

NAUSET MARSH MONITORING REPORT
OCTOBER, 1990

Cape Cod National Seashore
South Wellfleet, Massachusetts

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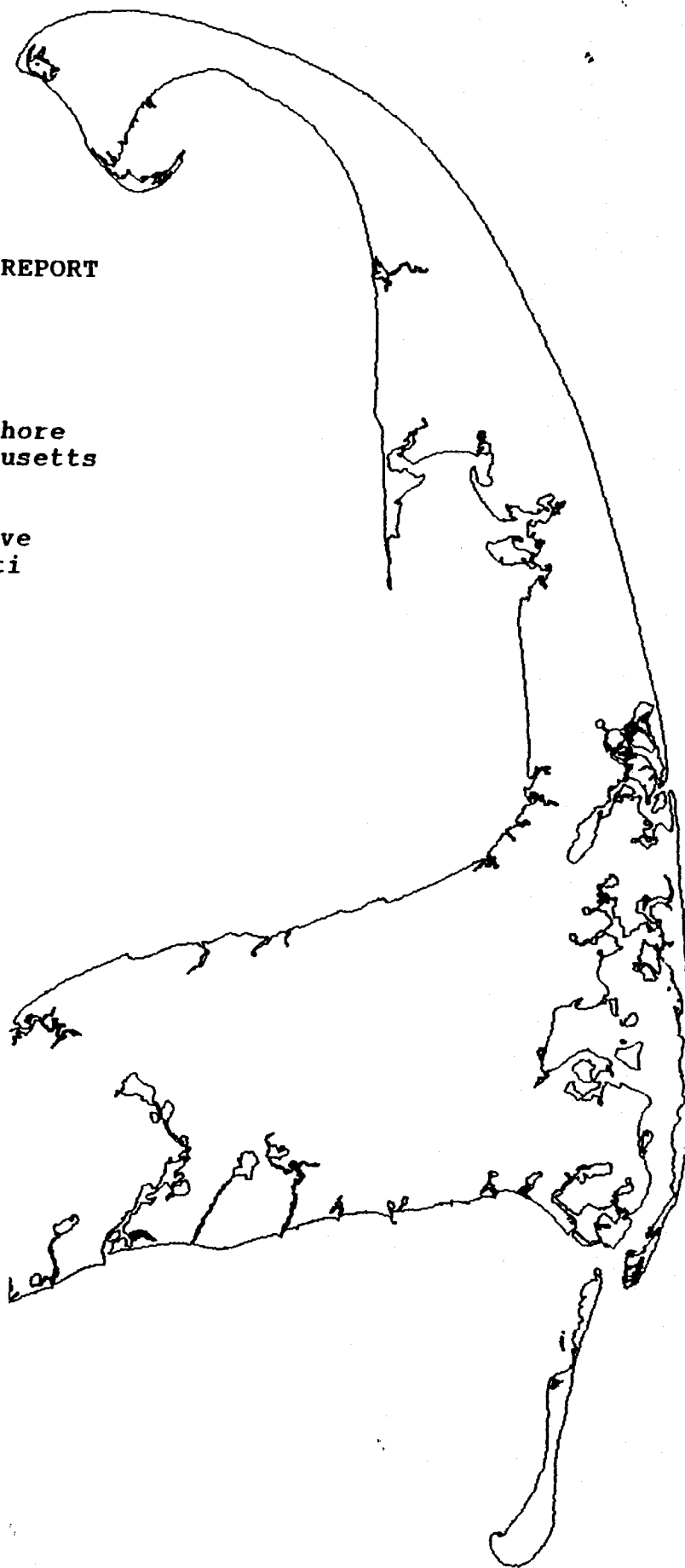


TABLE OF CONTENTS

List of Figures.....	iii
List of Tables.....	iv
Acknowledgements.....	v
Introduction.....	1
Materials and Methods.....	2
Physical Parameters.....	2
Water Quality.....	4
Vegetation.....	9
Fauna.....	10
Results.....	10
Physical Parameters.....	10
Water Quality.....	11
Vegetation.....	39
Fauna.....	42
Discussion.....	43
Water Quality.....	43
Vegetation.....	47
Fauna.....	48
Bibliography.....	50
Appendix A.....	52

LIST OF FIGURES

1.	Map of Nauset Marsh.....	3
2.	Bathymetric map of Salt Pond.....	5
3.	Bathymetric map of Town Cove.....	7
4.	Salt Pond tide height.....	12
5.	Salt Pond anoxia.....	13
6.	Salt Pond DO variations, 0-2 meters.....	14
7.	Salt Pond DO variations, 3-6 meters.....	15
8.	Salt Pond DO variations, 4.5-5.5 meters.....	16
9.	Salt Pond temperature and DO, low tide.....	17
10.	Salt Pond temperature and DO, high tide.....	18
11.	Salt Pond temperature variations.....	20
12.	Salt Pond salinity variations.....	21
13.	Salt Pond channel temperature and salinity.....	22
14.	Salt Pond temperature and light, low tide.....	23
15.	Salt Pond temperature and light, flood tide.....	24
16.	Salt Pond DO variations, 13 day profiles.....	26
17.	Salt Pond DO comparison, June 28 and July 1.....	27
18.	Salt Pond salinity, June 28 and July 1.....	28
19.	Salt Pond temperature, June 28 and July 1.....	29
20.	Salt Pond salinity and temperature, June 28.....	30
21.	Salt Pond DO and temperature, June 28.....	31
22.	Salt Pond salinity and temperature, July 1.....	32
23.	Salt Pond DO and temperature, July 1.....	33
24.	Groundwater NO ₃ -N, Hemenway Landing.....	35
25.	Groundwater NO ₃ -N, Nauset Bay.....	36
26.	Groundwater NO ₃ -N, Orleans windmill.....	37
27.	Groundwater NO ₃ -N, Orleans Yacht Club.....	38
28.	DO and NO ₃ -N relationship.....	40
29.	<u>Cladophora gracilis</u> biomass and S.D.....	41

LIST OF TABLES

1. NO₃-N found in groundwater transects.....34
2. Nesting waterbirds in Nauset Marsh.....42

ACKNOWLEDGEMENTS

This monitoring program was funded by the North Atlantic Regional Office of the National Park Service. The monitoring effort would not have been possible without this funding. The Rutgers University report on Nauset Marsh (Roman & Able, 1989) provided the basis for implementation of this monitoring effort. Many individuals assisted with the development of the monitoring protocol. Dr. Charles Roman, now at the University of Rhode Island's Coastal Research Center in Narragansett, Rhode Island, was project leader for the original Nauset Marsh research program that has guided the 1990 monitoring activities. He also assisted in establishing protocols and providing assistance throughout this study. Henry Lind and Heather Coleman, Natural Resources Officers for the Town of Eastham, provided knowledge and assistance in field operations. Sandy McFarlane of the Town of Orleans also provided input into program design. Several members of the Cape Cod National Seashore staff participated in various ways, including review of this report by David Crary and David Manski.

A special thank you is extended to John Portnoy, Research Biologist at Cape Cod National Seashore, who gave his time and knowledge throughout the field season in the laboratory and in the marsh.

INTRODUCTION

Nauset Marsh is a 945 hectare back-barrier estuary which directly exchanges with the Atlantic Ocean via Nauset Inlet. Composed primarily of Spartina alterniflora marsh, this marine ecosystem also includes tidal kettle ponds, shallow tidal channels, intertidal mud flats, intertidal sand flats, and eelgrass (Zostera marina) beds. Recent increases in residential development along the southern and western shores of the marsh may be responsible for increased nutrient loading in the system through run-off and leaching. Surface run-off introduces nitrogenous fertilizers. Septic systems and leachate fields allow nitrogenous wastes to enter the groundwater and eventually enter the marsh. Cultural eutrophication of Nauset Marsh is a threat to natural and economic resources. Besides this influx of nitrogen and other nutrients, the close proximity of the Orleans town center and Route 6 may also result in the accumulation of toxic heavy metals and hydrocarbons. Unchecked, human-induced factors will alter the natural progression of this system. The institution of a monitoring program would permit these changes to be detected and allow appropriate, timely resource management decisions to be made (Roman and Able, 1989).

Already designated a highly vulnerable area by the Cape Cod Planning and Economic Development Commission (1981), Nauset Marsh is extremely susceptible to accidental and incidental petroleum spills. The increased numbers of seasonal recreational boaters, combined with local fishermen, has the potential to disturb the environment with engine exhaust and oily bilge discharges. Though certainly less frequent, it is conceivable that tanker accidents could result in large amounts of oil entering the marsh. The effects that the oil spill from the Exxon Valdez tanker had upon the wildlife and habitat of the Prince William Sound were devastating. However, in the aftermath, it became evident that substantive baseline information was extremely important in documenting the effects of such an event. Implementation of a long-term monitoring project should prelude such a useful database for Nauset Marsh.

More persistent environmental change may result from subtle alterations to coastal systems. Nitrate loading from human development adjacent to coastal estuaries has been identified as a likely cause of a number of changes to these systems (Valiela, et. al., 1990). These changes may be manifested in the reduction of the extent of eelgrass (Zostera marina) beds in a marsh as macroalgae increase, and the resultant changes in benthic fauna, including many commercially important species.

Long-term monitoring of the natural processes in Nauset Marsh is important given the dynamic inlet. Earlier maps and

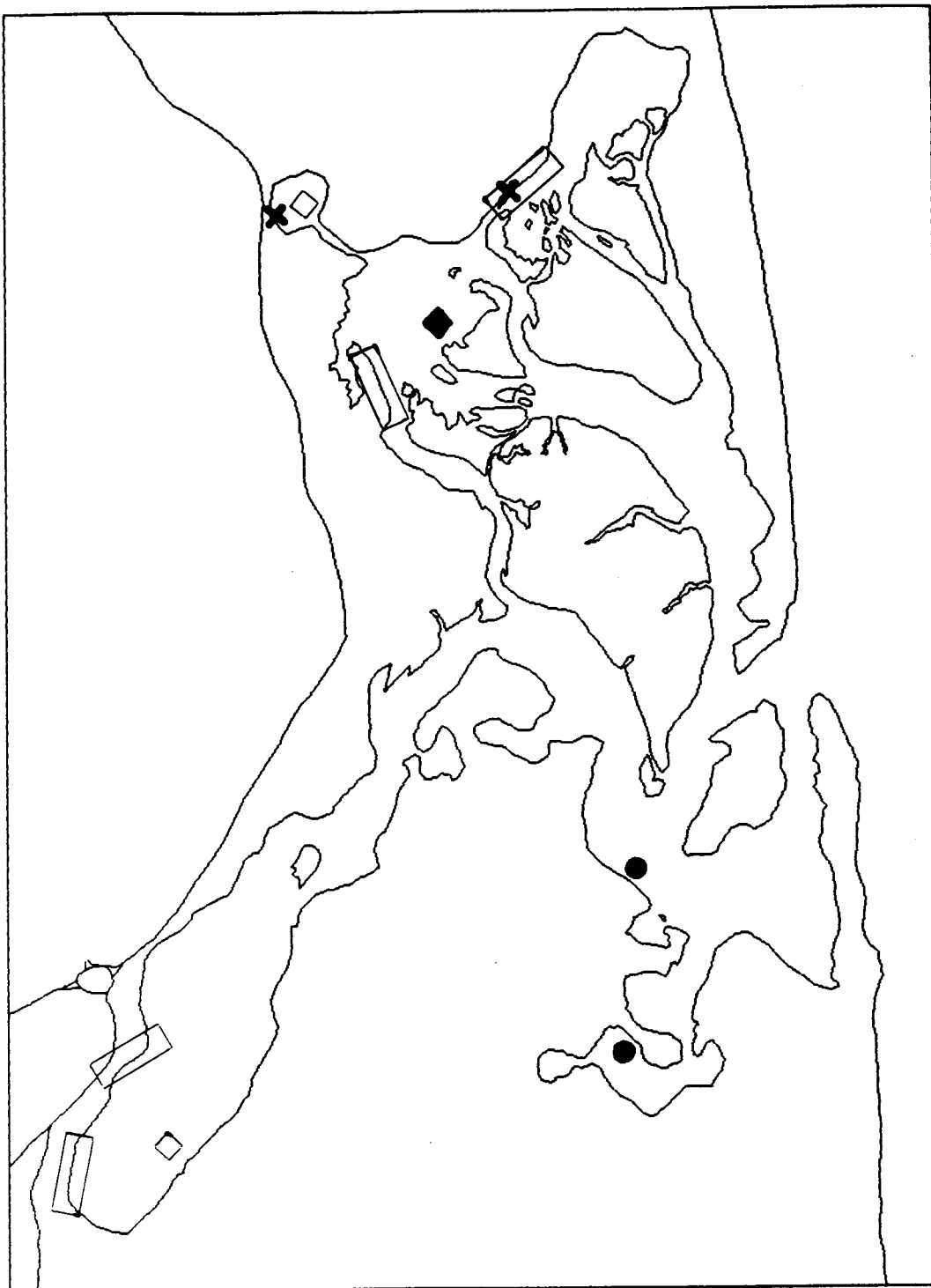
aerial photographs indicate that the most stable location of the inlet is to the south, at Nauset Harbor (Aubrey and Speer, 1984). From 1950 to 1960 the inlet migrated north, until severe storms relocated it to its southern location in the 1960's. Since then, the inlet has moved northward, and in recent years has migrated at about 100 meters per year. Today, it is near its northernmost historical location. Having deeper tidal channels, the southern location is preferred hydrodynamically and an imminent breach is predicted at this location (Aubrey and Speer 1984; 1985; Speer and Aubrey 1985; Roman and Able, 1989). Through a long-term monitoring program, the effects which this relocation may have upon the physical, chemical, and biological parameters would be better understood.

The objectives of this long-term monitoring program are to detect changes in cultural eutrophication and provide a substantial database of the wildlife and habitat in a vulnerable marine ecosystem. This database could also be used in the aftermath of an oil spill or hurricane, or the relocation of Nauset Inlet. Time and funding constraints dictated selective sampling of likely indicator species and water quality parameters. After reviewing the monitoring guidelines from Roman and Able (1989) and discussions with the principal author of that report, it was decided that the monitoring program would initially concentrate on physical attributes (tide, temperature, salinity, and conductivity), water quality (dissolved oxygen profiles in Salt Pond and Town Cove and groundwater nitrate), vegetation (Cladophora biomass and eelgrass wasting disease), nesting and migrating shorebirds, and habitat mapping. These parameters are the focus of this report. Nesting shorebird data collected from other sources in 1990 were incorporated into this report. Migrant waterbird studies have been completed on several occasions and a migrant waterbird study is currently underway through the University of Rhode Island Coastal Research Center. Habitat mapping, based on aerial photographs, is scheduled to be completed in 1991.

MATERIALS AND METHODS

Physical Parameters

Temperature, salinity, and conductivity were assessed at least weekly at Salt Pond and Nauset Bay during high tide as estimated by the tide chart printed by the Eastham Conservation Commission and Natural Resources Department. The station at Salt Pond was located at the end of the town dock, while the station in Nauset Bay was located at the Lyman house (2nd house on left on Tomahawk Trail) access path (Figure 1). Measurements of temperature, salinity, and conductivity were made at mid-depth



SCALE: 1 : 35000

- ☐ Dissolved oxygen profile.
- X** Physical observations.
- Zostera collection.
- Cladophora Collection.
- ☐ Nitrate transects.

Figure 1. Map of the Nauset Marsh barrier beach complex.

using the YSI model 33 S-C-T meter. Observation time and weather conditions were also recorded. Tide heights were assessed during a single 24 hour tide study in Salt Pond (see 24 hour dissolved oxygen profile for methods).

Water Quality

I. Dissolved Oxygen

Salt Pond: Temperature, conductivity, salinity, incident light, and dissolved oxygen (DO) profiles of Salt Pond were performed daily at 1000 hours for an 18 day period (June 18 - July 5). These profiles were performed at the deepest point of the pond (Figure 2), described by Lind (pers. comm.) as well as Anderson and Stoltzenbach (1985). A 12' rowboat was used to access the sampling location, marked by a lobster buoy connected to a steel anchor.

At 1.0 m intervals, the physical parameters were determined using an S-C-T meter (YSI Model 33, Simpson Electric Co., Elgin, IL 60120). Incident light was measured using an underwater photometer (Protomatic, Dexter, MI 48130), beginning on June 20.

DO water samples were retrieved at the same intervals using a Kemmerer bottle (Forestry Suppliers, 301 Cass St., Saginaw MI 48602). The sample was discharged into a 300 ml BOD bottle allowing approximately two volumes to overflow, and fixed according to the azide modification method (American Public Health Association, 1985, p. 418). On June 27, a peristaltic pump (GeoPump2, Geotech Environmental Equipment Inc., Denver Colorado 80211) was used to obtain water samples. Weighted with lead flashing, a 9.0 m section of calibrated tubing was attached to the pump's tubing. The tube was lowered to the desired depth and a bottle full of water was collected and discarded. This removed the residual water from the tube. After allowing approximately two volumes of water to overflow, the bottle then was filled with the sample. The sample was fixed and held at room temperature before titrations by filling the BOD caps with water to prevent contamination by atmospheric oxygen. If stratification was observed after the temperature profile, the profile's interval was decreased to 0.5 m through the thermocline. By June 27, the entire profile was performed at 0.5 m intervals. Fixed samples were titrated in the lab using a digital titrator and 2.0 N sodium thiosulfate. The concentration of DO is reported as percent saturation after correction for chlorinity (American Public Health Association, 1985, p. 413).

To observe diurnal effects during an anoxic event in Salt Pond, a 24 hour profile was conducted hourly from 0900 July 31 to

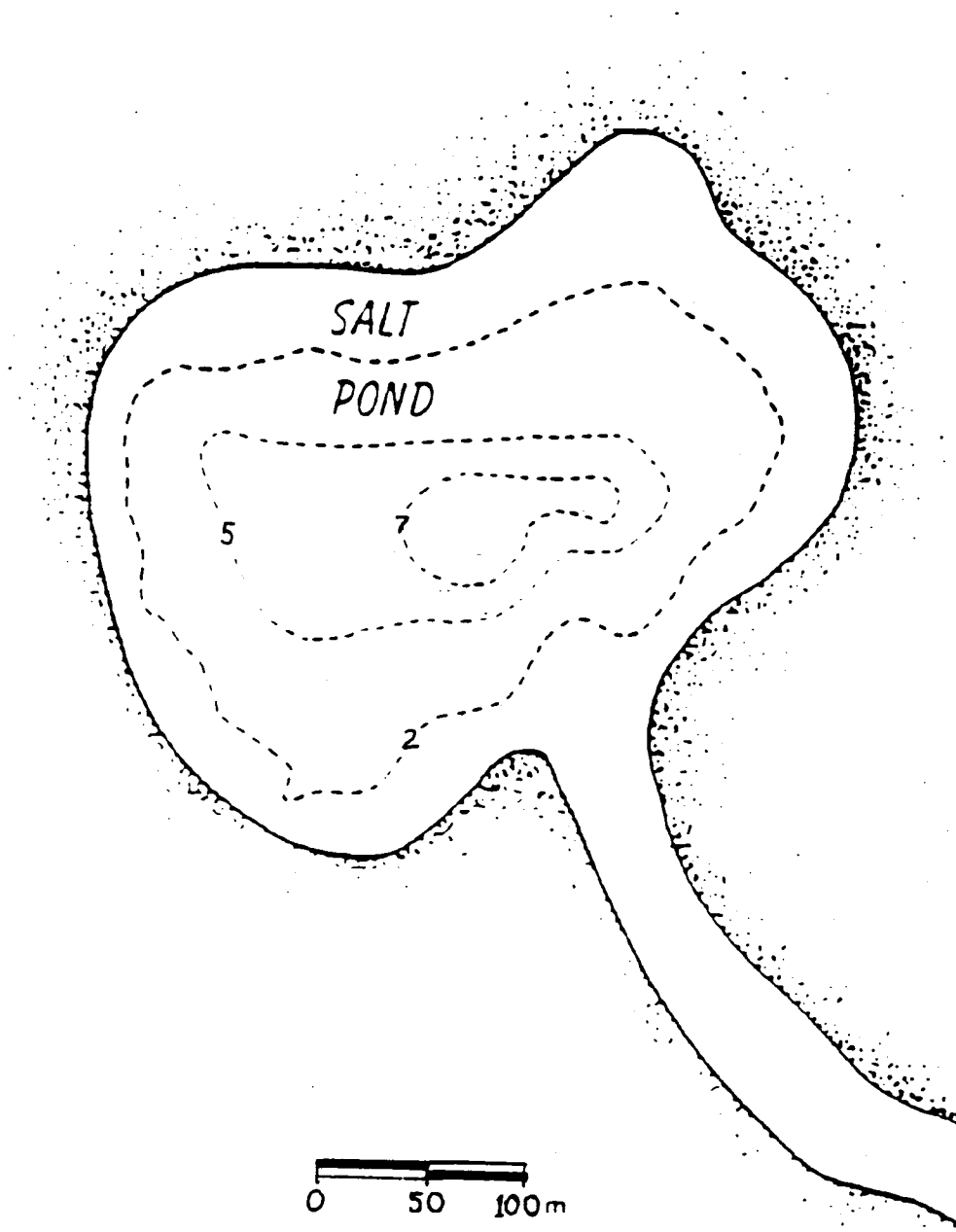


Figure 2. Bathymetric map of Salt Pond, Eastham, Massachusetts (from Anderson and Stoltzenbach, 1985). Contours are in meters at slack low tide.

0900 August 1, 1990. During this study, temperature, salinity and conductivity profiles were determined with the S-C-T meter. During daylight hours, incident light was measured at each depth. Samples for dissolved oxygen analyses were collected with the peristaltic pump, fixed in the field, and titrated at a temporary lab set up in the basement of the Salt Pond Visitor Center. Measurements were made every meter between surface and 8 meters; and also at meters 3.5, 4.5, and 5.5 to bracket the thermocline.

During this 24 hour study, tide heights were also observed. A 1"x2" board calibrated in tenths of feet was nailed to an existing wood support (near the town dock at Salt Pond). Tide heights were recorded whenever the observers embarked or disembarked the dock, i.e. about twice an hour. Data obtained were relative heights in feet. Absolute heights can be determined once the tide staff is registered to a benchmark.

