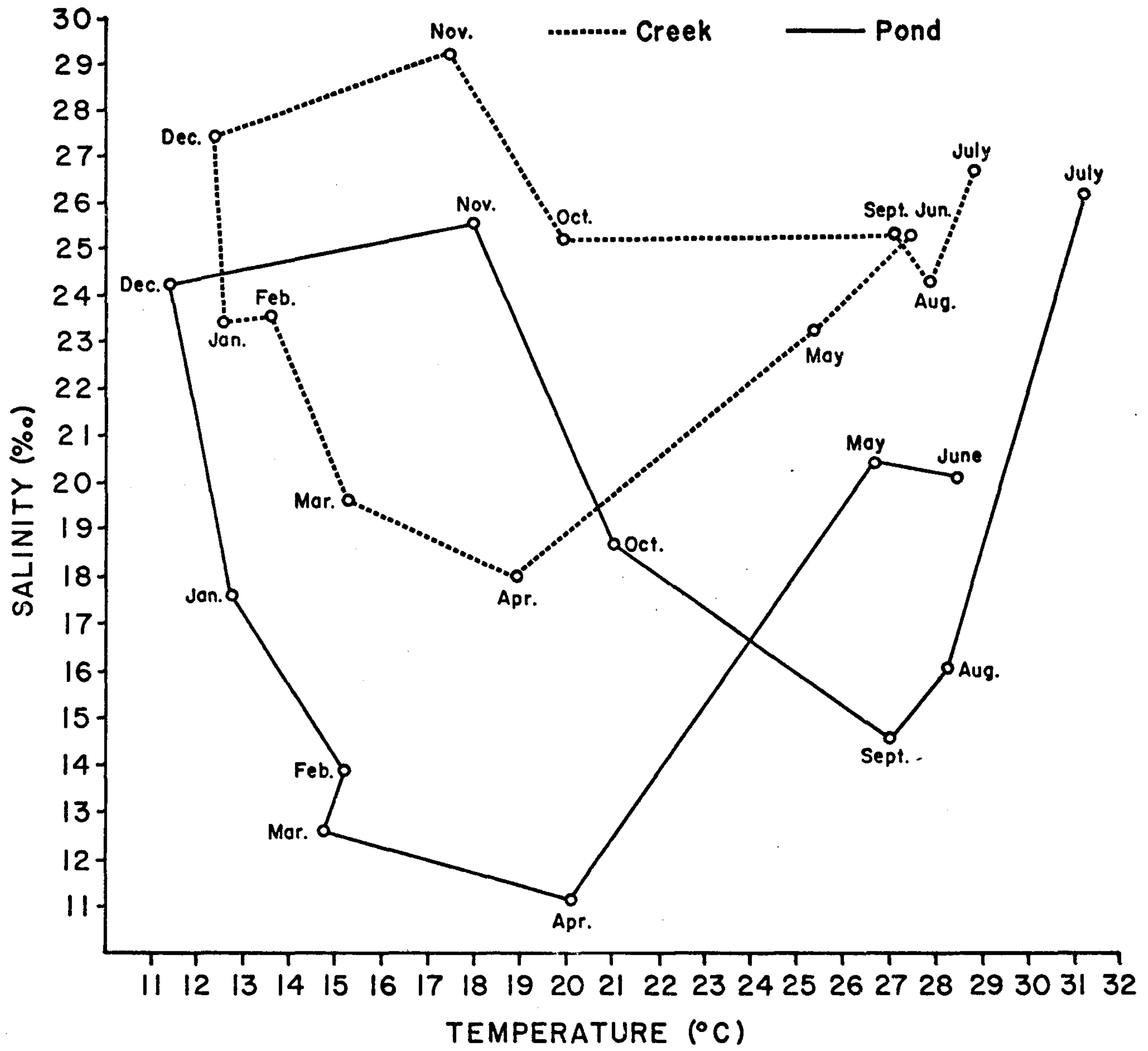
Table 1 Contd. Hydrographic Data

	Dissolved Oxygen (ml/l)				pH			
	Creek		Pond		Creek		Pond	
Date	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
24 June 74	4.1	3.7	4.4	4.2	7.4	7.5	7.5	7.6
1 July	4.1	4.1	6.8	6.6	7.2	7.3	7.7	7.8
8 July	4.1	3.8	5.7	5.3	7.5	7.5	7.5	7.5
16 July	4.3	4.4	6.4	6.2	7.6	7.6	8.3	8.3
24 July	4.5	4.1	6.5	6.4	7.3	7.4	8.0	7.8
30 July	2.4	2.2	4.6	4.3	7.7	7.6	8.5	8.5
7 August	2.9	3.3	3.7	3.4	7.2	7.1	7.7	7.7
13 August	3.0	2.7	8.3	2.8	7.2	7.3	8.1	7.1
20 August	2.4	2.2	4.0	2.5	6.7	6.6	6.9	6.8
27 August	1.3	1.3	2.7	2.5	6.1	6.2	6.4	6.2
3 September	1.7	1.7	3.3	3.2	6.8	6.9	6.9	7.1
10 September	1.3	1.0	4.3	3.5	5.9	6.6	6.8	6.9
17 September	3.4	3.2	5.5	3.8	6.4	6.7	7.1	6.7
23 September	2.8	2.7	4.7	4.8	6.4	6.4	7.1	6.7
30 September	2.0	2.1	5.2	5.4	6.5	6.6	6.9	7.0
8 October	5.1	4.8	5.9	5.9	6.8	6.9	7.2	7.4
16 October	2.9	2.7	6.5	4.8	6.9	6.8	7.1	6.8
21 October	1.9	1.8	2.7	3.0	6.9	6.9	7.3	7.3
30 October	3.4	3.4	6.9	7.1	7.2	7.1	8.2	8.3
6 November	4.2	4.4	5.4	5.4	7.6	7.7	8.0	8.0
13 November	4.0	3.6	6.4	6.0	7.4	7.3	7.8	7.8
20 November	5.1	5.2	7.4	7.3	6.5	6.7	6.9	7.0
25 November	5.0	5.2	7.6	7.8	7.4	7.4	8.1	8.0
2 December	6.1	5.9	6.8	7.1	6.6	7.0	7.4	7.6
9 December	5.9	--	6.7	6.6	7.3	--	7.6	7.6
16 December	6.3	6.2	7.1	7.3	7.7	7.6	7.9	7.9
23 December	6.6	6.6	7.3	7.8	7.7	7.7	7.8	8.2
2 January 75	5.7	5.9	6.5	6.3	7.4	7.4	7.9	8.1
7 January	4.6	--	6.5	5.9	7.3	7.4	7.6	7.9
14 January	5.4	6.2	6.4	4.5	7.8	7.9	7.9	7.7
21 January	4.5	5.2	6.7	5.9	7.2	7.2	7.6	7.7
28 January	5.9	5.7	6.5	--	6.9	7.0	7.1	7.1
4 February	5.9	5.4	7.4	6.0	7.1	7.1	7.4	7.2
12 February	5.7	5.9	8.4	8.3	7.1	7.1	7.6	7.3
19 February	6.1	4.0	6.4	6.4	7.1	7.1	7.5	7.4
26 February	5.2	5.1	7.1	5.7	7.1	7.1	7.5	7.2
4 March	5.7	5.7	7.1	6.9	6.9	6.9	7.2	7.0
10 March	5.2	5.3	6.5	6.4	6.8	6.8	7.1	6.9
18 March	--	3.8	5.3	5.0	6.9	6.8	7.3	7.2
24 March	--	5.7	7.0	6.4	6.8	6.9	7.2	6.9
1 April	4.0	3.9	5.3	5.3	6.9	6.9	7.2	7.2
7 April	5.0	4.5	6.6	6.6	6.9	6.9	7.4	7.4
15 April	4.7	4.8	7.0	6.2	6.7	6.8	7.2	7.0
21 April	5.7	5.9	6.9	7.0	7.3	7.3	7.3	7.4
29 April	4.1	4.3	5.7	5.4	6.8	6.9	7.2	7.1
6 May	2.7	2.7	4.8	5.0	6.9	6.9	7.1	7.1
12 May	2.9	2.6	6.2	4.6	6.7	6.7	7.2	7.0
19 May	4.0	3.8	4.8	4.4	6.8	7.0	7.1	7.0
27 May	2.7	2.8	5.0	4.8	6.7	6.8	7.2	7.0
2 June	1.9	2.0	2.3	2.2	6.8	6.8	7.0	7.0
16 June	3.0	3.4	4.1	4.1	6.9	6.9	7.2	7.2
23 June	2.0	1.8	4.0	3.8	6.7	6.7	6.9	6.9
$\bar{x}$	4.07	3.97	5.83	5.37	7.01	7.05	7.42	7.36
s	± 1.48	± 1.49	± 1.43	± 1.52	± .41	± .36	± .43	± .49

Table 1 Contd. Hydrographic Data

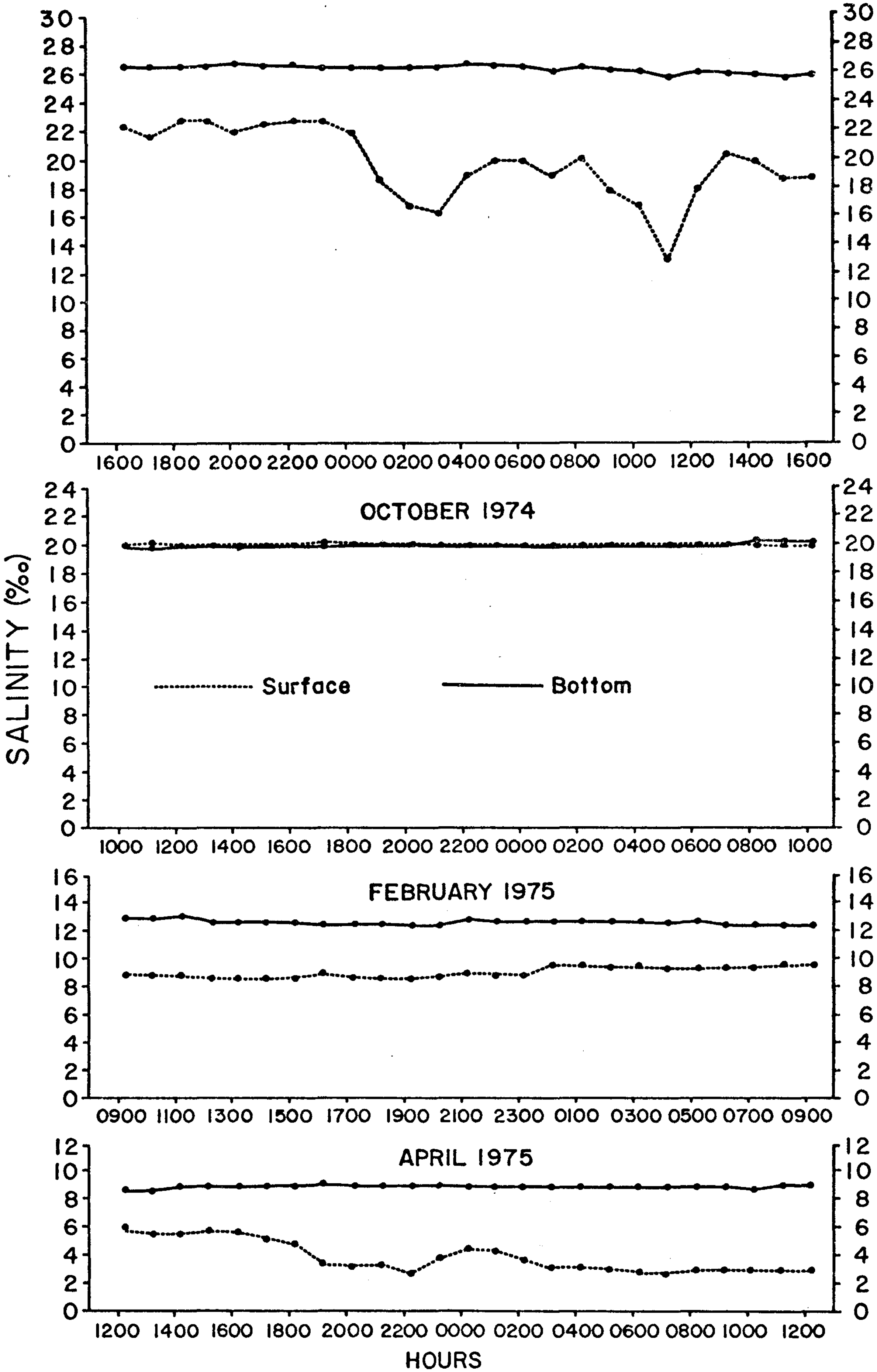
Date	Turbidity (FTU)				Light Penetration (meters)			
	Creek		Pond		Creek		Pond	
	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
24 June 74	8.0	8.0	11.5	14.5	1.0	--	1.0	--
1 July	15.0	15.5	14.0	19.0	0.8	--	0.7	--
8 July	6.5	20.5	15.5	15.5	1.0	--	0.5	--
16 July	16.0	47.0	11.0	18.0	0.4	--	0.6	--
24 July	12.0	13.0	12.0	26.0	0.7	--	0.6	--
30 July	12.0	13.0	14.5	19.5	0.6	--	0.5	--
7 August	13.0	56.0	12.0	27.0	0.6	--	0.6	--
13 August	17.5	31.0	8.0	17.0	0.4	--	0.7	--
20 August	22.0	27.4	2.6	6.7	0.4	--	0.8	--
27 August	13.0	21.0	8.0	9.0	0.5	--	0.7	--
3 September	29.0	52.0	11.0	16.0	0.5	--	0.7	--
10 September	33.0	57.0	7.0	13.0	0.3	--	1.0	--
17 September	11.0	11.0	5.5	8.5	0.9	--	1.1	--
23 September	18.0	19.0	5.5	8.8	0.6	--	1.2	--
30 September	12.0	19.0	6.3	7.1	0.5	--	0.7	--
8 October	14.4	14.0	5.0	8.0	0.5	--	1.3	--
16 October	4.9	6.0	7.1	6.8	1.3	--	1.2	--
21 October	16.0	15.0	3.5	6.6	0.6	--	1.2	--
30 October	37.0	78.0	8.0	9.0	0.4	--	0.8	--
6 November	15.0	19.0	7.2	7.6	0.9	--	1.0	--
13 November	7.5	10.5	4.4	7.9	1.1	--	0.9	--
20 November	37.4	24.0	17.0	18.5	0.2	--	0.7	--
25 November	23.0	21.0	4.5	6.0	0.7	--	0.9	--
2 December	6.4	7.3	2.4	2.6	1.4	--	1.2	--
9 December	19.0	--	1.9	2.3	0.7	--	1.2	--
16 December	7.1	6.9	2.2	2.5	1.6	--	1.2	--
23 December	21.0	26.0	2.2	3.6	0.8	--	1.2	--
2 January 75	5.3	6.6	2.1	5.8	1.3	--	1.1	--
7 January	15.0	17.0	22.0	45.0	--	--	1.2	--
14 January	6.0	6.2	2.5	5.3	1.4	--	1.2	--
21 January	14.0	17.0	2.0	3.8	0.7	--	1.2	--
28 January	7.0	7.7	3.1	5.8	1.5	--	0.8	--
4 February	7.8	9.2	4.7	3.9	1.2	--	1.0	--
12 February	5.4	5.2	2.6	3.7	1.7	--	1.1	--
19 February	24.0	11.0	2.6	8.9	1.7	--	1.2	--
26 February	4.7	17.5	5.9	6.8	1.5	--	0.9	--
4 March	14.0	14.0	4.3	10.1	0.7	--	1.0	--
10 March	7.0	12.5	10.0	9.5	0.9	--	0.7	--
18 March	8.6	13.0	13.0	13.0	0.9	--	0.7	--
24 March	17.0	18.0	12.5	13.0	0.5	--	0.5	--
1 April	16.0	22.0	15.0	17.0	0.4	--	0.4	--
7 April	20.0	22.0	15.0	16.0	0.7	--	0.5	--
15 April	23.0	28.0	16.0	18.0	0.4	--	0.4	--
21 April	23.5	22.0	12.0	14.5	0.5	--	0.5	--
29 April	13.0	14.0	14.5	19.5	0.7	--	0.5	--
6 May	34.0	41.0	16.0	25.0	0.4	--	0.4	--
12 May	17.0	27.0	13.0	25.0	0.6	--	0.7	--
19 May	33.0	30.0	14.0	22.0	0.4	--	0.5	--
27 May	9.3	8.9	15.0	18.0	0.8	--	0.5	--
2 June	37.5	44.0	16.0	17.0	0.4	--	0.6	--
16 June	10.5	12.5	14.5	18.5	0.9	--	0.5	--
23 June	16.0	21.0	14.0	19.5	0.7	--	0.6	--
$\bar{x}$	16.07	21.28	9.08	12.92	.79	--	.82	--
s	$\pm$ 9.07	$\pm$15.18	$\pm$ 5.33	$\pm$ 8.16	$\pm$ .39	--	$\pm$ .28	--

