

NAUSET MARSH MONITORING REPORT FOR 1991

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EXECUTIVE SUMMARY

Methods are being developed for the monitoring of surface and ground water quality, macroalgal production, and eelgrass vigor in selected habitats of the Nauset Marsh system, Cape Cod National Seashore (Massachusetts). Temperature, salinity and dissolved oxygen profiles and hypolimnetic anoxia were measured during the summer in Salt Pond, where DIN:DIP concentrations indicated nitrogen-limitation of primary production. Macroalgal biomass was found to be highly clumped in distribution across intertidal flats; sampling error was greatly reduced by enlarging quadrats to $10\overset{\circ}{\underset{\wedge}{\text{ft}}}^2$. Groundwater nutrient concentrations varied directly with the density of upgradient shoreline residential development. Eelgrass wasting disease was present in the sites examined and shows the characteristics of a very actively diseased population. Studies of stratification, anoxia and episodic mixing of Salt Pond showed that both atmospheric cooling and the intrusion of cold oceanic water caused the stratification observed during the summer months.

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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 leach nitrogenous wastes into groundwater which eventually flows into the marsh. Cultural eutrophication of Nauset Marsh is a threat to environmental and economic values. Besides this influx of nitrogen and other nutrients, the close proximity of the Orleans town center and Route 6 may also result in the contamination by toxic heavy metals and hydrocarbons. Unchecked, human-induced factors will alter the natural development of this system. The institution of a monitoring program would permit these changes to be detected and allow appropriate planning decisions to be made through evidence produced by natural resource monitoring (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, have 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.

More persistent environmental change may result from subtle alterations to coastal systems. Nutrient 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.

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), and vegetation (Cladophora biomass and eelgrass wasting disease). These parameters are the focus of this report.

I. WATER QUALITY

Water quality measurements were made throughout the summer in Salt Pond. Parameters included dissolved oxygen, temperature, conductivity, salinity & density, and orthophosphate-phosphorus, ammonium-nitrogen and nitrate-nitrogen. Minimum temperature profiles were made to aid in determining the causes of stratification and destratification in Salt Pond, a tidal kettle hole which exhibits seasonal hypolimnetic anoxia.

MATERIALS AND METHODS

1. Dissolved Oxygen

Temperature, conductivity, and salinity profiles of Salt Pond were performed daily between 1000 and 1400 hours from 18 June to 9 August 1991. Dissolved oxygen (DO) measurements were made daily seven meters below the surface. When hypoxia or

anoxia was observed at this depth, a DO profile was obtained. Sampling was performed at the deepest point of the pond (Lind, pers. comm.; Anderson and Stolzenbach, 1985), which was marked with a lobster buoy connected to a 50 lb. mushroom anchor. With this system, the same location in the pond could be returned to with confidence and a 14' aluminum skiff could be moored to it with ease.

Beginning at the bottom of the pond, the physical parameters were determined at 1.0 m intervals using a salinity-conductivity-temperature (S-C-T) meter (YSI Model 33) and probe. When thermal stratification was observed, sampling was done at 0.5 m intervals through the thermocline. Water samples for DO analysis were collected at the same intervals using a Kemmerer bottle. 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). Fixed samples were titrated in the lab using a digital titrator and 2.0 N sodium thiosulfate (Hach Co.).

2. Salinity and Density

In an attempt to obtain more accurate salinity values, salinity titrations were performed on two separate occasions, July 12 and 22. Samples were collected using the Kemmerer bottle at the same depth intervals as those for DO, stored in screw cap

glass bottles (Corning Glass Works) and refrigerated until analyzed. Analysis was performed using a modification of the mercuric nitrate method (American Public Health Association, 1985). The titration procedure involved taking a 5.0 ml sample of a 1:20 dilution of the sample in distilled water, adding 0.5 ml of reagent for chloride concentrations greater than 100 mg/L and 1 drop of 0.1 N nitric acid, and titrating using 2.256 N mercuric nitrate from a digital titrator (Hach Co.). The chlorinity of the original sample was then calculated by multiplying the digits on the titrator by 0.1.

In a similar manner, the chlorinity of a locally collected seawater sample was titrated. At the University of Rhode Island, the salinity of a subsample of this standard was determined using an AutoSal, an automatic salinometer. Since chlorinity and salinity are directly related (Peter Doering, pers. comm.), the salinity of the Salt Pond samples could be calculated. To assess the degree of stratification on these dates, density was determined according to the following formula,

$$1 + \{0.001[(28.14 - 0.0735T - 0.00469T^2) + (0.802 - 0.002T)(S - 35)]\}$$

where T is temperature in degrees centigrade and S is salinity. A more commonly used measure of density, sigma-t was calculated by subtracting one from the density and multiplying this value by 1000.