Chlorophyll analysis in Salt Pond: During the 24 hour study of Salt Pond samples were collected and filtered for chlorophyll analysis. At each sampling, water was collected at the surface and at 1, 2, and 3 meters. At the temporary lab, 1.5 liters of water collected from the surface was filtered through a .45 μ m glass fiber filter using a Millipore Vacuum Pump (Millipore Corporation, Bedford Ma. 01730). The filter was then folded into quarters and placed in a labeled plastic bag. This process was repeated for samples from 1 and 2 meters. For the water sample from 3 meters, only 1 liter of water was filtered. Duplicate samples were filtered for each time and depth. Filters were immediately frozen for future chlorophyll analysis (American Public Health Association, 1985, p. 1067).

Town Cove: On August 8, temperature, conductivity, salinity, light, and DO profiles were performed weekly at the deepest point of Town Cove (Figure 3) during high tide. These profiles were conducted using the same methods as employed in Salt Pond. Cape Cod National Seashore's motorized skiff was used for transportation. Since the hydrodynamics of Town Cove have been previously studied (Teal, 1983), no daily profile over a tidal cycle or 24 hour study was performed.

II. Groundwater Nitrate-Nitrogen Analysis

In an effort to establish representative monitoring locations for nitrogen influx into Nauset Marsh, transects were established along the shoreline at Nauset Bay and Hemenway Landing, both in Eastham, and two transects were established in Town Cove in Orleans (Figure 1). The Nauset Bay transect was located in the marsh behind the Lyman house on Nauset Road. It began at a large rock located 75 m north of the Lyman house

TOWN COVE ORLEANS/EASTHAM, MA.

BENCHMARK DESCRIPTION (MASS. COORDINATES - FT.)

- 1 GOOSE HUMMOCK: X=1,013,850 Y=293,290
- 2 ROCKY POINT: X=1,016,250 Y=294,465
- 3 YACHT CLUB: X=1,012,813 Y=290,710

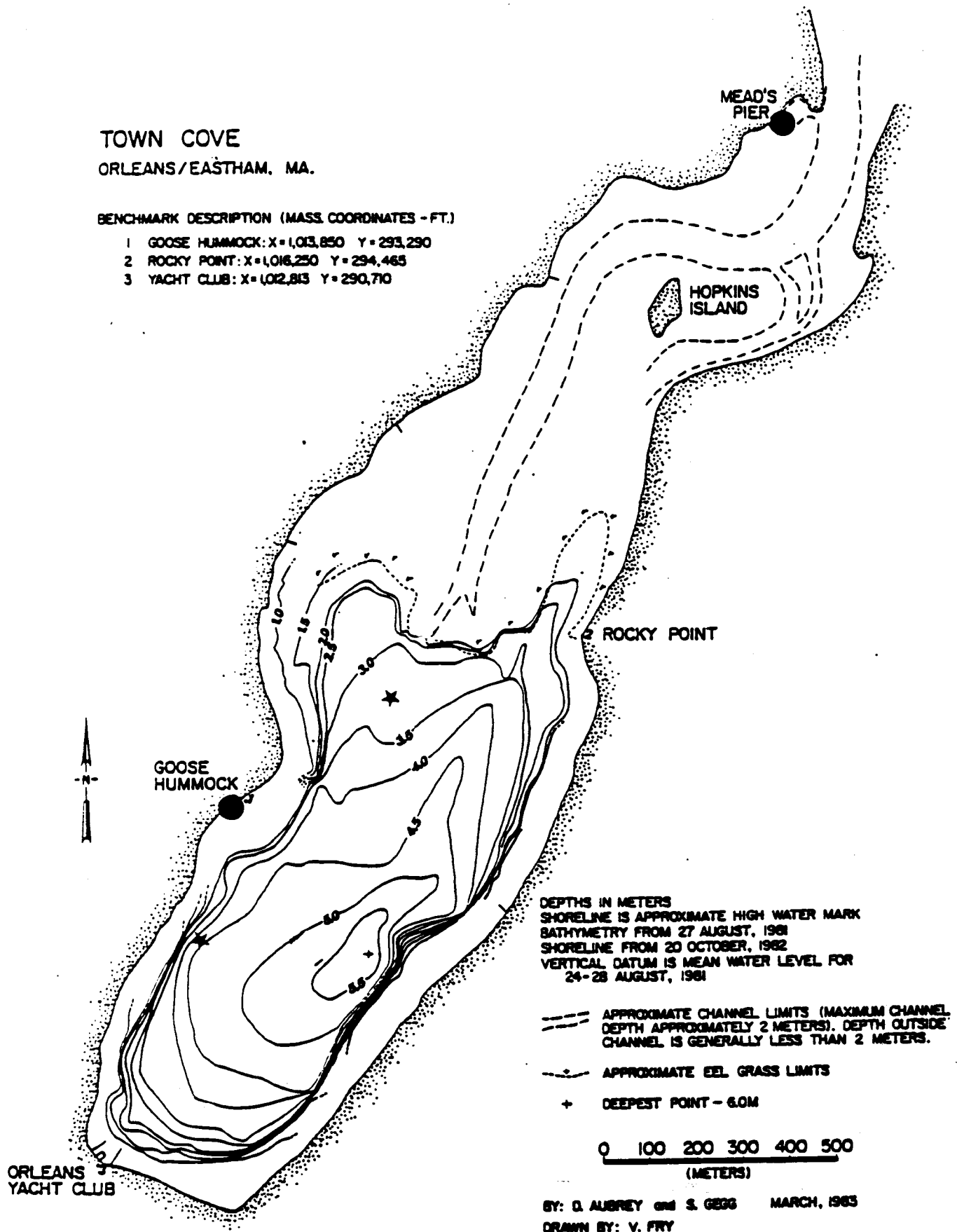


Figure 3. Bathymetric map of Town Cove, Eastham and Orleans, Massachusetts (from Teal, 1983).

access path and extended northward. The transect located at Hemenway landing (at the end of Hemenway Road) extended north from the north end of the town parking lot. One of the Town Cove transects was established behind the large windmill across from the Stop and Shop on Route 6A. This "Windmill" transect began at a small black locust tree marked with a red "X" and continued south. The Windmill transect was considered exploratory for both sampling and analysis procedures and was not permanently marked. The other Town Cove transect was on the northern side of the town landing at the Orleans Yacht Club. At three of the transects, the groundwater was sampled at 1.0 m intervals for the first 10 meters and at 5.0 m intervals thereafter. The 20 meter Yacht Club transect was sampled at one meter intervals. Some sites could not be sampled due to low soil porosity and poor infiltration of the groundwater into the sampling point. Initially, the Nauset Bay transect extended for 124 m, the Hemenway transect for 55 m, the Windmill transect for 39 m and the Yacht Club transect for 20m.

Groundwater was sampled with a hand-driven (8mm i.d.) stainless steel temporary well-point. Just above the point, 4 rows of 2 mm holes were bored. At the other end, a flange approximately 3 cm in diameter was welded to the rod, 36 cm from the top to accept a 2 kg driver. At each point along a transect, the well-point was hammered into the ground until ground water was encountered and the tube from the peristaltic pump was forced over the exposed end of the well-point. Water was pumped until it was clear of silt and sand, then an aliquot of approximately 240 ml was collected in a specimen cup. Salinity was either field-measured with the S-C-T meter or, for the Yacht Club transect, inferred from subsequent Cl determination (mercuric nitrate method). If the sample appeared fresh, an additional 240 ml was collected in a clean, rinsed specimen cup, capped, and stored on ice. When brought back to the lab, all samples were immediately filtered using a 0.45 μ m pore size membrane filter and a vacuum pump and refrigerated. At sites in the Nauset Bay and Hemenway transects where a water sample could be obtained without aeration (bubbling), an additional sample was collected in a BOD bottle and fixed for dissolved oxygen analysis. Nitrate-nitrite-nitrogen concentrations were determined by the cadmium reduction method (American Public Health Association, 1985, p. 394; Appendix A). The cadmium reduction method measures nitrate and nitrite, but oxidized water samples contain almost no nitrite, so hereafter the values resulting from cadmium reduction will be treated as nitrate-nitrogen ($\text{NO}_3\text{-N}$). $\text{NO}_3\text{-N}$ values were converted to micro-moles / liter = $\mu\text{M/l}$ for eventual comparison with other "land margin ecosystem research" in the Cape Cod area. Dissolved oxygen concentrations were determined by the Winkler method (azide modification).

Vegetation

I. Cladophora Biomass

The biomass of Cladophora gracilis was determined biweekly beginning July 1, 1990. The site chosen (Figure 1) was an exposed, C. gracilis-covered mud flat located in Salt Pond Bay, east of Salt Pond's inlet. A canoe was used for transportation to the site. At low tide, random samples (chosen by throwing a marker over one's head) were harvested by placing a bottomless five gallon bucket over the C. gracilis and removing all of the algae from within. The algae was then rinsed in a 3 mm sieve in an attempt to remove a majority of the mud and fauna. Each sample was then drained of water and placed in a plastic bag. Samples were kept separate at all times.

In the lab, the samples were further cleaned by rinsing them under running water. Invertebrates were removed by hand. After wringing out as much water as possible, samples were placed in individual, small (13.0 cm x 7.9 cm x 27.3 cm) brown paper bags and dried at 60°C to constant weight (about 72 hours). Empty bags were also dried at 60°C so their mass could be subtracted from the total. Knowing the area sampled (the bucket's area), the biomass of C. gracilis (g/m²) could be calculated. After experimentation during the first two weeks, it was determined that 10 samples should be harvested to reduce variability without overburdening the staff with cleaning time.

II. Eelgrass Wasting Disease

To determine the impact that Labyrinthula has on eelgrass (Zostera marina), eelgrass was collected from two locations, Mill Pond and Snow Shore Landing, both in Orleans (Figure 1). Individual, mature plants were removed at the rhizome with at least 3-4 nodes. Reproductive plants, having thinner stems and fruiting bodies on their blades, were avoided. Ten samples were taken from each of two locations at low tide in waist-deep water, away from the edge of the eelgrass beds. Plants were placed in labeled (date, site, contents, and direction of collection) heavy duty plastic freezer bags (26.8 cm x 27.9 cm). Any free water in the bags was poured out so the samples were damp, but not wet. All bagged samples were then placed in a double 6-pack styrofoam cooler (approximate dimensions of 40 cm x 30 cm x 50 cm) which was wrapped in brown paper and shipped via U.S. overnight mail to the Jackson Estuarine Lab. Samples were collected bi-weekly through September and monthly through May, 1991.

In Mill Pond, samples were collected from Zostera beds in front of the landing. Six plants were harvested parallel to

shore and 4 were collected perpendicular to it. Of the 6 samples, 3 came from each side of the landing, approximately 1 m apart. Ten samples were also collected from Snow Shore Landing and placed in plastic bags. The site was located approximately 265 meters south of the landing, at the single large, triangular rock.

Fauna

I. Nesting Birds

Cape Cod National Seashore staff and the Massachusetts Audubon Society contributed information. Data were collected on frequent visits to each site; daily at Coast Guard Spit and less regularly at other sites. The data were presented at the annual Massachusetts tern and plover summary meeting in early August, and updated based on information acquired after that meeting. In addition to pedestrian, pet and oversand vehicle restrictions, management actions included the use of predator exclosures at Coast Guard Spit for individual plover nests, and a large tern and plover predator exclosure at the Nauset Heights colony.

II. Migrant Birds

University of Rhode Island study sites in Nauset Marsh include the New Island flats, Nauset Bay, and the southern end of Coast Guard Spit for migrating and staging gulls, terns and shorebirds, and winter waterfowl surveys in Salt Pond Bay. Survey frequency varies depending on site, season and accessibility, but most sites in Nauset Marsh were checked weekly from July through September.

A survey of night-heron roost use near Hemenway Landing has been previously conducted and declines in that roost are suspected (Nikula, 1984 and pers. comm.) Although night-herons were observed leaving this roost on several occasions during the summer, no quantitative observations were made.

RESULTS

Physical Parameters

Salinity and conductivity in both Salt Pond and Nauset Bay were highly variable. In Nauset Bay salinity ranged from 34.1 ppt on 6/15/90 to 23.0 ppt on 7/10/90. The conductivity ranged from 54,539.5 umhos on 7/13/90 to 37,706.2 umhos on 7/10/90. In Salt Pond the salinity ranged from 32.8 ppt on 7/23/90 to 21.4

ppt on 7/30/90, while the conductivity ranged from 51,763.8 umhos on 7/19/90 to 38,335 umhos on 7/30/90. The temperature in both Salt Pond and Nauset Bay increased during the course of the summer. In Nauset Bay the temperature ranged from a low of 11.8 °C on 6/15/90 to a high of 23.9 °C on 7/19/90. In Salt Pond the temperature ranged from a low of 15.2 °C on 6/15/90 to 22.5 °C on 7/19/90.

Water Quality

I. Dissolved Oxygen

24 hour profiles: The 24-hour profile conducted on Salt Pond from July 31-August 1, 1990, occurred during a neap tide series. Tidal amplitudes should have been normal; however, weather patterns dominated by Hurricane Bertha, which was 300 miles offshore, generated local high tides that were several feet above normal. Tidal range on July 31 was recorded as being approximately 3.8 feet (Figure 4). The evening high tide on July 31 occurred near 2100 hours EDT; low tide in Salt Pond was observed at 1543 hours July 31 and at 0550 hours on August 1. It must be noted that heights are relative and not tied to a known datum. Tidal elevations with respect to mean low water can be determined once the tide staff is tied in to an existing benchmark. High tide was reported for Salt Pond at 2200 hours; low tides were at 1612 hours (July 31) and again at 0500 hours (August 1). Figure 4 indicates that the tide was slightly asymmetrical; the tide flooded rapidly and ebbed slowly. The tide flooded for approximately 5 hrs., 22 min., while it ebbed for 8 hrs., 45 min. The ebbing tide was thus 3 hrs., 23 min. longer than the flood.

Bottom water anoxia was observed at varying depths in the pond throughout the observation period. Figure 5 shows the depth at which anoxia was first observed during each sampling. This anoxic layer was closest to the surface (3.5 m) at 1500 hours; it was furthest (5.5 m) from the surface at 2021 and 2230 hours. Over the entire sampling period, the anoxic layer occurred at a deeper depth during darkness (4.5-5.5 m) than during daylight (3.5-4.5 m).

At any given depth in the epilimnion (meters 0-3), dissolved oxygen remained relatively constant over time. Generally, DO was highest at 3 meters (Figures 6, 7, 9 and 10). Daylight did not seem to result in any appreciable increase in surface dissolved oxygen. Figure 6 suggests that the DO's for the first two meters were higher after 1900 hours. No statistical tests were performed to substantiate this. At dawn (0650 hours, Aug 1), the surface had the lowest dissolved oxygen measurements, 4.9 ppm.

Relative Changes in Tide Heights

0910 July 31 - 0757 August 1

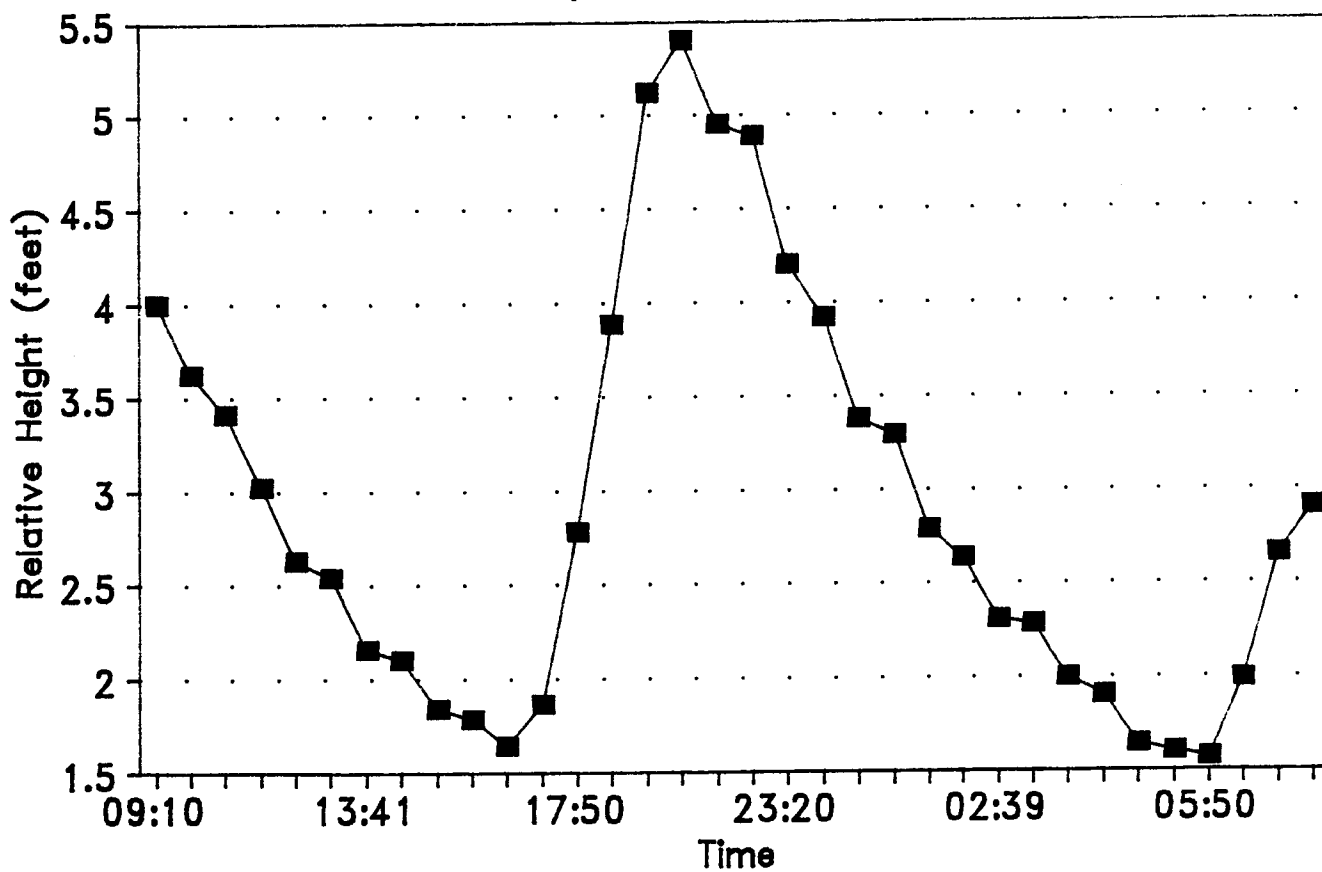


Figure 4. Changes in the tide height of Salt Pond from 0910 on July 31 to 0757 August 1, 1990.

Depth Where Anoxia is Observed (Salt Pond, July 31, 1990)

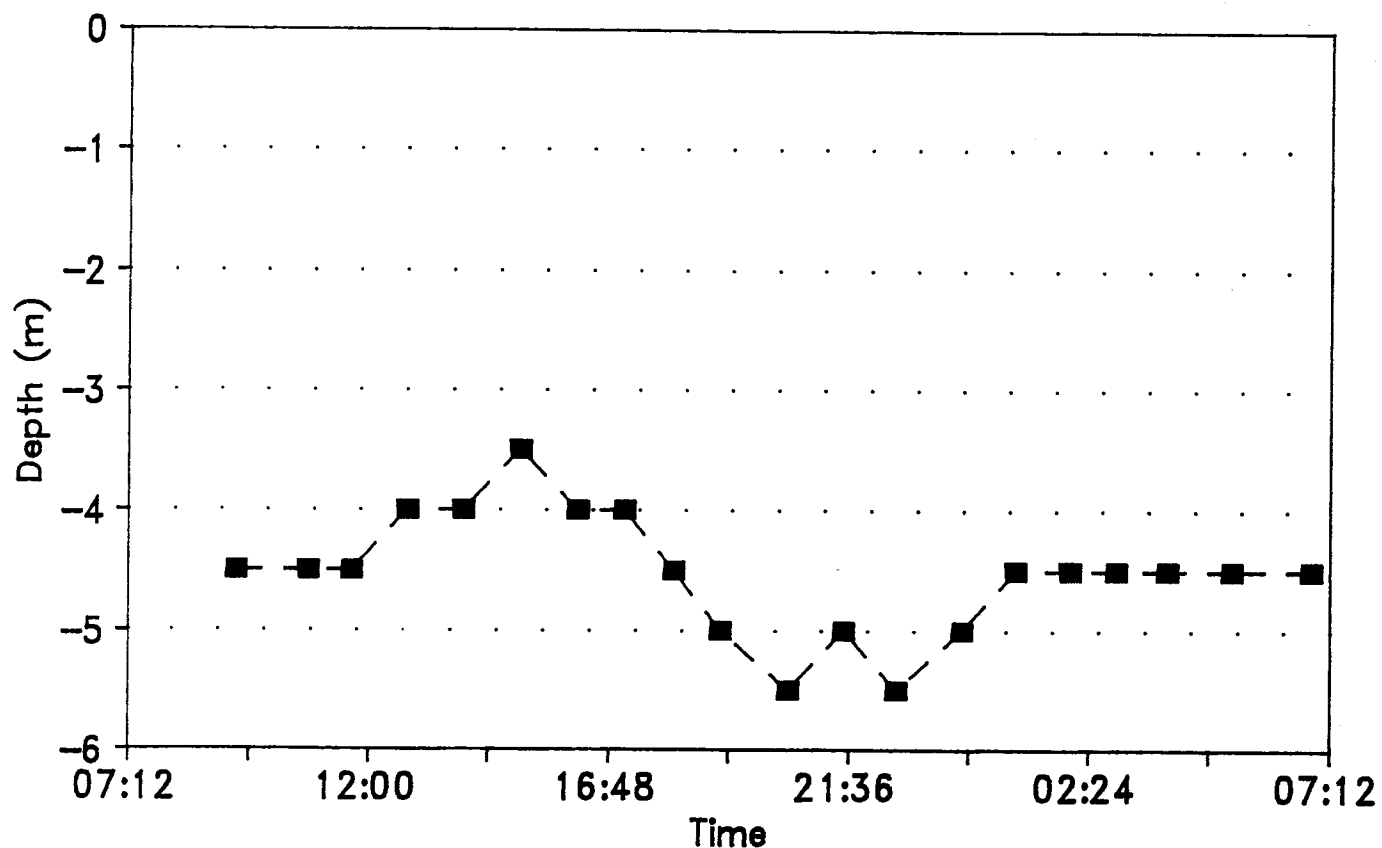


Figure 5. Depth from surface at which the anoxic layer was first observed in Salt Pond from July 31 to August 1, 1990. Movement of the anoxic layer is evident over a period of time.