Figure 2. Monthly averages of surface and bottom temperatures and salinities in Adams Creek and Hitchcock's Pond during the year-study.



Creek
Pond
Nov.
Dec.
Oct.
Sept. Jun.
July
Aug.
Jan.
Feb.
May
Mar.
Apr.
Nov.
Dec.
Oct.
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
SALINITY (‰)
TEMPERATURE (°C)
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32

Figure 3. Haloclines in Hitchcock's Pond during four seasonal 25 hour stations. The October 25 hour station shows an atypical situation, as diurnal stratification was evident during most sampling periods.



SALINITY (‰)
OCTOBER 1974
FEBRUARY 1975
APRIL 1975
Surface
Bottom
HOURS
1600 1800 2000 2200 0000 0200 0400 0600 0800 1000 1200 1400 1600
1000 1200 1400 1600 1800 2000 2200 0000 0200 0400 0600 0800 1000
0900 1100 1300 1500 1700 1900 2100 2300 0100 0300 0500 0700 0900
1200 1400 1600 1800 2000 2200 0000 0200 0400 0600 0800 1000 1200

during flood tides, and stronger gradients during ebb.

Temperature

Winter creek and pond temperatures were similar (Figure 2), as pond temperatures exhibited slightly more thermal fluctuation. Highest temperatures were measured at the surface on July 16, 1974 (33.3°C in the pond; 32.0°C in the creek) (Table 1). Air temperature at the time was 33.0°C. Lows occurred in December on the bottom (8.8°C and 9.6°C for the pond and creek respectively). Air temperature was 6.0°C. Adams Creek temperatures were clearly related to the tide stages. Highest diurnal temperatures occurred in the creek during ebb; the lowest occurred during flood. Highest pond temperatures were recorded in the afternoon or early evening following the rising air temperature; lowest normally occurred from midnight through early morning, but this pattern was not maintained when a large differential existed between air and water temperature. Temperature gradients were less evident in both environments than previously described haloclines. Surface and bottom temperatures were the same at a majority of the stations. In both environments, surface water was often cooler, but less frequently in the tidal creek which was more thermally homogenous than the pond, probably due to mixing.

Mean diurnal temperatures of the four seasonal 25 hour stations illustrated pond water temperatures to be higher than creek water. On one occasion during the rain-inundated station of the summer, pond and creek values were equal. Otherwise, slightly higher temperatures

(∿ 2.0°C) were recorded in the pond for all other 25 hour stations. During the winter 25 hour station, warmer bottom temperatures were observed from midday until the following morning (Figure 4). Warmer than surface bottom water was maintained almost throughout the summer 25 hour station. A gradient of 2.6°C existed at one time over the one meter pond depth interval. The largest observed diurnal temperature change in the creek (surface and bottom water) of 4.4°C occurred during the winter 25 hour station (Figure 4). The impoundment exhibited its largest recorded diurnal change in the spring, a 6.7°C fluctuation over 25 hours.

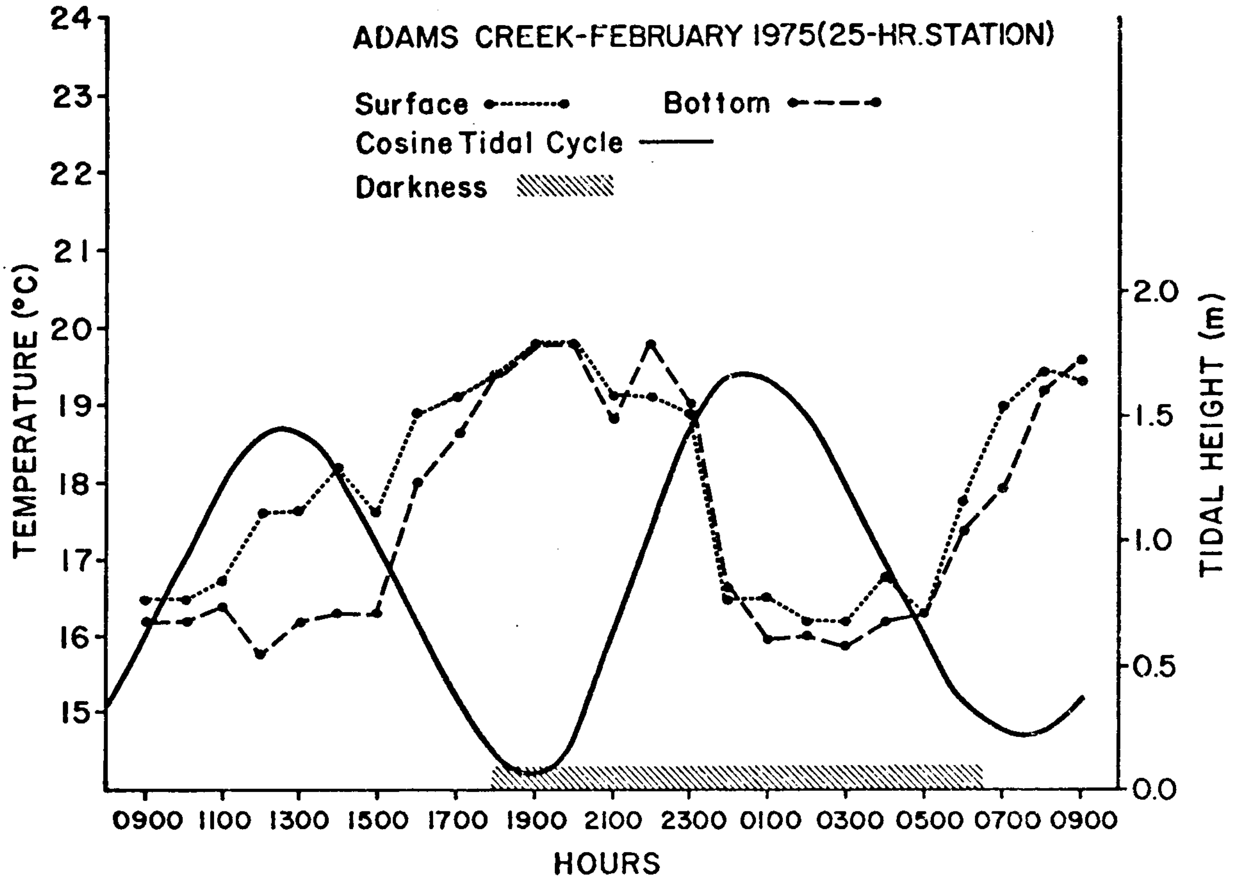
Dissolved Oxygen

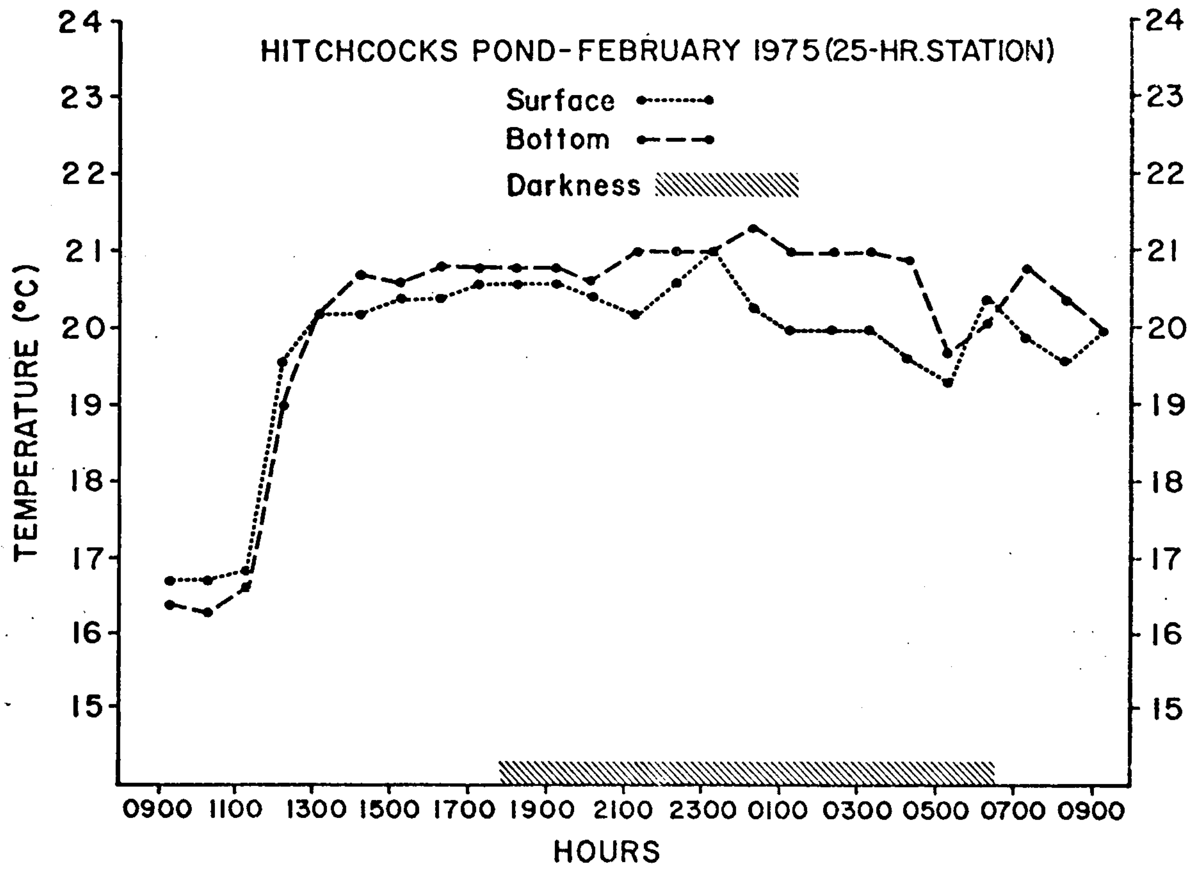
Dissolved oxygen levels were always higher in Hitchcock's Pond than in Adams Creek (Table 1). Highest dissolved oxygen concentrations occurred in winter and spring. The lowest oxygen level (1.0 ml/l) was observed in a creek bottom sample in the fall. The lowest observed pond D.O. value (2.2 ml/l) was recorded on the bottom in June; its highest concentration (8.4 ml/l) was a surface sample during February. Surface dissolved oxygen values of 8.3 ml/l (157% saturated) in the pond were associated with a filamentous blue-green algae bloom (Oscillatoriaceae) in August 1974. Seasonal 25 hour stations indicated that highest dissolved oxygen values occurred in the late afternoon and lowest from one to three hours after sunrise.

