A BASELINE STUDY OF SELECTED IMPOUNDMENTS IN GEORGETOWN COUNTY

SOUTH CAROLINA SEA GRANT CONSORTIUM

A BASELINE STUDY
OF
SELECTED IMPOUNDMENTS
IN
GEORGETOWN COUNTY

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The coastal wetlands are among the most productive natural ecosystems in the world. The production of large quantities of organic materials in these systems tends to make them and the associated coastal waters important habitats for commercially important fish, shellfish and waterfowl. Such productivity has been the subject of extensive reviews by Teal and Teal (1969), Keefe (1972), Gulf South Research Institute (1977), and Chapman (1977), among others.

Impoundments in these systems are made generally for better utilization and management of the marsh productive processes. In the coastal areas of South Carolina, impounded areas of the wetlands, often the remnants of the once flourishing rice fields, are managed to provide winter feeding and resting habitats fro migratory waterfowl and thus serve the needs of sportsmen for good waterfowl hunting grounds. More recently, the high productivity in these areas has stimulated interest in the possible use of impounded marsh systems as aquaculture production units. The success of the use of impounded wetlands in other parts of the world, notably in the Far East, for aquaculture purposes is well-known (see e.g., Bardach et al.; Ling, 1977). Culture techniques for shrimp, mollusks, and fish have been developed to utilize in a more directly commercial way the high productivity of the wetlands. The availability of these techniques and the wide expanse of old ricefields and impoundments in South Carolina often present economically-tempting aquacultural prospects.

As more South Carolinians become interested in aquaculture enterprises, it has become almost imperative to assess and possibly develop the aquaculture potential of the vast wetland areas of the state. Specifically, the Georgetown County Development Commission, meeting with a number of State agencies and universities, is developing a master aquaculture work plan for the county.

As part of the master plan, the study described in this report, which is supported by the South Carolina Sea Grant Consortium, is a first step towards the assessment of aquaculture potential of selected brackish and freshwater impoundments in Georgetown County. The objective of the study is to provide a baseline profile of the ponds in terms of their basic physicochemical parameters and biological productivity patterns. These baseline data can serve as a preliminary appraisal of the feasibility of utilizing these areas for aquaculture purposes and provide information needed for decision making on the utilization of the wetlands. Following the descriptive profiles of the selected ponds, there is a general discussion of aquaculture literature pertinent to the South Carolina wetland systems.

METHODOLOGY

Study Areas

The baseline study was conducted in selected brackish- and freshwater impoundments situated along the major natural water systems in Georgetown County, South Carolina (Fig. 1). The brackish systems studied were ponds in Annandale Plantation (AP) in the Santee River delta and in Estherville Plantation (EP) along Winyah Bay. The freshwater impoundments were located in Keithville Plantation (KP) along the Black River and in Waverly Plantation (WP) along the Waccamaw River.

Except in Waverly Plantation where only one pond was studied, two ponds in each of the plantations were monitored and sampled. In each case, one pond (Pond 1) served as the primary study site where a rather intensive sampling schedule was done. Periodic sampling was also done in the second pond (Pond 2) to provide some information on variability of conditions within the same wetland area.

Each pond generally has perimeter ditches along the dikes containing most of the pond water, and a shallower, often densely vegetated midfield or interior area bounded by the ditches. Unless otherwise noted, depths reported here refer to mid-channel depths of the perimeter ditches.

Sampling Methods

Due to the short time involved, the study focused on basic water quality parameters, sediment types, phytoplankton productivity, and zooplankton abundance and diversity. The sites were sampled three times between June 20 and July 15, 1981 to assess ranges of early summer pond conditions. During the third sampling, samples were taken at four-hour

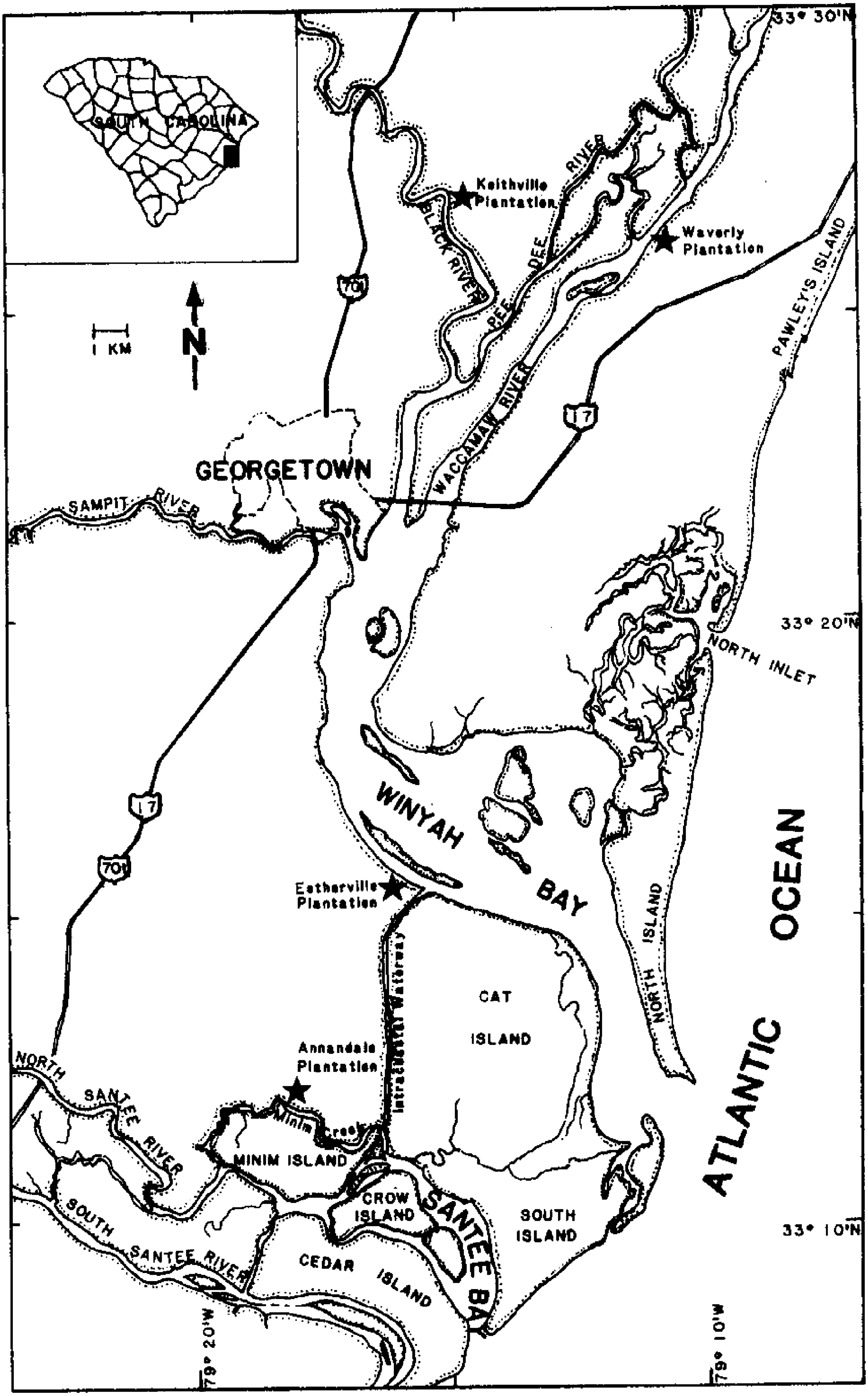

Fig. 1. Map of Georgetown County, showing locations of study sites.

intervals over a 24-hour period to establish diel patterns of temperature, pH, and dissolved oxygen content.

Each sampling consisted of *in situ* measurements of basic hydrographic parameters (water clarity, temperature, salinity, pH, and dissolved oxygen) and collection of samples of surface and bottom water as well as sediment for later laboratory analyses. Water clarity was measured using a Secchi disk. Temperature and salinity were recorded with a Beckman induction salinometer (Model RS5-3); dissolved oxygen content was measured with a portable YSI oxygen meter (Model 57). Water and sediment pH readings were taken with an Orion Research Ionalyzer (Model 407A). Bottom water and sediment samples were taken with a manually operated pump and a box corer, respectively. In the laboratory, turbidity, expressed in formazin turbidity units, (FTU's, which are equivalent to the Jackson turbidity units, JTU's), was measured with a Hach DR-EL/1 water analysis kit. Nutrient analyses were made on an O.I. Corp. T.O.C. Analyzer (Model 524C) for dissolved organic carbon and on a Technicon Autoanalyzer II for total nitrogen, ortho-phosphate, and total phosphorus. (Nitrate and nitrite could not be analyzed due to color interference from tannin in the water.) Photosynthetic pigments were analyzed using a Turner fluorometer.

Vegetation cover was analyzed using infrared aerial photographs verified by ground truth for species identification. Phytoplankton productivity was measured during the third sampling with the light-dark bottle oxygen production technique (Vollenweider, 1974). Zooplankton samples were collected with a 153-micron mesh plankton net with 50 cm mouth diameter.

RESULTS

ANNANDALE PLANTATION

The two Annandale Plantation ponds are located along the bank of Minim Creek, a tributary of North Santee River (Fig. 2). Each pond is filled directly from the creek through a screened double-gate water trunk. When filled, the perimeter ditches of Pond 1 ranged in depth from 80 to 210 cm 31.5 to 82.7 in.), with an average depth of 120 cm (47.2 in.). In Pond 2, the ditches were 75 to 205 cm (29.5 to 80.7 in.) deep, the mean depth being 102 cm (40.2 in.). The densely vegetated shallower midfield areas in both ponds were covered with 30 to 50 cm (11.8 to 19.7 in.) of water.

Physico-chemical conditions

During the study period, the ponds were characterized by low Secchi disk visibility, relatively constant salinity, alkaline waters and sediment, and supersaturated and stratified dissolved oxygen profiles (Table 1). Surface water temperatures in Pond 1 ranged from 29.9°C to 34.5°C; temperatures at mid-depths and bottom were one to three degrees cooler. Temperature patterns in Pond 2 were basically similar to Pond 1. Salinity varied very little temporally and vertically; Pond 1, however, had slightly higher salinity readings than Pond 2. Water pH values averaged 7.7 for Pond 1 and 7.5 for Pond 2. The bottom mud in both ponds was predominantly silty clay with considerable vegetative debris and had pH values ranging from 6.0 to 8.4 in Pond 1 and 6.0 to 7.7 in Pond 2.