24 Hour Dissolved Oxygen Series

Salt Pond – Upper Level

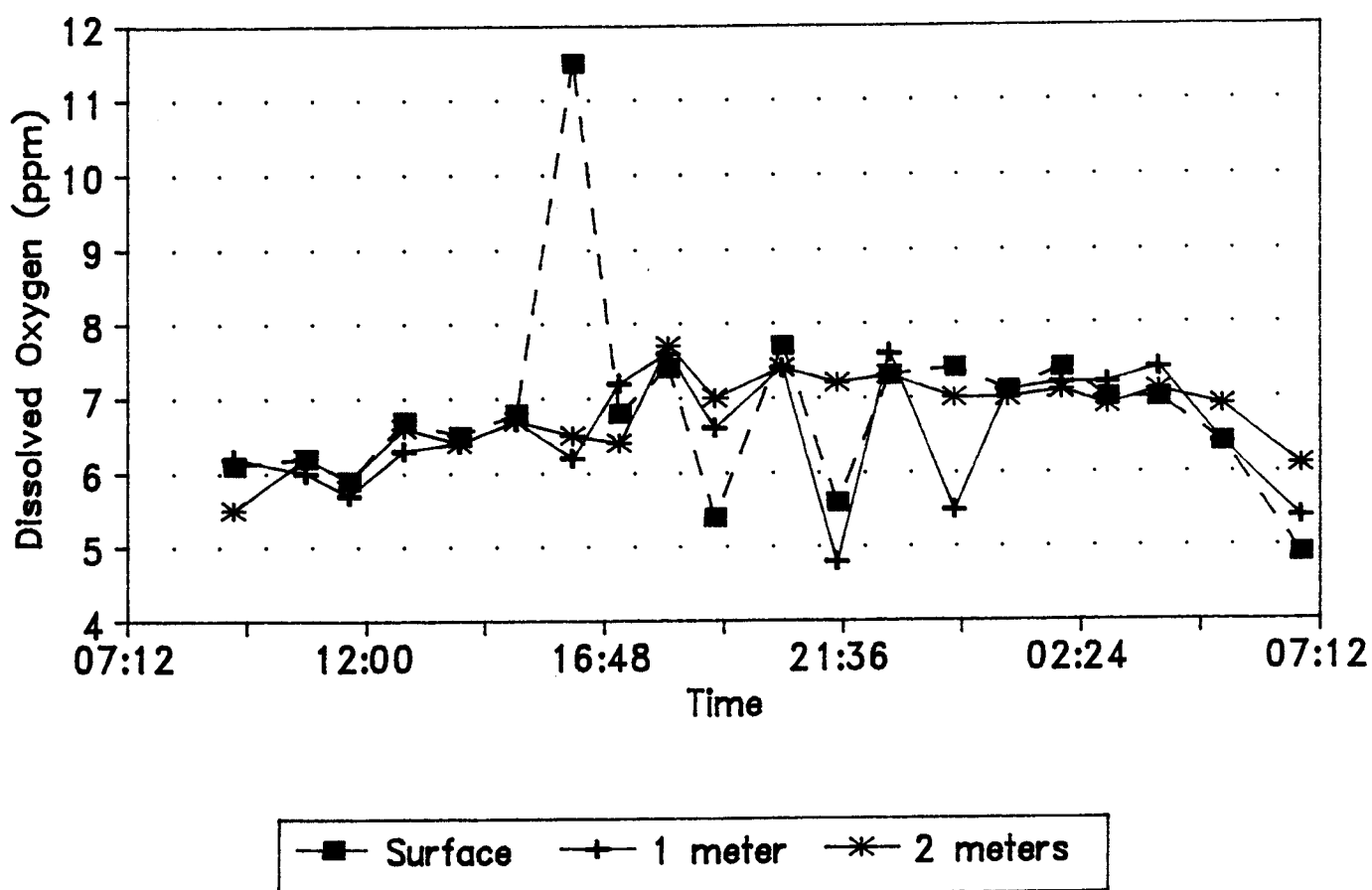


Figure 6. Variations of dissolved oxygen results from the surface to 2.0 meters. The amounts dissolved oxygen in the waters of Salt Pond were determined every hour starting July 31, 1990 at 0920 to 0720 August 1, 1990.

24 Hour Dissolved Oxygen Series

Salt Pond – Mid Level

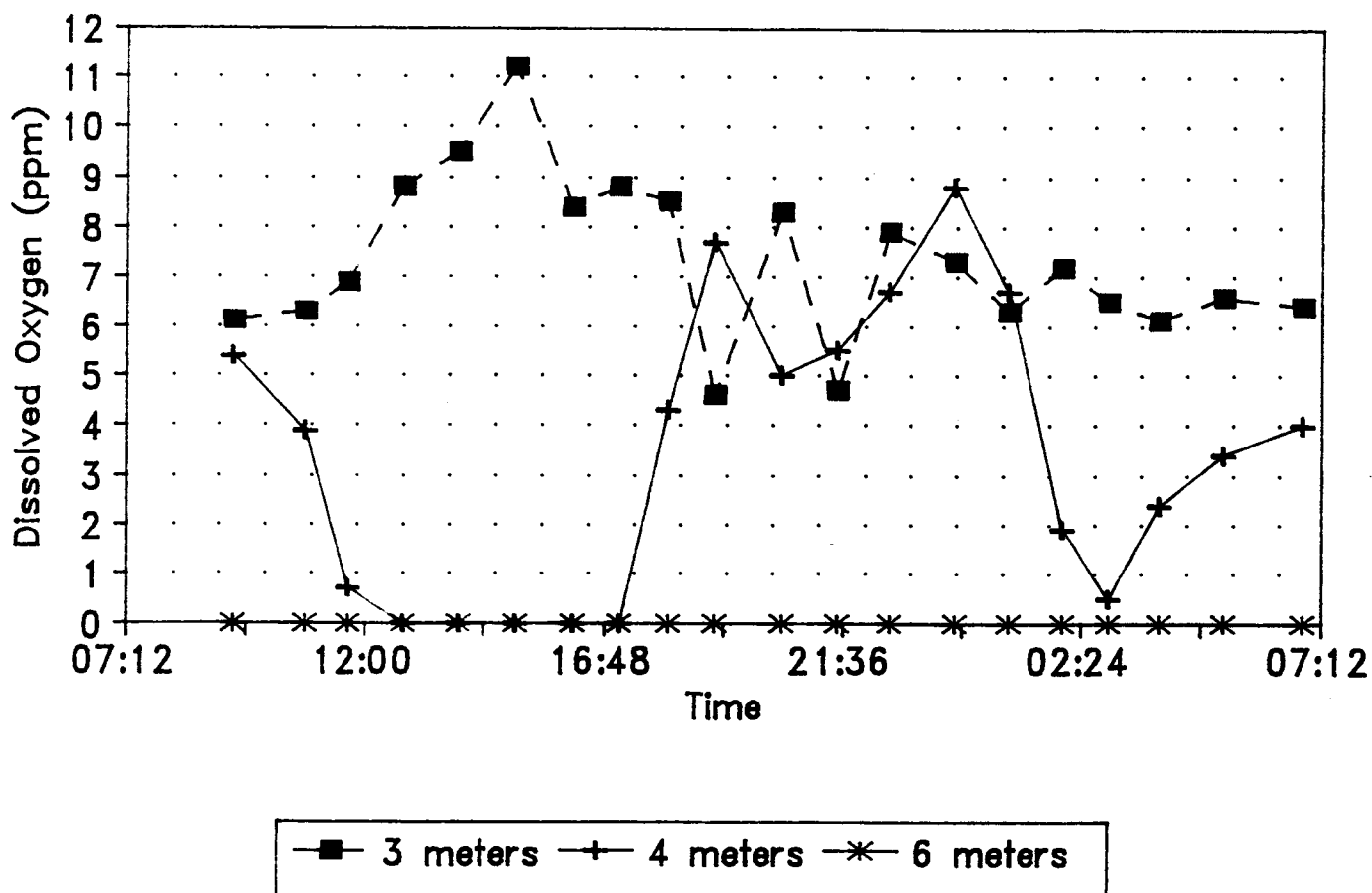


Figure 7. Variations of dissolved oxygen results from 3.0 to 6.0 meters. The amounts of dissolved oxygen in the waters of Salt Pond were determined every hour starting July 31, 1990 at 0920 to 0720 August 1, 1990.

24 Hour Dissolved Oxygen Series

Salt Pond – Lower Level

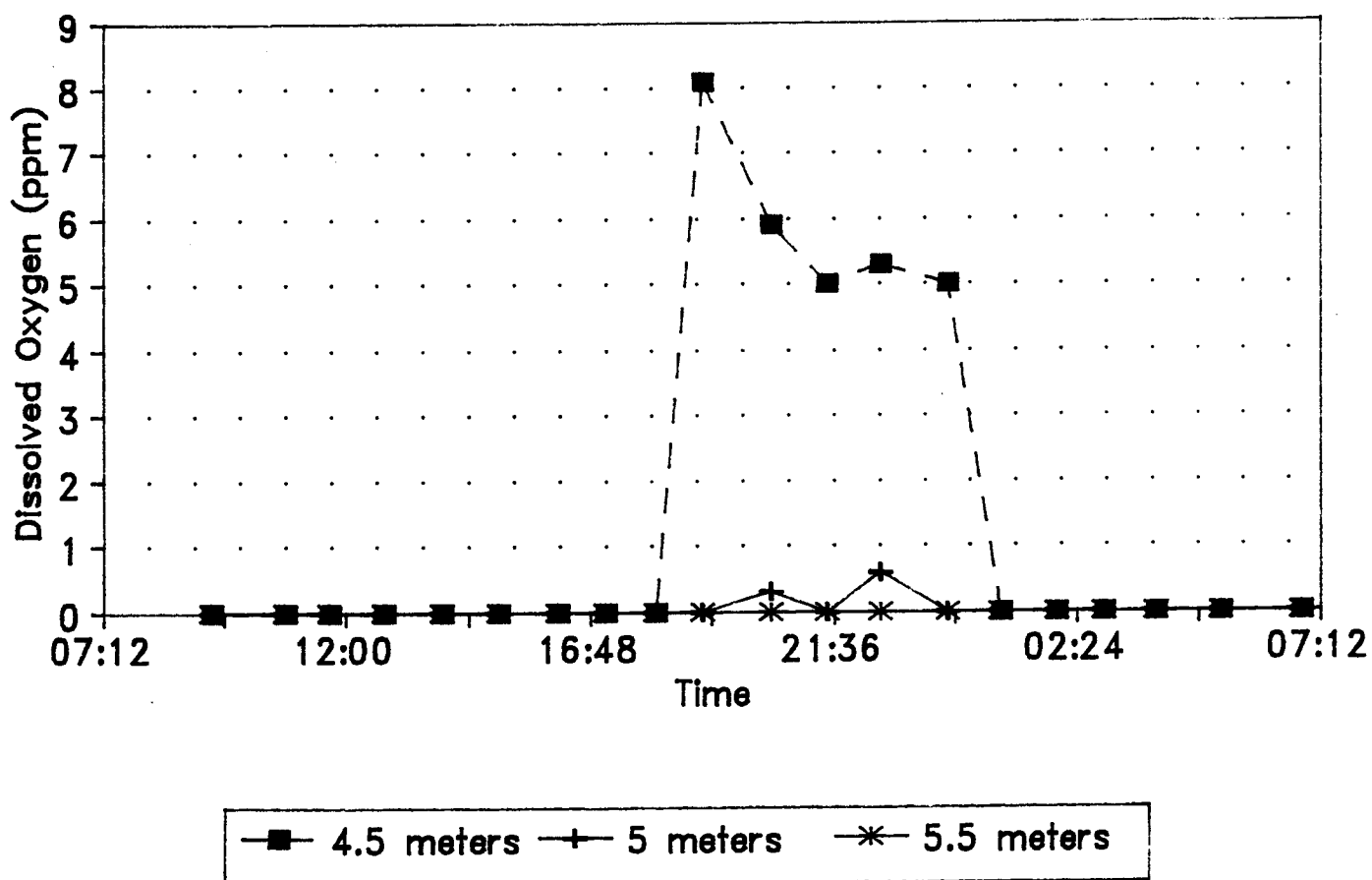


Figure 8. Variations of dissolved oxygen results from 4.5 to 5.5 meters. The amounts of dissolved oxygen in the waters of Salt Pond were determined every hour starting July 31, 1990 at 0920 to 0720 August 1, 1990.

Low Tide Temp and DO Profiles

Salt Pond - July 31, 1990

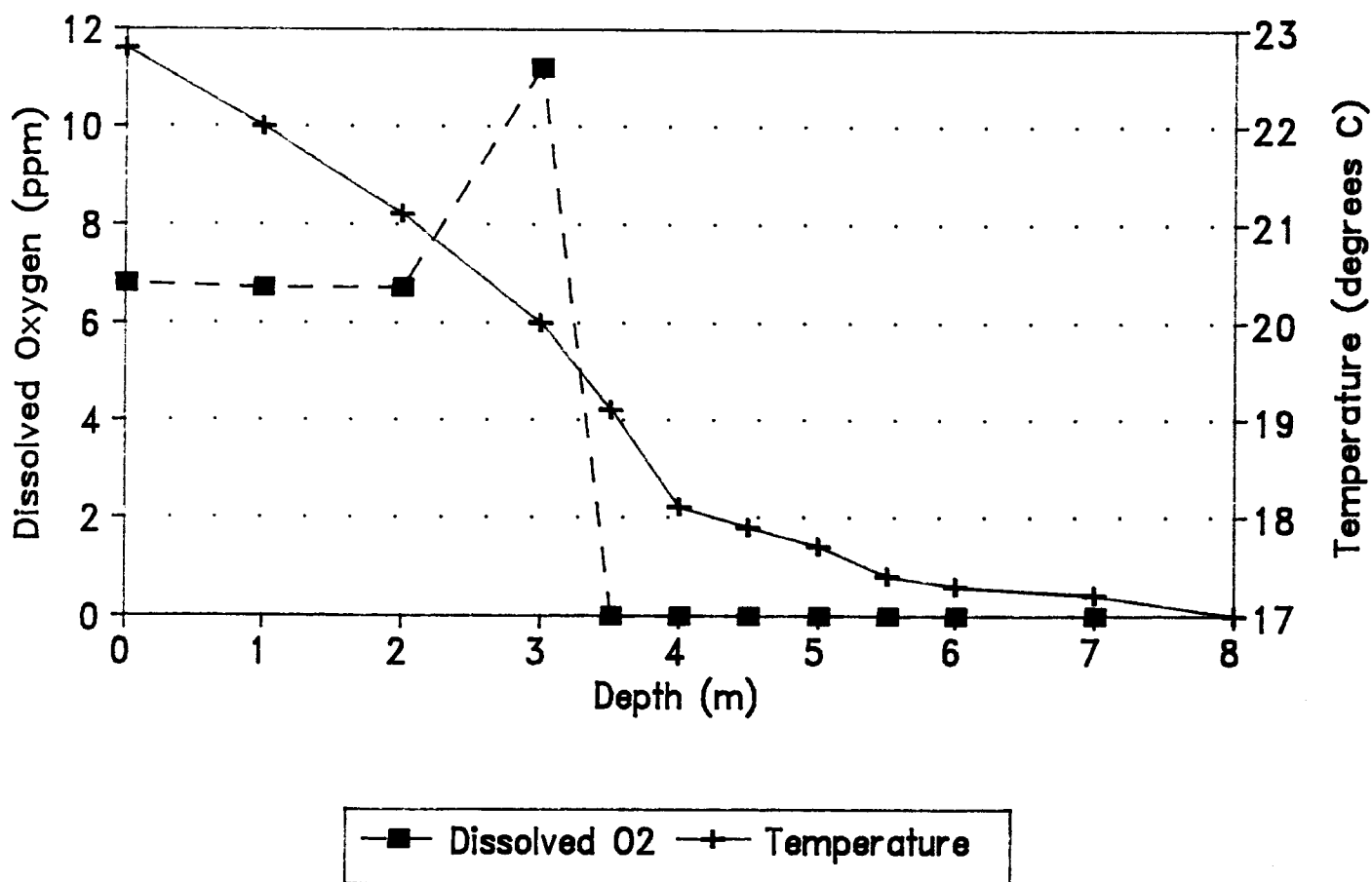


Figure 9. A comparison of temperature and dissolved oxygen in Salt Pond on July 31, 1990. This profile was conducted at low tide (1500 hours).

High Tide Temp and DO Profiles

Salt Pond - July 31, 1990

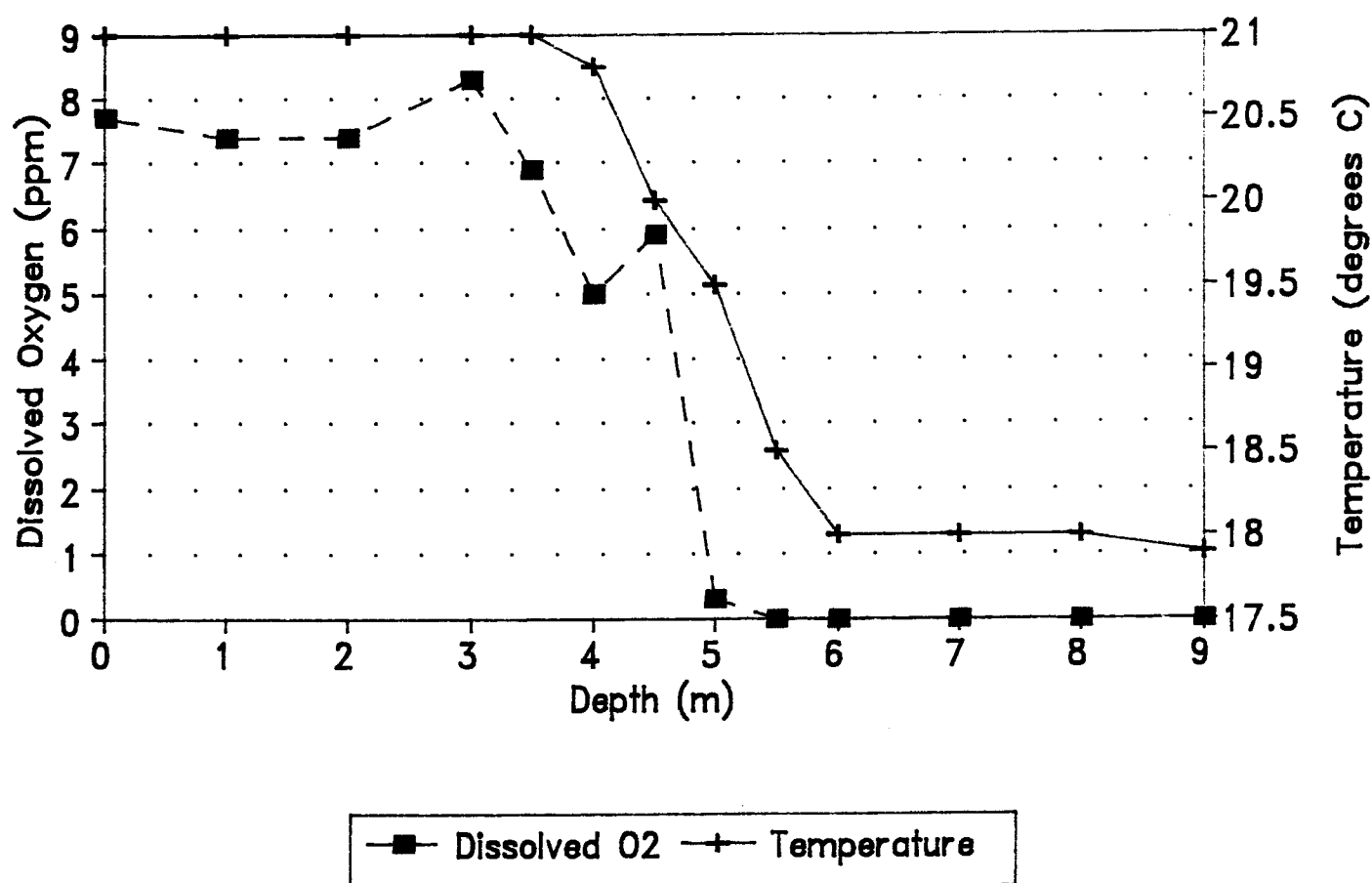


Figure 10. A comparison of temperature and dissolved oxygen in Salt Pond on July 31, 1990. This profile was conducted at high tide (2020 hours). Note the apparent influx of highly oxygenated water at upper depths (0 - 4 meters).

Generally, the decline in DO was precipitous, dropping from 5 ppm or more to 0 within 0.5 - 1.0 meters (Figure 7). A more gradual decline (Figure 8) was observed for the 2021 and 2230 hours samples. At the 2021 hour observation (Figure 10) the DO's at 3, 4, 4.5, 5, and 5.5 meters were 8.3, 5.0, 5.9, 0.3, and 0.0, respectively. A similar profile was observed at 2230 hours. Dissolved oxygen values at 4 meters demonstrated a cyclic pattern over the course of the day, ranging from 0 ppm at 1245 hours to 8.8 ppm at 2350 hours. Water below 5.5 meters was anoxic throughout the entire observation period (Figures 7 and 8).