Hydrogen Sulfide

Although no scheduled analyses of H_2S were incorporated into the

Figure 4. Comparison of creek and pond diurnal temperatures during the February 25 hour station. The tidal cycle is superimposed over Adams Creek temperatures.


ADAMS CREEK-FEBRUARY 1975(25-HR.STATION)
Surface
Bottom
Cosine Tidal Cycle
Darkness
TEMPERATURE (°C)
TIDAL HEIGHT (m)
24
23
22
21
20
19
18
17
16
15
2.0
1.5
1.0
0.5
0.0
0900 1100 1300 1500 1700 1900 2100 2300 0100 0300 0500 0700 0900
HOURS


HITCHCOCKS POND-FEBRUARY 1975(25-HR.STATION)
Surface
Bottom
Darkness
TEMPERATURE (°C)
24
23
22
21
20
19
18
17
16
15
0900 1100 1300 1500 1700 1900 2100 2300 0100 0300 0500 0700 0900
HOURS

comparative study, consideration was given to the possibility of toxic levels of H_2S evolving during the heavy mortality period of bottom tray oysters in August 1974 (Figure 11). Therefore, H_2S was measured at approximately the same time the following year and though no conclusions can be reached from a single sampling period, results are presented in Table 2 showing simultaneous higher sulfide and oxygen levels in the impounded water.

Table 2.

August 1975 H_2S Concentrations (ml/l)

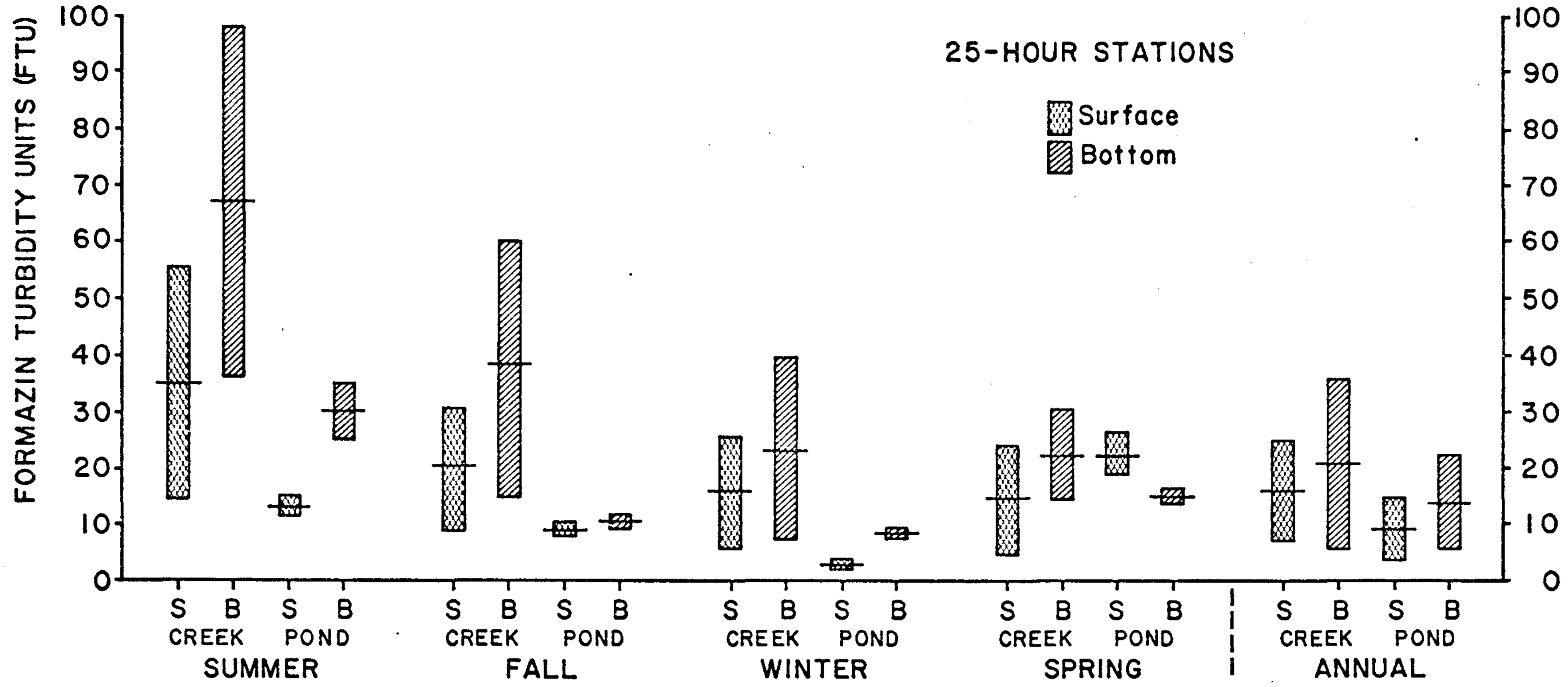
	Temperature (°C)	Oxygen (ml/l)	Sulfide (ml/l)
Creek, Surface	31.0	2.4	.016
Creek, Bottom	31.0	2.2	.060
Pond, Surface	33.0	3.6	.087
Pond, Bottom	33.0	3.6	.092

Turbidity and Light Penetration

Turbidity was highest in both environments in summer and the following spring. Greater turbidity was nearly always observed in the creek (Table 1). The turbidity data illustrates diurnal fluctuations in both environments at seasonal intervals. Higher standard deviations on either side of the mean in the tidal creek emphasize the importance of tidal stage at the time of sampling (Figure 5).

Average light penetration for both creek and pond over the year was approximately 0.8 m. The Secchi disc was recorded on the bottom of the

Figure 5. Mean turbidity values and standard deviations in both environments during the seasonal 25 hour stations. Annual values are averaged results of weekly sampling.



FORMAZIN TURBIDITY UNITS (FTU)
25-HOUR STATIONS
Surface
Bottom
0
10
20
30
40
50
60
70
80
90
100
S B S B
CREEK POND
SUMMER
FALL
WINTER
SPRING
ANNUAL

pond in many instances which would underestimate the pond's mean annual light penetration. Weekly light penetration values are listed in Table 1.

Chlorophyll a

Pond chlorophyll a levels during seasonal 25 hour stations and throughout the year study averaged 30% higher than the creek (Figure 6). A diurnal chlorophyll a fluctuation was also observed in the impounded water during all 25 hour stations (Figure 7) similar to the daily rhythm of photosynthesis (Shimada, 1958; Doty & Oguri, 1957; Holmes & Haxo, 1957; Yentsch & Ryther, 1957).

Table 3.

Mean Diurnal and Annual Total
Chlorophyll a Concentrations (μg/l)

	Summer 25 Hour Station		Fall 25 Hour Station	
	Creek	Pond	Creek	Pond
Surface	43.6 ± 29.8	45.8 ± 11.2	12.5 ± 8.4	17.3 ± 2.6
Bottom	50.6 ± 31.9	86.3 ± 16.7	16.8 ± 9.0	20.0 ± 2.1
	Winter 25 Hour Station		Fall 25 Hour Station	
	Creek	Pond	Creek	Pond
Surface	17.5 ± 10.1	15.0 ± 2.3	16.8 ± 12.4	34.3 ± 15.0
Bottom	18.4 ± 17.6	42.1 ± 5.7	10.2 ± 4.6	83.2 ± 11.4
	Annual Values from Weekly Sampling			
	Creek	Pond		
Surface	17.7 ± 14.7	29.8 ± 27.2		
Bottom	17.3 ± 14.8	33.6 ± 24.9		

Figure 6. Average creek and pond chlorophyll a and particulate carbohydrate diurnal concentrations during the seasonal 25 hour stations.

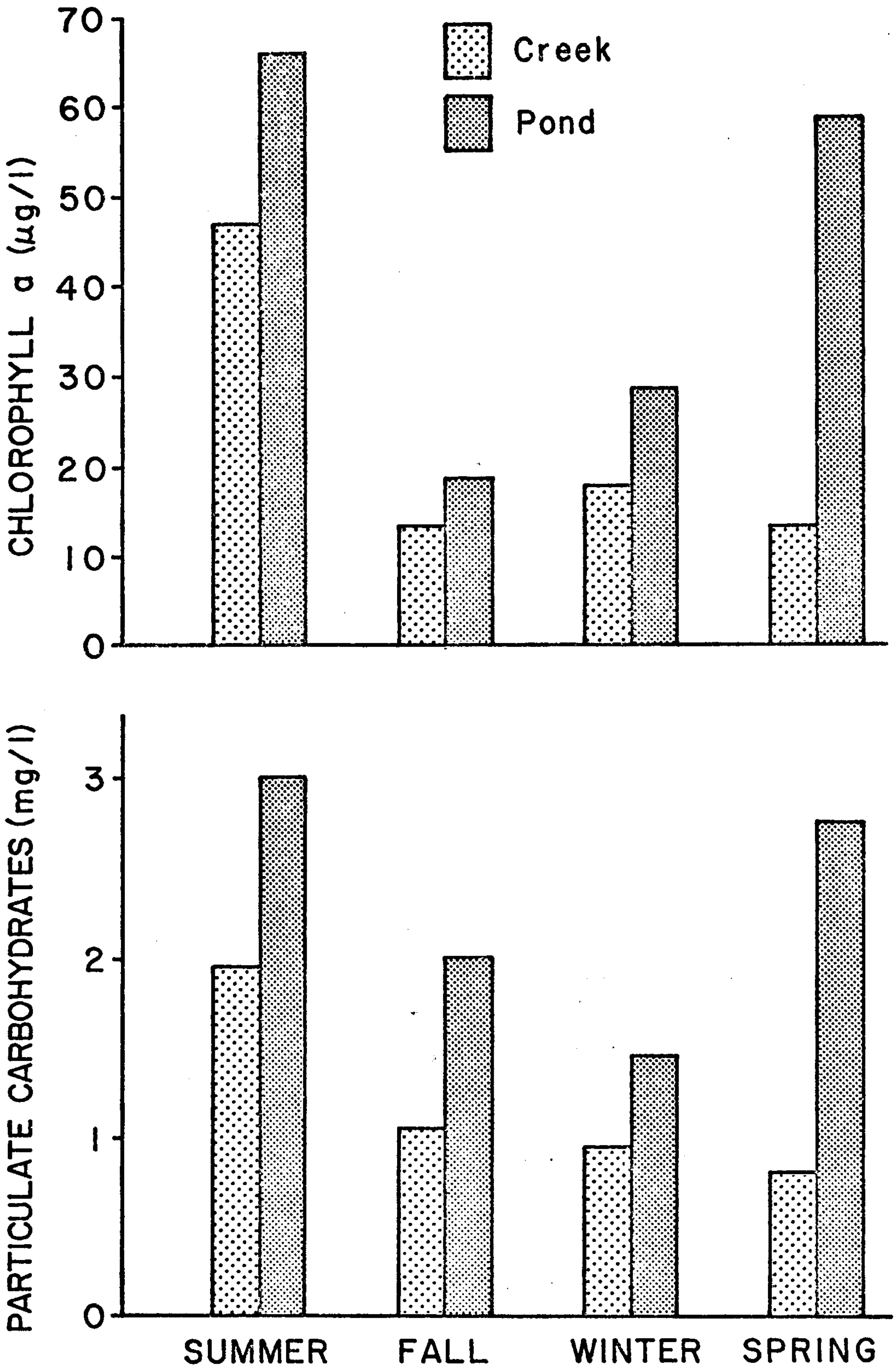

Creek
Pond
CHLOROPHYLL a (µg/l)
70
60
50
40
30
20
10
0
PARTICULATE CARBOHYDRATES (mg/l)
3
2
1
0
SUMMER
FALL
WINTER
SPRING

Figure 7. Diurnal chlorophyll a fluctuation in Hitchcock's Pond during the August 25 hour station. A bloom of Oscillatoraceae was found at this time.