Dissolved oxygen (DO) concentrations in both ponds indicated supersaturation in the top layers of the water column as well as vertical stratification (Fig. 3). Primarily due to the heavy phytoplankton bloom during the third sampling, DO values for the top 50 cm in Pond were over

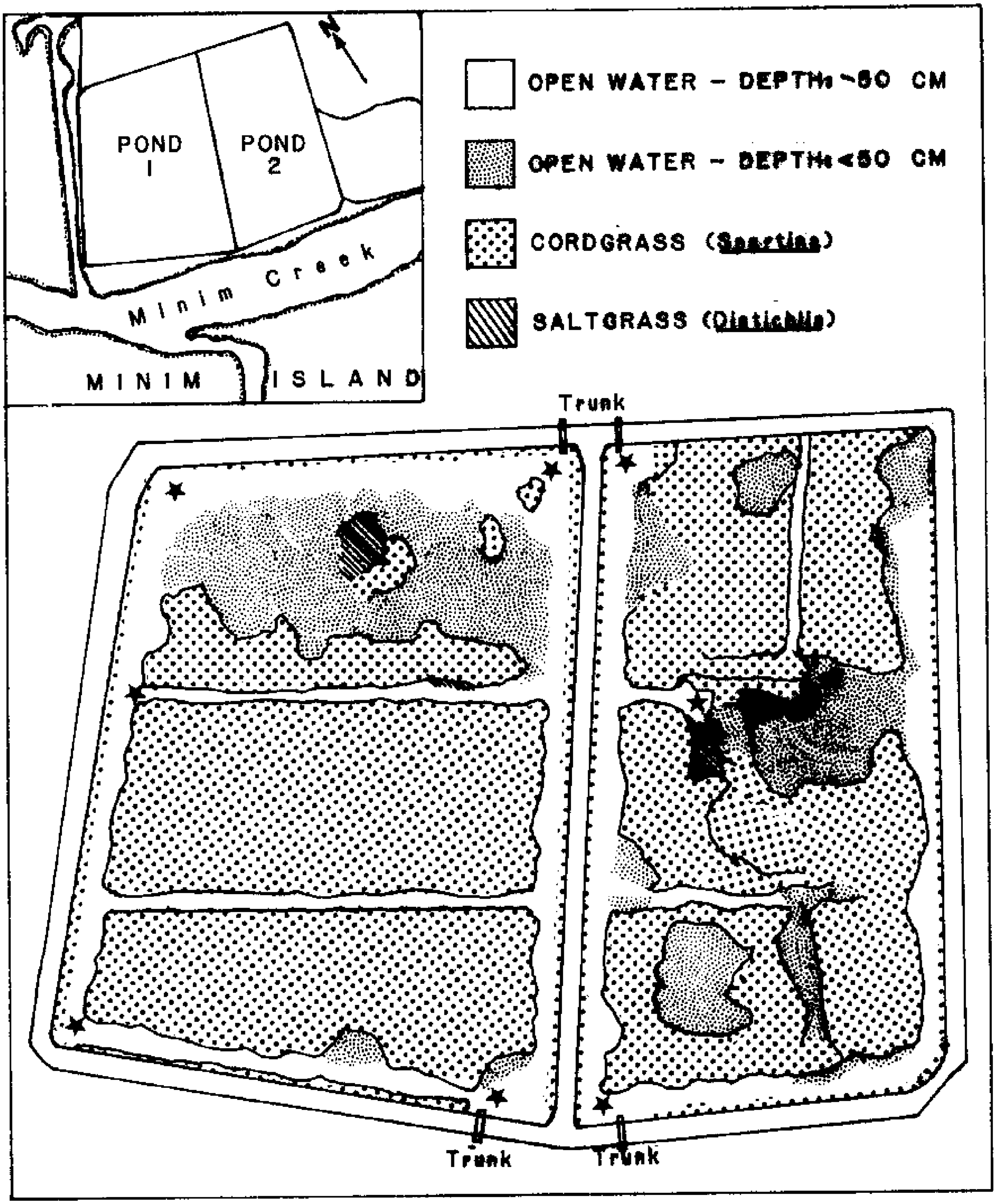

Fig. 2. Location and patterns of vegetation and water depth of the Annandale Plantation ponds. Stars indicate sampling stations.

Table 1. Summary of early summer conditions of Annandale Plantation ponds monitored from June 20 to July 13, 1981. Values given are ranges, with means in parentheses.

	POND 1			POND 2		
AREA (ha)	12.4			6.6		
WATER DEPTH (cm)	80 - 210 (120)			75 - 205 (102)		
SECCHI DISK VISIBILITY (cm)	21 - 45 (30.5)			29 - 54 (34.4)		
SEDIMENT pH	6.0 - 8.4 (7.5)			6.0 - 7.7 (6.8)		
WATER COLUMN PARAMETERS:	*Surface*	*Mid-depth*	*Bottom*	*Surface*	*Mid-depth*	*Bottom*
Temperature (°C)	29.2 - 34.6 (32.0)	28.8 - 34.4 (31.6)	27.0 - 33.3 (30.9)	28.1 - 36.7 (32.3)	27.6 - 33.5 (31.0)	27.6 - 33.5 (30.9)
Salinity (°/oo)	24.2 - 27.0 (26.4)	23.6 - 26.9 (26.0)	24.2 - 26.6 (25.7)	21.3 - 24.8 (23.9)	22.9 - 24.9 (24.0)	23.2 - 25.6 (24.2)
pH	6.3 - 9.0 (7.7)	6.4 - 9.3 (7.9)	6.4 - 8.6 (7.6)	6.5 - 9.0 (7.6)	6.7 - 8.9 (7.7)	6.6 - 7.6 (7.2)
Turbidity (FTU's)	40 - 68 (51.0)	---	50 - 85 (62.5)	58 - 98 (81.5)	---	55 - 95 (70.0)
Dissolved Oxygen Content (ppm)	4.3 - 13.5 (9.2)	3.8 - 12.7 (8.5)	0.2 - 3.9 (1.7)	5.1 - > 20 (14.2)	4.0 - 20 (7.7)	0.2 - 3.0 (1.0)
Gross Primary Production (mg C/m^3/hr)	527.3 - 600.0 (558.6)	---	40.9 - 147.4 (101.4)	---	---	---
Net Primary Prodcution (mg C/m^3/hr)	443.3 - 576.4 (499.3)	---	13.5 - 54.4 (33.0)	---	---	---
Chlorophyll-*a* (mg Chl-*a*/m^3)	27.4 - 46.9 (38.7)	---	37.3 - 50.1	79.8 - 682.9 (361.3)	---	38.7 - 518.1 (192.9)
Dissolved Organic Carbon (ppm)	7.8 - 9.0 (8.4)	---	7.5 - 9.1 (8.4)	12.0 - 19.0 (14.8)	---	11.7 - 17.1 (14.2)
Total Nitrogen (µg-atom/liter)	46.8 - 254.8 (119.3)	---	45.3 - 124.4 (91.5)	54.7 - 312.0 (164.2)	---	50.9 - 338.8 (154.3)
Total Phosphorus (µg-atom/liter)	0.3 - 3.1 (2.0)	---	0.4 - 4.4 (1.8)	0.7 - 20.0 (9.0)	---	1.1 - 9.4 (3.6)
Orthophosphate (µg-atom/liter)	0.007 - 1.02 (0.29)	---	0.06 - 0.18 (0.15)	0.20 - 1.70 (0.78)	---	0.15 - 1.25 (0.45)

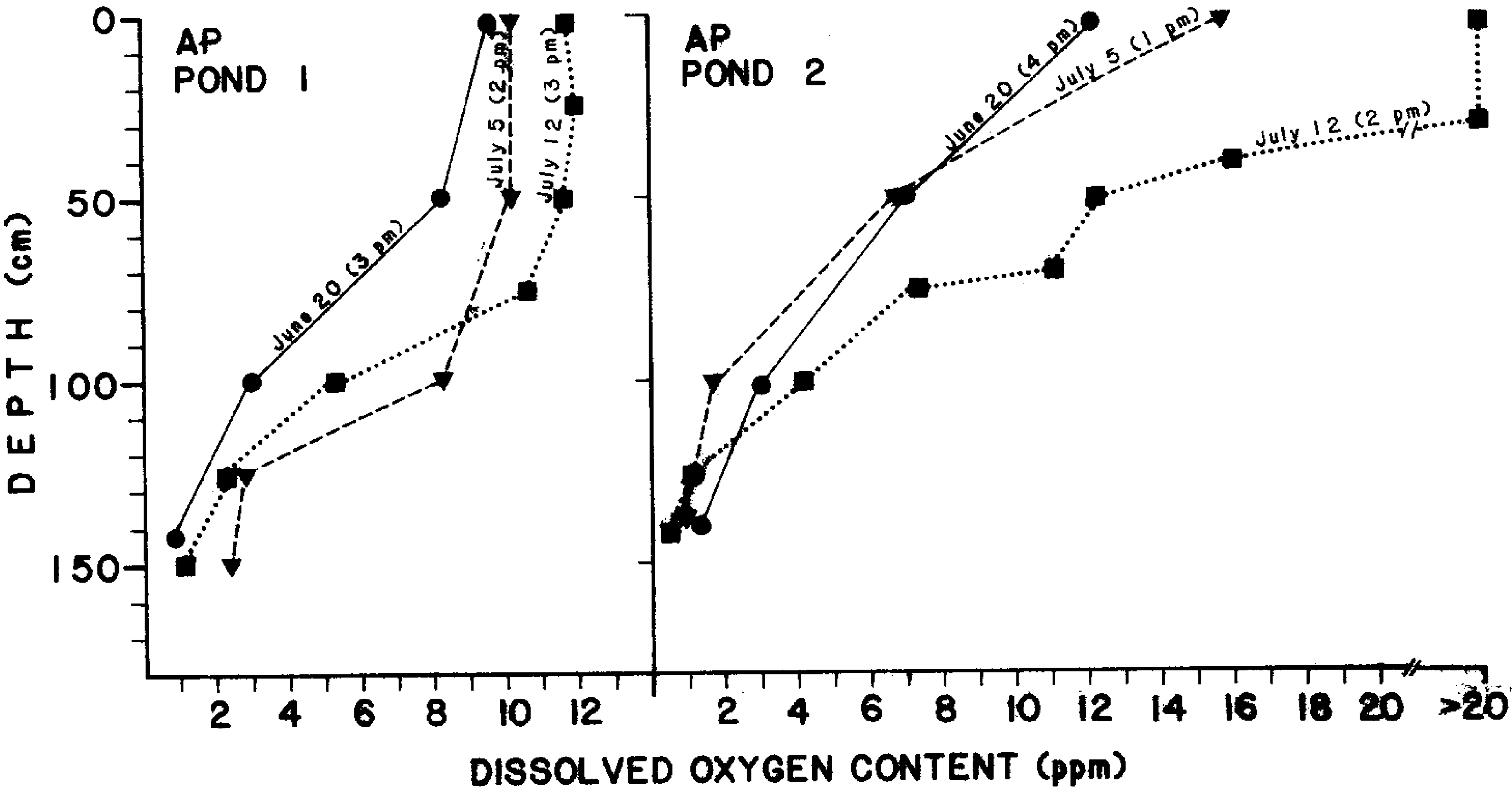

Fig. 3. Vertical profile of dissolved oxygen in the Annandale Plantation ponds.