Temperatures decreased with depth (Figure 11). Until 1610 hours, temperatures at 3 and 4 m were relatively constant. During this time period, there was approximately a 2°C drop between these two depths. From 1610 to 2230 hours, temperatures increased 3°C at 4 m and 2°C at 3 m. They slowly decreased after that. Compared to those nearer the surface, temperatures at 6 m were quite stable throughout the day, ranging from 16.9 to 18.0°C. No temperature values were reported for observations after 0255 hours due to the S-C-T meter malfunctioning. Salinity observations (Figure 12) were highly variable, ranging from 23 ppt at 0920 hours to 34 ppt at 1353 hours. From 1500 hours to 0357 hours salinity measurements were more constant, varying between 29 ppt and 31 ppt. Salinity values decreased with depth, making the validity of the salinity measurements questionable at times (2021, 2128, 0357 hours). Measurements of temperature and salinity (Figure 13) were made in the channel connecting Salt Pond to Salt Pond Bay during every other observation. Both parameters were quite variable over time. Whether this variation is actual or introduced by the S-C-T meter is difficult to ascertain.

Depth profiles were constructed for temperature and dissolved oxygen values obtained at low (1500 hours) and high (2021 hours) tides. Generally, at least two distinct temperature clines existed. There was always a distinct hypolimnion where temperature and dissolved oxygen values were lowest, but constant. In this layer, incident light was negligible (Figures 14 and 15), less than 1 foot-candle, largely due to precipitated iron sulfide (FeS) suspended in the anoxic water column (Portnoy, pers. comm.). Figure 9 indicates that temperatures decreased linearly through the first 4 meters, from 22.8 to 18.2°C. Below 4 m, temperatures were more constant, dropping from 17.9 to 17.0°C. Dissolved oxygen values were highly correlated with temperatures. Peaking at 2 m (11.5 ppm), DO's decreased to 0 ppm at 3 m and remained so to the bottom. In the epilimnion, incident light was rapidly attenuated (Figure 14); only 90% of the light available at the surface was available at 3 m. However, high tide presented a slightly different profile (Figure 10). Temperatures dropped almost 3°C over 2 meters, leveling off

24 Hour Temperature Series

Salt Pond - Multilevel

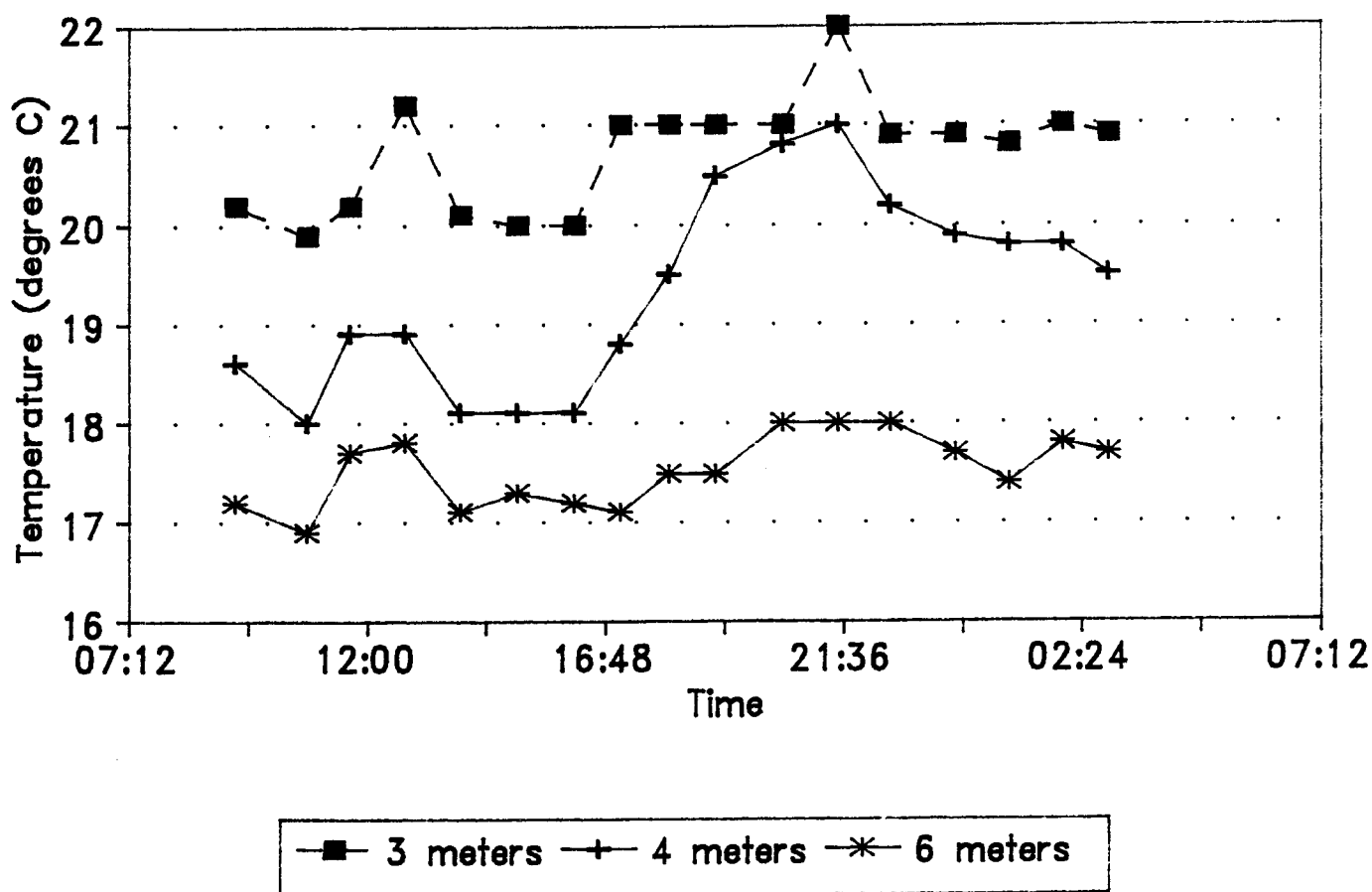


Figure 11. Variations of temperatures at selected depths. The temperatures in the water of Salt Pond were determined every hour during the period of observation.

24 Hour Salinity Series

Salt Pond - Multilevel

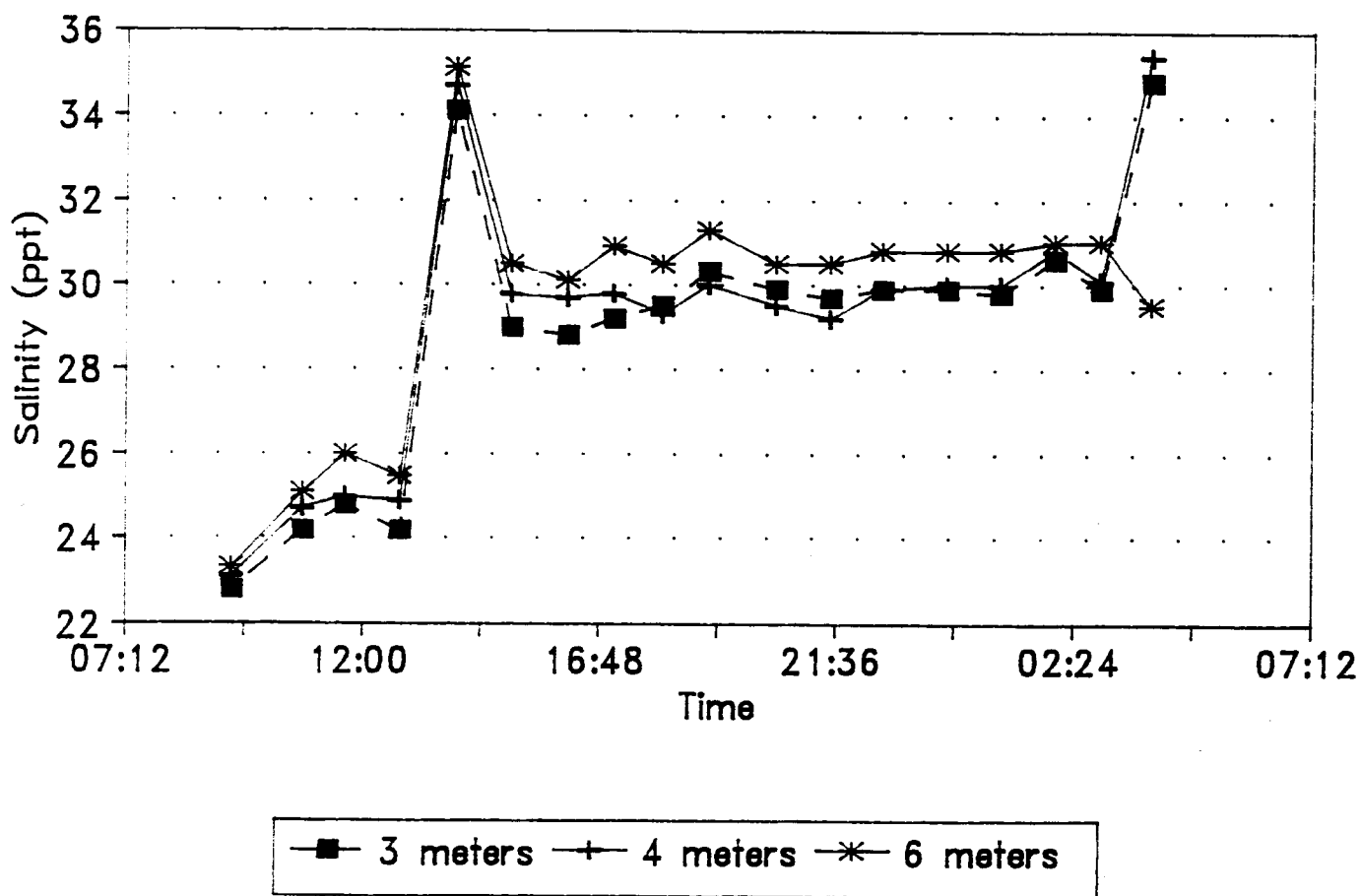


Figure 12. Variations of salinity at selected depths. The salinity of Salt Pond was determined every hour during the period of observation. Salinity values are approximate, and accuracy was probably affected by equipment malfunction.

Temperature and Salinity

Salt Pond Channel, July 31, 1990

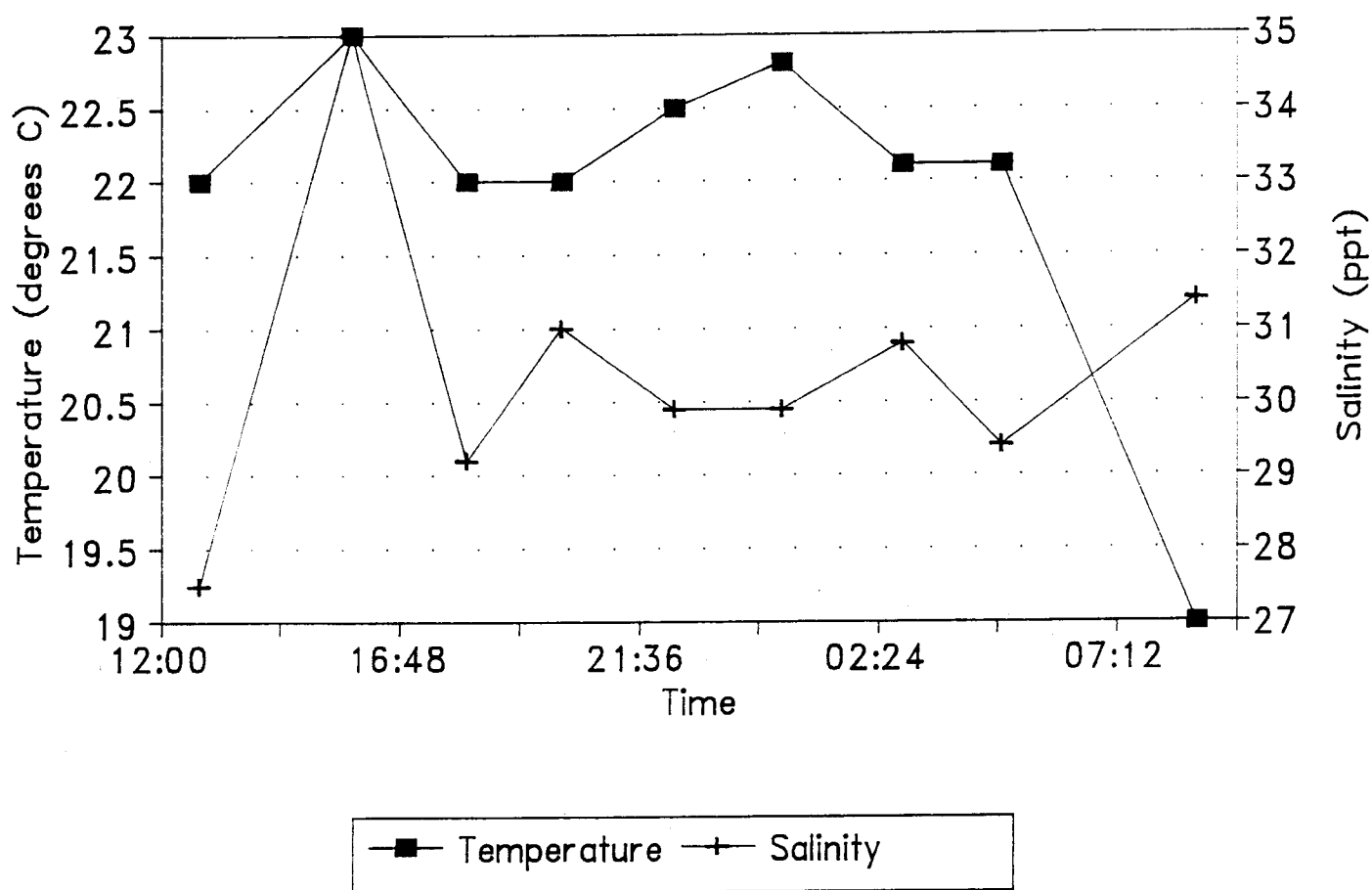


Figure 13. Shown are both the temperature and salinity in Salt Pond Channel. These measurements were taken every two hours during the period of observation.

Low Tide Temp and Light Profiles

Salt Pond – July 31, 1990

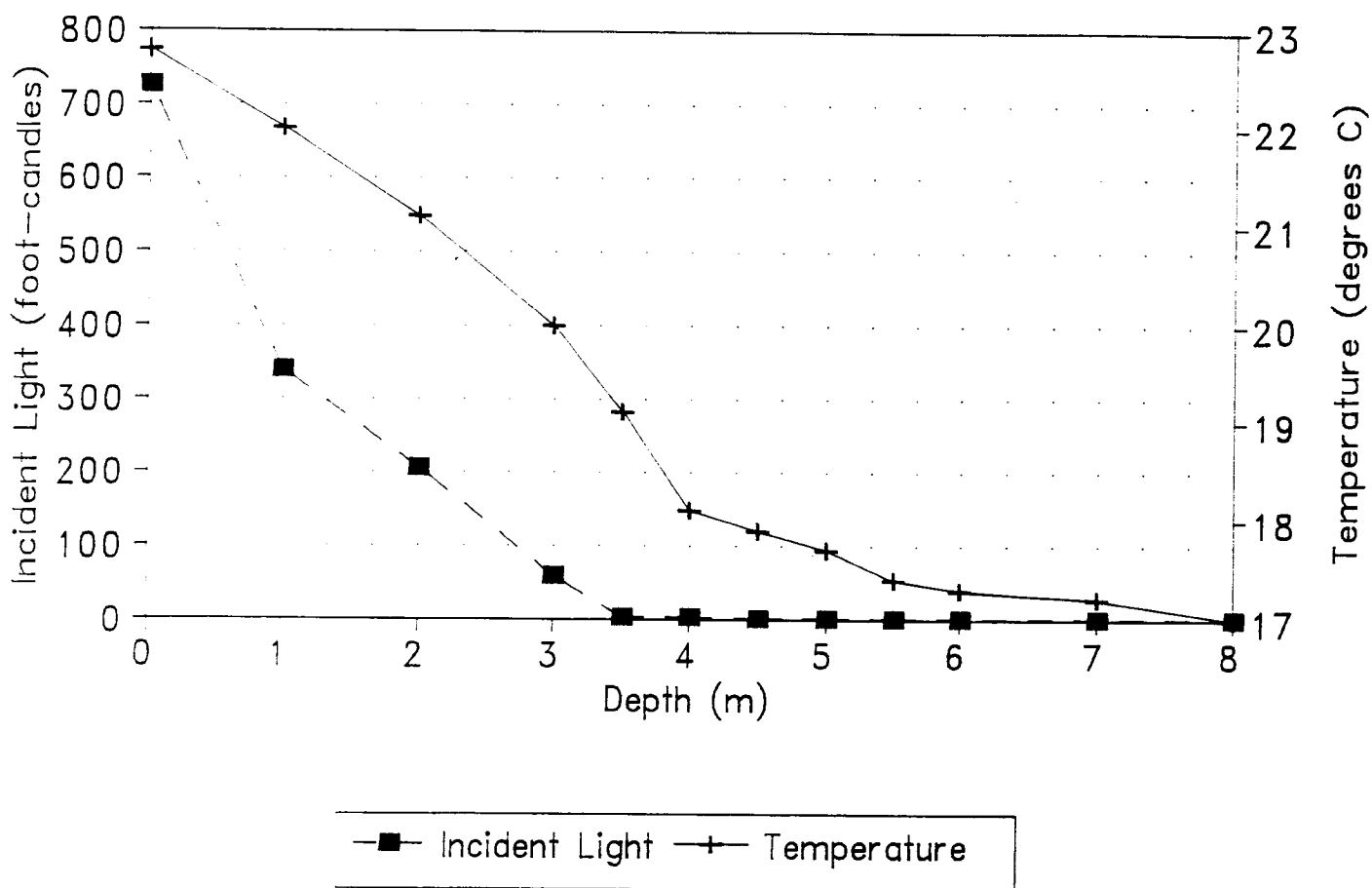


Figure 14. A comparison of the decline of both light and temperature in Salt Pond at low tide, 1500 hours, July 31, 1990.

Flood Tide Temp and Light Profiles

Salt Pond - July 31, 1990

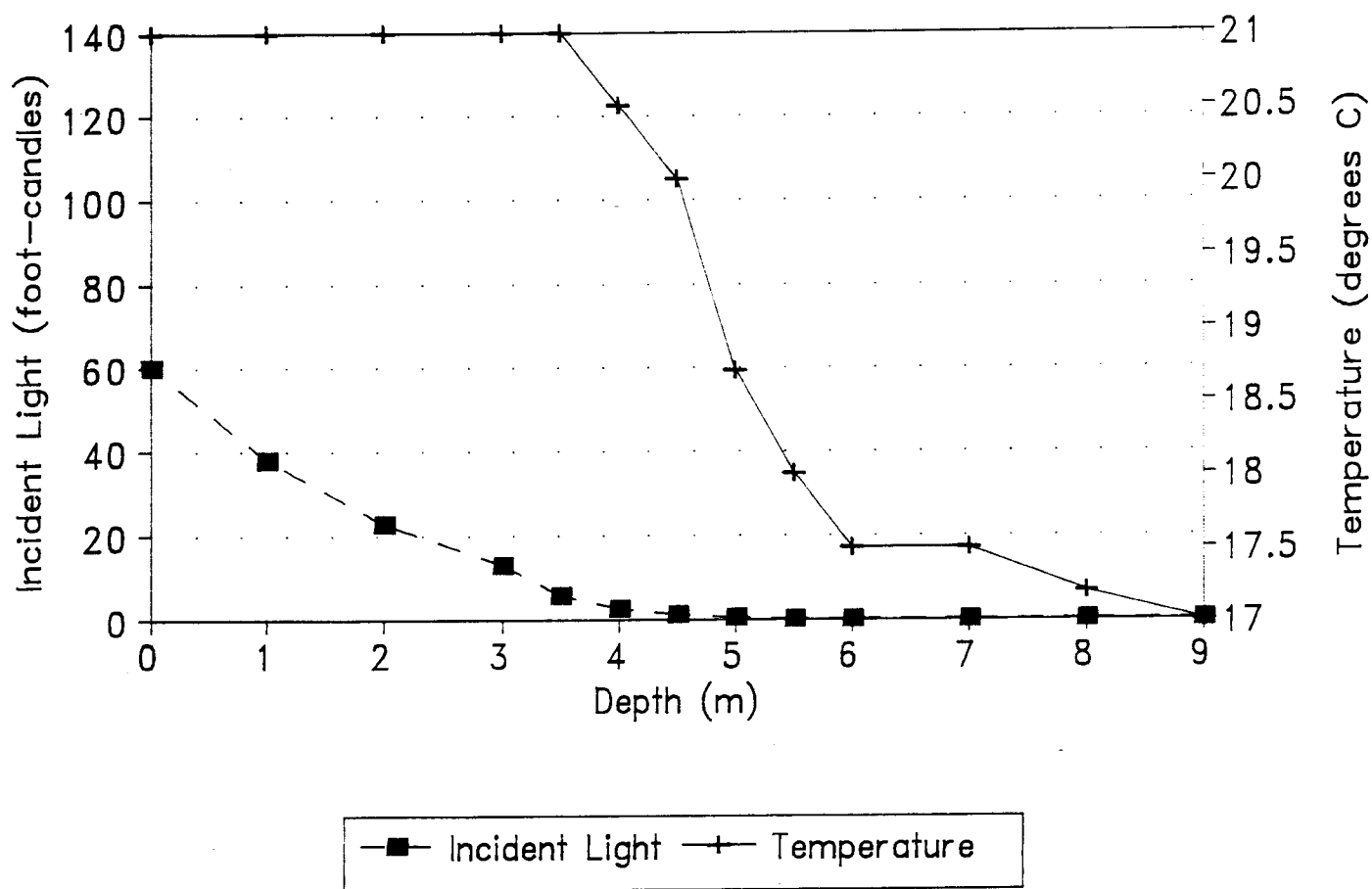


Figure 15. A comparison between temperature and light during the flood tide in Salt Pond, 1900 hours, July 31, 1990.

(18.0°C) at 6 m, while dissolved oxygen values dropped from 8.2 ppm at 3 m to 0 ppm at 5.5 m. Above and below this layer were the epilimnion and hypolimnion, respectively, where temperatures (as well as DO's) were constant. Again, incident light rapidly diminished through the epilimnion (Figure 15). Though less light was available than during low tide (due to dusk), only 90% of the light available at the surface was present at 3 m.