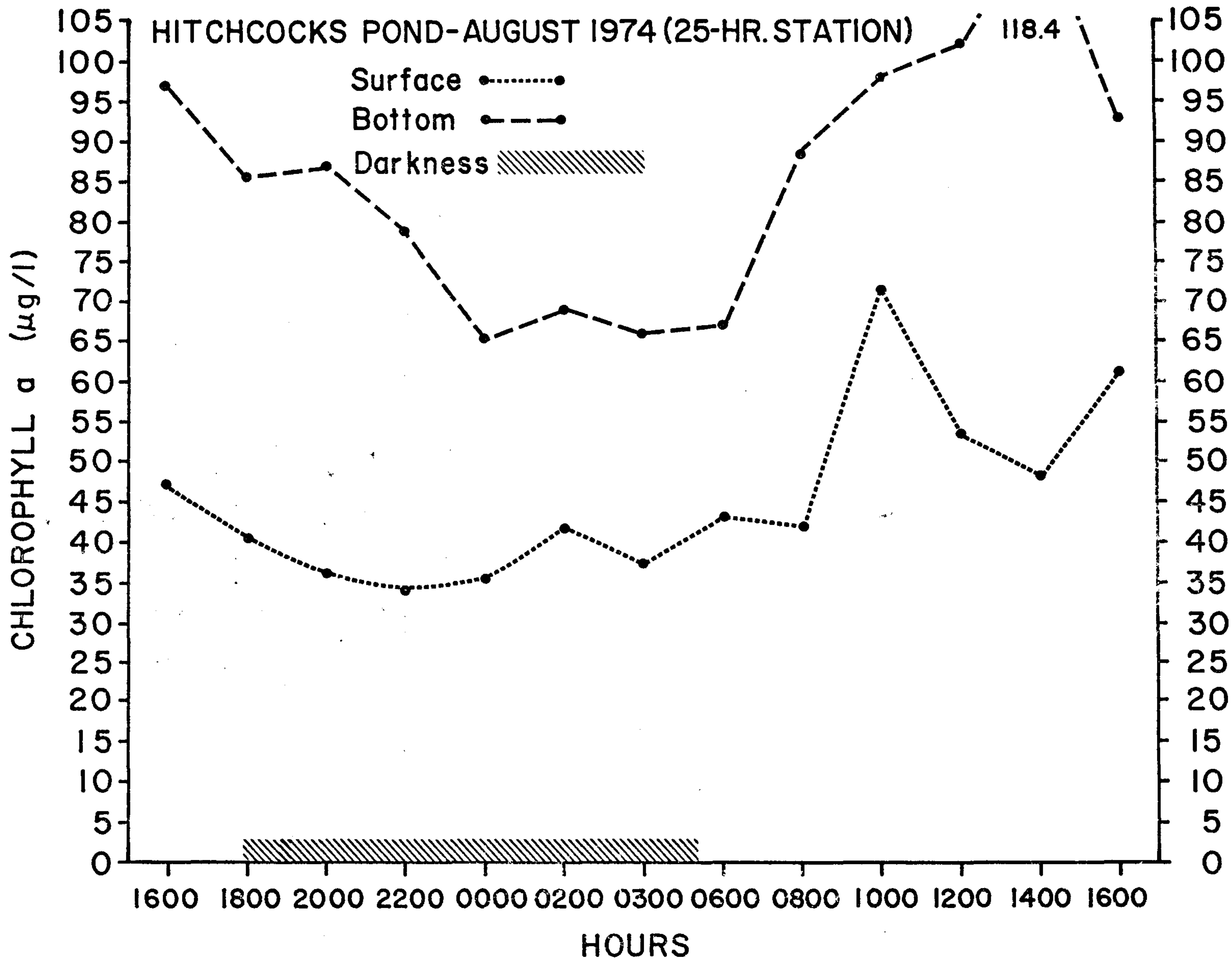
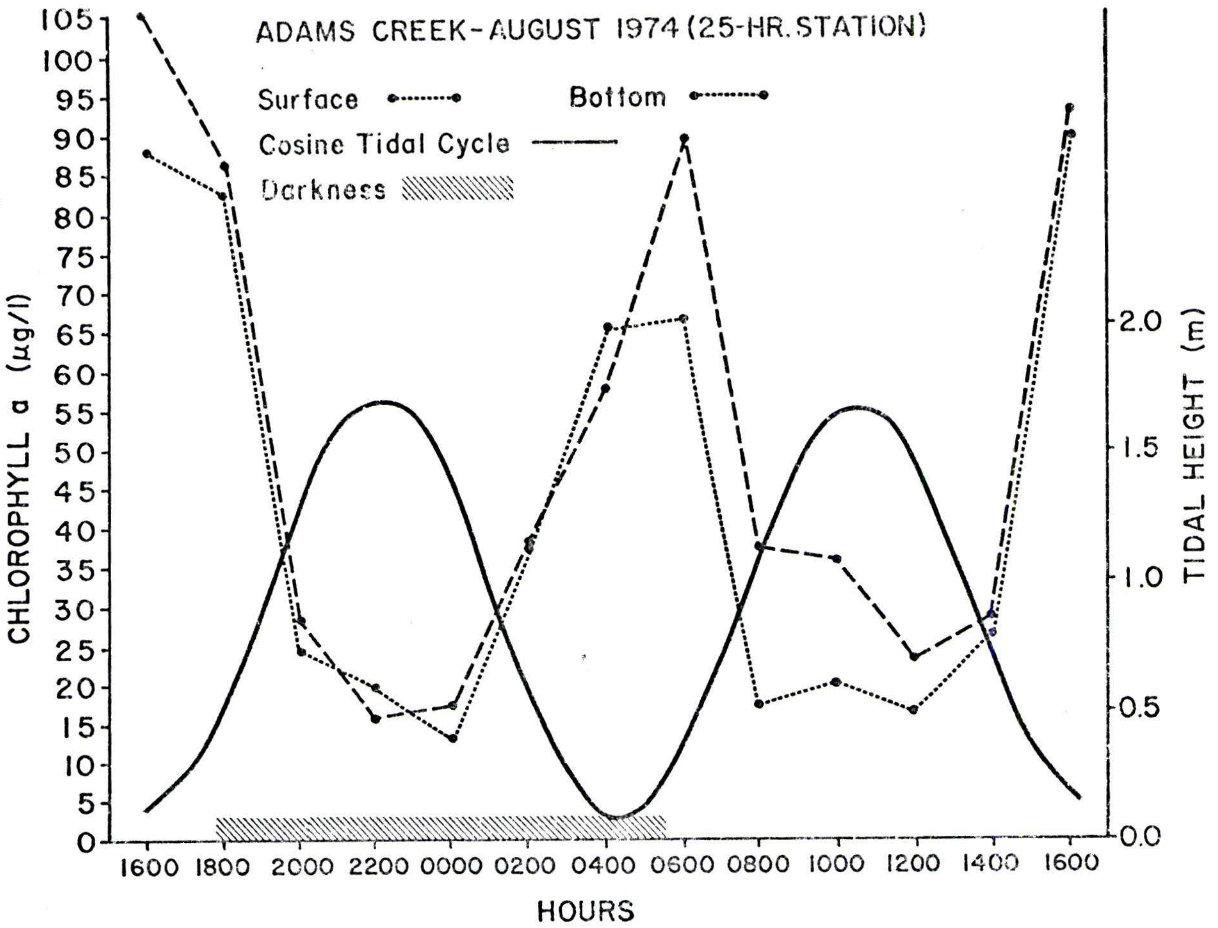

HITCHCOCKS POND-AUGUST 1974 (25-HR. STATION)
118.4
Surface
Bottom
Darkness
CHLOROPHYLL a (μg/l)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1600
1800
2000
2200
0000
0200
0300
0600
0800
1000
1200
1400
1600
HOURS

Figure 8. Inverse correlation between chlorophyll a and PCHO concentrations with the tidal height.


ADAMS CREEK-AUGUST 1974 (25-HR. STATION)
Surface
Bottom
Cosine Tidal Cycle
Darkness
CHLOROPHYLL a (µg/l)
TIDAL HEIGHT (m)
HOURS
1600 1800 2000 2200 0000 0200 0400 0600 0800 1000 1200 1400 1600

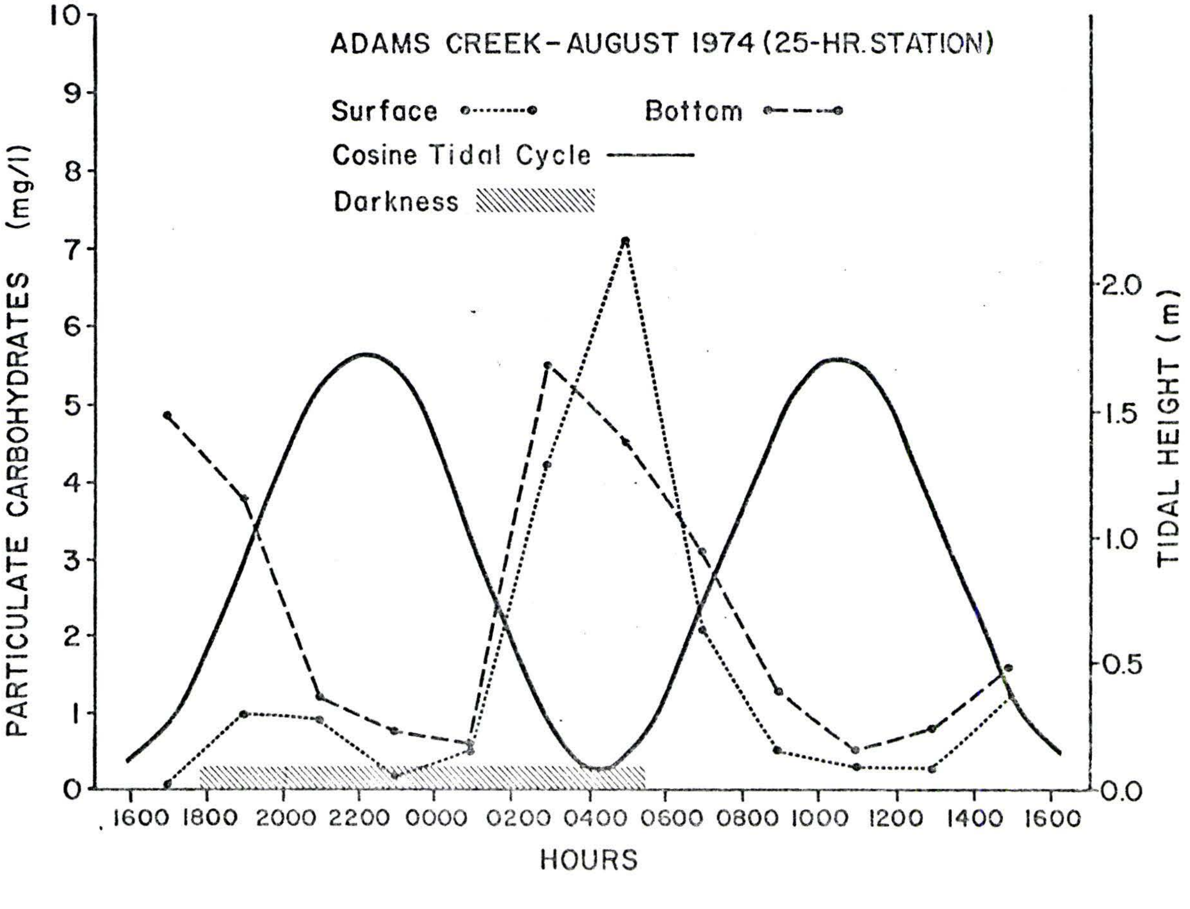

ADAMS CREEK-AUGUST 1974 (25-HR. STATION)
Surface
Bottom
Cosine Tidal Cycle
Darkness
PARTICULATE CARBOHYDRATES (mg/l)
TIDAL HEIGHT (m)
HOURS
1600 1800 2000 2200 0000 0200 0400 0600 0800 1000 1200 1400 1600

Table 4. Chlorophyll a and Carbohydrates

	Chlorophyll a (μg/l)				Dissolved Carbohydrates (mg/l)			
	Creek		Pond		Creek		Pond	
Date	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
24 June 74	10.7	15.6	12.6	16.8	--	--	--	--
1 July	6.7	8.7	14.8	19.5	5.4	2.3	8.8	13.7
8 July	10.8	8.9	16.1	45.5	5.4	1.5	6.6	3.9
16 July	11.1	13.8	11.3	22.6	3.6	1.2	3.7	2.3
24 July	15.8	13.7	16.3	21.0	5.1	1.3	8.2	2.6
30 July	9.7	9.7	28.6	33.2	4.6	2.4	5.1	2.5
7 August	20.2	35.9	72.7	98.4	--	--	--	--
13 August	22.0	17.4	103.2	50.5	4.3	6.2	1.8	3.2
20 August	10.0	13.9	15.3	22.9	3.7	3.8	6.0	4.0
27 August	10.1	11.6	19.8	22.6	3.8	3.9	3.0	3.0
3 September	20.2	27.7	15.5	23.5	6.8	3.7	2.8	5.8
10 September	21.5	22.7	10.4	29.9	--	--	--	--
17 September	11.7	11.0	14.6	11.9	2.8	5.0	2.5	12.2
23 September	6.9	15.6	18.4	27.0	3.2	8.3	4.7	6.0
30 September	8.4	10.0	18.2	15.1	2.0	2.2	8.0	3.2
8 October	8.5	8.2	4.9	9.5	2.2	1.6	3.2	4.9
16 October	8.2	5.8	7.9	11.2	4.4	3.5	6.8	3.6
21 October	8.6	8.4	11.7	15.9	1.2	2.6	5.5	2.9
30 October	16.7	15.9	17.5	23.0	--	--	--	--
6 November	13.5	14.7	13.4	17.7	1.5	4.6	5.7	6.0
13 November	9.1	6.1	12.2	21.4	1.7	3.1	6.2	7.1
20 November	4.1	--	16.7	17.1	7.6	6.5	9.4	12.1
25 November	21.8	19.9	22.2	19.9	6.2	6.2	9.1	5.4
2 December	7.9	4.3	15.4	15.8	2.9	0.8	3.0	2.2
9 December	14.8	--	10.9	13.0	2.7	--	4.2	2.9
16 December	--	--	--	--	2.2	2.0	3.0	6.5
23 December	14.7	16.5	23.7	12.2	4.6	4.4	3.2	4.4
2 January 75	--	--	--	--	1.6	1.7	2.8	3.6
7 January	23.3	27.2	4.8	22.6	0.7	0.5	0.5	0.1
14 January	9.5	3.7	10.7	29.1	0.5	0	0.4	1.1
21 January	15.5	15.5	13.0	16.5	1.4	1.0	1.9	1.5
28 January	5.2	5.2	3.8	4.4	0.3	0.4	0.8	0.2
4 February	5.2	4.7	13.8	7.2	0.2	0.3	1.2	5.6
12 February	5.1	5.5	9.9	14.9	1.1	3.0	1.2	0.6
19 February	7.0	9.7	15.6	43.5	--	--	--	--
26 February	4.7	10.7	18.3	6.3	1.3	0.5	1.2	1.4
4 March	37.2	37.2	13.4	29.9	0.7	2.1	1.6	0.9
10 March	8.8	8.8	26.0	18.7	3.4	2.0	1.7	2.0
18 March	7.2	7.0	63.8	65.9	0.6	1.4	3.2	4.5
24 March	48.9	46.5	98.7	47.6	1.5	1.7	2.9	1.8
1 April	30.7	11.2	92.6	83.0	2.3	1.5	3.5	4.3
7 April	38.5	11.4	69.7	76.0	1.3	1.1	4.4	4.1
15 April	15.6	14.3	51.4	97.6	--	--	--	--
21 April	75.4	78.4	74.3	80.4	3.4	2.6	3.3	2.9
29 April	21.3	12.0	70.2	76.3	1.0	0.8	2.9	2.3
6 May	61.7	57.5	89.8	68.7	2.2	7.8	7.6	2.2
12 May	19.8	18.3	55.2	73.5	1.8	1.4	3.7	1.8
19 May	47.0	46.4	34.9	45.7	3.0	3.2	3.0	3.2
27 May	19.7	11.2	46.0	43.7	1.0	1.7	2.2	2.1
2 June	20.0	23.1	28.6	29.1	--	2.7	1.1	5.3
16 June	15.1	13.5	22.9	35.2	0.1	0	0	1.2
23 June	18.4	16.3	19.8	25.7	3.9	--	0.7	0
$\bar{x}$	17.69	17.32	29.83	33.57	2.69	2.60	3.75	3.78
s	± 14.68	± 14.67	± 27.20	± 24.88	± 1.86	± 2.03	± 2.51	± 2.98