20 ppm. The stratification of dissolved oxygen generally occurred around the 1-meter depth, with bottom DO values being below 3 ppm.

Diel patterns

Such DO supersaturation and stratification became more noticeable in the diel pattern of DO fluctuations (Fig. 4). Maximum DO concentrations occurred during the afternoon and minimum values around sunrise. Throughout the 24-hour period, significant differences between surface and bottom DO values were evident; the DO profile at the 50-cm depth closely followed the surface pattern. The pH curves generally followed that of the dissolved oxygen without significant difference between surface and bottom pH profiles. Although not statistically significant, temperature differences between the surface and bottom water were noted during the afternoon. Secchi disk visibility was between 21 and 35 cm during the daylight hours.

Nutrients

In Pond 1, concentrations of nutrient elements were generally higher at the surface than at the bottom (Table 1). Orthophosphate values averaged 0.29 μg-atom/leter at the surface and 0.15 μg-atom/liter at the bottom. Surface concentrations of total nitrogen and total phosphorus were about 120 and 2 μg-atom/liter, respectively; corresponding bottom values were 92 and 1.8 μg-atom/liter. Much higher values of nutrients were obtained in Pond 2. Surface nutrient concentrations averaged about 0.8 μg-atom/liter for orthophosphate, 9 μg-atom/liter for total phosphorus, and 164 μg-atom/liter for total nitrogen; corresponding bottom averages were 0.5, 3.6, and 154 μg-atom/liter, respectively.

Productivity patterns

Indicative of the high primary productivity in the ponds was the

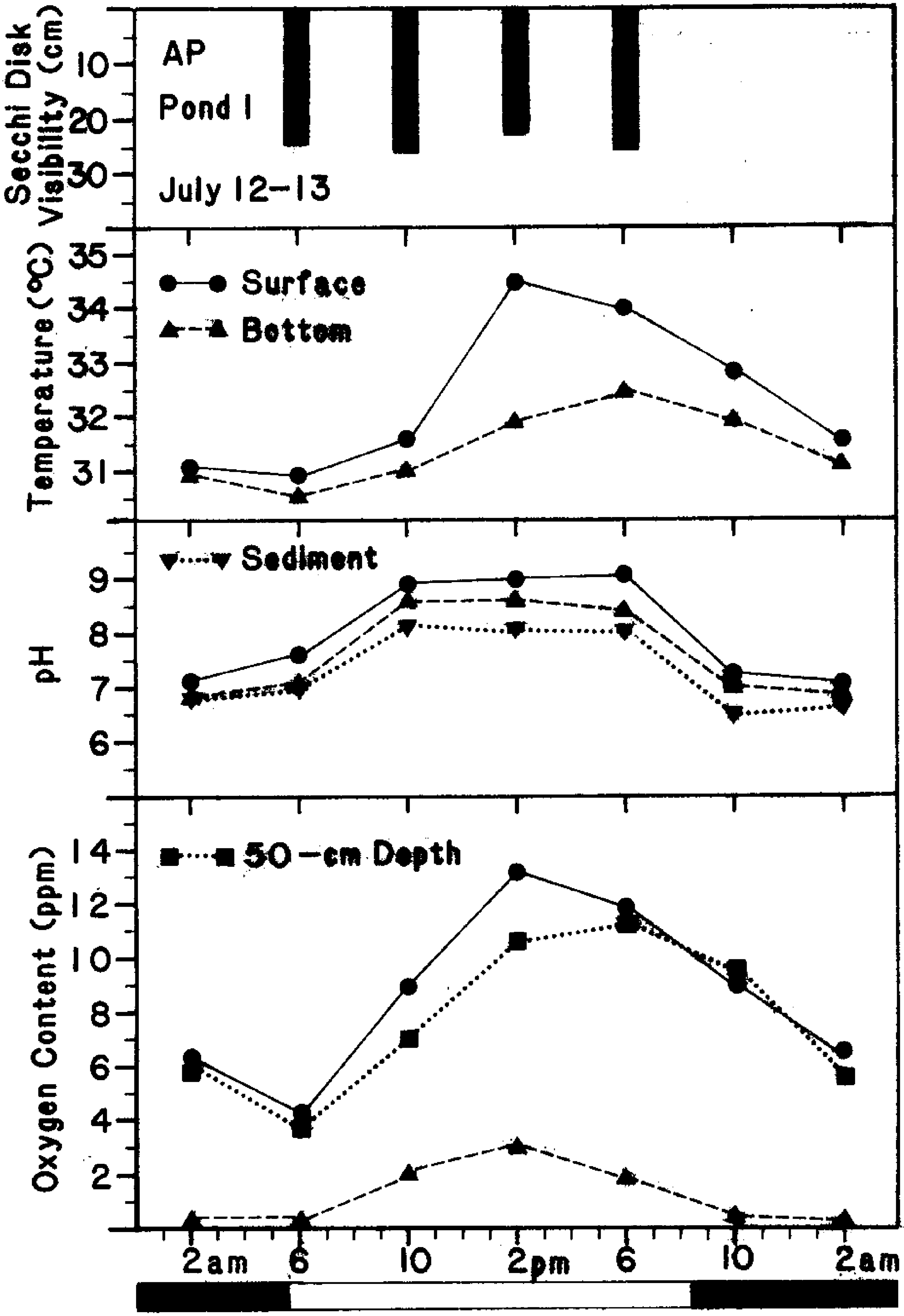

Fig. 4. Diel patterns of water clarity, temperature, pH, and dissolved oxygen content in Annandale Plantation Pond I.

expanse of cordgrass (*Spartina alterniflora*) which practically covered the pond areas bounded by the perimeter ditches (Fig. 2). Small clumps of the saltgrass *Distichlis* were also found in some parts of the midfield areas. Added to the high *Spartina* productivity was the similarly high phytoplankton productivity in the water column. Surface gross production values ranged from 527 to 600 mg C/m^3/hr, while bottom values ranged from 41 to 147 mg C/m^3/hr (Table 1). During the one-month monitoring period, phytoplankton abundance, as measured by chlorophyll-*a* analyses, fluctuated between 27 and 50 mg chlorophyll-*a*/m^3 in Pond 1 (Table 1). In Pond 2, however, surface phytoplankton abundance increased from 80 mg chlorophyll-*a*/m^3 on June 20, to 683 mg cholorphyll-*a*/m^3 on July 12; corresponding bottom values were 39 and 518 mg chlorophyll-*a*/m^3. Similarly, higher values of dissolved organic carbon (DOC) were recorded for Pond 2; Pond 1 averaged about 8 ppm DOC, while Pond 2 averaged about 14 ppm DOC.

Zooplankton

Calanoid copepods, mainly *Acartia* with some *Pseudocalanus*, dominated the zooplankton in Pond 1 (Table 2). Accounting for over 95% of the samples, calanoid copepod densities increased from 16 individuals/liter on June 20, to 228 individuals/liter on July 12. The cyclopoid copepod *Oithona* was collected only during the first sampling. Most of the other components of Pond 1 zooplankton were larval stages of grass shrimp (*Palaemonetes*), xanthid crabs, polychaetes and gastropods.

Table 2. Composition and abundance of zooplankton in Annandale Plantation Pond 1. Density = No. of individuals x $1000/m^3$; % = percentage of total sample.

Date	June 20		July 5		July 12	
	Density	%	Density	%	Density	%
Calanoid copepods	15.51	95.7	56.98	97.6	227.37	98.5
Cyclopoid copepods	0.28	1.7	---	---	---	---
Grass shrimp zoeae	0.24	1.5	0.48	0.8	2.37	1.0
Polychaete larvae	0.06	0.3	0.64	1.1	0.75	0.3
Copepod nauplii	0.06	0.3	0.10	0.2	0.07	0.03
Crab zoeae	---	---	0.17	0.3	0.13	0.06
Gastropod larvae	0.06	0.3	0.02	0.03	---	---
Ostracods	---	---	---	---	0.07	0.03

ESTHERVILLE PLANTATION

Located along the western channel of Winyah Bay, Pond 1 in Estherville Plantation is very shallow throughout its 10-hectare area (Fig. 5). The perimeter ditches range from 50 to 80 cm in depth, with the midfield area averaging about 30 cm deep. Pond 2, bounded by the Intracoastal Waterway on the east and the State Secondary Highway No. 18 on the south, was not effectively sampled due to the ongoing construction work along the main dikes and ditches. The Pond 2 midfield was sampled only once and the data presented in Table 3 reflect only the conditions along the ditch nearest the water trunk.

Physico-chemical condistions

Due to its shallowness, Pond 1 was marked by high temperatures and supersaturated daytime dissolved oxygen patterns throughout the water column (Table 3). Temperatures ranged between 30.0 and 36.4°C, without much difference between surface and bottom. Dissolved oxygen values reached 18 ppm at times, with minimum values being about 5 and 1 ppm for the surface and bottom water, respectively. For the most part, the Secchi disk was clearly visible all the way to the bottom. Salinity fluctuated between 19 and 22 ^{o}/oo and water pH averaged 7.3. With pH ranging from 6.8 to 7.1, the bottom mud of the perimeter ditches was mostly silty black clay, while the midfield bottom was covered with a complex of black and red clays.

During the monitoring period, the main ditch of Pond 2 had dense growth of algal mats, causing dissolved oxygen values to reach above 20 ppm at times. Salinity varied from 21.3 to 24.7, while pH fluctuated between 7.1 and 7.7. Temperature averaged 32°C on the surface and 30.4°C at the bottom.