18 day profiles: The eighteen day profile series on Salt Pond was conducted from June 18 to July 5. All of the collections occurred daily at approximately 1000 hours. During the eighteen day period anoxia was observed at various depths in the pond on several occasions (Figure 16). The anoxic layer was detected at meters 6 and 7 during the first day's profile and again during three profiles near the end of the series. Mixing was indicated when DO for each meter depth interval fell within 10% for all intervals.

Two dates have been selected as examples of well-mixed and anoxic events. June 28 was selected for a period of mixing. July 1 was selected for detected anoxia. Both dates had the same amount of DO at meter 4 (Figure 17). June 28 then showed little variance in the amount of DO with the increasing depth. July 1 showed a rapid decline in the amount of DO through meter 6, when it became anoxic, a good indication of stratification. When the salinity is compared between the two dates (Figure 18) there is little correlation other than that after meter 5 they both stayed relatively stable. The temperatures of both dates decreased with depth (Figure 19). They declined at different rates on both dates until meter 5 where they both ranged between 14-15°C.

On June 28 temperature did not correlate with salinity (Figure 20). Most incident light was attenuated within the top 3 meters. Temperature continued a slow decline past 3 meters. During June 28 the dissolved oxygen reached supersaturation at meter 1.5 (Figure 21) and then declined to seventy percent with some variations. None of the data from June 28 indicates obvious stratification.

The salinity on July 1 showed a rise while temperature decreased (Figure 22). The salinity rose from 24.2-25.3(ppt). It reached the high point at 5 meters and didn't vary to the bottom. While the temperature showed a decline from 18.7-14°C. At meter 5 the temperature varied in between 14.7-14°C. The readings for both temperature and salinity were high at the surface to meter 1. They then generally stabilized until meter 4 when they again dropped. On both days approximately ninety percent of the light did not penetrate past meter 3 showing a stratification of light. Both temperature and DO were stratified on July 1 (Figure 23). The temperature and dissolved oxygen show

Dissolved Oxygen Variations

Salt Pond - 18 Day Series

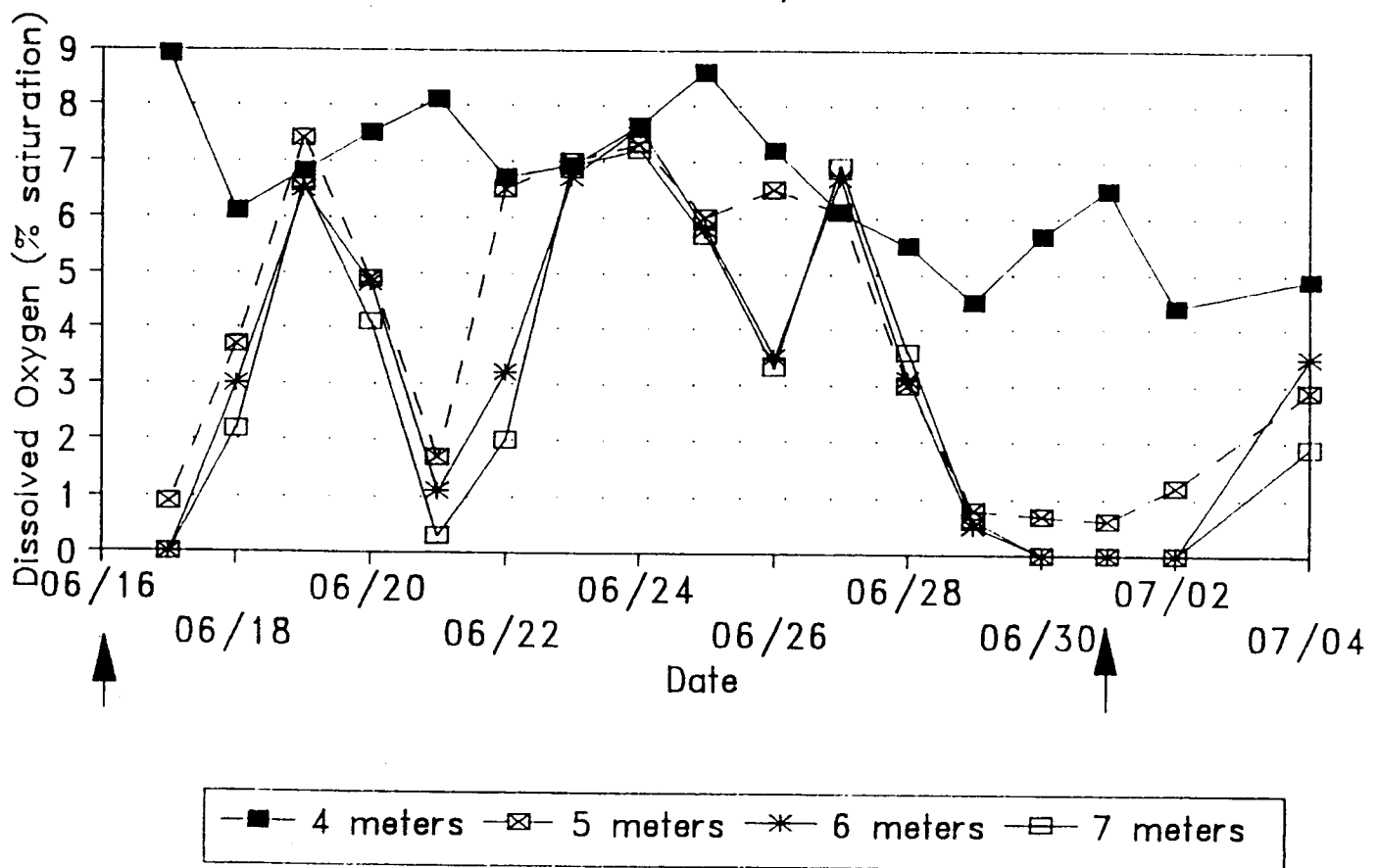


Figure 16 Variations of dissolved oxygen at selected depths. The percent saturation of dissolved oxygen in the waters of Salt Pond, Eastham, was determined daily at 1000 hours at one-half meter intervals from June 18 to July 5, 1990. Arrowheads indicate a 1000 high tide.

Dissolved Oxygen Comparison

June 28 and July 1, 1990

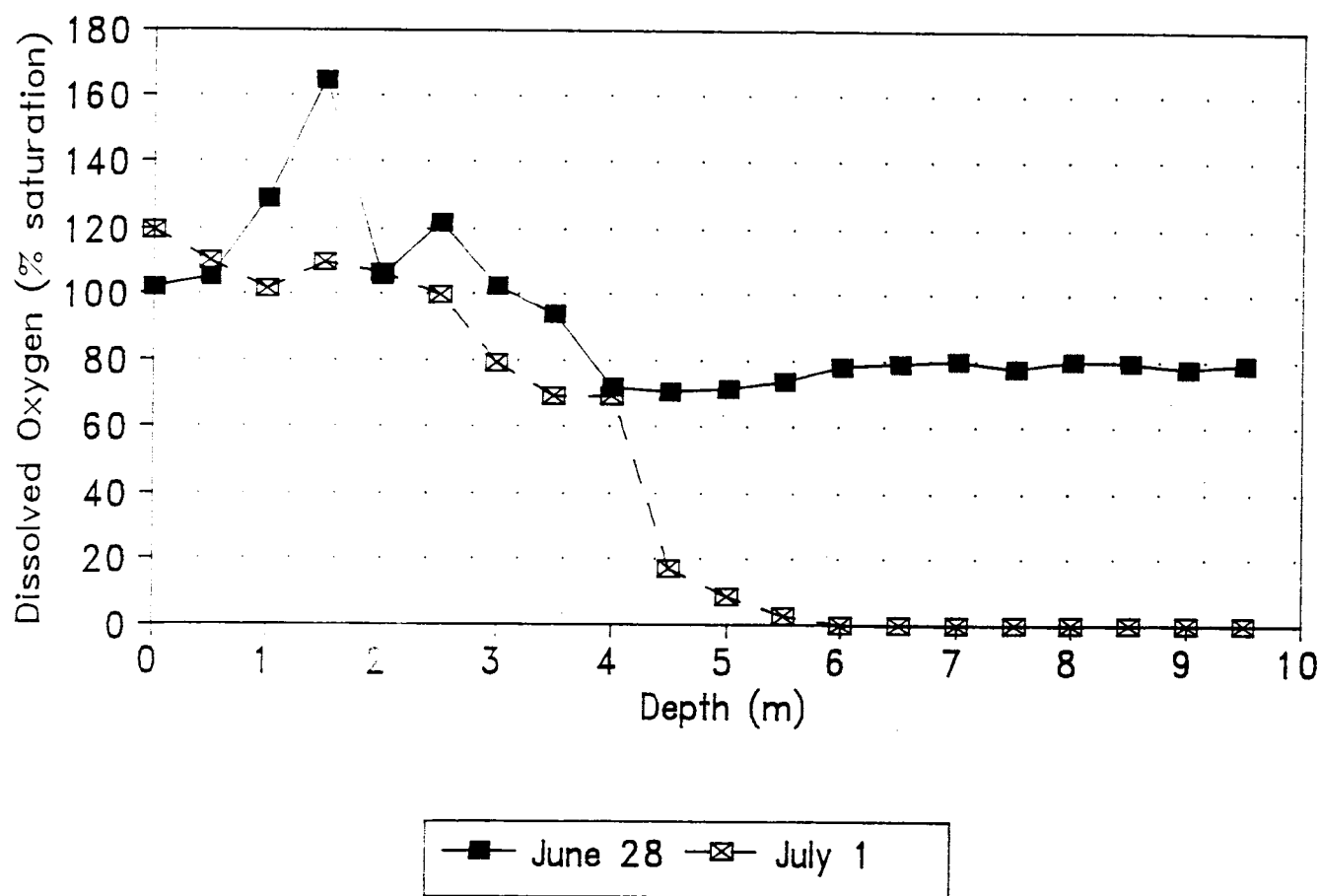


Figure 17. A comparison of the percent saturation of dissolved oxygen occurring on June 28 and July 1, 1990 in Salt Pond. The measurements were collected every half meter at 1000 hours.

Salinity Profile Comparison

June 28 and July 1, 1990

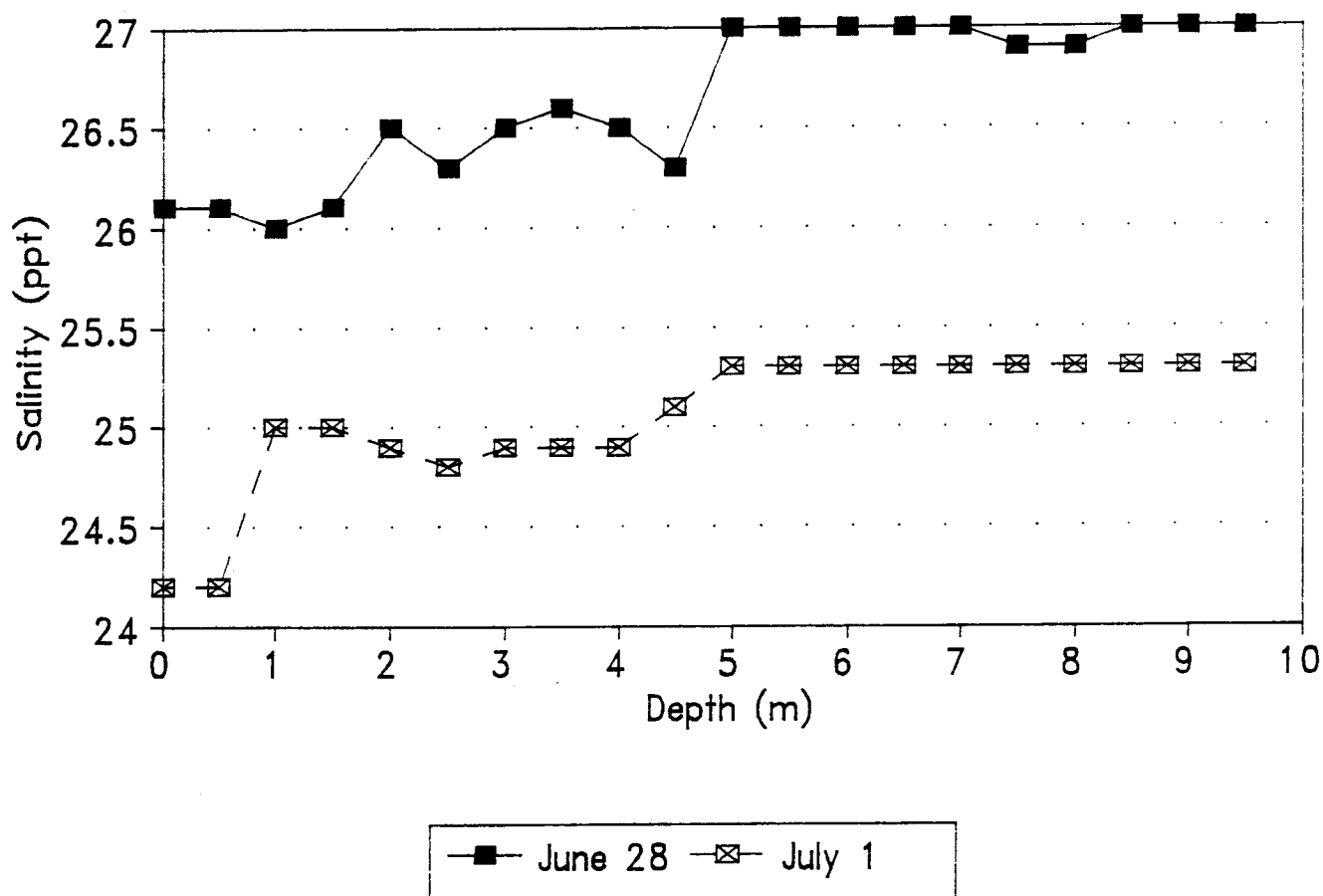


Figure 18. A comparison of salinity profiles. The measurements were taken on two dates representative of stratification (June 28, 1990) and mixing (July 1, 1990) in Salt Pond at 1000 hours.

Temperature Profile Comparison

June 28 and July 1, 1990

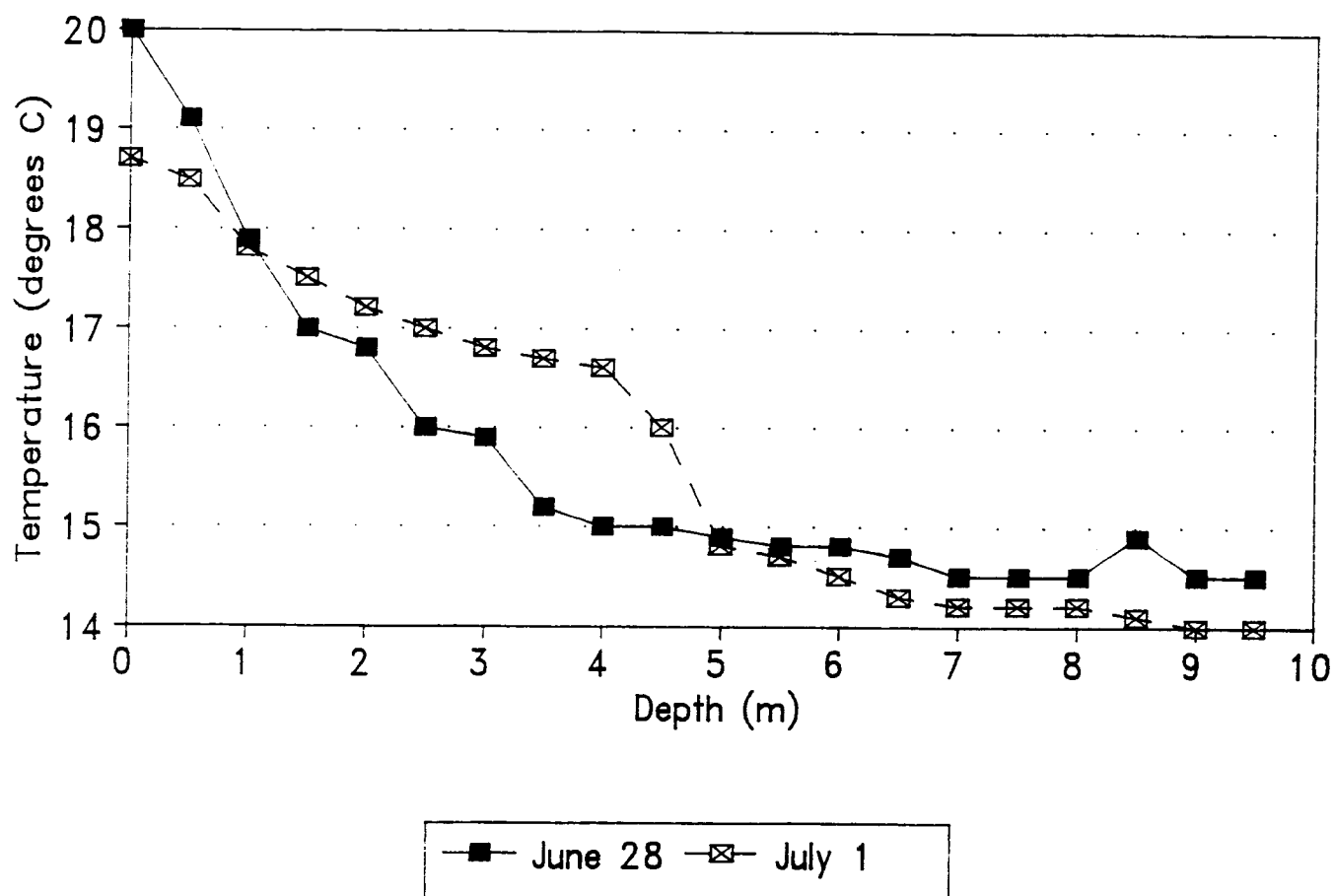


Figure 19. A comparison of temperature profiles. The measurements were taken on two dates representative of stratification (June 28, 1990) and mixing (July 1, 1990) in Salt Pond at 1000 hours.

Salinity and Temperature Profile Salt Pond – June 28, 1990

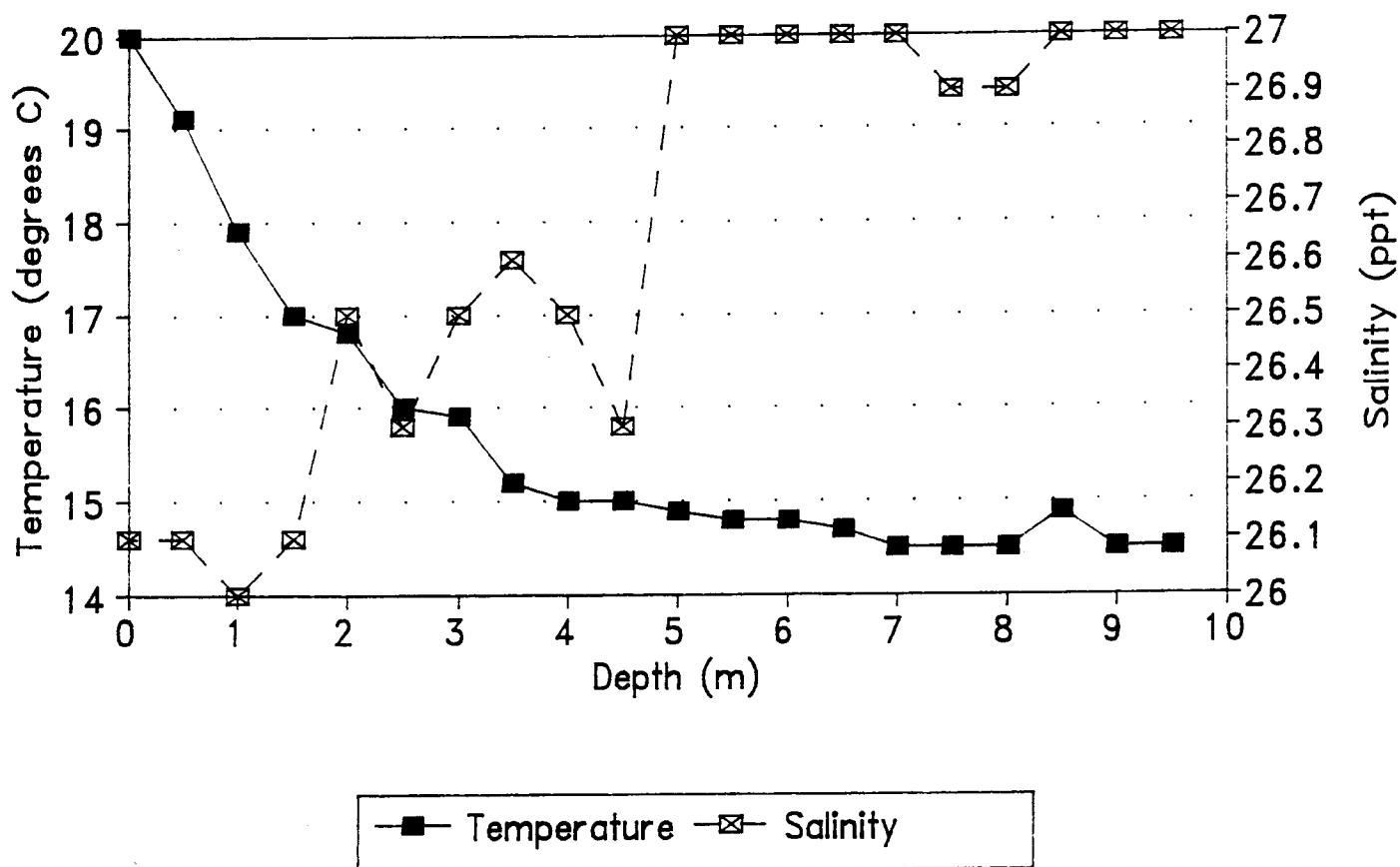


Figure 20. Observations of salinity and temperature in Salt Pond on June 28, 1990.