Particulate Carbohydrates (mg/l)

Date	Creek Surface	Creek Bottom	Pond Surface	Pond Bottom
24 June 74	--	--	--	--
1 July	--	--	--	--
8 July	--	--	--	--
16 July	--	--	--	--
24 July	--	--	--	--
30 July	--	--	--	--
7 August	0.3	0.5	1.5	3.1
13 August	--	--	--	--
20 August	0.4	0.4	0.4	0.6
27 August	0.6	0.5	0.5	0.5
3 September	0.6	0.6	0.3	2.0
10 September	0.3	1.0	0.5	0.6
17 September	0.2	0.2	0.3	0.2
23 September	0.3	0.3	0.2	0.3
30 September	0.2	0.1	0.4	0.4
8 October	0.7	0.4	0.5	0.7
16 October	0.4	0.3	0.5	0.5
21 October	0.6	0.1	0.6	1.0
30 October	0.1	0.9	2.8	1.2
6 November	0.2	0.1	1.6	1.8
13 November	0.5	0.4	1.2	0.7
20 November	0.4	0.6	1.0	0.8
25 November	0.3	0.4	0.9	0.8
2 December	0.9	0	0.2	0.3
9 December	0.7	--	0	0
16 December	0.5	0	0.2	0.1
23 December	1.0	0.6	0.2	0.7
2 January 75	0.2	0	0.1	0.2
7 January	0.5	0.7	0	0.3
14 January	0	0	0.4	0.1
21 January	0.6	0.4	0.2	0.2
28 January	0.2	0.3	0.2	0.2
4 February	0.3	0.3	1.0	0.3
12 February	0	0	0	0.1
19 February	1.0	0.5	1.0	2.1
26 February	0.1	0.6	0.9	0.3
4 March	1.4	1.3	0.7	1.6
10 March	0.7	0.4	1.7	1.0
18 March	0.4	0.3	2.7	3.2
24 March	1.4	2.2	5.4	1.5
1 April	1.5	0.6	2.2	2.7
7 April	3.6	1.2	4.1	3.8
15 April	1.2	1.1	4.9	1.9
21 April	3.8	3.6	3.1	3.4
29 April	1.0	1.1	2.9	2.8
6 May	4.9	2.8	5.3	5.7
12 May	1.7	1.7	6.5	6.3
19 May	4.2	4.1	4.0	3.8
27 May	0.5	0.4	5.3	2.3
2 June	1.3	1.6	5.0	2.8
16 June	1.1	1.5	4.1	3.2
23 June	1.8	0.7	3.7	2.7
$\bar{x}$	0.95	0.79	1.76	1.53
s	± 1.11	± .90	± 1.88	± 1.52

Chlorophyll a concentrations varied inversely with the tidal cycle in Adams Creek as highest concentrations occurred at low tide (Figure 8).

With the exception of the August bloom, weekly sampling illustrated chlorophyll a to be maintained ∿15 μg/l in the creek during summer, fall, and winter. Increases were observed in early March, with further build-up through April and mid-May, followed by a summer decline (Table 4). This pattern was simulated in the pond, but at higher chlorophyll concentrations.

Chlorophyll a and particulate carbohydrate (PCHO) concentrations showed a substantial negative correlation with tidal height (Table 5). The spring 25 hour station illustrated poorest chlorophyll a correlation. However, a flow-thru Turner Model III fluorometer was used during this sampling period, with six-hour interval calibrations by a spectrophotometer. Figure 8 illustrates the inverse relationship of both chlorophyll a and PCHO during an August 25 hour tidal period.

Table 5.

Correlation Coefficients: Values of r.

Tidal Height vs. Chlorophyll a

Station	Surface	Bottom	$\overline{X}$	
Summer	0.857**	0.807**	0.840**	n = 13
Fall	0.852**	0.555*	0.747**	df = 11
Winter	0.764**	0.814**	0.813**	
Spring	0.467**	0.561*	0.538 ns	

Table 5. (cont.)

Tidal Height vs. PCHO

Station	Surface	Bottom	$\overline{X}$	
Summer	0.666*	0.812**	0.814**	n = 12
Fall	0.552 ns	0.456 ns	0.610*	df = 10
Winter	0.031 ns	0.785**	0.749**	
Spring	0.662*	0.521 ns	0.701*	

pH

The pH values throughout the year were generally higher in the pond than the creek (Table 1). Hourly measurements showed that pH usually increased during the day and decreased at night. Greatest surface to bottom pH differentials occurred during largest concentrations of chlorophyll *a*.

Phytoplankton

Dominant phytoplankters at each sample depth are listed seasonally in Table 6. Blue-green algae was clearly the dominant flora in the pond during all 25 hour stations. The creek illustrated an environment usually predominated by a heterogeneous diatom population.

Table 6.

Three dominant preserved phytoplankters during seasonal 25 hour stations

Summer 25 Hour Station

CREEK		POND	
Surface	Bottom	Surface	Bottom
Oscillatoria sp.	*Euglenoid*	*Oscillatoria* sp.	*Oscillatoria* sp.
Eutrepia sp.	*Amphora* sp.	*Eutrepia* sp.	Chroococcaceae
Navicula sp.	*Cyclotella* sp.	*Glenodinium* sp.	*Euglenoid*

Table 6. (cont.)

Fall 25 Hour Station

CREEK		POND	
Surface	Bottom	Surface	Bottom
Nitzschia longissima (Breb.) Ralfs.	*Cyclotella* sp.	Chroococcaceae	Chroococcaceae
Cyclotella caspia Grun.	*Amphora ovalis* Kutzing	*Thalassiothrix delicatula* Cupp.	*Thalassiothrix delicatula* Cupp.
Navicula sp.	*Chaetoceros* sp.	*Cocconeis scutellum* Euremberg.	*Skeletonema costatum* (Grev.) Cleve.

Winter 25 Hour Station

CREEK		POND	
Surface	Bottom	Surface	Bottom
Asterionella glacialis Castracane (=*A. japanica* Cleve *ex* Gran.)	*Melosira nummuloides* (Dillw.) Agardh.	Chroococceacea	Chroococceacea
Nitzschia longissima (Breb.) Ralfs.	*Asterionella glacialis* Castracane (=*A. japanica* Cleve *ex* Gran.)	*Nitzschia longissima* (Breb.) Ralfs.	*Nitzschia longissima* (Breb.) Ralfs.
Chaetoceros lorenzianus Grunow.	*Thalassionema nitzschioides* Grun.	Oscillatoriaceae	Oscillatoriaceae

Table 6. (cont.)

Spring 25 Hour Station

CREEK		POND	
Surface	Bottom	Surface	Bottom
Chroococcaceae	Chroococcaceae	Chroococcaceae	Chroococcaceae
Skeletonema costatum (Grev.) Cleve.	Amphiprora alata (Ehr.) Kutzing.	unidentified pennate	Nitzschia panduriformis Gregory.
Nitzschia sigma (Kutz.) W. Smith	Nitzschia sigma (Kutz.) W. Smith	Thalassionema nitzschioides Grun.	unidentified pennate

Dissolved Carbohydrates (DCHO)

Dissolved carbohydrate levels in the creek and pond were highest from July to December. The lowest level in both environments occurred in January, increasing slightly throughout the spring (Table 4).

Average values for DCHO measured only during weekly sampling were 18% higher in the pond. Surface and bottom annual mean concentrations were: 2.6 μg/l - creek; 3.8 μg/l - pond). One of the lowest DCHO values (1.9 μg/l) occurred in the pond during the August phytoplankton bloom.

Particulate Carbohydrates (PCHO)

Particulate carbohydrate concentrations in the pond showed positive correlation with chlorophyll a (r = 0.753**). Pond PCHO values were higher than the creek values during all 25 hour stations (Figure 6) and throughout the year (Table 4). This was similar to pigment comparisons.

Particulate carbohydrate values also varied inversely with the tide stage (Figure 8), but to a lesser degree than chlorophyll a (Table 5).

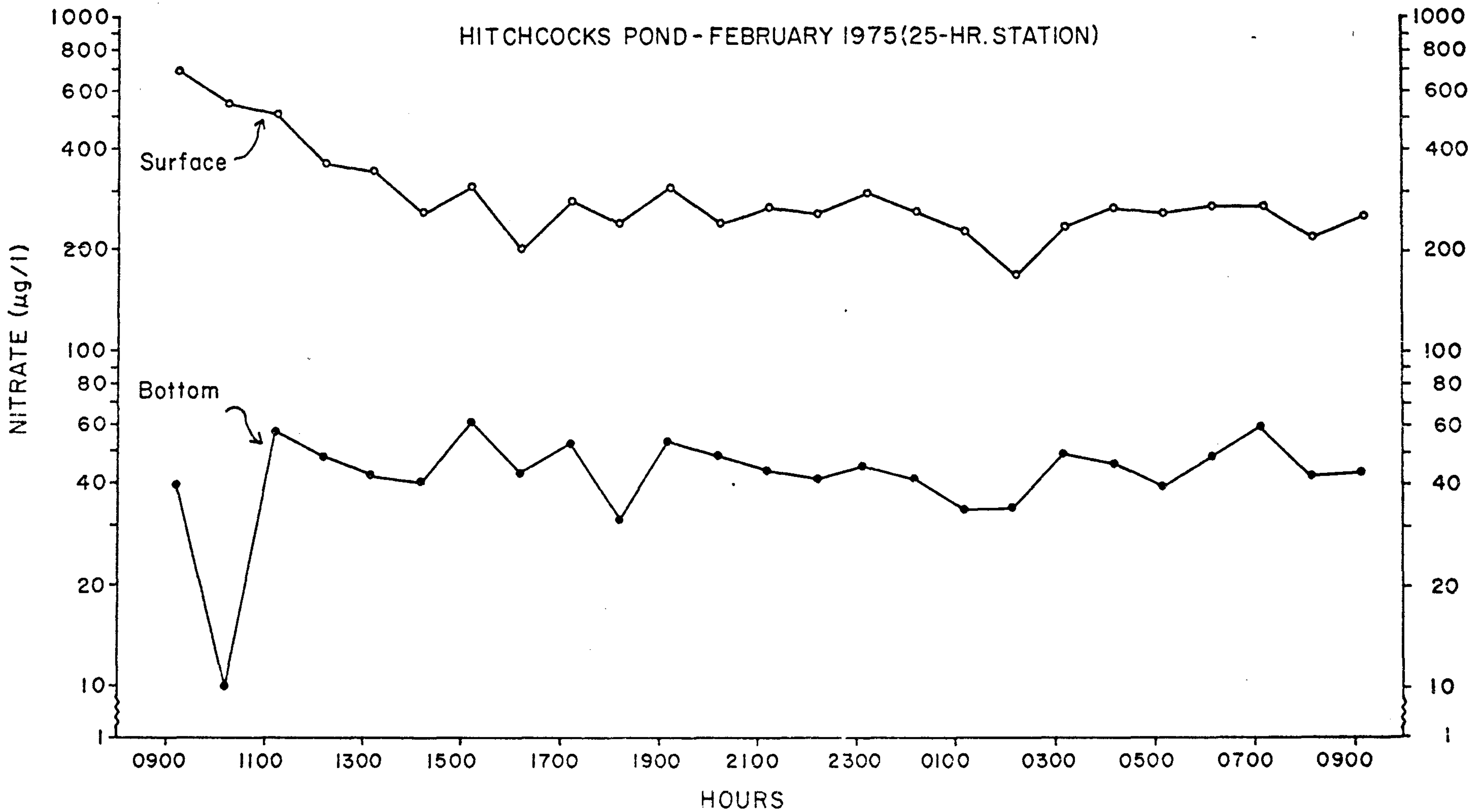
Nutrients

Nitrates. Uric acid, a nitrogenous excretory product of birds was observed to contribute extremely high concentrations of nitrate to both creek and pond. Figure 9 illustrates surface and bottom nitrate values obtained in the pond during a fortuitous circumstance of the February 25 hour station when guano was rinsed from the pier prior to initial sampling. The high NO_3^- concentrations were recorded for 25 hours. This occurred again during the April 25 hour station. Dispersion, assimilation and reduction to NO_2^- presumably account for the lowering values with time. Correspondingly high orthophosphate values were not obtained. The addition of nitrogen in this manner was recorded and observed a number of times, but more frequently in the pond. Throughout the year, average surface-bottom nitrate levels were higher in the creek (Table 7).