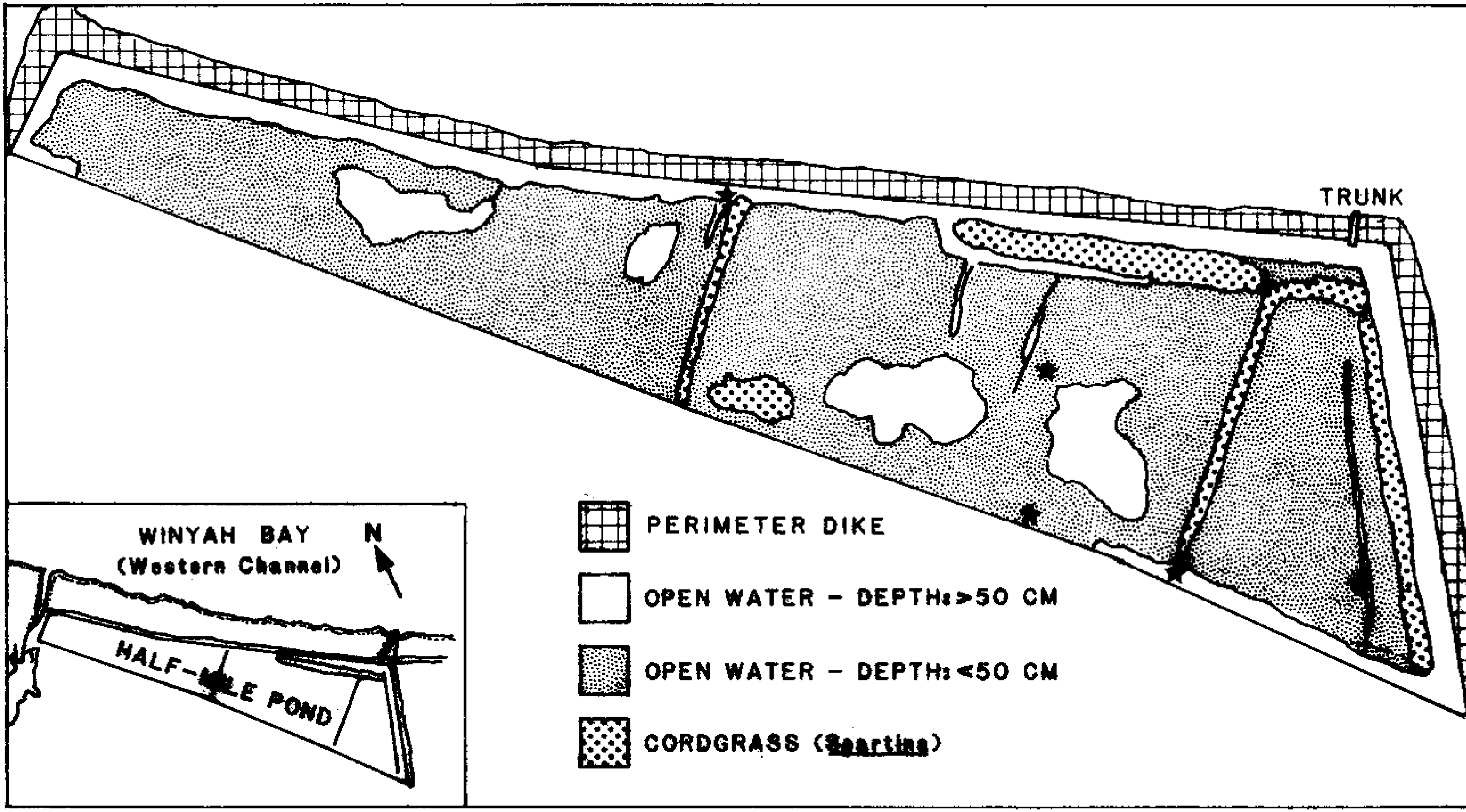

Fig. 5. Location and patterns of vegetation and water depth of Eatherville Plantation Pond I. Stars indicate sampling stations.

Table 3. Summary of early summer conditions of Estherville Plantation ponds monitored from June 20 to July 14, 1981. Values given are ranges, with means in parentheses.

	POND 1		POND 2		
AREA (ha)	10		18.2		
WATER DEPTH (cm)	50 - 80 (72.4)		105 - 215 (163.3)		
SECCHI DISK VISIBILITY (cm)	26 - 45 (38.8)		16.5 - 35 (24.6)		
SEDIMENT pH	6.8 - 7.1 (7.0)		6.4 - 7.2 (6.9)		
WATER COLUMN PARAMETERS:	*Surface*	*Bottom*	*Surface*	*Mid-depth*	*Bottom*
Temperature (°C)	30.0 - 36.4 (33.5)	30.0 - 34.6 (32.2)	31.1 - 33.2 (32.0)	27.9 - 33.3 (31.4)	27.5 - 33.1 (30.4)
Salinity (°/oo)	19.0 - 22.0 (21.4)	18.9 - 21.9 (20.9)	21.3 - 24.6 (22.6)	24.3 - 24.7 (24.5)	21.8 - 24.7 (23.2)
pH	6.0 - 8.1 (7.3)	---	7.3 - 7.7 (7.5)	7.3 - 7.6 (7.4)	7.1 - 7.3 (7.1)
Turbidity (FTU's)	32 - 58 (41.7)	---	65 - 115 (78.9)	---	35 - 125 (80.1)
Dissolved Oxygen Content (ppm)	4.9 - 18.0 (10.4)	1.3 - 17.7 (7.9)	7.2 - > 20 (12.7)	3.4 - 14.5 (10.0)	2.0 - 4.8 (3.6)
Gross Primary Production (mg C/m^3/hr)	177.8 - 306.4 (233.2)	85.9	---	---	---
Net Primary Production	127.1 - 246.8 (187.2)	26.6	---	---	---
Chlorophyll-*a* (mg Chl-*a*/m^3)	5.3 - 25.7 (10.9)	4.6 - 7.1 (5.7)	64.6 - 424.7 (234.7)	---	12.4 - 158.0 (91.8)
Dissolved Organic Carbon (ppm)	6.7 - 8.2 (7.2)	7.5 - 9.2 (8.2)	26.7	---	25.1
Total Nitrogen (µg-atom/liter)	175.4 - 762.4 (508.4)	664.0 - 696.0 (675.7)	236.8 - 488.8 (322.3)	---	431.2 - 506.4 (468.8)
Total Phosphorus (µg-atom/liter)	0.4 - 1.4 (0.9)	0.6 - 1.5 (1.2)	8.1 - 63.2 (32.3)	---	3.5 - 68.8 (36.2)
Orthophosphate (µg-atom/liter)	0.04 - 0.40 (0.12)	0.04 - 0.09 (0.07)		---	---

Diel patterns

Except during late afternoon and early evening, temperatures between surface and bottom water differed by less than a degree (Fig. 6). Dissolved oxygen concentrations reached maximum values in late afternoon and minimum values before sunrise. The diel pattern of pH was not monitored due to equipment malfunction. Averaged Secchi disk visibility fluctuated around 35 cm.

Nutrients

Total nitrogen concentrations in Pond 1 were very high, ranging from 175 to 762 μg-atom/liter at the surface and from 644 to 696 μg-atom/liter at the bottom. Total phosphorus content, however, was quite low, ranging from 0.4 to 1.4 μg-atom/liter at the surface and from 0.6 to 1.5 μg-atom/liter at the bottom. Orthophosphate values ranged from 0.04 to 0.08 μg-atom/liter at the surface and from 0.04 to 0.09 μg-atom/liter at the bottom.

Productivity patterns

Except for narrow stands of *Spartina alterniflora*, the vegetation of Pond 1 was predominantly widgeon grass (*Ruppia maritima*) found in the pond's "open" water areas less than 50 cm deep (Fig. 5). Surface phytoplankton gross productivity averaged 233 mg C/m^3/hr. Chlorophyll-*a* values were relatively low, ranging from 5 to 26 mg chlorophyll-a/m^3. On the other hand, measurements of photosynthetic pigments in Pond 2 were much higher, averaging 235 mg chlorophyll-a/m^3 in the surface and 92 mg chlorophyll-a/m^3 at the bottom. Due to the shallowness of the pond and the dense growth of widgeon grass in Pond 1, and the dense algal mats in Pond 2, which rapidly clogged up the plankton net, zooplankton tows were not taken from either pond.

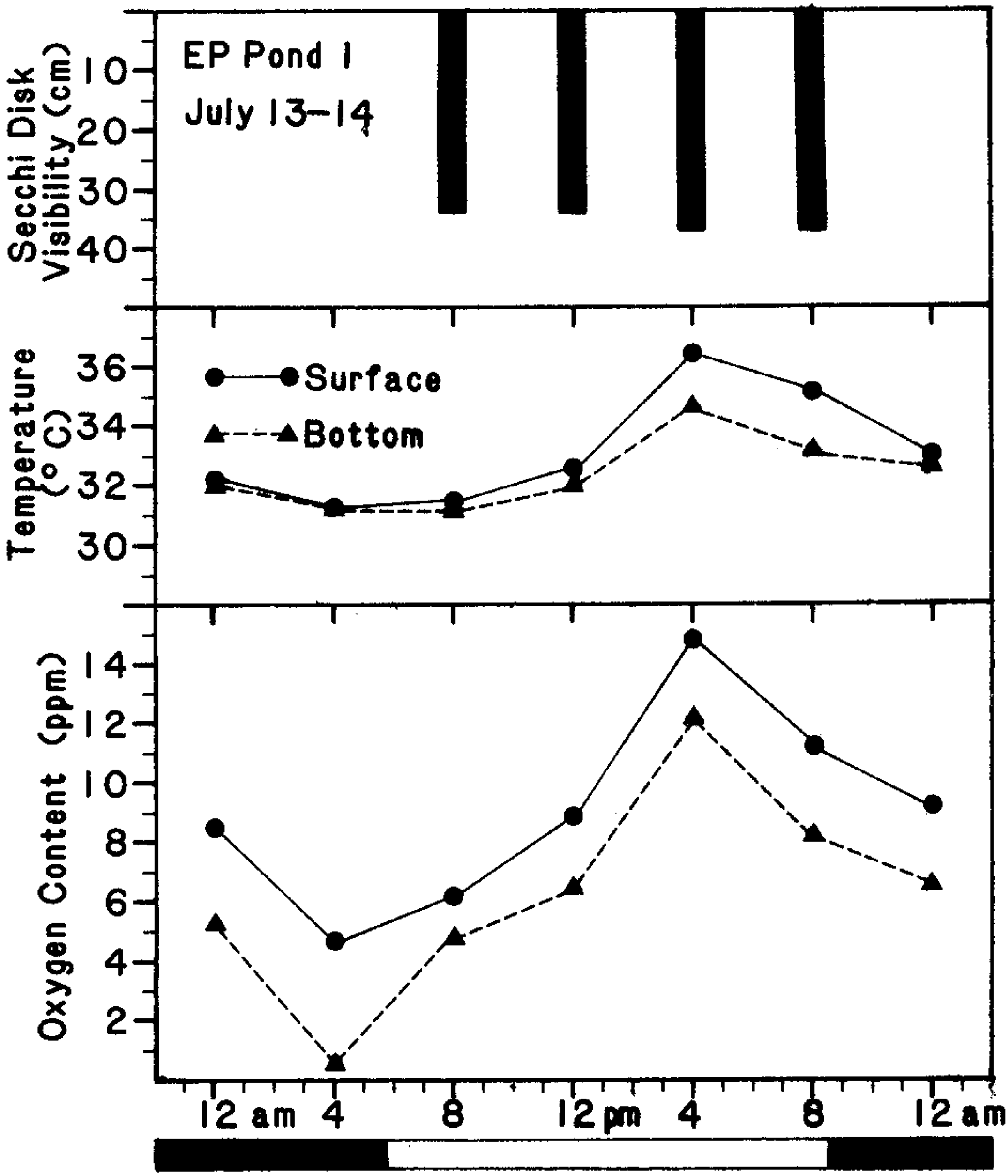

Fig. 6. Diel patterns of water clarity, temperature, and dissolved oxygen content in Estherville Plantation Pond I.