D0 and Temperature Profile Salt Pond – June 28, 1990

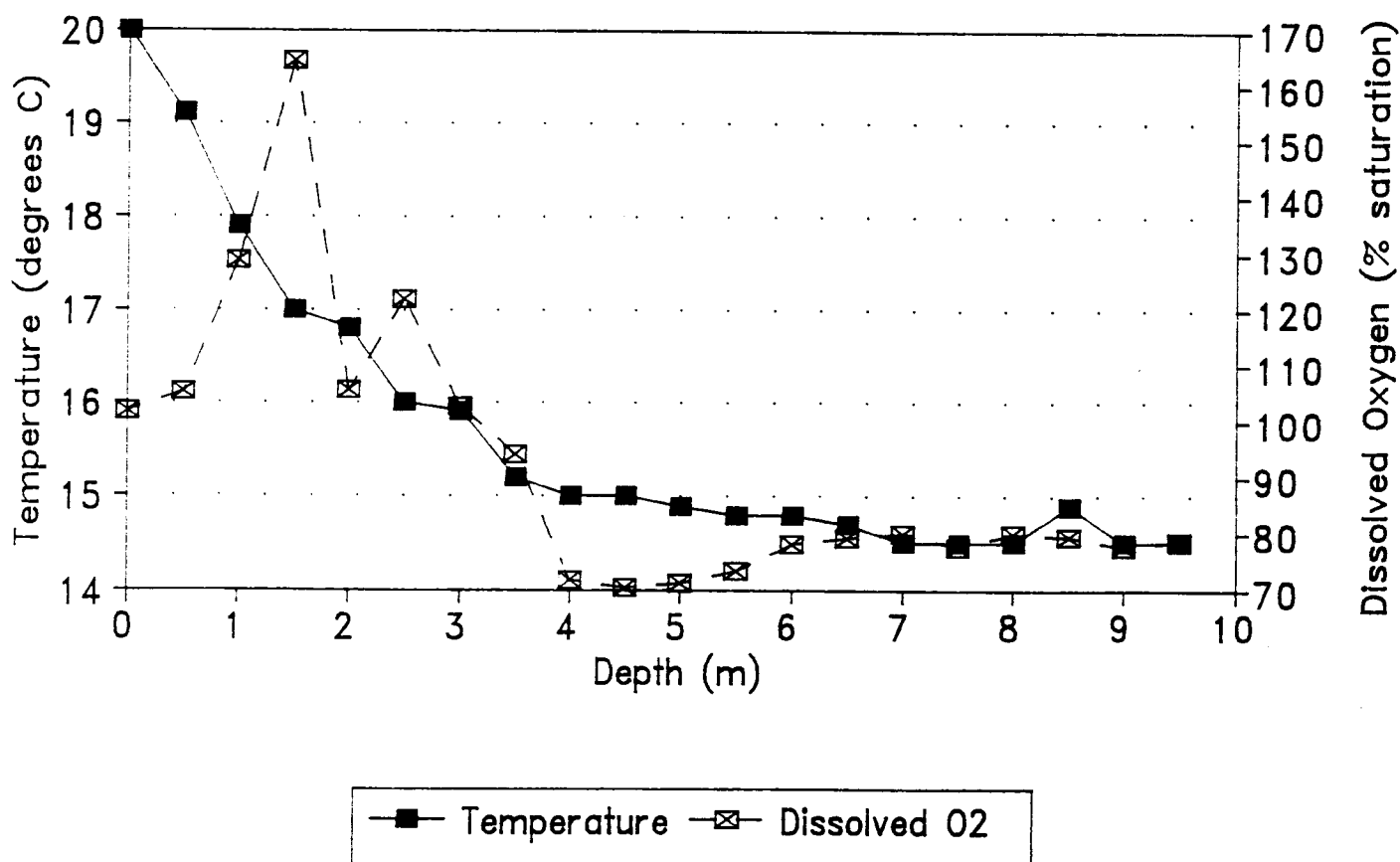


Figure 21. Observations of dissolved oxygen and temperature in Salt Pond. These measurements were taken on June 28, 1990 at 1000 hours.

Salinity and Temperature Profile

Salt Pond - July 1, 1990

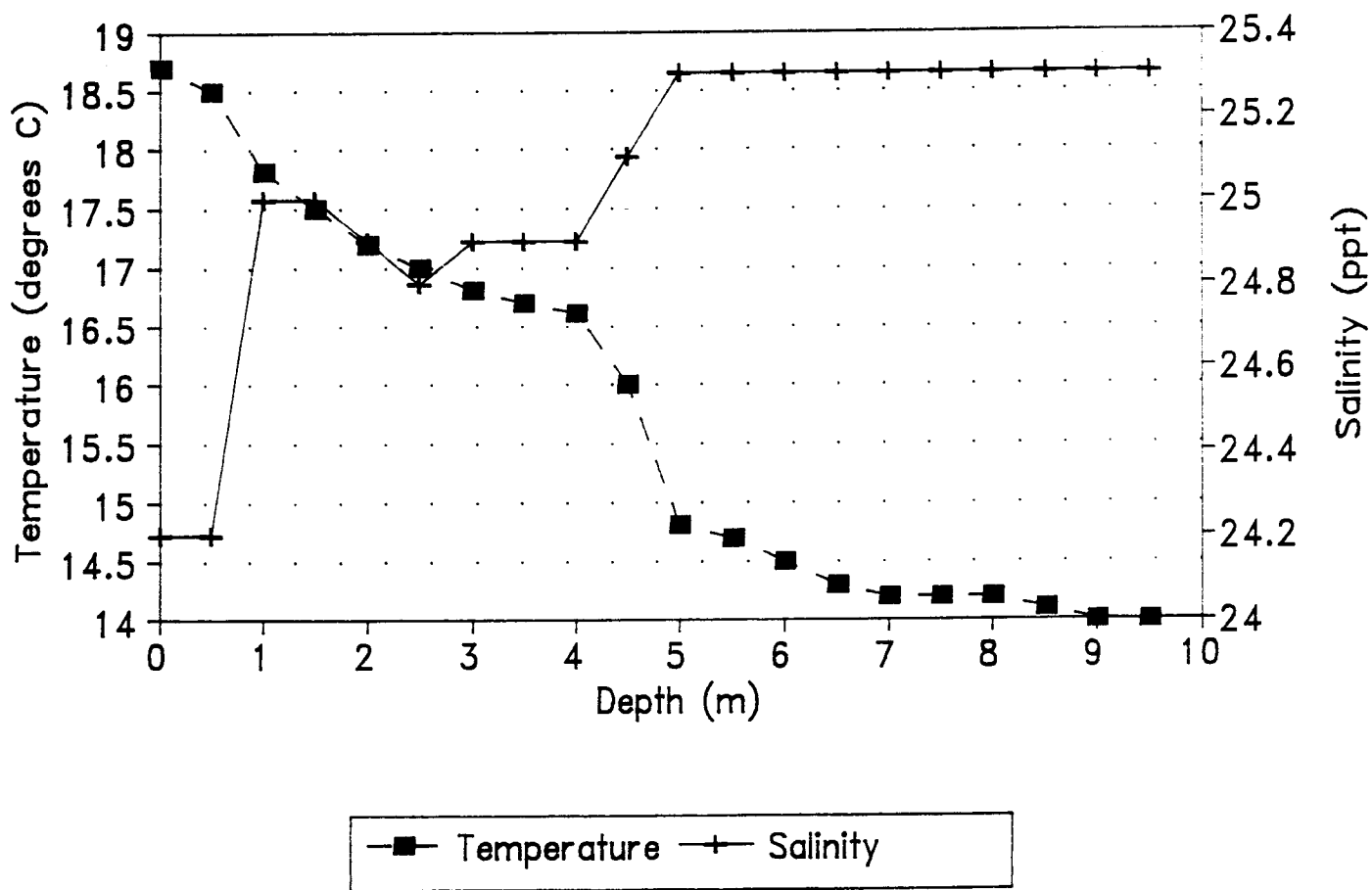


Figure 22. Observations of salinity and temperature in Salt Pond on July 1, 1990.

D0 and Temperature Profile

Salt Pond - July 1, 1990

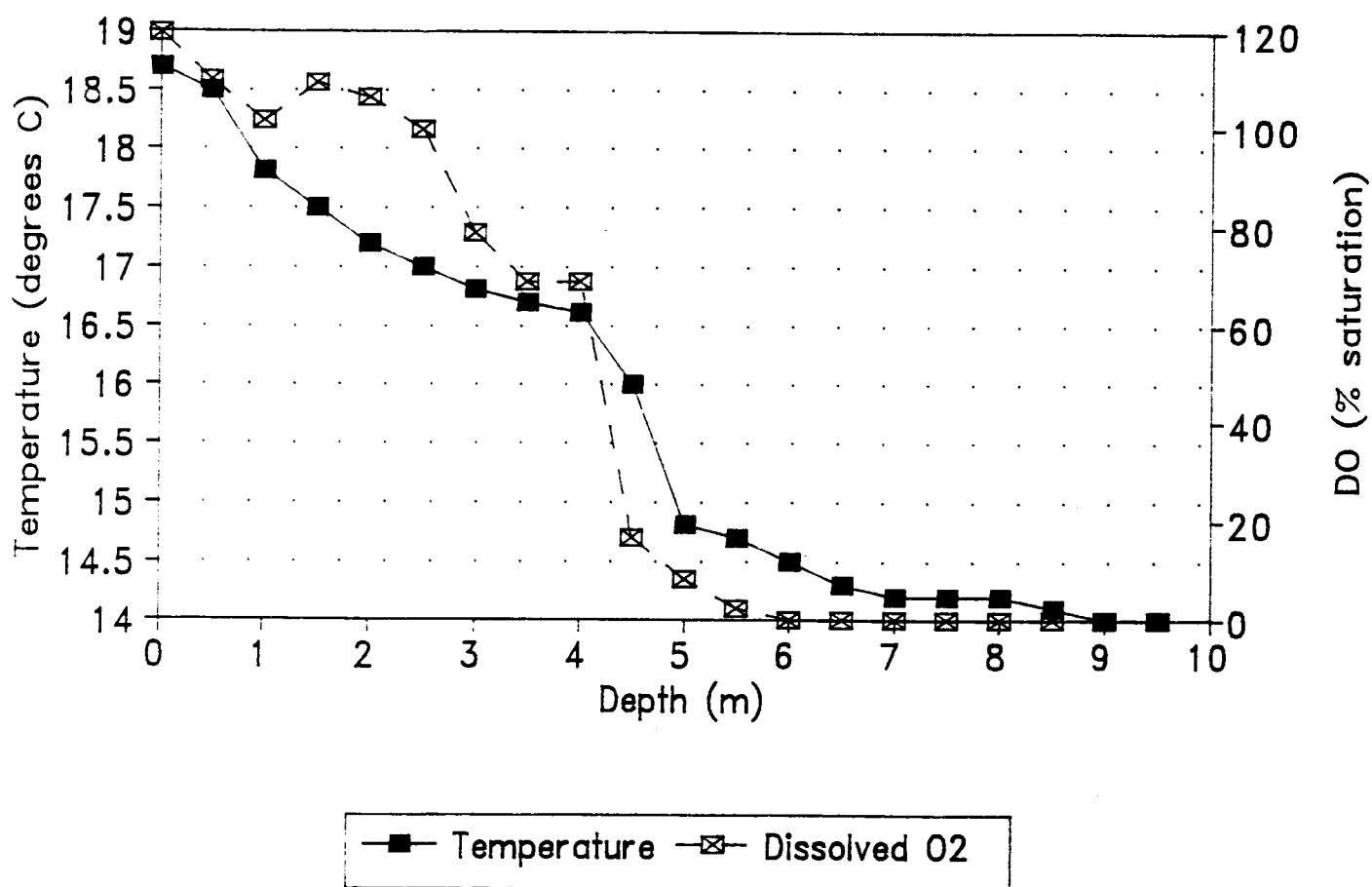


Figure 23. Observations of dissolved oxygen and temperature in Salt Pond. These measurements were taken on July 1, 1990 at 1000 hours.

a sharp decline between meters 4 and 5.

II. Groundwater Nitrate-Nitrogen Analysis

Nitrate-nitrogen ($\text{NO}_3\text{-N}$) concentrations were extremely variable along transects at all sites studied (Figures 24-27 and Table 1). Averages, standard deviations and coefficients of variation are listed in Table 1. Concentrations which were below the detection limit (0.05 ppm) were included in the figures as 0 $\mu\text{M/l}$. Sites at which groundwater could not be obtained were skipped over. Subsequent coring revealed that these tightly packed sediments were salt marsh clay deposits. At the Hemenway and Windmill sites, the initial ten stations were sampled at 1 meter intervals along a transect established at the approximate spring high tide line. Samples were taken every 5 meters after the initial ten meters. Values obtained from Hemenway landing (Figure 24) ranged from 117.5 $\mu\text{M/l}$ at 5 m to 19.8 $\mu\text{M/l}$ at 8 m. There was great variation between samples obtained only 1 meter apart. Overall, $\text{NO}_3\text{-N}$ peaked at 5 m and steadily decreased northward over the next 10 m, and remained below 10 μM over the next 35 m.

<u>LOCATION</u>	<u>TRANSECT LENGTH (m)</u>	<u>n=</u>	<u>MEAN ($\mu\text{M/l}$)</u>	<u>+ S.D. ($\mu\text{M/l}$)</u>	<u>C.V.</u>
Hemenway	50	15	50.186	35.135	0.700
Nauset Bay	140	20	39.754	83.816	2.108
Windmill	39	10	25.262	37.674	1.491
Yacht Club	20	23	181.696	184.077	1.013

Table 1. $\text{NO}_3\text{-N}$ in groundwater along four shoreline transects in Nauset Marsh ($\mu\text{M/l}$ = micro-moles/liter).

Sampling at Nauset Bay was primarily done in two Phragmites communis patches, both of which were located just seaward (east) of houses. The first extended approximately 25 m; water was retrieved from depths of 100 cm or more. The second patch was sampled at depths of less than 50 cm. Concentrations of adjacent samples only 1 m apart showed much variation even when they were extracted from the same patch of Phragmites. Figure 25 shows that in the first patch, values were initially high (310.7 $\mu\text{M/l}$ at 3 m) and rapidly dropped off (below detection limit at 4 m). Increasing from 7.6 $\mu\text{M/l}$ at 123 m to 62.0 $\mu\text{M/l}$ at 124 m, nitrogen concentrations in the second patch were only measurable within 8 m of its edge.

Groundwater Nitrate Values Hemenway Landing

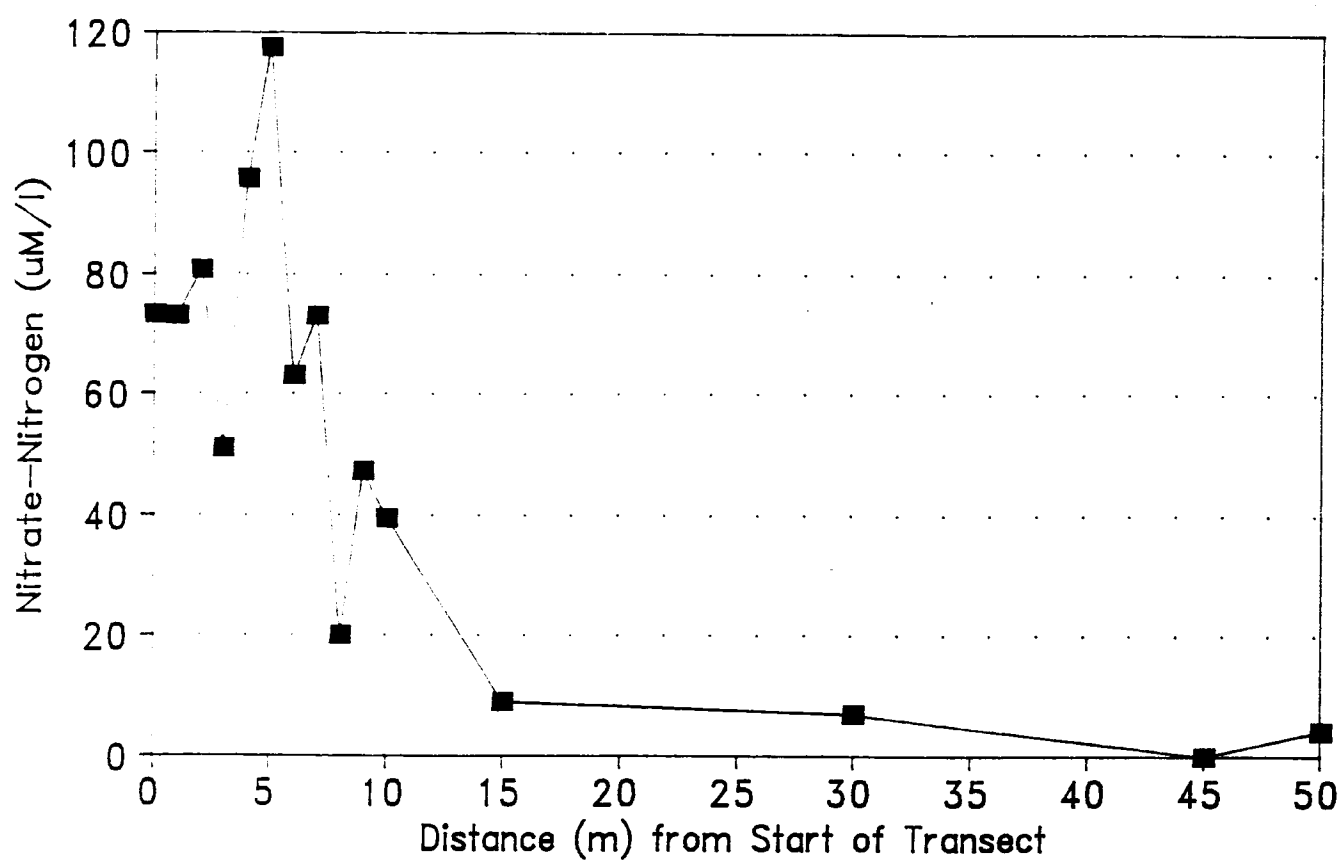


Figure 24. Groundwater $\text{NO}_3\text{-N}$ at Hemenway Landing.

Groundwater Nitrate Values Nauset Bay

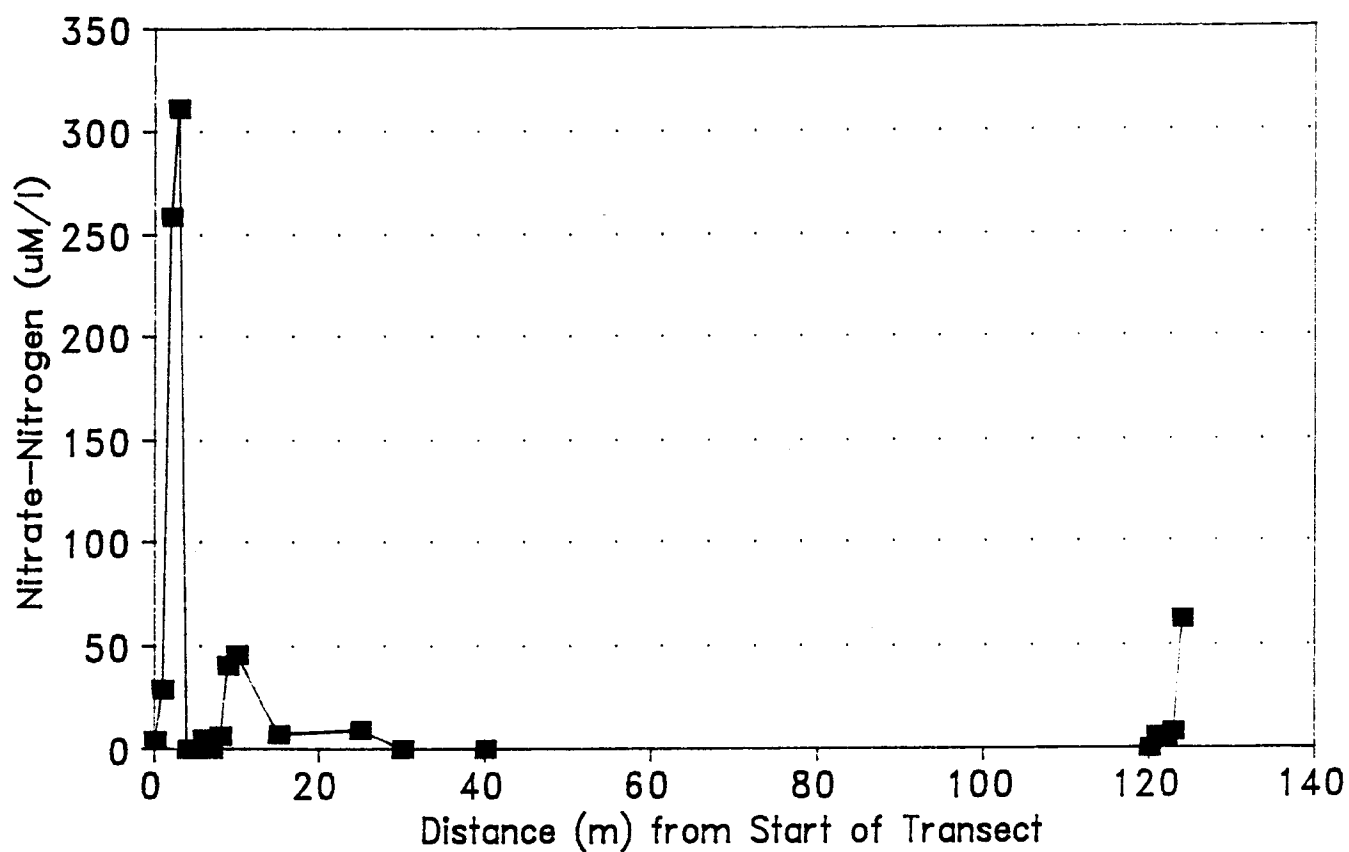


Figure 25. Groundwater $\text{NO}_3\text{-N}$ at Nauset Bay.