Creek nitrate values were consistantly higher in summer and fall than in the pond. Low pond NO_3^- concentrations (2.0 micrograms/l, surface and bottom) were found from the end of October to mid December, a depletion reflected to a lesser extent in the creek.

Nitrites. On numerous occasions throughout the study, nitrite depletion was recorded in the pond. Zero values never persisted in consecutive sampling for more than two-week intervals. Pond NO_2^- values averaged 2.0 μg/l for the year (Table 7). Pulses observed in February

Figure 9. Surface and bottom nitrate nitrogen values in Hitchcock's Pond during a 25 hour station when bird excrement was rinsed from the pier prior to initial sampling. Data is illustrated on a logarithmic scale.



HITCHCOCKS POND - FEBRUARY 1975 (25-HR. STATION)
Surface
Bottom
NITRATE (µg/l)
1000
800
600
400
200
100
80
60
40
20
10
1
0900
1100
1300
1500
1700
1900
2100
2300
0100
0300
0500
0700
0900
HOURS

Table 7. Nutrients

Date	Nitrates (µg/l) Creek Surface	Creek Bottom	Pond Surface	Pond Bottom	Nitrites (µg/l) Creek Surface	Creek Bottom	Pond Surface	Pond Bottom
24 June 1974	6.1	6.5	31.0	0	2.3	2.6	1.2	1.2
1 July	21.4	15.9	15.2	2.3	0	2.0	5.1	0.9
8 July	2.9	40.0	22.6	16.5	0.6	5.8	5.4	0.3
16 July	25.5	11.2	5.6	1.2	7.3	19.6	1.4	1.4
24 July	9.3	0.7	8.8	15.9	1.2	5.6	1.7	6.2
30 July	16.1	12.1	3.3	20.8	4.2	2.6	3.4	5.1
7 August	42.1	40.8	3.5	0	6.2	6.8	0	0
13 August	18.8	32.0	0.9	0	16.2	21.9	1.9	--
20 August	10.4	6.3	1.5	0.8	21.8	11.2	0.6	3.4
27 August	14.1	15.1	1.2	--	8.0	7.3	0.9	--
3 September	39.0	25.6	34.4	--	6.5	8.7	2.7	--
10 September	--	4.7	10.6	9.2	--	2.3	1.0	1.3
17 September	1.4	4.0	12.8	21.8	1.4	2.3	1.2	2.0
23 September	9.3	16.6	31.2	26.1	3.3	2.3	1.7	1.9
30 September	37.4	15.1	24.2	2.6	2.6	1.7	0	0.6
8 October	4.6	5.6	10.9	8.2	2.4	2.5	1.4	1.3
16 October	3.7	6.4	3.3	6.0	2.3	1.7	0.6	1.7
21 October	18.7	19.1	2.2	4.0	2.8	3.7	0.6	2.3
30 October	5.6	4.0	0.4	3.0	1.4	3.7	0.3	1.2
6 November	11.4	14.2	1.2	--	2.6	2.6	0.9	--
13 November	5.1	5.8	0.5	--	1.2	1.2	0.9	--
20 November	9.5	9.1	2.1	2.1	1.7	1.4	1.4	1.4
25 November	6.1	6.4	0.4	2.9	2.3	2.0	0.3	0.6
2 December	7.0	5.7	0	1.5	1.4	2.0	1.4	2.0
9 December	4.2	--	0.7	1.4	1.4	--	0	0
16 December	3.2	3.2	3.5	--	0.3	0.3	0	0
23 December	5.5	5.4	64.4	19.3	0.5	0.6	2.8	2.4
2 January 1975	10.0	7.1	7.5	1.8	2.3	2.4	1.6	1.7
7 January	4.8	3.7	4.9	4.3	0.5	0.9	0	0.3
14 January	19.3	5.1	--	--	0.3	0.5	--	--
21 January	4.4	98.8	42.4	5.0	1.2	1.6	1.3	1.3
28 January	35.0	8.2	105.6+	34.7	3.5	1.6	4.0	2.1
4 February	11.7	13.2	180.3+	56.1	2.3	2.6	9.7	3.8
12 February	2.9	0.7	395.2+	112.8+	2.4	2.1	11.1	5.5
19 February	12.0	12.0	362.8+	49.5	1.0	1.3	7.5	2.3
26 February	11.5	14.1	2.1	8.5	0.4	0.4	0	0.3
4 March	4.4	4.7	16.5	4.2	0.2	0.2	0	0
10 March	10.3	7.8	3.0	4.7	0.2	0.2	0.2	0.2
18 March	7.9	31.0	4.6	3.3	1.6	2.3	0.3	0.2
24 March	66.2	21.7	15.6	26.8	1.4	1.4	0.8	1.2
1 April	15.7	15.1	5.3	6.0	2.1	3.1	2.4	2.4
7 April	22.8	6.3	--	2.1	4.2	3.1	2.0	1.7
15 April	20.7	15.4	698.9+	6.3	1.7	1.8	1.0	0
21 April	391.2+	322.1+	333.2+	183.4+	18.3	18.2	13.3	9.1
29 April	24.6	23.6	7.3	8.1	2.0	2.0	1.5	0.3
6 May	--	--	--	--	3.9	--	5.9	--
12 May	5.2	--		--	1.4	--	0.7	2.1
19 May	52.2	7.0	4.5	--	6.6	4.6	4.3	--
27 May	--	--	33.0	--	--	--	--	--
2 June	--	39.4	--	--	--	--	--	--
16 June	13.4	13.9	4.7	3.9	2.7	2.9	1.3	1.7
23 June	--	--	--	--	2.2	2.8	1.7	2.0
$\bar{x}$	15.08	12.92	11.20	10.29	3.35	3.87	2.23	1.80
s	± 13.96	±10.38	±14.13	±13.32	±4.43	±4.84	±2.91	±1.86

+Annual mean values excludes times(+) of bird excrement.

Table 7. cont/d. Nutrients

Date	Orthophosphates (µg/l) Creek Surface	Creek Bottom	Pond Surface	Pond Bottom	Silicates (µg/l) Creek Surface	Creek Bottom	Pond Surface	Pond Bottom
24 June 1974	--	--	--	--	1398	1609	2522	1398
1 July	8.0	3.0	0	0	1258	1159	2907	1398
8 July	16.0	57.0	0	17.0	1264	2907	3504	3585
16 July	56.0	79.0	0	3.0	2768	3330	2452	2908
24 July	16.0	0	0	45.0	2171	3014	3014	2768
30 July	0	53.0	--	--	2417	3892	3751	2592
7 August	--	--	60.0	--	2782	1405	1005	2592
13 August	65.0	--	--	--	2712	3484	1869	2417
20 August	112.0	112.0	32.0	53.0	2641	2438	984	2515
27 August	--	146.0	9.0	17.0	3070	3077	204	176
3 September	120.0	155.0	0	50.0	3295	3014	274	218
10 September	135.0	160.0	25.0	70.0	1356	3646	710	457
17 September	25.0	50.0	29.0	35.0	653	1145	442	766
23 September	135.0	160.0	27.0	60.0	3541	2522	639	653
30 September	95.0	40.0	35.0	15.0	2908	3154	541	632
8 October	65.0	80.0	9.0	25.0	794	1075	379	197
16 October	50.0	47.0	1.0	40.0	2304	1279	548	2234
21 October	98.0	100	0	15	3498	3920	379	913
30 October	165	195	35	52	1159	3512	372	386
6 November	40.0	80	40	40	927	801	379	408
13 November	65	90	50	65	1166	1250	548	632
20 November	115	80	30	50	1117	702	660	660
25 November	95	22	30	25	1116	817	506	745
2 December	50	36	121.5	0	1138	2301	1188	871
9 December	--	--	5	0	745	--	632	478
16 December	88.5	21	15.5	68	805	717	197	365
23 December	5.5	33	22	16.5	527	674	864	429
2 January 1975	24	30	17	33.5	576	745	534	400
7 January	29	42	13	28.5	309	288	464	253
14 January	9	12	0	48	443	534	267	295
21 January	66	98	12	16.5	731	906	408	246
28 January	36	30	3	15				
4 February	65	64.5	11	15				
12 February	43.5	25.5	13.5	22				
19 February	75.5	83.0	37.5	39.5				
26 February	15.5	121.5	18	21				
4 March	73.5	71.5	8	46				
10 March	17	71.5	56	64				
18 March	67.5	105.0	85.0	87				
24 March	87	73	72	34				
1 April	102	115.5	121.5	112.5				
7 April	73.5	72	90	93.5				
15 April	72	108	51	36				
21 April	123	109.5	121.5	115.5				
29 April	46.5	49.5	66	106.5				
6 May	150.1	174	114	138				
12 May	84	66	25.5	45				
19 May	154.5	154.5	103.5	109.5				
27 May	10.5	9	30	43.5				
2 June	158.5	136.5	43.5	69				
16 June	82.5	85.5	102	112.5				
23 June	153	177	141	132				
$\bar{x}$	71.64	80.91	39.42	48.19	1664.1	1977.2	1067.5	1115.7
s	±46.32	±50.32	±39.54	±36.20	±1021.0	±1200.6	±1048.8	±1013.9

and April coincided with bird excretions. The creek showed no NO_2^- on one occasion; a surface value in July. Otherwise it maintained a mean value for the year of 3.6 µg/l -- 30% higher than the pond. Large peaks were observed in July, August and April. The April high value resulted from bird excretions.

Orthophosphates. Mean surface-bottom orthophosphate levels were higher in the creek than the pond throughout the year (Table 7). This trend was also evident during all 25 hour stations. Large variations were recorded in each environment with bottom values usually higher than surface.

Silicates. Silicate values were similar to orthophosphate concentrations; in that they were higher in the creek throughout the year (Table 7). Again, all seasonal 25 hour creek stations had higher silicate values than pond stations. Beginning in January 1975, atypical values were obtained in both environments until the end of the experiment due to an autoanalyzer malfunction. These erroneous values were not incorporated in Table 7.

Tides and Water Movements

Tidal ranges were 1.8 meters (mean), and 2.1 meters (Spring) in Adams Creek. Reliable bottom current velocity measurements in Adams Creek were attained only during the summer 25 hour station due to mechanical and calibration problems with the current meter. Highest current velocities (up to 3.6 m/sec) were observed at mid to late ebb.

Lowest velocity (0.5 m/sec) occurred irregularly during flood and early ebb. Tidal stage affects both chlorophyll a and particulate carbohydrate concentrations (Figure 8).

Growth

Best oyster growth during the 16 month period occurred in floating trays, followed by midwater trays, and poorest in the bottom trays. Growth was significantly higher in the pond than in the creek (Figure 10). A two-way Anova without replication showed highly significant differences in location and depth ($\alpha = 0.01$) for an eleven month period from 27 September 1974 to 30 October 1975 (Table 8). A common application of the two-way anova without replication is the repeated testing of the same individuals over a period of time (Sokol and Rohlf, 1969). Each number incorporated in the anova represents mean length increases of 150 oysters over the prescribed time period. F max test showed homogenity of variance.