KEITHVILLE PLANTATION

Receiving their water supply from Black River, the ponds studied in Keithville Plantation have relatively deep perimeter ditches and wide expanse of densely-vegetated flats covered by less than 20 cm of water (Fig. 7). The ditches in both ponds have depths ranging from about a meter to two meters and represent the only open water areas in the systems.

Physico-chemical conditions

Despite some salinity values measured in the water (averaging 3 $^{o}/oo$, Table 4), the ponds may be considered as freshwater impoundments for all practical purposes. Surface water temperature ranged from 25 to 35^{o}C during the course of the study, with the bottom water being two to three degrees cooler. Lower pH values were recorded for the bottom water which tended to be nearly anoxic. Disturbance of the silty black clay bottom by the grab corer often released bubbles smelling strongly of hydrogen sulfide. Although the surface water reached up to 150% saturation during mid-afternoon, oxygen values were generally low, with significant differences between surface and 50-cm depth readings.

Diel patterns

Dissolved oxygen at the surface reached minimum concentration shortly after sunrise and maximum values in the late afternoon (Fig. 8). Except during the early morning hours, distinct differences between the surface and 50-cm depth oxygen profiles were noted. Throughout the day, the bottom water maintained practically anoxic levels. Temperatures differed from one to four degrees between surface and bottom. The pH fluctuated in close synchrony with the dissolved oxygen curves, with the bottom water slightly more acidic than the surface water. The water was clearest in the morning, the Secchi disk visibility being 64 cm.

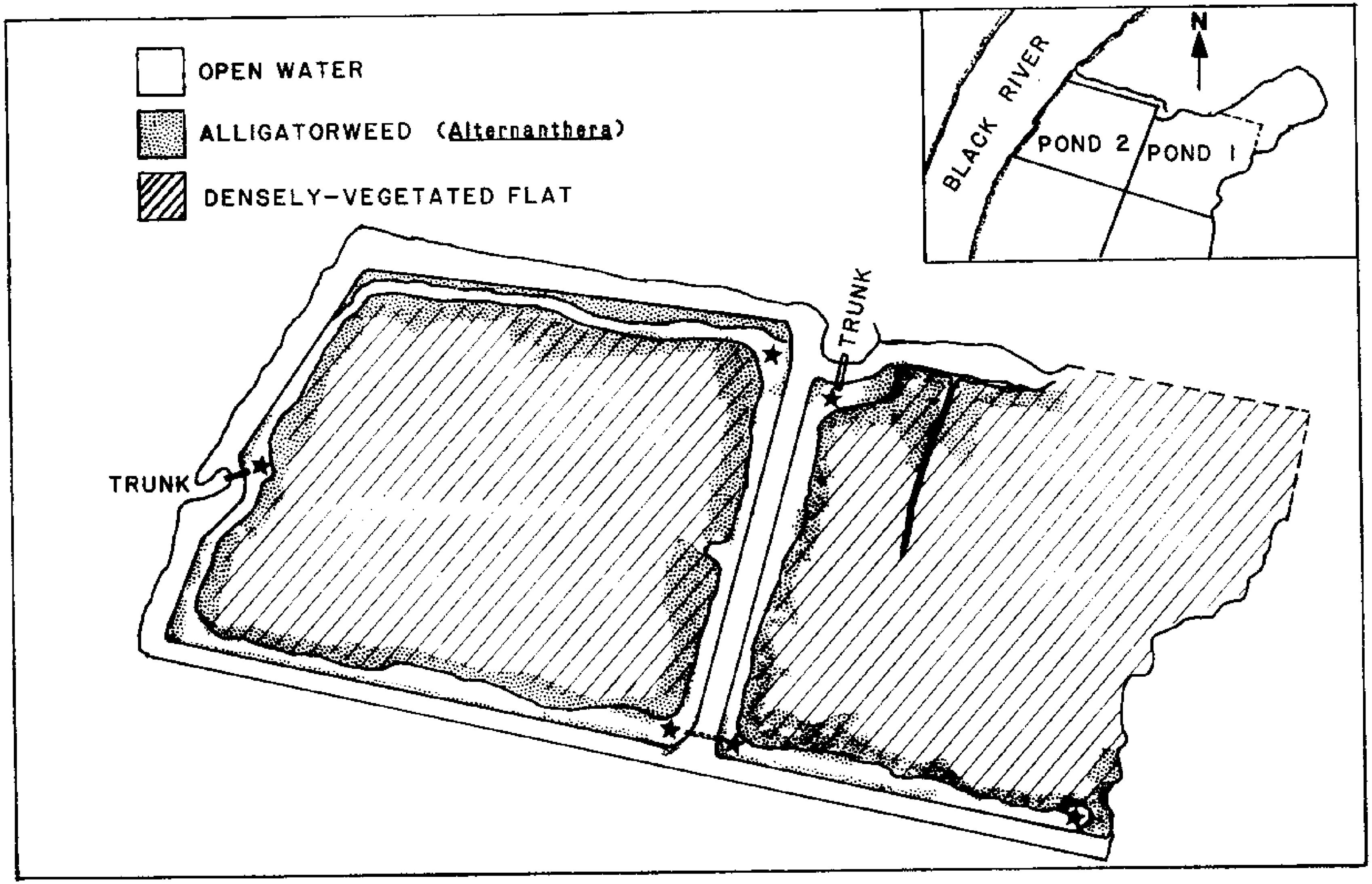

Fig. 7. Patterns of vegetation and water depth of the Keithville Plantation ponds. Stars indicate sampling stations.

Table 4. Summary of early summer conditions of Keithville Plantation ponds monitored from June 21 to July 11, 1981. Values are ranges, with means in parentheses.

	POND 1			POND 2		
AREA (ha)	5			6.2		
WATER DEPTH (cm)	118 - 205 (160.2)			116 - 200 (157.4)		
SECCHI DISK VISIBILITY (cm)	45 - 77 (59.2)			63 - 70 (66.0)		
SEDIMENT pH	5.0 - 7.9 (6.3)			4.3 - 6.1 (5.4)		
WATER COLUMN PARAMETERS:	*Surface*	*Mid-depth*	*Bottom*	*Surface*	*Mid-depth*	*Bottom*
Temperature (^oC)	25.9 - 34.7 (30.6)	25.9 - 31.9 (29.9)	25.4 - 30.3 (28.3)	26.9 - 31.3 (29.6)	26.4 - 30.5 (28.8)	26.8 - 30.1 (28.1)
Salinity (o/oo)	1.6 - 3.2 (3.0)	2.8 - 3.6 (3.1)	2.4 - 4.2 (3.3)	1.5 - 3.0 (2.6)	2.8 - 3.4 (3.1)	1.4 - 4.3 (3.1)
pH	5.6 - 8.9 (7.3)	5.4 - 8.7 (7.2)	5.4 - 8.0 (6.6)	6.7 - 7.2 (6.8)	6.3 - 6.8 (6.7)	5.1 - 6.5 (6.0)
Turbidity (FTU's)	22 - 55 (34.6)	---	25 - 40 (34.7)	25 - 50 (40.3)	---	30 - 52 (41.3)
Dissolved Oxygen Content (ppm)	1.0 - 11.5 (6.2)	1.0 - 7.1 (3.1)	0.1 - 3.0 (0.7)	6.0 -14.6 (8.9)	4.8 - 7.5 (6.1)	0.6 - 3.7 (1.2)
Gross Primary Production (mg $C/m^3/hr$)	46.9 - 49.9 (48.6)	---	0 - 12.4 (6.5)	---	---	---
Net Primary Production (mg $C/m^3/hr$)	37.5 - 40.5 (39.3)	---	0	---	---	---
Chloraphyll-*a* (mg Chl-*a*/m^3)	20.4 - 149.3 (64.7)	---	11.2 - 54.3 (30.9)	6.6 - 20.1 (13.3)	---	---
Dissolved Organic Carbon (ppm)	8.6 - 16.4 (12.9)	---	12.3 - 17.7 (15.2)	---	---	---
Total Nitrogen (µg-atom/liter)	40.5 - 116.0	---	48.1 - 157.0	---	---	---
Total Phosphorus (µg-atom/liter)	1.7 - 4.3 (3.1)	---	1.4 - 19.2 (8.8)	---	---	---
Orthophosphate (µg-atom/liter)	0.24 - 1.61 (0.60)	---	1.01 - 1.74 (1.61)	---	---	---