Groundwater Nitrate Values Orlean's Windmill

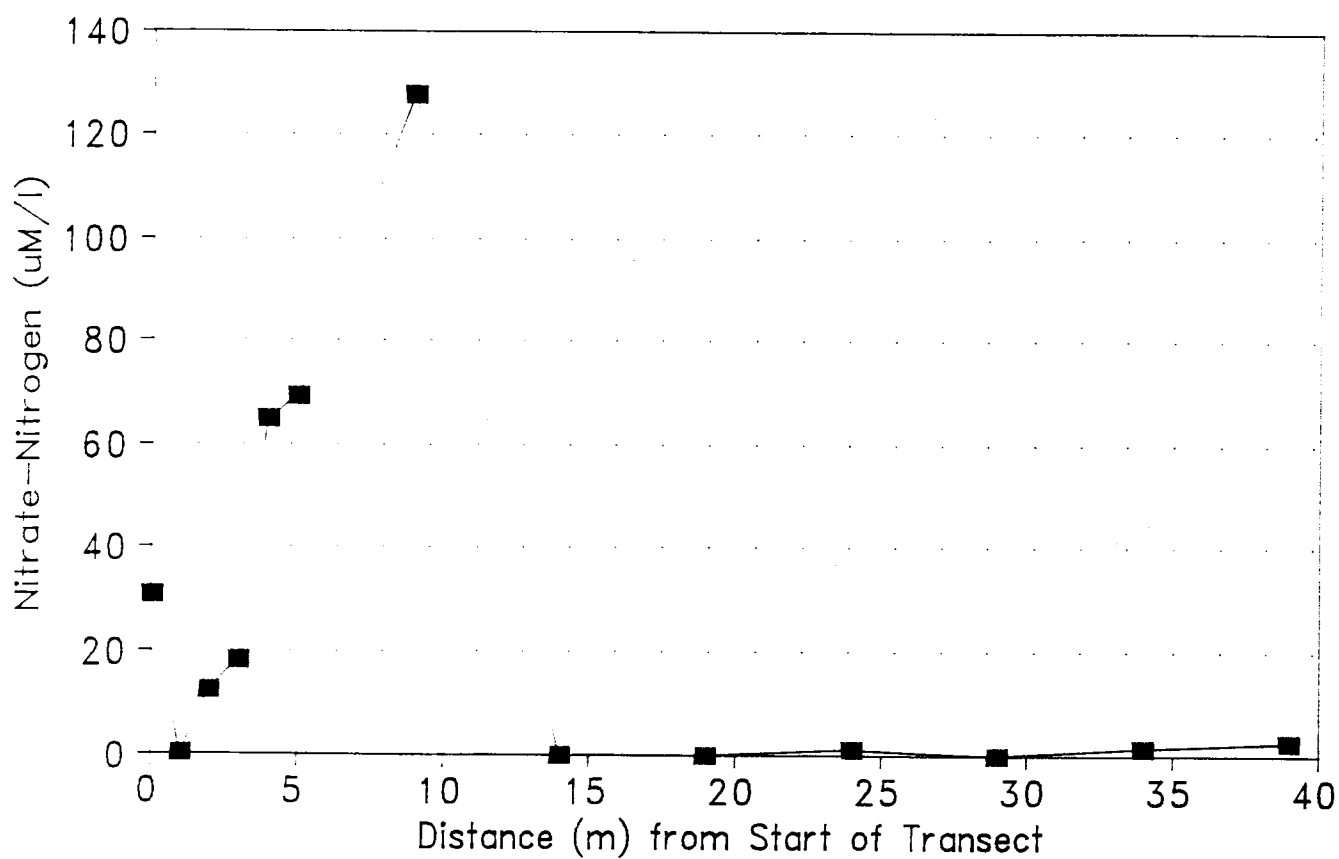


Figure 26. Groundwater $\text{NO}_3\text{-N}$ at the windmill in Town Cove.

Groundwater Nitrate Values

Orlean's Yacht Club

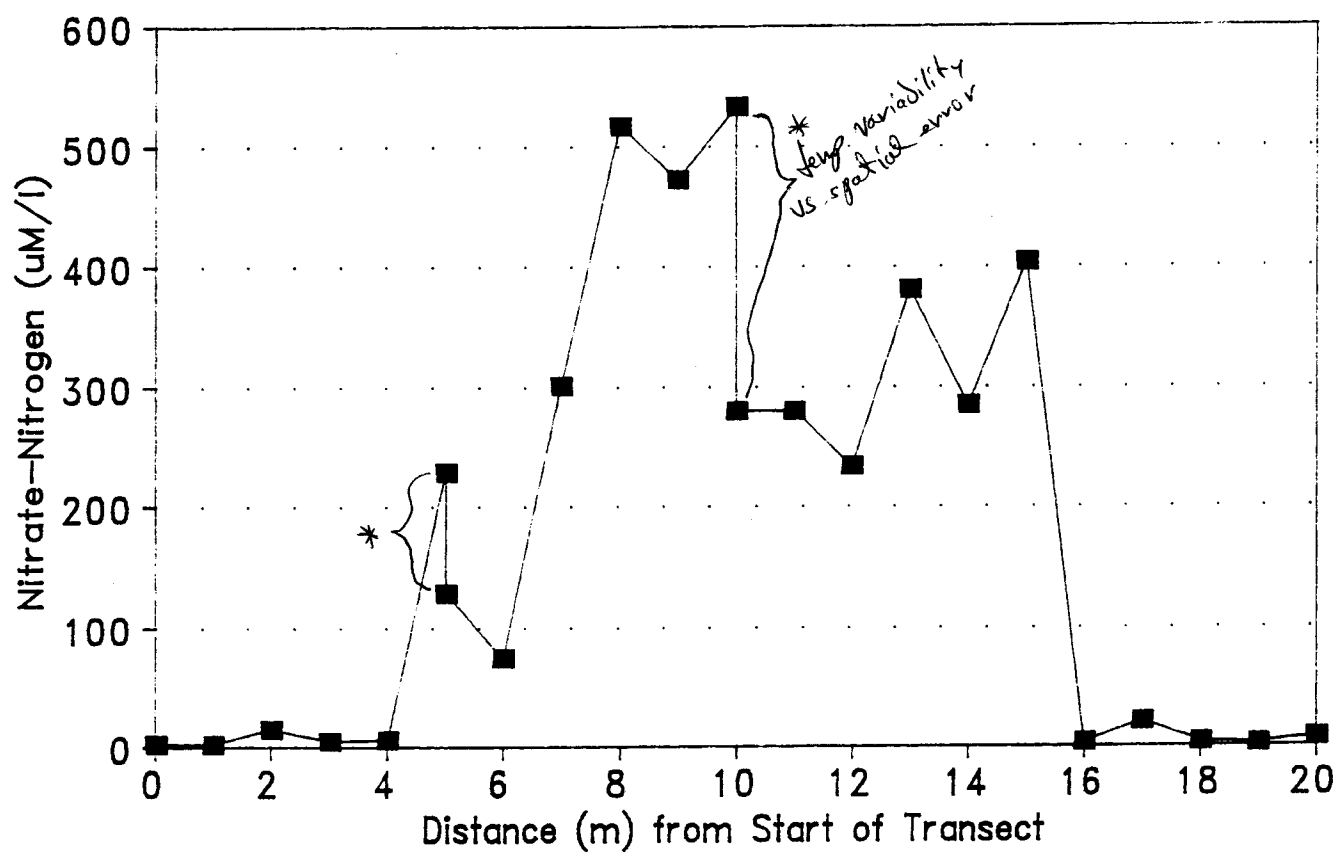


Figure 27. Groundwater $\text{NO}_3\text{-N}$ adjacent to the Orlean's Yacht Club in Town Cove.

After sampling every meter for the first 5 m, the groundwater of the Windmill site was subsequently sampled every 5 m. No samples were obtained at 14 or 19 m due to the presence of clay. Concentrations here were also quite variable (Figure 26), peaking at 127.6 $\mu\text{M}/\text{l}$ (9 m). Samples collected from 1, 24, 29, 34, and 39 m yielded no detectable nitrogen.

The Orleans Yacht Club transect ranged from a high concentration of 532.7 $\mu\text{M}/\text{l}$ (10 m) to a low of 1.3 $\mu\text{M}/\text{l}$ (1 m) (Figure 27). The transect was fairly short compared to other transects but has a more continuous data set. Samples were taken on different dates at meters 5 and 10, differing values for these points are attributed to the high spatial variability of nitrogen in the groundwater and a poorly marked transect starting point. The graph shows distinctly elevated nitrogen levels between meters 4 and 16.

At sampling stations along the Hemenway Landing transect where groundwater could be collected without significant aeration, samples for dissolved oxygen analyses were taken. Since nitrate represents an oxidized form of nitrogen, an effort was made to relate nitrate-nitrogen concentrations of a sample to dissolved oxygen concentrations. Figure 28 shows the scatter plot and least squares line of this relationship. No correlation existed; an R-squared value of 0.087 was calculated. Eliminating the single out-lying point ([DO] of 1.5 ppm, $[\text{NO}_3\text{-N}] = 0.550$ ppm) did little to improve the correlation of the two parameters (R-squared = .381). This is expected since denitrification will not occur in the presence of O_2 , albeit in trace amounts. In general, water sampled early in this study are representative of a well-aerated aquifer.

Vegetation

1. *Cladophora* Biomass

The observed biomass of *C. gracilis* decreased with each sampling (Figure 29). The following weeks showed a substantial decline in average biomass; during the last collection only an average of 141.75 g/m² was harvested. Standard deviation of *C. gracilis* biomass was highest during the first week when only 5 replicate samples were taken. Doubling the number of replicates in the second sampling almost halved the standard deviation. Due to an observable decrease of *C. gracilis*, the variation among the fourth week's samples was greater than the second week's. During the first two collections there was a dense mat of *C. gracilis* covering the mud flat. Uncovered sections of the mudflat were observable during the third collection; other samples collected during the fourth week contained the algae *Spongomorpha* and

Correlation of NO₃-N vs DO Hemenway Landing

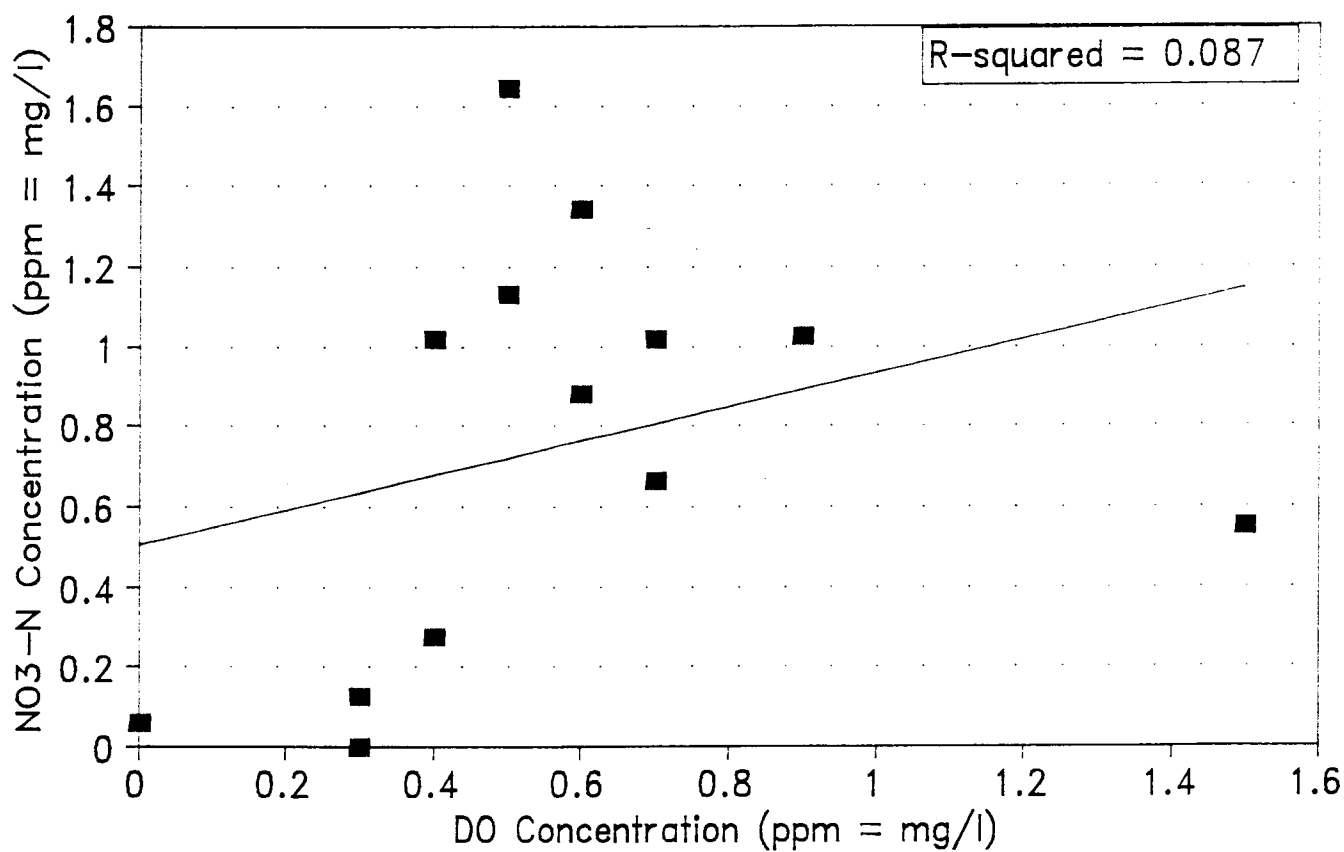


Figure 28. The relationship between dissolved oxygen and nitrate concentrations.

Observed Biomass of Cladophora

Salt Pond Bay, 1990

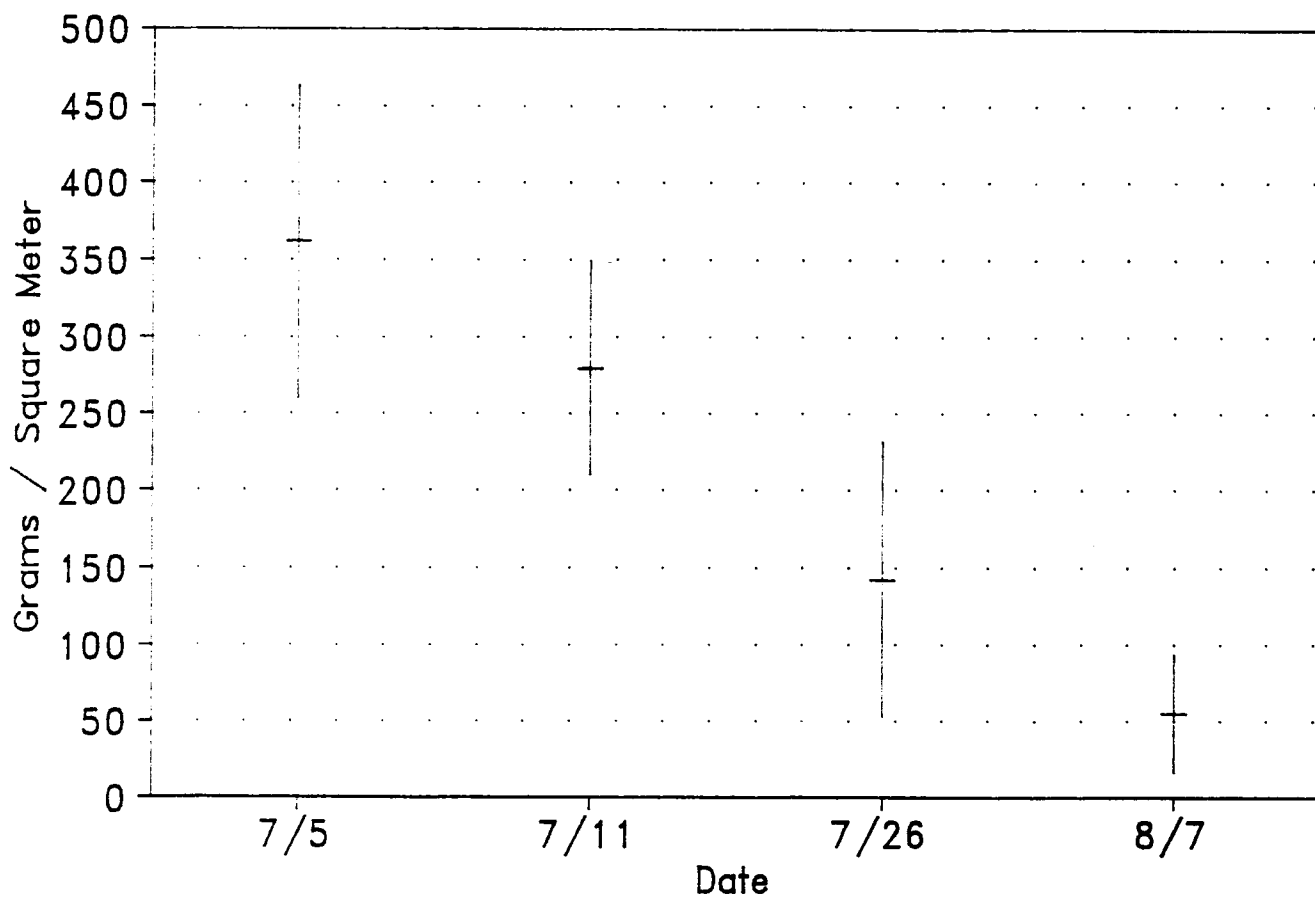


Figure 29. Mean biomass and standard deviation of Cladophora collected in Nauset Marsh on several different dates during summer, 1990.

Ectocarpus. In all of the samples harvested, large numbers of small gastropods and mollusks (gemma clams and blue mussels) as well as smaller numbers of nereid worms were observed and removed.

II. Eelgrass Wasting Disease

Analysis of the samples collected will be summarized in an end of the year report. Results will be compared to other east coast locations in a final report expected in August, 1991.

Fauna

I. Nesting Birds

Table 2 lists the results from each of the three waterbird nesting sites in the Nauset system.

	<u>Number of Territorial Pairs</u>	<u>Productivity</u>
<u>New Island</u>		
American Oystercatcher	1	Failed
Laughing Gull	956	
Roseate Tern	25+	
Common Tern	3837	
Arctic Tern	8	1 chick
Black Skimmer	2	4 fledged
<u>Nauset Heights</u>		
Piping Plover	4	4 fledged
Common Tern	2	
Least Tern	884	High
<u>Coast Guard Spit</u>		
Piping Plover	5	16 fledged
American Oystercatcher	1	Failed

Table 2. Nesting waterbirds at three sites in Nauset Marsh.

II. Migrant Birds

Migrant waterbird results from the University of Rhode Island study were not analyzed for the purposes of this report. These data will be summarized in a final report for that project.

DISCUSSION

Water Quality

I. Dissolved Oxygen

Salt Pond: Throughout the observation period, Salt Pond's water quality profile was stable with little mixing observed. For photosynthesis to affect the dissolved oxygen concentrations of the epilimnion, the algae would need to be extremely close to the surface. The availability of light diminishes too quickly to permit much of this activity below 2-3 m. Even if there is an abundance of chlorophyll near the surface (results from chlorophyll analyses are not yet available), little change was observed in DO from daylight to darkness; therefore photosynthesis played a small role in the dissolved oxygen content of the epilimnion. A diurnal variation in dissolved oxygen, typical in freshwater lakes, streams, and ponds, was not evident. At the bottom of the pond, in the hypolimnion, there was an extremely high rate of respiration; dissolved oxygen availability was restricted to the point of anoxia. Typically this is indicative of decomposition. However, a large amount of reduced iron compounds (likely to be FeS and FeS_2), were also observed on the filters used for chlorophyll analysis. This was only evident in the hypolimnion. It might be interesting to resolve the biological and chemical components of this reducing environment. Profiling the biological and chemical oxygen demands within Salt Pond might therefore be indicated.

A cursory examination of Figure 5 seems to indicate that the width of the anoxic layer varies; at times it rises, while at other times it sinks. However, when these data are compared with the tidal height data (Figure 4), it becomes evident that the anoxic layer rose higher in the water column as the tide began to ebb. It was highest at the observation made at dead low tide (1800 hours). Moreover, this anoxic layer was the furthest from the surface at high tide (5.5 m below the surface). A similar cyclic pattern was observed for the dissolved oxygen values at 4 meters. They peaked during high tide and dropped off to 0 at low tide. Thus, it seems that during low tide, water is leaving from only the epilimnion of Salt Pond. The width of this layer decreased a full 2 m from high to low tide. Further

substantiation is obtained from the temperature profiles in Figures 9 and 10. During low tide, hypolimnion temperatures became stable near 4 meters; hypolimnion temperatures leveled off at 6 meters at high tide. Again, a two meter variation in the epilimnion width was observed. Salinity measurements taken in Salt Pond and in its channel were unreliable. Moreover, salinity could not be measured precisely enough to permit an understanding of density to be understood. One of the best methods (Teal, 1983) of demonstrating that only the surface waters are receding during low tide is to compare the densities of the outflow with those of the Pond itself. Another option would have been to begin the profiles at the bottom of the pond. Unlike the surface, the elevation of the pond's substrate does not tidally fluctuate. This would allow the width of each layer to be ascertained; one could then be more certain that Salt Pond's low tide outflow originated from only the epilimnion. An anomalous situation occurred during the nighttime low tide. Although DO's were low at 4 meters, they did not reach 0 ppt until 4.5 m. Thus, the beginning of the anoxic layer did not approach the surface as it did during the afternoon, but remained at 4.5 m. Beginning profiles at the bottom would have provided more insight into this day/night phenomenon.

There were no substantial changes between daytime and nighttime observations. Temperatures were relatively constant at a given depth (Figure 11). In the epilimnion, some fluctuation was seen; high tide resulted in the influx of uniformly warm water, while low tide pond temperatures at three and four meters were lower. Since the temperatures during high tide at 4 m approach those of low tide at 3 m, one explanation is simply the influx of water. Salt Pond gains an extra meter of depth at high tide, making 4 m measurements occur where 3 m measurements were made during low tide. The obvious way of correcting this is to begin profiling from the bottom. Another possibility originates from the incoming water itself. This incoming water passes over Salt Pond Bay, before entering Salt Pond. As it passes over these mud flats, the water has ample time to warm. Moreover, water remains over these flats and warms for an entire afternoon. When these warm waters enter Salt Pond, they quickly mix with the remaining water of the epilimnion and produce a uniform layer (Figure 10). However, during low tide the surface waters have a chance to warm up, while the deeper waters do not. The result is an epilimnion that has linearly decreasing temperatures (Figure 9).