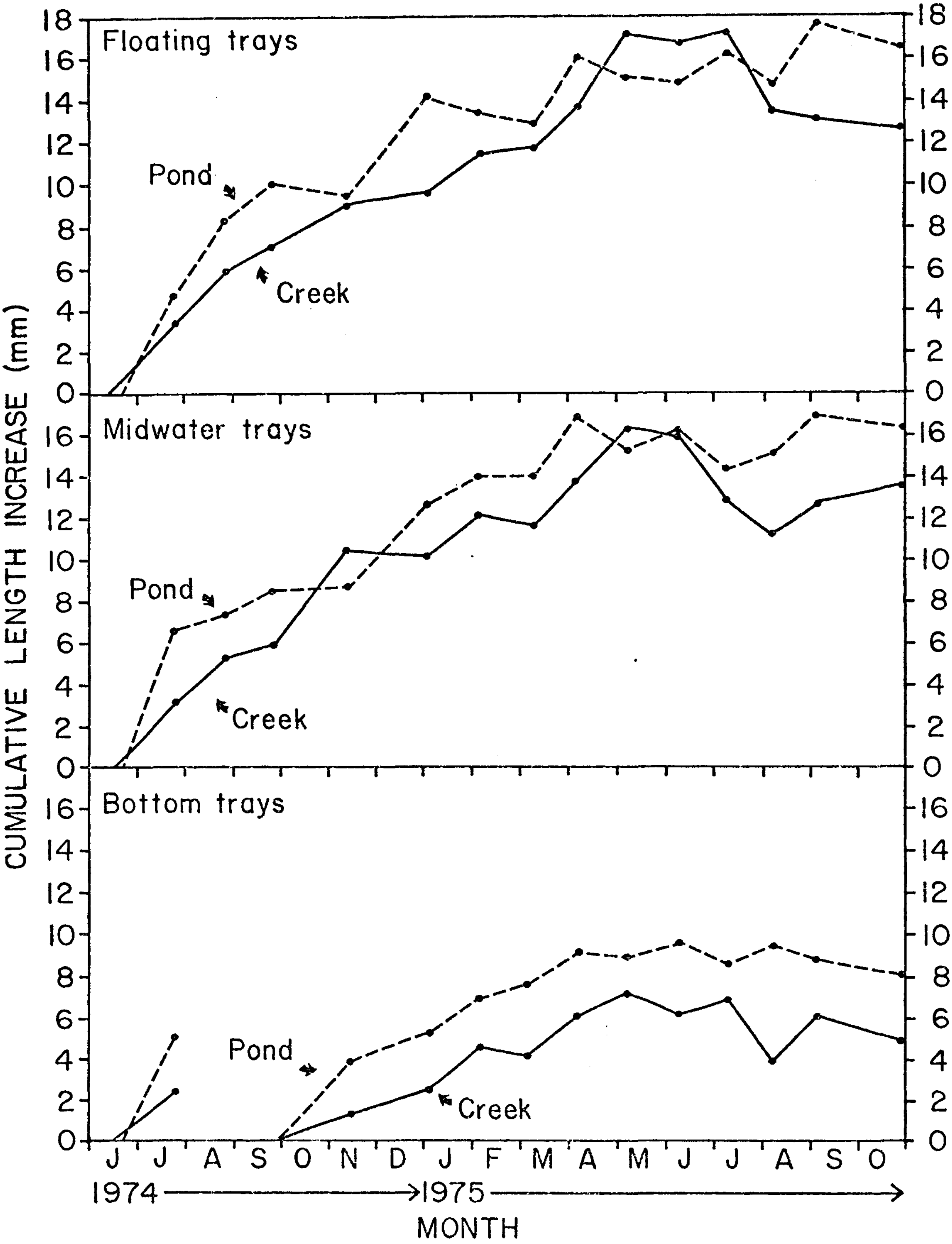
Table 8.

Two-Way Anova Without Replication Comparing Cummulative Increases in Oyster Lengths at Depths and in Both Environments from 27 September 1974 to 30 October 1975

	df	SS	MS	F
Locations	1	15.36	15.36	99.1**
Depths	2	91.36	45.68	294.7**
Error	2	.31	.16	
Total	5	107.03		

F max = 1.03

Figure 10. Cummulative length increases of oysters at three depth intervals in the creek and pond during a 16 month period.



Floating trays
Pond
Creek
Midwater trays
Pond
Creek
Bottom trays
Pond
Creek
CUMULATIVE LENGTH INCREASE (mm)
J J A S O N D J F M A M J J A S O
1974
1975
MONTH

Market size oyster (> 75 mm) were first measured in floating and mid-water trays of the pond slightly more than six months after transplanting in January. Growth continued at a slower rate throughout fall, winter and spring after an initial period of rapid growth immediately following transplanting. Accelerated growth did not occur during the second summer.

Survival

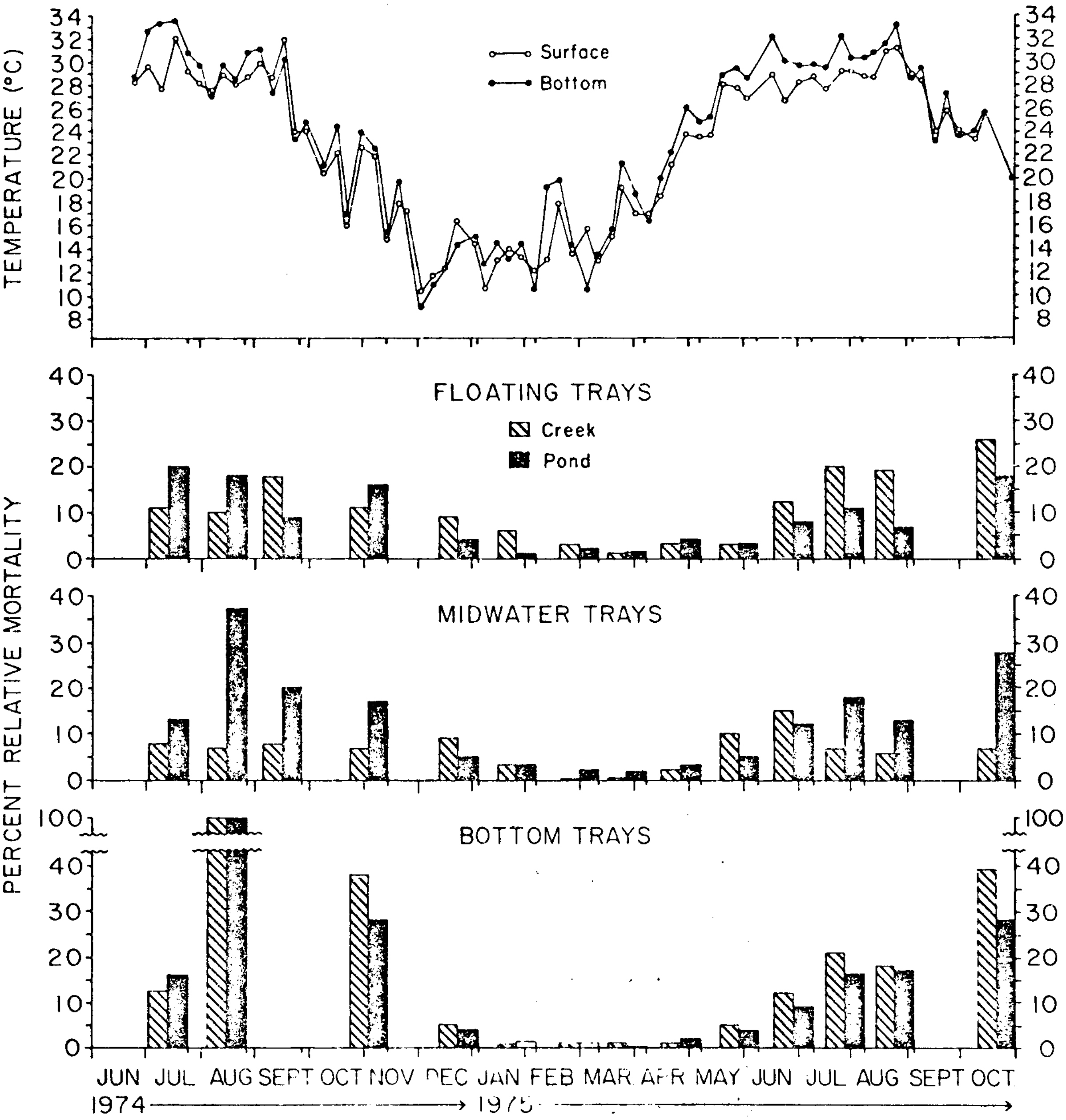
Survival was highest during the winter and spring and lowest during late summer and fall (Figure 11). Heavy mortalities occurred in August after a two month growth period. In the pond this ranged from 56% in mid-water, 40% in floats to complete die off of bottom oysters; in the creek 21% in mid-water, 35% in floats and complete mortality of bottom oysters.

At the end of the experiment, highest percentage survival (50%) was found in the creek mid-water oysters. Next highest survival occurred in the pond floating trays (46%) followed by the pond bottom group (29%). Lowest survival occurred in the creek bottom trays (18%).

Labyrinthomyxa marina

Incidence of *L. marina* was monitored in gapers throughout the year. Intensity ranged from very light to heavy based on a scale suggested by Quick and Mackin (1971). Mud minnows, *Fundulus heteroclitus* and other scavengers substantially decreased the gaper count found during warmer months. However, the majority of gapers examined showed medium to heavy infections. Total percent incidence of infection was 70% (Table 9). Unpublished data (Anderson, 1973) has shown a mean infection intensity

Figure 11. Percent mortality of oysters at three depth intervals in the creek and pond during a 16 month period relative to seasonal surface and bottom temperatures.


TEMPERATURE (°C)
Surface
Bottom
PERCENT RELATIVE MORTALITY
FLOATING TRAYS
Creek
Pond
MIDWATER TRAYS
BOTTOM TRAYS
JUN JUL AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY JUN JUL AUG SEPT OCT
1974
1975

of 21% during the summer months in the Wando River seed area where the transplants were obtained.

Table 9.

Chronological Record of Thioglycollate Tests for *Labyrinthomyxa marina*

Date Collected	Location & Depth	# Gapers Examined	# Infected
24 July 1974	Creek, Float	1	1
	Pond, Float	3	3
	Pond, Mid-water	1	1
	Pond, Bottom	3	3
27 September 1974	Creek, Float	1	0
	Creek, Mid-water	2	2
	Pond, Mid-water	1	0
29 October 1974	Creek, Float	5	4
	Creek, Bottom	1	1
	Pond, Surface	1	1
	Pond, Mid-water	4	2
14 November 1974	Creek, Float	1	1
	Pond, Float	4	4
	Pond, Mid-water	2	2
	Pond, Bottom	1	1
4 January 1975	Creek, Mid-water	2	1
	Pond, Mid-water	2	0
10 March 1975	Pond, Mid-water	2	0
4 April 1975	Pond, Bottom	3	1
	TOTALS	40	28

Total percent incidence infection = 70%

Following the summer kill of the bottom oysters in August, five random live samples were removed from each tray (15 oysters at each depth) and examined by thioglycollate tests (Ray 1954c) (Table 10).

Table 10.

Percent Incidence of
Infection of Stochastic Sampling

Depth	Creek	Pond
Floats	67%	73%
Mid-water	53%	58%

Predators

The boring sponge (*Cliona* sp.) and oyster drills (*Urosalpinx cinerea*, *Eupleura caudata*) were not observed during the year in either environment. Salinity was too low for other predators such as conchs and starfish even if they had managed to enter the covered trays (Wass, 1972). An unidentified polychaete that successfully survived transplanting was noticed on a number of the Wando seed oysters. Large numbers of curved mussels (*Brachidontes recurvus*) were found growing on creek midwater oysters during the warmer months. The pond and remaining creek oysters had fewer attached curved mussels. Barnacles (*Balanus eburneus* and *Balanus balanoides*) as well as mud worm blisters of *Polydora websteri* were observed occasionally. Large numbers of blue crabs (*Callinectes sapidus*) and occasional stone crabs (*Menippe mercenaria*) were noticed in both creek and pond, but not inside the oyster trays. Oyster crabs, *Pinnotheres ostreum* were also evident during shucking at the end of the experiment.

Oyster Meat Yield

Baird (1957) has established a high correlation of wet weight with dry weight; an analysis which saves considerable time and lends itself to subsequent culinary examinations. Total wet meat production at the end of the year study illustrated that yield was directly associated with survival. However, comparative meat volume was highest in the pond floating trays (2.3 liters, 46% survival), followed by creek mid-water trays (2.2 liters, 50% survival). Total pond production was 5.4 liters of wet volume at the end of the experiment and Adams Creek produced 4.2 liters.

$$\text{Oyster meat yield} = (\bar{y}) = \frac{(\text{wet meat volume (liters)}}{(\text{unshucked shell stock (liters)}} \times 100)$$

was similar at all three pond depth intervals ($\bar{y}$ = 10.4 $\pm$ .38). Creek values showed variation at all three depths: floats (9.8), mid-water (6.3), and bottom (11.4). Oysters maintained at the depth and location of poorest survival and growth (creek-bottom) contained the largest meats in correspondingly larger shell cavities. Although cumulative length was poor, oysters were fatter.

DISCUSSION

Salinity conditions throughout the study fell within the acceptable ranges for oyster growth for both creek and pond. The range most suitable for C. virginica growth is within the mesohaline (5.0 - 18.0 $^{o}/oo$) and polyhaline (18.0 - 30 $^{o}/oo$) zones (Galstoff, 1964). Transplanting Wando seed from a salinity area of $\overline{x}$ = 11 $^{o}/oo$ to one that initially averaged 29 $^{o}/oo$ for both environments appeared to have no adverse effects. In fact, cumulative length increases in the creek and pond at all depths illustrated rapid growth during the first month.

Observed water tempetures were never low enough to cause cessation of oyster feeding. Adversely high temperatures (> 32°C) were recorded for both creek and pond during the summer. The temperature regime affects feeding, rate of water transport, respiration, gonad formation and spawning (Galstoff, 1964). Maximum rate of ciliary activity is at 25°C to 26°C. Below 6°C to 7°C C. virginica ceases feeding; above 32°C ciliary movement rapidly declines (Galstoff, 1964). However, Collier (1954) describes a lower optimum temperature range for C. virginica (between 15°C and 25°C) on the Gulf Coast. Larger temperature fluctuations occurred in the pond, probably resulting from the greater influence of ambient temperature and insolation on a smaller water volume. Carriker (1959) observed heating of Home Pond water by insolation, as the pigmented black bottom of the pond, when visible, absorbed and retained more heat than its adjacent tidal creek. The higher mean diurnal temperature of nearly 2.0°C observed in the pond during the seasonal 25 hour stations is considered to be caused to a large extent by this insolation process. Afternoon warming was not revealed during weekly sampling which normally occurred in the mornings. Annual means of the creek and pond showed a comparatively higher pond temperature of 0.6°C.