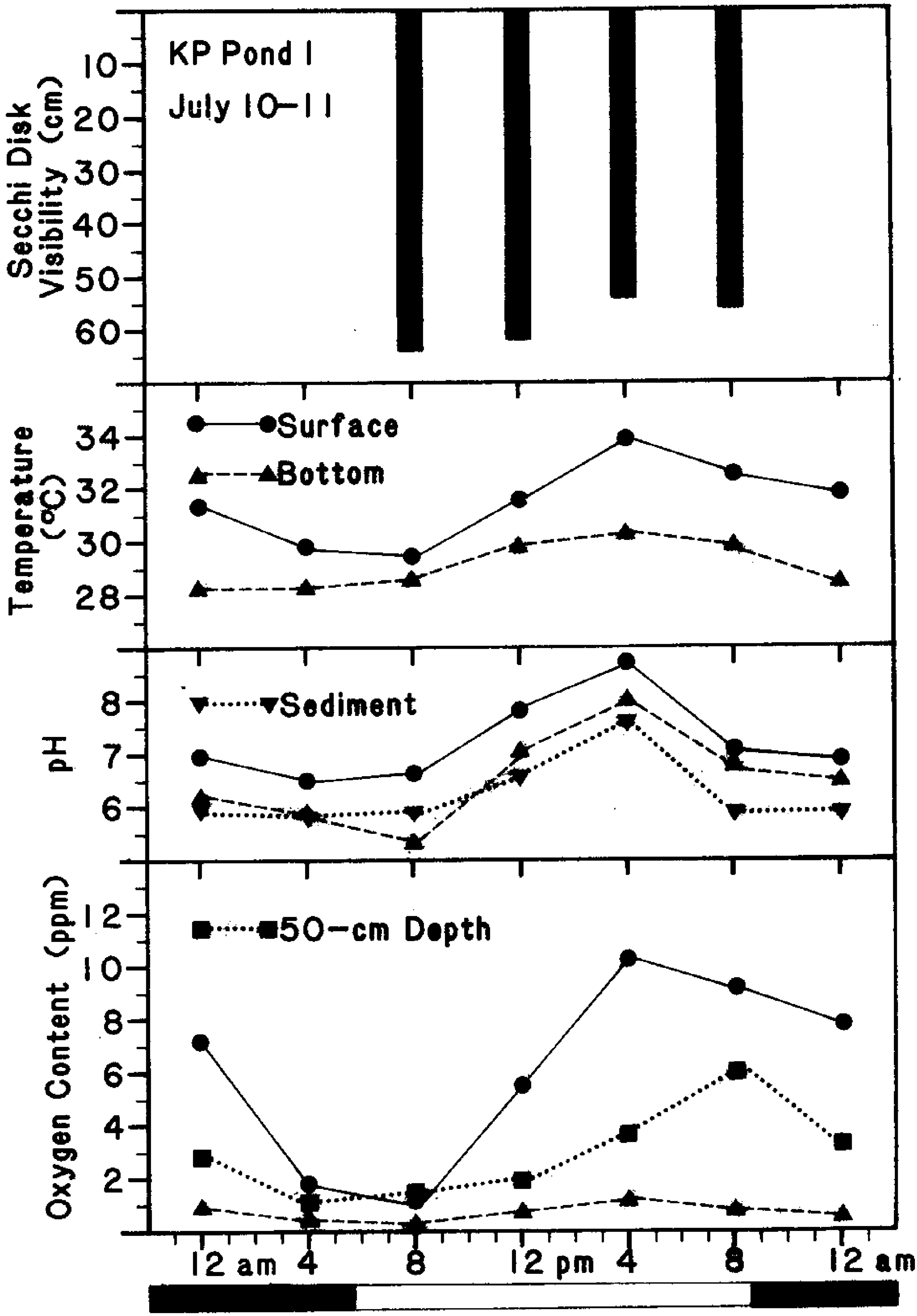

Fig. 8. Diel patterns of water clarity, temperature, pH, and dissolved oxygen content in Keithville Plantation Pond I.

Nutrients

Nutrient concentrations in Pond 1 were generally higher at the bottom than at the surface (Table 4). Total nitrogen content averaged about 71 μg-atom/liter at the surface and about 77 μg-atom/liter at the bottom. Mean concentrations of total phosphorus were 3.1 μg-atom/liter at the surface and 8.8 μg-atom/liter at the bottom. Orthophosphate values averaged 0.5 and 1.5 μg-atom/liter at the surface and bottom, respectively.

Productivity patterns

The densely-vegetated flat was covered by luxuriant assemblages of grasses dominated by cattails (*Typha* spp.), common reed (*Phragmites communis*), and wild millet (*Echinochloa* spp). Along the slopes of the dikes and fringes of the flats were dense growth of alligatorweed (*Alter-nanthera* spp.).

The water column, on the other hand, was characterized by relatively low phytoplankton production. Gross production averaged less than 50 mg C/m^3/hr at the surface and about 6 mg C/m^3/hr at the bottom (Table 4). Photosynthetic pigment values ranged from 20 to 149 mg chlorophyll-a/m^3 at the surface and from 11 to 54 mg chlorophyll-a/m^3. Dissolved organic carbon averaged 12.9 ppm at the surface and 15.2 ppm at the bottom.

Zooplankton

The composition and relative abundance of zooplankton in Pond 1 exhibited some changes during the one-month study period (Table 5). Ostracods, rotifers (mostly *Keratella, Platyias,* and other brachionids), and calanoid copepods predominated during the first two sampling times. Although their densities increased during the third sampling, their relative proportion in the samples declined as cyclopoid copepods became

Table 5. Composition and abundance of zooplankton in Keithville Plantation Pond 1. Density = No. of individuals x $100/m^3$; % = percentage of total sample.

Date	June 21		July 4		July 11	
	Density	%	Density	%	Density	%
Cyclopoid copepods	0.46	5.1	1.21	6.1	478.2	87.6
Calanoid copepods	1.38	15.3	5.91	29.5	34.8	6.6
Copepod nauplii	0.31	3.4	5.64	28.2	4.5	0.8
Ostracods	4.76	52.5	4.56	22.8	5.04	0.9
Cladocerans	---	---	0.67	3.4	2.02	0.4
Rotifers	2.15	23.7	1.48	8.7	11.09	2.0
Midge larvae	---	---	0.13	0.7	6.55	1.2
Crab zoeae	---	---	---	---	1.51	0.3
Jellyfish medusa	---	---	0.13	0.7	---	---

more numerous. The cyclopoid copepods increased in density and accounted for about 88% of the sample during the third sampling.

WAVERLY PLANTATION

Located along the Waccamaw River, the Waverly Plantation pond virtually had no open water (Fig. 9). The perimeter ditches, ranging in depth from 60 to 240 cm, were clogged with floating and submerged weeds and algal mats. The vegetated flat, bounded on three sides by the ditches, was covered by tall grasses, with some black willows on higher grounds.

Physico-chemical conditions

The pond was characterized by low water clarity, acidic water and sediment, and distinct temperature and dissolved oxygen stratification (Table 6). Secchi disk visibility ranged from 34 to 50 cm and averaged 44 cm. Temperatures at the surface and at the bottom differed by as much as five degrees. Dissolved oxygen content was relatively high in the top few centimeters, even reaching values greater than 20 ppm. Due to the abundance of submerged and floating weeds and algal mats, stratification of dissolved oxygen occurred around 50 cm depth, with the bottom water being nearly totally anoxic for the most part (Fig. 10). Disturbance of the hard, black clay bottom anywhere along the ditches released strong methane and hydrogen sulfide bubbles.

Diel patterns

Surface dissolved oxygen concentrations dropped to less than 2 ppm during early morning and reached about 300% saturation values in the mid-afternoon (Fig. 11). Dissolved oxygen readings at the bottom 50-cm depth fluctuated between one and two ppm throughout the day; bottom values were always less than 1 ppm. A short term thermal stratification was noted. The thermal diel pattern was marked by fluctuating surface temperatures (29 to 35^{o}C) and relatively constant bottom temperature between 28 and 29^{o}C. Secchi disk visibility fluctuated around 40 cm.

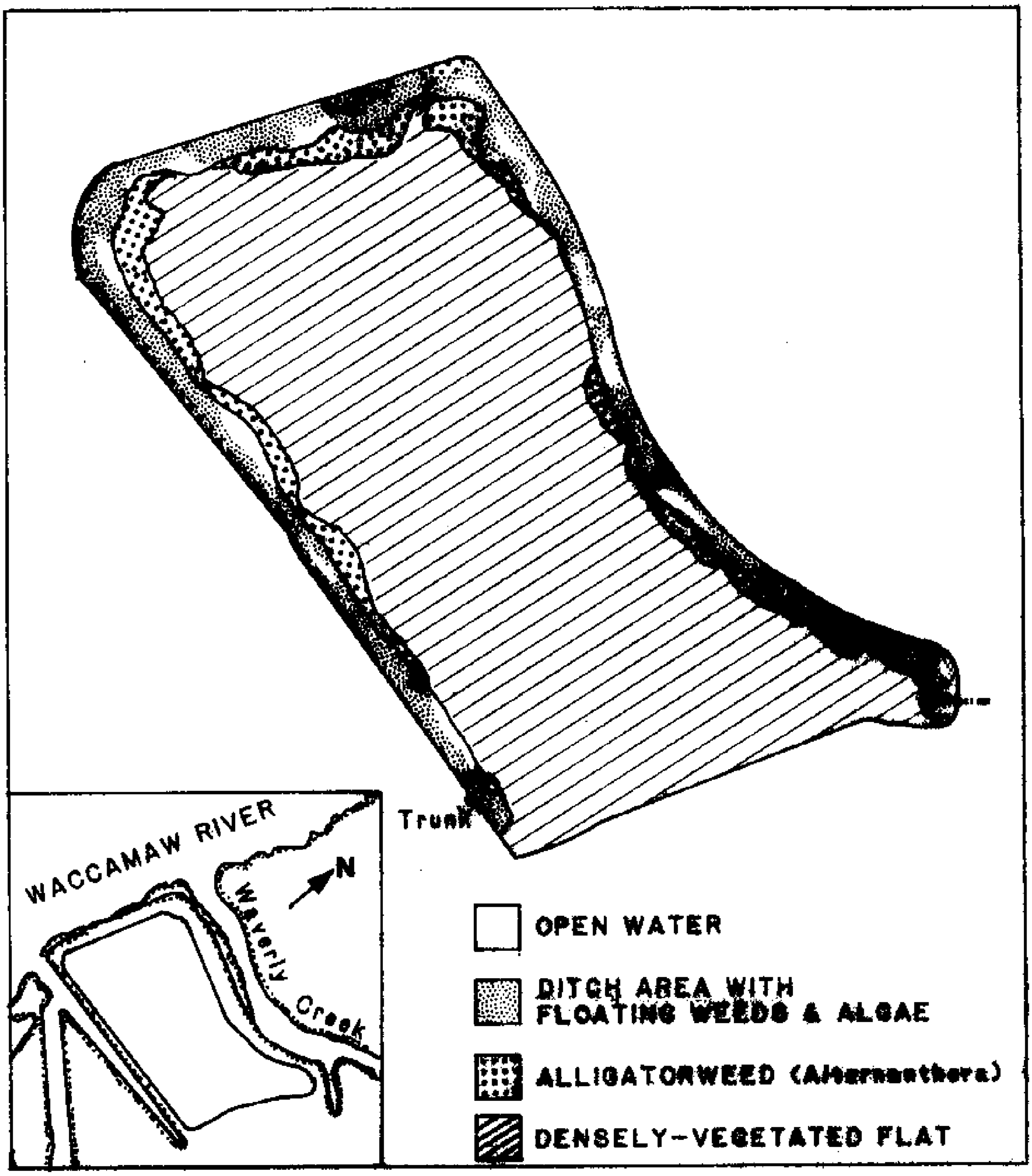

Fig. 9. Location and vegetation pattern of the Waverly Plantation pond. Stars indicate sampling stations.

Table 6. Summary of early summer conditions of the Waverly Plantation pond monitored from June 21 to July 15, 1981. Values given are ranges, with means in parentheses.