Water rushes into Salt Pond much faster than it leaves. Besides resulting in the net transport of suspended particulate matter into Salt Pond, greater flood rates facilitate the mixing of the epilimnion. Although the density of the incoming water is not great enough to plunge into the anoxic hypolimnion, the

momentum of the flooding tide should cause surface waters to become well mixed (Figure 10). Figure 10 also indicates that the rapidity of the flood tide may also cause some turbulence at the interface of the aerated surface waters and the anoxic bottom waters. Instead of sharply dropping off to 0 ppm as they do during low tide (Figure 9), dissolved oxygen values decrease to 0.3 ppm.

In Town Cove, Teal (1983) found that the relationship of the inflow's density to the density stratification of the Cove determined whether bottom water was renewed or not. If the density of the tidal inflow was greater than surface waters (and the bottom waters for that matter), mixing occurred; bottom waters were renewed. However, if it was less than that of surface waters, inflow only mixed with surface waters to the extent that its momentum allowed. In these cases no mixing occurred and the residence time for bottom waters greatly increased. Once bottom waters became anoxic, storm events, not tidal exchange, were found to restore Town Cove to a mixed body of water.

Density measurements in Salt Pond were limited by the equipment. Being unreliable at best, salinity measurements obtained from the S-C-T meter were highly variable. It was difficult to compare salinity measurements obtained from the tidal inflow in Salt Pond's channel to those of Salt Pond itself. Obtaining more accurate information on water density and inflow intrusion into Salt Pond may be accomplished with a refractometer. Better salinity measurements are needed for a clear understanding of summertime anoxic events. Nevertheless, it was observed that tidal exchange played no role in renewing bottom waters. Even a storm-generated tidal amplitude of 1.16 m had little effect on mixing. It is likely then that the density of tidal inflow is less than or equal to surface waters and mixing occurs mostly through a momentum-exchange process. Night-time cooling may cause mixing events in summer. No water plunges beneath surface waters. Salt Pond probably remains anoxic at depth until an extremely severe storm generates high tides, strong winds, and increased wave action. A thermocline's change in temperature can cause mixing, but this only occurs in the fall and spring. Daily monitoring of the dissolved oxygen of bottom waters at a representative depth (6-6.5 m) would allow the length of anoxic events (and extreme stratification) to be determined.

Nauset inlet is currently closer to the Salt Pond inlet than at any other recorded location, yet with this higher tidal amplitude, there are significant anoxic events. The relocation of the inlet to the south and subsequent reduced amplitude would likely only increase the frequency or magnitude of anoxic events. To fully understand the anoxic events, a more comprehensive

program examining the causes of summertime mixing is required.

II. Groundwater Nitrate-Nitrogen Analysis

Examining bodies of water for certain nutrients is frequently difficult and often confusing. If there is only limited input of the nutrient of interest, dilution in the water column and algal uptake may reduce concentrations to levels undetectable by available analytical techniques. If detectable, these nutrients may not be uniformly distributed throughout the aquatic system. Circulation, stratification, tidal action, and geomorphic dynamics may limit the extent to which a nutrient is distributed (and therefore diluted). Moreover, if the major source of the nutrient is from groundwater seepage, its origin remains unknown and management decisions are more difficult to make. Sampling the water column may therefore be unsatisfactory for certain nutrients.

Nitrogen is one of these nutrients. Generally absent from oligotrophic tidal channels and ponds, nitrogen influx into a marine system such as Nauset Marsh increases macrophyte growth and eutrophication. Besides tidal influx, groundwater seepage is the primary method by which nitrogen enters the marsh (Valiela, et. al., 1990; Giblin and Gaines, 1990). Originating from septic systems and surface run-off in developed areas, nitrogen enters the groundwater and works its way seaward, frequently reappearing as distinct plumes wherever groundwater discharges. Because Cape Cod groundwater is well aerated (Frimpter & Gay, 1979), $\text{NO}_3\text{-N}$ should predominate.

Due to the high variability in the $\text{NO}_3\text{-N}$ observed to date along these transects, it is too early to compare developed vs. undeveloped land with regards to nutrient contributions into Nauset Marsh. It is clear that there are unnaturally high levels of nitrogen input over a broad region. The highest concentrations were observed along the shore next to the Orleans Yacht Club. In a study of the dissolved inorganic nitrogen in the water column of Town Cove (Teal, 1983), the highest concentrations were found in the near-shore water adjacent to the Orleans Yacht Club. Samples from the Windmill transect, also expected to be high due to adjacent development, were in fact lower than those found in Nauset Bay. The impact that a single residential dwelling can have on a transect may be considerable. Another factor to consider in the interpretation of these nitrogen figures is the absence of ammonia determinations. $\text{NH}_3\text{-N}$ may be present in high concentrations at short distances from septic systems, but generally is converted to nitrate rapidly through nitrification (Valiela, et. al., 1990). Ammonia is readily utilized by marine organisms. A water table map would

help to interpret flow direction and the likely source of specific plumes.

In all locations, distinct nitrate plumes were observed. In Nauset Bay one observed plume with $\text{NO}_3\text{-N}$ 300 times above background levels, was no more than 3 m wide. For this reason, sampling should never take place at intervals greater than 5 m. High variability inherent to each site, due to the presence of distinct plumes. The presence of discrete Phragmites patches in Nauset Bay, seems to indicate that nutrient conditions are similar throughout the patch. Nevertheless, much variation exists among the nitrate-nitrogen values within each one. High variability within these patches is interpreted as an artifact of differing sampling depths. At shallow depths, plant uptake of $\text{NO}_3\text{-N}$ was probably important. Subsequent sampling depths should exceed 50 cm below the ground surface to avoid the Phragmites root zone.

Vegetation

1. Cladophora Biomass

With increases in eutrophication, more nutrients become available to support additional primary productivity. One of the first to take advantage of this are the opportunistic chlorophytes, especially C. gracilis (Valiela, et. al., 1990; Roman and Able, 1989). Productivity measurements of this algae may yield some indication as to the eutrophication of the marsh. Observing the amount of productivity over time would indicate increased eutrophication. However, Lind (pers. comm.) has suggested approximately a four year cyclic pattern in the abundance of C. gracilis, with 1990 being an abundant year.

Harvests of C. gracilis were conducted every two weeks. Biomass could be determined since primary production (the amount of seasonal growth) represents the difference between maximum and minimum biomass. As the biomass of each collection decreased in magnitude, it was unlikely that any of them could represent a maximum. Roman and Able (1990) determined that in 1985-86 the primary production peaked at 638 g/m^2 in June. Unfortunately, there is not a 1990 value to compare with this. To determine one, it is necessary to continue the biweekly harvesting through the end of August. After sampling monthly through the fall and winter, one should again begin biweekly sampling in the beginning of May. This needs to be done yearly if any meaningful results are to be obtained. Another alternative that is possible after a primary productivity has been calculated would be to determine the biomass weekly during the month when it peaks. This value could then be compared annually.

Although it may prove useful as an indicator of eutrophication, C. gracilis may be underestimated as habitat for a variety of organisms which could otherwise not exist on an exposed mudflat. Besides the numerous juvenile mussels, many gemma clams and small gastropods, typically found in sandier locations, were thriving. During future summertime harvests, it might prove interesting to determine the biomass of C. gracilis's infauna and compare it to that of the surrounding mudflat. The survival rate of these fauna is unknown.

II. Eelgrass Wasting Disease

Thorough discussion of the results of the eelgrass wasting disease investigation will be forthcoming in the summer of 1991.

Fauna

I. Nesting Birds

New Island is currently home to the largest colony of Common and Arctic Terns in Massachusetts. The Nauset Heights Least Tern colony is the largest colony recorded north of Long Island, New York in recent years. Roseate Tern numbers at New Island are low (25+ pairs), but this is the second largest colony in the state (compare to Bird Island in Buzzard's Bay which had 1,547 pair this year). These figures emphasize the importance of the Nauset Marsh system for nesting terns in Massachusetts. Both Black Skimmers and American Oystercatchers are at the northern edge of their range here. One oystercatcher nest was lost to high tides (Coast Guard Spit), the reason for lack of production by the other pair (New Island) is unknown. The production of four fledged young by two skimmer pairs may represent a high for the state. Oystercatchers and skimmers are both expanding their range northward, and are recent nesters in Nauset Marsh.

Least Terns have benefitted greatly from the use of a large predator exclosure around a major portion of the Nauset Heights colony for the second year. Nauset Heights is a town-managed beach and the tern management program is carried out by the Massachusetts Audubon Society. The success of the exclosure appears to have resulted in the evacuation of several nearby Least Tern colonies that traditionally do not produce many young (Coast Guard Spit, Marconi, High Head, and a much reduced population at Monomoy National Wildlife Refuge). Reported numbers of Arctic Terns may be an artifact of increased observer effort on New Island. Positive identification of this species among several thousand pairs of similar terns provides a challenge. The production of only one Arctic Tern chick from this site is indicative of a troubled population.

Piping Plover production in the outer Cape Cod area was high this year, particularly on the Nauset Marsh spits. At least twenty young fledged from nine nests. This productivity correlates with intensive predator exclosure use at both nesting sites and increased oversand vehicle restrictions at Nauset Heights (Coast Guard Spit is permanently closed to public oversand vehicle use). At Coast Guard Spit, where exclosures only reduce egg predation, not chick predation, red fox populations were considered lower than in previous years, based on un-quantified early summer track observations (MacIvor, pers. comm.). Fox are considered the primary predator of plovers in Cape Cod National Seashore.

II. Migrant Birds

An attempt should be made to monitor roosting night-heron activities in Nauset Marsh in the future. It is possible that nesting may take place adjacent to the marsh, but this has not been verified.

BIBLIOGRAPHY

- American Public Health Association. 1985. Standard methods for the examination of wastewater, sixteenth edition. 1985. American Public Health Association, Washington, D.C. 1268pp.
- Anderson, D. M. and K. D. Stolzenbach. 1985. Selective retention of two dinoflagellates in a well-mixed embayment: the importance of diel vertical migration and surface avoidance. *Marine Ecology - Progress Series* 25:39-50.
- Aubrey, D. G. and P. E. Speer. 1984. Updrift migration of tidal inlets. *Journal of Geology* 92:531-545.
- Aubrey, D. G. and P. E. Speer. 1985. A study of non-linear tidal propagation in shallow inlet/estuarine systems. Part I: observations. *Estuarine, Coastal and Shelf Science* 21:185-207.
- Cape Cod Planning and Economic Development Commission. 1981. Cape Cod coastal oil spill response plan. Cape Cod Planning and Economic Development Commission, Barnstable, MA.
- Frimpter, M. H. and F. B. Gay. 1979. Chemical quality of ground water on Cape Cod, Massachusetts. U.S. Geol. Surv. Water Resources Investigation 79-65. 11pp.
- Giblin, A. E. and A. G. Gaines. 1990. Nitrogen inputs into a marine embayment: the importance of groundwater. *Biogeochemistry* 10:309-328.
- Nikula, B. 1984. Observations of a night-heron roost in Eastham, Massachusetts. Unpublished report to the National Park Service. 10pp.
- Roman, C. T. and K. W. Able. 1989. An ecological analysis of Nauset Marsh, Cape Cod National Seashore. Rutgers University, National Park Service Cooperative Research Unit. 181pp.
- Roman, C. T., K. W. Able, M. A. Lazzari and K. L. Heck. 1990. Primary productivity of angiosperm and macroalgae dominated habitats in a New England salt marsh: a comparative analysis. *Estuarine, Coastal and Shelf Science* 30:35-45.
- Short, F. T. 1989. Sustaining Eelgrass to manage a healthy estuary. *Proceedings of Sixth Symposium on Coastal and Ocean Management/ASCE*, Charleston, S.C. 3689-3706.

- Short, F. T., B. W. Ibelings and C. Den Hartog. 1988. Comparison of a current eelgrass disease to the wasting disease in the 1930s. *Aquatic Botany* 30:295-304.
- Speer, P. E. and D. G. Aubrey. 1985. A study of non-linear tidal propagation in shallow inlet/estuarine systems Part II: Theory. *Estuarine, Coastal and Shelf Science* 21:207-224.
- Teal, J. M. 1983. The coastal impact of ground water discharge: an assessment of anthropogenic nitrogen loading in Town Cove, Orleans, Massachusetts. Wood's Hole Oceanographic Institution, Woods Hole, Massachusetts.
- Valiela, I., J. Costa, K. Foreman, J. M. Teal, B. Howes and D. Aubrey. 1990. Transport of groundwater-borne nutrients from watersheds and their effects on coastal waters. *Biogeochemistry* 10:177-197.

APPENDIX A

NITRATE-NITROGEN CADMIUM REDUCTION METHOD

General

By passing a nitrate-containing solution through a column of copper coated cadmium, the nitrate is stoichiometrically reduced to nitrite. When this nitrite is reacted with sulfanilamide and complexed with N-(1-naphthyl)-ethylenediamine, an azo dye is produced which can be quantified spectrophotometrically at 540 nm. This protocol is adapted from American Public Health Association (1985, p. 394); alterations are capitalized. Suspended matter and high concentrations of metals are the common interferences in the samples analyzed. Filtration and the addition of EDTA alleviate these problems.

Reagents

- 1) Distilled Water
This must be nitrate-free. The distilled water available in the lab is of sufficient purity.
- 2) Concentrated NH_4Cl -EDTA
Dissolve 13 g ammonium chloride and 1.7 g of EDTA in 900 ml of distilled water. Add concentrated ammonium hydroxide dropwise until the pH is 8.50. Make the solution up to 1000 ml with distilled water. This solution is used in great quantities; tripling the amount made is helpful.
- 3) Dilute NH_4Cl -EDTA
Dilute 600 ml of concentrated NH_4Cl -EDTA to 1000 ml with distilled water.
- 4) Concentrated HCl
- 5) 6N HCl
Dilute conc. HCl 1:1 with distilled water.
- 6) Cadmium (Fisher Scientific)
Presort the cadmium before weighing in order to exclude large, odd shaped granules. If possible, use 40-60 mesh granules.
- 7) 2% Cupric Sulfate Solution
Dissolve 20 g $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ in 1000 ml distilled water.

- 8) Sulfanilamide (Fisher Scientific)
Dissolve 5 g sulfanilamide in a solution of 50 ml conc. HCl and 300 ml distilled water. Make the solution up to a final volume of 500 ml. This reagent is stable for many months.
- 9) N-(1-naphthyl)-ethylenediamine dihydrochloride (NED) (Fisher Scientific)
Dissolve 500 mg (0.5 g) NED in 500 ml distilled water. Reagent is light sensitive so store in a dark bottle. When reagent turns brown, discard and prepare new. A new standard curve must be run with each fresh preparation of NED.
- 10) Standard Nitrate Solution
Dry potassium nitrate (KNO_3) at 105°C for 24 hours. Dissolve 0.7218 g in distilled water, dilute to 1000 ml, and preserve with 2 ml chloroform. This stock solution (100 mg/l) is stable for 6 months. To prepare the standard (10 mg/l), dilute 50 ml of this stock solution to 500 ml with distilled water.
- 11) Standard Nitrite Solution (Fisher Scientific)
Dry potassium nitrite (KNO_2) in a dessicator for 24 hours. To prepare a stock solution (100 mg/l), dissolve 0.6072 g in distilled water and dilute to 1000 ml. Preserve with 2 ml chloroform. Diluting 50 ml of the stock solution to 500 ml with distilled water yields the standard nitrite solution (10 mg/l).

Equipment

- 1) Reduction Column (Fisher Scientific)
- 2) 18" piece of plastic tubing (2 mm i.d.)
- 3) Small hose clamp
- 4) Ring stand with clamps
- 5) Glass wool

The reduction apparatus is prepared by first placing a small plug of glass wool into the bottom of the reduction column. The section of plastic tubing is then attached to the end of the glass column and secured with the hose clamp. A ring stand supports this entire apparatus. To keep the solution from draining below the level of the cadmium, a clamp is used to hold the tube above the water level.

- 6) Bausch and Lomb Spectronic 20 Spectrophotometer (540 nm)
Allow the spectrophotometer 10-15 min to warm up. Set the wavelength at 540 nm, zero it, then set 100% T with the prepared blank. It is easier (and more exacting) to read the %transmittance (it's a linear scale) and calculate the absorbance from the formula:
$$\text{Abs} = \log (100/\%T).$$

Column Preparation, Activation, and Maintenance

Wash 12.5 g Cd with 50 ml of 6.0 N HCl until Cd is shiny. After rinsing well with distilled water, add 50 ml of 2% cupric sulfate solution and swirl for 5 minutes. The blue color should have faded. (A brown precipitate may develop, but ignore this and keep swirling.) Decant off solution, add another 50 ml of cupric sulfate, and swirl until a brown precipitate develops. Pour off the solution and copiously wash with distilled water (at least 10 times) to remove all of the precipitate. DO NOT USE A STIRRING ROD TO DO ANY OF THE MIXING. SIMPLY SWIRL. COGENT AGITATION REMOVES THE COPPER COATING FROM THE CADMIUM.

Fill up the column with distilled water and slowly add the copper-treated cadmium to a height of 18.5 cm. TAP THE COLUMN TO ENSURE THAT IT IS WELL-PACKED. Drain down the water so its level is 0.5 - 1.0 cm above the cadmium and rinse the column with 200 ml of dilute ammonium chloride-EDTA solution at a rate of 7-10 ml/min. SINCE ALL REDUCTIONS ARE DONE AT THIS RATE, IT IS USEFUL TO DETERMINE THE DISCHARGE TUBE HEIGHT AT WHICH THE SOLUTION FLOWS AT 7-10 ML/MIN. PLACING A CLAMP AT THAT HEIGHT ELIMINATES THE NEED TO CONSTANTLY TIME THE RATE. To activate the column, pass a solution (at 7-10 ml/min) containing 25 ml of a 1 mg/l nitrate solution and 75 ml of conc. NH_4Cl -EDTA through it.

When the column is not in use, store it in dilute ammonium chloride-EDTA solution. Never allow the column to dry or the solution level to drop below the cadmium. This introduces air and affects the reduction efficiency. If this happens, empty the cadmium from the column into a beaker of dilute NH_4Cl -EDTA, fill the column with this solution, and repack it with the same cadmium. Check the efficiency of this column with 2-3 standards (see below); it may be necessary to develop another standard curve if it is too low. An alternate method of checking the column's reduction efficiency is to prepare a 1 ppm nitrite standard and treat it as any other sample. If the efficiency ($\text{Abs } 1 \text{ ppm nitrite} / \text{Abs } 1 \text{ ppm nitrate}$) is less than 75%, the column should be repacked. (This latter method proved less reliable than the former.) Assuming all things work well, the cadmium column should be effective for approximately 100 samples. Nevertheless, the following guidelines are important:

- 1) RINSE THE COLUMN BETWEEN SAMPLES WITH APPROXIMATELY 30 ML DILUTE NH₄CL-EDTA.
- 2) CHECK 2-3 STANDARDS AFTER EVERY 20 SAMPLES TO BE SURE THE EFFICIENCY HASN'T DECREASED APPRECIABLY. IF IT SEEMS TO HAVE, RUN THE REST OF THE STANDARDS SO AS TO PRODUCE ANOTHER STANDARD CURVE.
- 3) REPACK THE COLUMN WITH FRESH CADMIUM AFTER EVERY 100 SAMPLES.

Standard Curve

Providing quantitative relevance to sample absorbencies, a standard curve is generated for this procedure by running nitrate standards ranging from 0.05 to 2.0 ppm. The standards are prepared in 100 ml volumetric flasks; 0.5, 1.0, 2.0, 5.0, 10.0, and 20.0 ml of the nitrate standard are diluted to 100.0 ml and taken through the same procedure as the samples. 75 ml of conc. NH₄Cl-EDTA is added to 25 ml standard; the resulting solution is run through the reduction column and reacted with sulfanilamide, conc. HCl, and NED. To set 100% T on the spectrophotometer, a blank, consisting of 25 ml distilled water and 75 ml conc. NH₄Cl, must also be prepared. ALTHOUGH IT IS NOT RUN THROUGH THE REDUCTION COLUMN, all other reagents (sulfanilamide, HCl, and NED) are added to it. The absorbencies of all solutions, standards and samples, are measured at 540 nm against this blank. Plotting the standard concentration against the measured absorbencies should result in a straight line Beer's Law graph. Determining the equation of the "least-squares" line, one can quickly calculate the nitrate-nitrogen concentration from the absorbance of an unknown sample. It must be kept in mind that this method measures nitrite concentrations; any nitrite intrinsic to the sample will be detected. Using the atomic weight of nitrogen, this nitrate/nitrogen value was converted to micro-Moles of nitrate per liter with the formula: $(\text{mg/l NO}_3\text{-N}) / (.014) = \mu\text{M/l NO}_3\text{-N}$.

Sample Preparation

To 25.0 ml of filtered (0.45 μm pore diameter) sample, add 75.0 ml of conc. NH₄Cl-EDTA. Run it through the column, collecting and discarding the first 25 ml. Collect the next 50 ml in a graduated cylinder placed at the 7-10 ml/min height. BE SURE TO HAVE THE COLLECTION VESSEL IN AN ICE BATH. NITRITE IS NOT STABLE AND WAS FOUND TO RE-OXIDIZE AT ELEVATED TEMPERATURES OF THE SUMMERTIME LAB. Decant these 50 ml into a 125 ml erlenmeyer flask and immediately add 2.0 ml sulfanilamide and swirl. After 2 minutes, add 5 drops of concentrated HCl and 2.0 ml NED while swirling. Color development is maximum between 10 minutes and 2 hours after the addition of NED. Read the solution's absorbance at 540 nm within these limits. If, after

adding the NED, the color appears too dark, make an appropriate dilution of the reduced sample. A 1:2.5 dilution (20 ml reduced sample and 30 ml distilled water) is the lowest and most useful dilution possible.