3. Salt Pond Nutrient Profiles

Nutrient analyses were performed in Salt Pond on July 22. Samples from the water column were obtained at intervals similar to those for DO and salinity using a Kemmerer bottle and refrigerated upon collection. At the lab, samples were filtered through a 0.45 μ m filter (Millipore Corp.). Quantitative analyses for orthophosphate-phosphorus, ammonium-nitrogen, and nitrate-nitrogen were performed on a Lachat QuikChem AE autoanalyzer using ascorbic acid, cadmium reduction methods, respectively (American Public Health Association, 1985). Artificial seawater was used as the carrier solution.

RESULTS AND DISCUSSION

1. Dissolved Oxygen

As depicted in Figures 1-4, temperature profiles were fairly similar over the course of the summer. The bottom 2-3 meters of Salt Pond was generally of uniform temperature. Above this, surface warming resulted in a linear rise in temperature. A 12 July thermal profile (Figure 1), representative of a mixed system, yielded temperatures of 19.1°C at the bottom and 22.8°C at the surface, 10 m from the bottom. A profile more typical of a mixed system was obtained on 24 July (Figure 3). Temperatures were uniformly 15°C over the bottom 5 m; the linear temperature

rise of the upper half of the Pond was due to surface warming. Even on 29 July, when the anoxic layer in Salt Pond was the thickest, the typical temperature profile was observed (Figure 4). Temperatures at the bottom were a constant 16°C and increased linearly from three meters above the bottom to the surface. Temperature profiles alone thus provided an unreliable indication of density stratification and the apparently incipient anoxia.

As a result, manual dissolved oxygen titrations were deemed the most reliable way to detect subsurface anoxia. Figure 5 demonstrates the fluctuations in DO over the course of the summer. Ranging from 0 ppm (1 and 29 July) to 7.7 ppm (27 June), concentrations of dissolved oxygen seven meters below the surface were quite variable. DO profiles are presented for the two days that complete anoxia was observed. Figure 6 depicts that on 1 July the anoxic layer was 2.5 m thick. The anoxic layer reached its maximum thickness (four and a half meters) on 29 July (Figure 4).

2. Salinity and Density

Malfunctioning probes prevented accurate and precise measurement of conductivity and salinity. Reliable values for these parameters could not be obtained with the YSI S-C-T meter and long probe. These parameters were not monitored after these

inaccuracies were recognized; however, to have an idea of the density of Salt Pond waters, salinity must be known. Due to time constraints, salinity titrations were only conducted twice, on 12 and 22 July. On both occasions, salinities varied with depth (Figures 12 and 13), ranging from 30-31.65 ppt. Water densities, a function of both salinity and temperature, were more useful values. Figure 14 demonstrates the density profile recorded on 12 July.

As expected, surface waters were less dense than waters at depth. Only one sigma-t unit (if the surface's density is eliminated) separated the densities of surface and bottom waters, suggestive of a fairly well-mixed pond (or a weakly stratified one). This correlates well with the temperature profile (Figure 1) which is also suggestive of a moderately mixed pond. The density profile recorded on 22 July (Figure 15) shows a difference of almost 2 sigma-t units in the densities of surface and bottom waters. According to Anderson and Stolzenbach (1985), this is indicative of a moderately stratified system. Figure 2 substantiates this stratification model. There is no large change in temperature and the anoxic layer is not very well developed. When water samples were collected on 22 July, the tide was flooding. A sample was taken in the inlet to represent the incoming water. Since the density of this water is less than any of the water already in Salt Pond, it is unlikely that mixing

would occur on this tide, and the hypoxia that is evident on Figure 2 would continue.

Fluoroscopy represents one other technique that could be used to further study stratification in Salt Pond. Introducing a dye in the inlet on a flood tide, one could collect water samples at the sampling station and determine the vertical distribution of the dye. When Salt Pond was weakly stratified (only fractional differences in sigma-t values), Anderson and Stolzenbach (1985) performed such a study using rhodamine dye. In the mixed system, they found that dye concentrations were quite uniform throughout the water column. Performing such a study when Salt Pond is stratified would thus be an instructive endeavor.