Sufficient oxygen levels were maintained throughout the year in both environments, even during pre-dawn sampling. Sparks, Boswell, and Mackin (1957) reported that oysters survived for several days in water containing less than 0.7 ml/l of dissolved oxygen ($\bar{x}$ temperature = 23°C). During the summer phytoplankton bloom in the pond, hourly recorded oxygen values throughout the 25 hour period never dropped below 2.8 ml/l (29.5°C).

Lower turbidity in the impoundment probably resulted from a greater settling capacity than the tidal creek (Figure 5) and permitted photosynthesis to occur deeper. As the oyster's energy is primarily derived from the organic particulate components such as detritus and living micro-plankton (Lund, 1957), higher levels of such components would be expected to be more favorable to oyster growth. This differentation could not be made from the turbidity measurement technique used.

Higher chlorophyll a measurements of photosynthetic capacity in the pond corroborates the higher dissolved oxygen concentrations. An earlier study by Ryther and Yentsch (1957) recorded chlorophyll a values so high from two salt water ponds that they were thought to be atypical.

The wide range of pH values in both environments could not be directly associated as inhibitive or favorable to oyster growth. Higher pond pH values are associated with higher pond chlorophyll a concentrations resulting from greater photosynthetic activity. When photosynthesis is high, pH is high as the algae have removed most of the CO_2 in the process attributed to assimilation. Additionally, bacterial production of ammonia from proteinaceous materials and reduction of nitrate to free nitrogen or ammonia increases the alkalinity and pH of the water (Revelle & Fairbridge, 1957). Riley & Chester (1971) state that variations in pCO_2, total CO_2 and pH are most extreme in isolated bodies of water, such as rock pools, where there is a relatively high concentration of living organisms, an effect often accentuated by summer stratification. In one instance, Orr (1947) found that photosynthesis increased the pH of surface water of a marine pool to 9.9.

Carbohydrates were selected for comparative assessment because of their possible stimulation of oyster pumping as well as direct energy utilization as reported by Collier, Ray and Magnitzky (1950). Carbohydrate thresholds below 4.8 μg/l resulted in termination of pumping and the oysters closed. Above this threshold concentration (which increased with rising temperatures), the pumping continued at a rate which fluctuated in accordance to alterations in the carbohydrate level (Collier, et al 1953). Butler (1962) in a later re-examination found little, if any correlation with pumping and increased levels of dissolved carbohydrates within 10-30°C temperature ranges. Also, there appeared to be no threshold below which oysters were inactive (Butler, 1962). Particulate carbohydrate levels in close correlation with chlorophyll _a_ were consistantly higher in the impoundment, but no association could be made _per se_ with oyster growth periods during the year-study.

Walsh (1965), Eppley, Gee and Saltman (1963), and others have presented data to support the hypothesis that DCHO is used by phytoplankton during bloom periods (DCHO concentrations were lower than when no bloom was present). These data are in agreement with one of the lowest DCHO values of 1.9 μg/l found in the pond during the August phytoplankton bloom. Also, highest concentrations of DCHO were found in areas of low tidal exchange and high productivity (Walsh, 1965).

Levels of chlorophyll _a_, dissolved oxygen, pH, dissolved and particulate carbohydrates were consistently higher in the impounded environment. Nutrients conversely were higher in the tidal creek. Nitrate appeared to be limiting during a bloom of Oscillatoraceae in the pond, while sufficient levels of orthophosphate and silicates were maintained. Goldman et al. (1972); Brewer and Goldman (1976) have pointed out that assimilation of NO_3^- during photosynthesis generates strong base whereas NH_4^+ uptake leads to acid production. Lowest pH values in the pond during the year were recorded during late August at the time of lowest nitrate levels following the bloom of Oscillatoraceae. High levels of ammonia may have been produced during this period of decomposition.

Though nitrogen fixation was likely in the environment studied, it did not compensate for the degree of nitrate uptake during the late summer bloom. In a recent study (Whitney, Woodwell and Howarth, 1975) six areas within a Long Island marsh were sampled: (1) non-vegetated areas of the high marsh, (2) pools of standing water in the high marsh, (3) sediments beneath strands of _Spartina alterniflora_, (4) flats exposed only at low tide, (5) water from the tidal creeks and channels, and (6) blue-green algal mats of the high marsh. Nitrogen fixation occurred in all areas except channel water; highest rates of fixation occurred in tidal pools.

Reduction below 10 μg/P/1 occurred very rarely in the creek, but took place at various times during the year in the pond predominantly in surface water where occassionally no orthophosphate was detected. Surface water depletions of orthophosphate in the impounded water, while bottom concentrations ramained sufficient, imply generation of the ion from the sediments. As the turnover rate of phosphate is probably more important than the actual orthophosphate concentration in maintaining high production (Pomeroy, 1960), a phosphate concentration above 10 μg/P/1 allows the growth rate of many species of phytoplankton to be independent of the phosphate concentration. However, as the concentration decreases below this critical level, cell division becomes inhibited and phosphorous deficient cells are produced (Riley & Chester, 1971).

Pomeroy, et al. (1969) have found that sediment in the Georgia marsh contained enough PO_4^{-3} for 500 years growth of marsh grass without replenishment by additional input or recycling. The phosphorous is combined in the crystal lattice of the illite clay and from this combination with the clay it can be released as free phosphate available for biological uptake (Pomeroy, Smith and Grant, 1965). Blooms in tidal creeks would receive sufficient phosphate from the sediments to continue for days or weeks at high rates of photosynthesis (Pomeroy, Smith & Grant, 1965).

No depleted silicate levels in either environment were ever observed. The dissolved silicon content of coastal waters is generally comparatively high due to the effect of run-off from land (Riley & Chester, 1971). Assuming no gross differences in each environment's nutrient composition, lower comparative nutrient values in the pond corroborate higher instantaneous biomass levels, which illustrates greater utilization, or more "tied-up" nutrients in the impounded water. Without net loss of cycling nitrogen to the estuary, accumulation of additional nitrogen from land runoff and bird excretions would probably favor a larger instantaneous biomass.

Continuous renewal of water from tidal exchange in the creek would appear to favor oyster growth more than the comparatively motionless impoundment. Under optimum conditions C. virginica filters water at the rate of 15 liters per hour and can take in water only from a distance up to 51 mm from the shell (Galstoff, 1964). Water circulation in the pond was almost totally influenced by windstress due to its shallowness. Other factors such as water influx from spring tides, rainfall and watershed runoff contributed to mixing and stratification on occasion. Van Dorn (1953) observed negligible bottom-stress over a range of wind-speeds up to ten meters/sec. in a rectangular artificial pond two meters deep. Pond surface water would experience considerably more movement in proportion to the windspeed. Stratification was common in Hitchcock's pond; however complete mixing occurred throughout the fall 25 hour station. This may have been caused by a windy condition prior to the sampling period (> 20 knots, U. S. Weather Bureau, Personal Communication).

Inverse relationships of chlorophyll _a_ with tidal stage as found in this study have been previously reported by Welch and Isaac (1967). More recently, Erkenbrecher and Stevenson (1975) have noted a similar association with particulate organic carbon and ATP. Odum and de la Cruz (1967) observed larger concentrations of organic detritus at mid-ebb than mid-floodtide, illustrating a net export of these materials. Net export of estuarine particulate material (Odum and de la Cruz, 1967, Reimold & Daiber, 1970) is an important factor in determining rationale for the higher biomass and organic levels in the impounded water where no export occurs. Highest creek export velocity occurred during mid to late ebb of the summer 25 hour station, a value expected to be higher during a spring tide. Odum and de la Cruz (1967) calculated a net export of 140 kg. and 25 kg. of organic for Spring and neap tides respectively from a 10-25 hectare marsh area studied over one tidal cycle.

Highest incidence of _Labyrinthomyxa marina_ infection in oysters was recorded in August. This probably caused most of the summer mortalities as other diseases and predators were not observed in tray-held oysters. Rationale for warm weather mortality resulting from _L. marina_ is further substantiated by the large percentage of medium to heavy infection intensities of gapers. These high intensity levels rule out the possibility of chronic secondary infection since the exposed meats are readily preyed upon. It has been established by exhaustive studies

(Mackin, 1951, 1953, 1956; Mackin & Boswell, 1956; Ray, 1954a, b, c,; Andrews & Hewett, 1957) that the fungus Labyrinthomyxa marina is a major cause of warm season mortalities of oysters. The disease flourishes at high temperatures and prefers moderate and high salinities (Quick and Mackin, 1971). This implication was further supported by greatly reduced winter mortalities during a period of "overwintering" of L. marina. In contrast, low mortality was associated with most favorable growth during the colder months, while the reverse was true during warm weather.

Best growth and survival was observed in both environments during cooler months and lower chlorophyll a and carbohydrate concentrations. Butler (1952) observed a similar seasonal growth in Florida oysters. Also, greater concentrations of chlorophyll a and PCHO found in the bottom waters of both environments did not compliment more favorable growth relative to mid-water and surface oysters. However, oyster growth was significantly higher during the year in an impounded environment sustaining a higher instaneous biomass.

Comparative growth assessment has illustrated that most rapid growth occurs in floating trays, and that growth and survival are higher in winter and lower in summer in both environments.

Greater oyster production in the pond is associated with a comparatively higher instantaneous biomass maintained throughout the year. Most rapid growth, though, occurred during the winter - spring when instantaneous biomass concentrations were relatively lower than summer and fall. Energy utilized by spawning and the associated warm weather mortality periods are thought to be primary reasons for depressed summer production.

Higher pH measurements in the pond along with associated chlorophyll *a* and nutrient data indicate an environment of NO_3^- assimilation. Lower comparative nutrient values in the impoundment to the point of apparent NO_3^- limitation illustrate a more favorable environment for autotrophic production.

SUMMARY AND CONCLUSIONS

1. Oyster growth in both environments was greatest in winter; poorest in summer.
2. Oyster yield was directly associated with survival.
3. A 12 month comparative oyster growth assessment has shown that cummulative length increase is significantly higher (α=0.01) in a salt water impoundment than its adjacent tidal creek. Furthermore, surface tray growth is significantly higher (α=0.01) than bottom trays in both environments.
4. Summer mortalities were directly associated with highest incidence of *Labyrinthomyxa marina*. Highest survival occurred during the winter and spring "overwintering" period of the pathogen.
5. Warm summer months appear to be the most unfavorable time for transplanting *C. virginica*. Highest mortalities, slowest growth (with the exception of initial transplant growth) and thermal stress occur during this period in association with highest intensities and incidence of *Labyrinthomyxa marina* infections.
6. Haloclines were maintained in the impoundment in contrast to little or no stratification in the creek due to mixing. Salinities were lower in the pond due to freshwater runoff.
7. A slight thermal differential in the impoundment (from 0.6°C to 2.0°C) due to heating by insolation was probably more favorable to pond oyster production in winter and less favorable during high summer temperatures.

8. Lower turbidity in the pond due to a greater settling capacity allowed photosynthesis to occur deeper.
9. *In vivo* flourescence proved to be a poor method of quantatative analysis in determining chlorophyll *a* concentrations in heterogeneous phytoplankton populations.
10. Tidal stage affects the concentrations of both chlorophyll *a* and particulate carbohydrates.
11. No correlation of oyster growth periods could be made with particulate or dissolved carbohydrate levels. Particulate carbohydrates were in close correlation ($r = 0.753^{**}$) with chlorophyll *a*, and similar to chlorophyll, were consistantly higher in the impoundment.
12. Utilization of dissolved carbohydrates by phytoplankton during bloom periods was illustrated during a bloom of blue-green algae in the impoundment.
13. Extremely high NO_3^- concentrations observed in both the creek and pond resulted from bird excretions. Correspondingly high orthophosphate values were not associated with these excretory products.
14. Nitrate nitrogen appeared to be limiting in the pond while sufficient levels of orthophosphate and silicate were maintained.
15. Higher levels of chlorophyll *a* ($\bar{x}$ = 30%), carbohydrates, pH, and dissolved oxygen were consistently observed in the impoundment. Lower comparative nutrient values in the pond associated with the higher instantaneous biomass levels indicated a more favorable environment for autotrophic production.

16. Greater oyster production in the pond was directly related to a higher instantaneous biomass maintained throughout the year.

RECOMMENDATIONS

1. Water flow is an important variable that should be a principal factor in future culture considerations. Exposure to larger volumes of surface water by increasing the mobility of floating trays would enlarge the oyster's grazing area.
2. Lowering the floodgate a certain level below MHW may enhance or inhibit pond production with a controlled amount of circulation. Results of this study indicate the recommendation would appear to be particularly favorable during periods of thermal stress, very low salinities, and unfavorably high instantaneous biomass. In advanced stages of eutrophication, the impoundment could be relieved of organic matter beyond its carrying capacity by floodgate control with a net reduction of instantaneous biomass absorbed by the estuary.
3. During the winter-spring period of most favorable growth, the over-wintering stage of *L. marina*, colder water, and less light, the instantaneous biomass could possibly be maintained at a higher concentration favoring further production by decreasing the volume of water in the pond.
4. Heterogeneity of pond productivity in respect to location has also been observed on a number of occasions. Gross observation of other impoundments in South Carolina and previous experimental data seem to establish the importance of the pond's watershed area, whether the peripheral vegetation is maritime forest, pasture land, or extensive marsh. Further research should consider pond

productivity and its association with the two variables: (1) rainfall and (2) nitrate.

5. Consideration of drainage frequency in relation to impoundment productivity should be assessed over an extensive period of time, i.e. does production increase or decrease with interval drainage?

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