AREA (ha)	18.5		
WATER DEPTH (cm)	60 - 240 (123.2)		
SECCHI DISK VISIBILITY (cm)	34 - 50 (43.6)		
SEDIMENT pH	5.9 - 6.2 (6.0)		
WATER COLUMN PARAMETERS:	*Surface*	*Mid-depth*	*Bottom*
Temperature (^{o}C)	26.0 - 35.4 (31.2)	24.7 - 31.8 (29.6)	24.8 - 31.1 (28.4)
pH	4.6 - 6.8 (6.0)	---	6.1 - 6.2 (6.1)
Turbidity (FTU's)	35 - 105 (65.5)	---	50 - 118 (74.3)
Dissolved Oxygen Content (ppm)	1.9 - > 20 (10.6)	0.8 - 3.8 (1.5)	0 - 0.6 (0.3)
Gross Primary Production (mg C/m^3/hr)	96.4 - 172.9 (122.4)	---	0
Net Primary Production (mg C/m^3/hr)	48.8 - 111.0 (70.4)	---	0
Chlorophyll-*a* (mg Chl-*a*/m^3	16.1 - 27.8 (22.1)	---	10.0 - 68.3 (38.7)
Dissolved Organic Carbon (ppm)	18.4 - 19.3 (18.9)	---	15.8 - 19.1 (17.8)
Total Nitrogen (μg-atom/liter)	154.0 - 167.0 (161.8)	---	147.4 - 185.6 (165.4)
Total Phosphorus (μg-atom/liter)	0.1 - 1.9	---	0.9 - 10.4 (5.7)
Orthophosphate (μg-atom/liter)	0.31 - 0.68 (0.47)	---	0.27 - 0.46 (0.39)

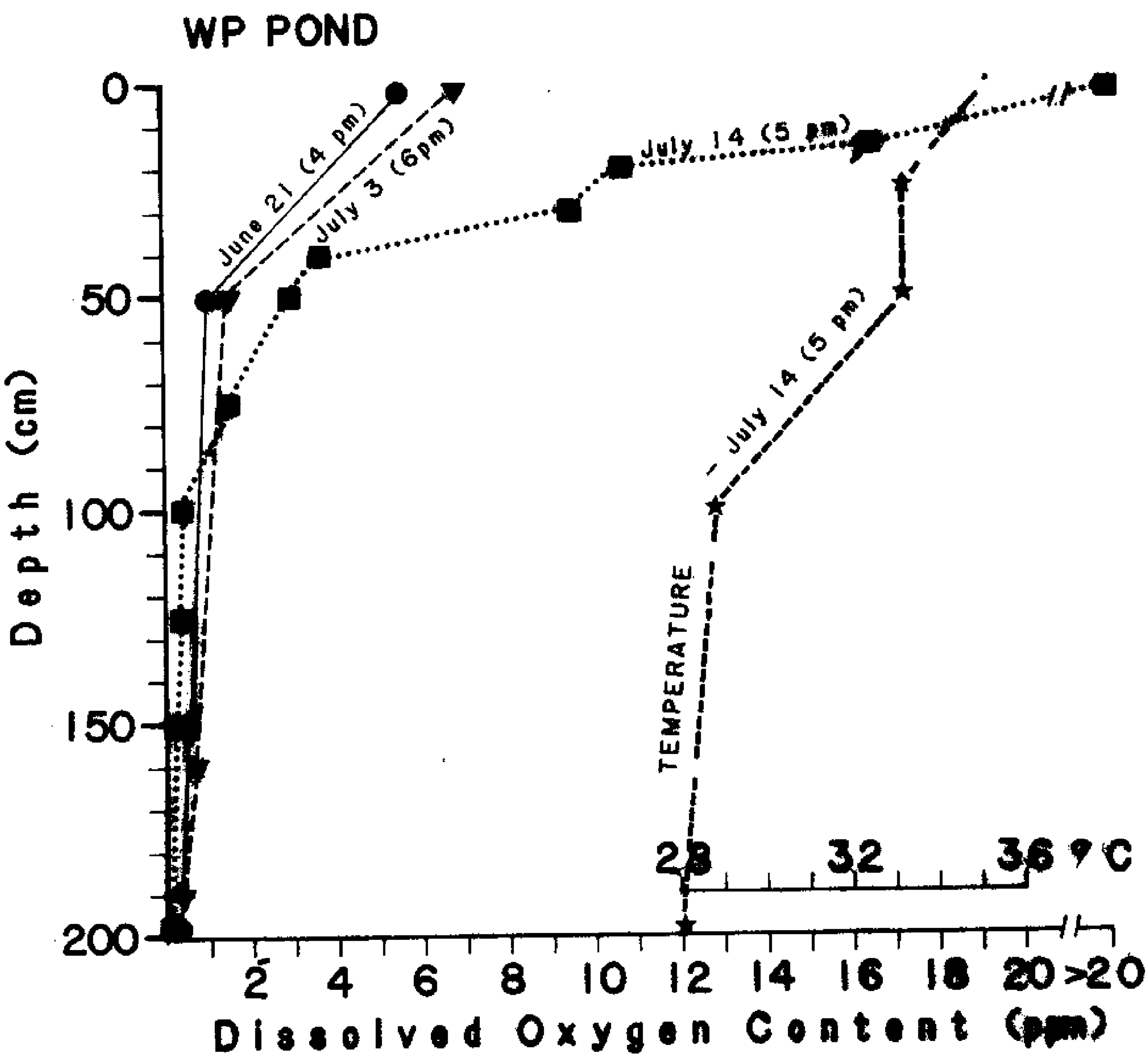

Fig. 10. Vertical profile of dissolved oxygen content and temperature in the Waverly Plantation pond.

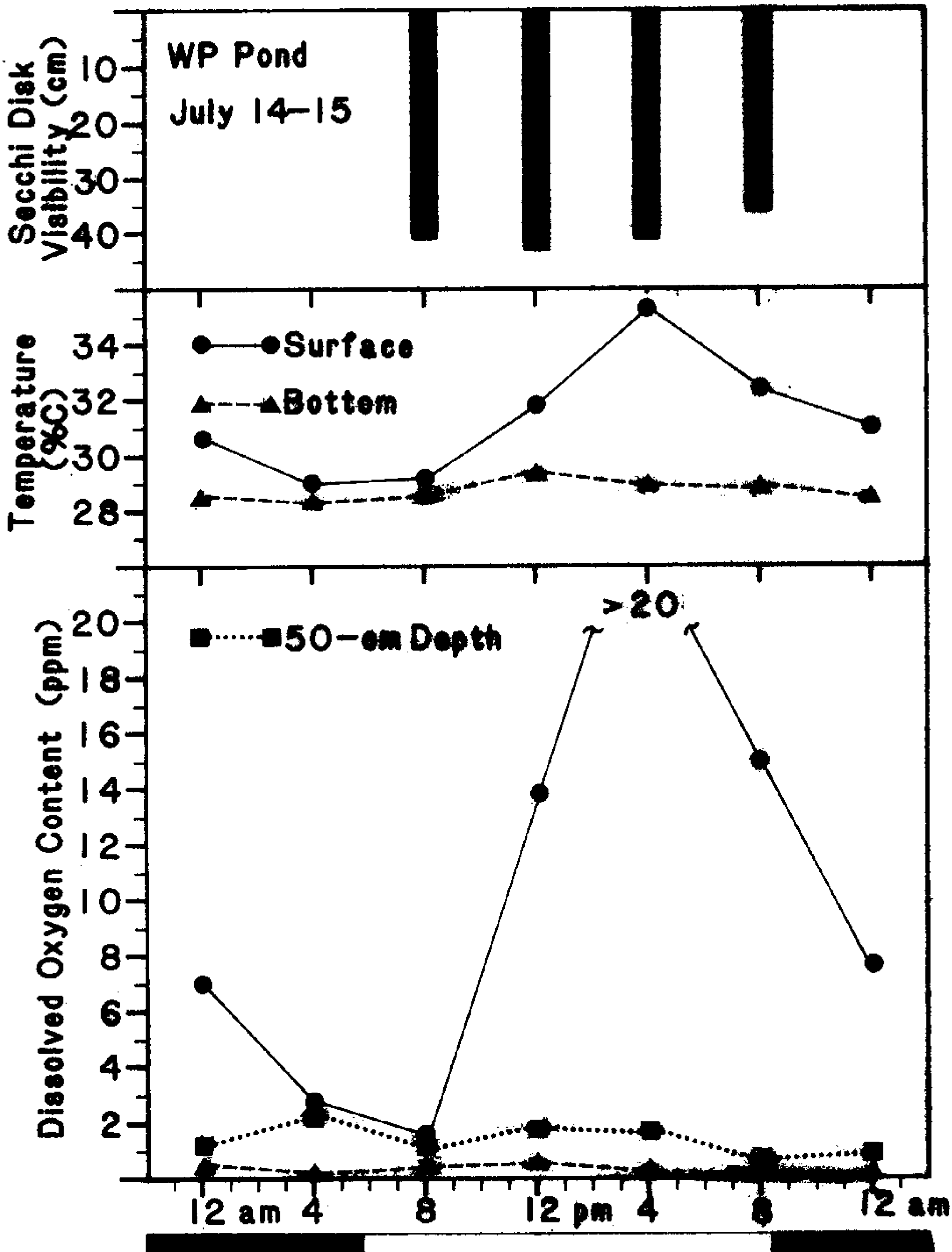

Fig. 11. Diel patterns of water clarity, temperature, and dissolved oxygen content in the Waverly Plantation pond.

Nutrients

Concentrations of total nitrogen and orthophosphate were generally similar at the surface and at the bottom. Total nitrogen content averaged about 162 μg-atom/liter at the surface and 165 μg-atom/liter at the bottom; corresponding orthophosphate mean values were 0.5 and 0.4 μg-atom/liter. On the other hand, total phosphorus content was higher at the bottom (5.7 μg-atom/liter) than at the surface (0.9 μg-atom/liter).

Productivity patterns

The area bounded by the ditches was in an advanced stage of vegetative succession, with irregularly distributed stands of swamp willow (*Salix nigra*) and luxuriant growth of grasses, primarily gama-grass (*Tripsacum dactyloides*) and beardgrass (*Erianthus* spp.). Dense clumps of alligatorweed (*Alternanthera*) fringed the flat and dike slopes. The ditches were practically all covered by algal mats and floating and submerged weeds, comprised predominantly of duckweed (*Lemna*), water milfoil (*Myriophyllum*), and naiads (*Najas*).

Phytoplankton gross productivity averaged about 120 mg C/m^3/hr at the surface with no gross production at the bottom. Chlorophyll-*a* values showed higher concentrations (39 mg chlorophyll-a/m^3) at the bottom than at the surface (22 mg/m^3). Dissolved organic carbon readings were consistently high during the study period, averaging 18.9 and 17.8 ppm for surface and bottom water, respectively. No zooplankton tows could be taken due to the clogged condition of the ditches.

DISCUSSION AND RECOMMENDATIONS

The baseline profiles of the studied impoundments indicate distinct variations in water quality and productivity patterns not only among ponds in different plantations but even between adjacent ponds. Such variability of conditions, even within a short period of time, should be taken into consideration when decisions are made to turn the present impoundments into full-scale aquaculture production systems. Although the success of utilizing impounded wetlands in other parts of the world offer tempting prospects, it should be borne in mind that most of these highly productive systems have been constructed and/or managed for specific aquaculture activities.

That the present impoundments are highly naturally productive need not be belabored. The potential use of South Carolina wetland impoundments has been the subject of the work done by Dean and his colleagues (Dean, 1975). The relatively more rapid growth and higher production of organisms introduced into wetland ponds during flooding have been documented by Bearden (1967), Coche (1967), Dean (1975), and Lunz (1956, 1957, 1968), among others, and extensively reviewed by Iversen (1968), Bardach et al. (1972), Huet (1972), and Ling (1977). Owners of some of the studied ponds have also reported sizable harvests from time to time of shrimp, crabs, and fish from their ponds.

Aquaculture literature is replete with good discussion of opportunities, contraints, and guides for assessment of the aquaculture potential in any locality (e.g., Webber, 1972; FAO, 1976; Pillay, 1977; National Research Council Committee on Aquaculture, 1978), which need not be repeated here. This portion of the report will focus primarily on the options available for the potential use of the present wetland impoundments for aquaculture.

Types and Objectives of Aquaculture

Utilization of the present impoundments for aquacultural practices may range from the manipulation of at least one stage of an organism's life before harvest for the purpose of increasing production to the propagation of the organism under complete human control. The systems may be geared towards either the extensive or intensive type of production. Extensive aquaculture normally involves large areas, low levels of capital investment per unit area, low operating costs, low general management, low yields per unit area, and only slight degree of control exerted by man over the environment; it also tends to be labor-intensive. On the other hand, intensive aquaculture tends towards smaller areas, dense stocking, stock selection and manipulation, high production per unit area or volume of water, partial mechanization of operations, and intensified management and environmental control.

The specific usage and possible modification of the impoundments would also depend on the particular objectives of the enterprise. Aquaculture may be practiced for the purposes of:

a) producing human food either for local consumption or export,

b) improving natural stocks through artificial recruitment and transportation,

c) producing sport fish,

d) producing ornamental fishes and other aquatic organisms,

f) recycling organic wastes, and

g) producing industrial fish or fishery products (for example, fish for reduction to fish meal or fertilizer, seaweeds for carrageenan and related products, and oysters for cultured pearls).

Thus, aquaculture may be undertaken for different purposes under different situations. Modifications of most of the present ponds may have to be done for their proper utilization as aquaculture production systems. Specific modifications would be dependent on the particular organisms desired to be cultured.

Prospective Candidate Species

From the technological viewpoint, there are a number of marine and freshwater species that lend themselves to productive pond culture. These species, for the most part, do have the necessary aquaculture methodology established, and their enviornmental and biological requirements are more or less known. However, for many of them, their marketability and/or gastronomic acceptance in South Carolina may be problems. The following is a brief overview of aquatic organisms with established production methodology and known environmental requirements, which can be potentially cultured in ponds.

Brackishwater Ponds

Among crustaceans, the commercial penaeid shrimp offers the most tempting prospect for brackishwater pond culture, either through natural stocking during pond flooding or stocking with hatchery-reared postlarvae. Natural stocking, however, is strongly dependent on the vagaries of nature and thus may not be relied on for continuous production every year. Similarly, at present there are no constant, reliable commercial sources of hatchery-reared postlarvae for stocking.

The blue crab, *Callinectes sapidus*, is a common inhabitant of brackish ponds and could yield good harvest practically throughout the year. Natural stocking of juveniles has to be relied on since there are no commercial hatcheries yet. Furthermore, the generally low salinity of the ponds is not conducive to natural larval rearing even if gravid females are placed in the ponds.

Oyster (*Crassostrea virginica*) and hard clam (*Mercenaria mercenaria*) culture in brackishwater ponds has limited potential unless management procedures can insure the maintenance of fairly constant high salinity and good water movement. Hatchery-reared seedlings are commercially available and production guidelines are given in Loosanoff and Davis (1963), Schwind (1977), Castagna and Kraeuter (1981), Foster (1981), and Manzi and Whetstone (1981).

Among fishes, mullet (*Mugil cephalus*) is the best candidate for pond production, either for food or bait. Fingerlings can easily be collected in the wild, naturally stocked during flooding, or can be raised following the methods presented by Nash and Shehadeh (1980) and Oren (1981). Hardy and tolerant of relatively adverse conditions, the mullet can effectively utilize the natural productivity of ponds and may be marketed locally or exported out of the state for food and/or bait.

Other fishes that may have some potential for pond culture include the spotted sea trout (*Cynoscion nebulosus*), red drum (*Sciaenops ocellata*), black drum (*Pogonias chromis*), croaker (*Micropogon undulatus*), and striped bass (*Morone saxatilis*), among others (Bearden, 1967; Perry and Avault, 1968; Avault et al., 1969; Perry, 1975; Colura et al., 1976; Powell, 1976; Perry et al., 1977; Branch and Strawn, 1978; Setzler et al., 1980). These species, however, still need to be studied further under South Carolina large pond conditions.

Freshwater Ponds

Among crustaceans, the red swamp crayfish (*Procambarus clarkii*) is the best candidate. Production guidelines are available (e.g., La Caze, 1976;

Alon and Dean, 1980; Huner and Barr, 1980) and it is now being extensively cultured in the state. Although with a limited growing season in the state, the giant Malaysian prawn (*Macrobrachium rosenbergii*) has good potential for pond culture (e.g., Smith et al., 1976, 1978; Willis and Berrigan, 1976, 1978; Dobkin et al., 1977; Hanson and Goodwin, 1977). Hatchery-reared juveniles for stocking are now commercially available.

Among fishes, the channel catfish (*Ictalurus punctatus*) may be pond cultured or cage cultured in ponds in monoculture or polyculture situations (e.g., Huet, 1972; Brown et al., 1974; Grizzell et al., 1975; Coche, 1978a, b; Jensen, 1980). With proven good food conversion ratios, the channel catfish, however, need deeper ponds. The rainbow trout (*Salmo gairdneri*) may have some potential for double-cropping with channel catfish during winter (Brown et al., 1974; Brown and Gratzek, 1980). Baitfishes, primarily the golden shiner (*Notemigonus crysoleucas*), fathead minnow (*Pimephales promelas*), bluntnose minnow (*P. notatus*), and goldfish (*Carassius auratus*), generally have good marketability and their production methodology is well-known (e.g., Johnson and Davis, 1978; Stickney, 1979; Brown and Gratzek, 1980). Sport fish, such as the largemouth bass (*Micropterus salmoides*), striped bass, and sunfishes (*Lepomis* spp.), may be cultured for fee fish-out operations (Davis, 1967; Bonn et al., 1976; Hutson, 1976; Stickney, 1979).

Potential Problems and Recommendations

Whatever species are finally chosen for pond raising for specific purposes may necessitate the overcoming of certain limitations inherent in the present ponds as well as modifications of the ponds associated structures. From the baseline profiles of the studied impoundments, several potential problem areas may be identified. These include pond areas, pond depths, water control/circulation, oxygen depletion, and salinity fluctuations.

Pond Area

The ponds studied range in size from 5 (KP Pond 1) to 18.5 ha. (WP Pond). As they are, they seem to be best suited for extensive type of operations and would need reduction in size and/or modification of water control structures if an intensive type of culture is desired. The large sizes of the ponds also tend to make them more difficult to manage and harvest or implement water management schemes. For example, the Estherville Plantation Pond 1 may be more suited for aquaculture purposes if it is divided into three smaller ponds; it can be divided easily by putting dikes along the narrow stands of *Spartina* cutting across the pond (cf. Fig. 5), and adding water sluice gates. The Waverly Plantation could be more effectively managed by putting one or two more water gates.

Pond Depth

Unlike wetland ponds in other parts of the world where the depths are more or less even throughout, the present ponds in Georgetown County generally have midfield flats covered by little water when flooded. The perimeter ditches generally hold most of the water in the pond and the deeper ditches tend to show water stagnation and oxygen depletion. Some ponds, similar to EP Pond 1, may have to be deepened to minimize heating during summer and prevent possible freezing during winter. Cultured organisms in shallow ponds (less than a meter deep) could be more susceptible to predation by birds and other animals. Unless there is good wind circulation of the water, the deep ditches tend to become anoxic, to the detriment of cultured organisms.

Water Control/Circulation

Most of the ponds could still have better water control by addition of one or two more water trunks to facilitate draining and to provide some water flow across the pond for possible mollusk or cage culture operations. The Keithville Plantation ponds could easily be turned into a semi-flow-through system, using water from Black River for flooding at one trunk and partly draining the pond through another trunk. The Waverly Plantation pond can be similarly modified.

Oxygen Depletion

The bottom water in all ponds tended to become anoxic at times. Deep ditches loaded with floating weeds and algal mats usually have no vertical mixing, making the bottom water oxygen-depleted practically all the time, as in the case of the Waverly Plantation pond. This may be remedied by eradicating the floating vegetation or providing better water circulation. Cutting ditches across the densely vegetated flats may also help improve water circulation and overall oxygenation of the water. Practically all of the potential species for culture require specific minimum oxygen concentrations which are well above the almost anoxic levels of the bottom layer of the water column in the present ponds. Heavy algal or submerged macrophytic blooms can cause oxygen depletion at nighttime, unless mechanical aeration is provided (cf. Boyd, 1979, for review). Water in perimeter ditches surrounded by wooded areas or tall grasses could also be subject to inadequate oxygen levels.

Salinity Fluctuations

The brackishwater ponds are all subject to salinity fluctuations, especially during heavy rains. About two weeks after the study period, the fairly high salinity of 24 to 26 ^{o}/oo in the Annandale Plantation ponds dropped to 15 to 17 ^{o}/oo after several days of heavy rains. During the same period, the salinity in Estherville Plantation Pond 1 dropped from 20-21 °/oo to 12 °/oo. Such salinity changes could have drastic effects on growth rates and survival of species with little tolerance to such changes.

The above discussion highlights the importance of the maintenance of good water quality in the ponds for success in any aquaculture ventrues. Extensive reviews on the need for and the maintenance of good water quality and proper pond management may be found in Iversen (1968), Bardach et al., (1972), Huet (1972), Milne (1972), Kinne (1976), Wheaton (1977), Boyd (1979), Stickney (1979), and Hepher and Pruginin (1981).

One last consideration that should be taken is that, although most of the desirable organisms with culture potential in the present ponds have been shown to exhibit good growth and high production in ponds, there is very little work done on their culture in large-scale ponds. Most of the experimental ponds used in culture studies have been in ponds less than 5 acres in size. Hence, a need for pilot demonstration projects for culturing organisms in the large wetland impoundments exists and should be addressed accordingly.

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