3. Salt Pond Nutrient Profiles

On 22 July, a day on which Salt Pond was moderately stratified, profiles were obtained for orthophosphate, nitrate, and ammonium (Table 1, Figures 16 and 17). Released from the sediments under anoxic conditions, orthophosphate ranged from 30 ppb 2 m below the surface to 127 ppb 10 m below the surface. As expected in a marine system, nitrate was the limiting nutrient (assuming a 16:1 Redfield assimilation ratio for phytoplankton), but became less limiting at depth due to release from the sediments.

Table 1. Dissolved oxygen and nutrient profile for Salt Pond, 22 July 1991.

<u>m</u> <u>Depth</u>	<u>ppb</u> <u>PO4-P</u>	<u>ppb</u> <u>DIN</u>	<u>uM</u> <u>PO4-P</u>	<u>uM</u> <u>DIN</u>	<u>N:P</u>	<u>DO</u>
0.0	36	20	1.2	1.4	1.2	6.8
1.0	37	6	1.2	0.4	0.4	7.3
2.0	30	16	1.0	1.1	1.2	8.0
3.0	31	44	1.0	3.1	3.1	8.5
4.0	32	33	1.0	2.3	2.3	9.3
4.5	45	45	1.4	3.2	2.2	8.5
5.0	48	6	1.5	0.4	0.3	7.3
6.0	83	21	2.7	1.5	0.6	7.3
7.0	98	136	3.1	9.7	3.1	2.6
7.5	109	182	3.5	12.9	3.7	2.0
8.0	106	206	3.4	14.6	4.3	0.8
9.0	120	413	3.8	29.3	7.6	0.4
10.0	127	491	4.1	34.9	8.6	0.0

Ammonium-nitrogen was fairly constant and low in the upper five meters of the water column (low of 2 ppb at 5 m) and increased to rather high concentrations in the more hypoxic depths (high of 485), indicating sediment regeneration of nitrogen. Presumably, these nutrients could be monitored from year to year, providing an indication of the trophic status of Salt Pond. However, two problems exist. First, all of the nutrient values are low, many being below the limit of detection. Second, nutrient concentrations can be influenced by physical (tidal), chemical (redox) and biological (algal uptake) factors, making water column nutrient analyses of limited value. Year-to-year comparisons would thus be difficult to interpret.

NO, NOTHING IS MISSING-

THIS IS JUST A BAD XEROX JOB.

II. GROUNDWATER NUTRIENTS

Groundwater phosphorous and nitrogen inputs to Nauset Marsh were examined with the anticipation that sites of uniform nutrient input could be located. Two locations, Salt Pond Bay in Eastham and the Orleans Yacht Club were sampled. The Salt Pond Bay transect was located just northeast of the inlet to Salt Pond, while the Yacht Club transect was located in the same place as in 1990 (Jones et al., 1990).

MATERIALS AND METHODS

Groundwater was sampled with a reinforced version of the stainless steel temporary well-point that was also used in 1990 (Jones et al., 1990). However, the well-point was not hammered down to groundwater; instead, the site was augured until groundwater was reached. Only then was the well-point tapped down and a water sample retrieved using a peristaltic pump.

Initially, at each site a 200 ml aliquot was obtained and its salinity determined with an S-C-T meter. If the sample wasn't fresh, but was brackish (salinity <10 ppt), the measured salinity was recorded. A sample was then collected in a 60 ml Nalgene sample bottle and refrigerated. When brought back to the lab, all samples were immediately filtered through a 0.45 μ m pore size membrane filter using a vacuum pump. Immediately subsequent

to filtration, ammonium-nitrogen, nitrate-nitrogen and orthophosphate-phosphorus concentrations were determined by automated flow injection analysis using phenolate, cadmium reduction and ascorbic acid methods, respectively (American Public Health Association, 1985).

The Salt Pond Bay transect was identified as an area of uniformly low nutrient input and was made permanent. Eleven PVC wells were installed at five meter intervals to facilitate continual monitoring of groundwater nutrients. A methodology for representative sampling of groundwater quality along both developed and undeveloped shorelines is being tested in the field (Portnoy and Roman, 1991).

RESULTS AND DISCUSSION

Sampling along groundwater transects was accomplished at Salt Pond Bay and the Orleans' Yacht Club. After much preliminary sampling at the Salt Pond Bay transect (Portnoy, unpubl. data), this site was selected as a permanent station for groundwater nutrient monitoring. From the eleven permanent PVC wells that were established at five meter intervals, water samples were collected for nutrient analyses. Ammonium-nitrogen, nitrate-nitrogen and orthophosphate-phosphorous concentrations were all monitored. At all wells, values were consistently low.

Ammonium-N ranged from 0.015 to 0.312 ppm, nitrate-N from 0.038 to 0.239 ppm, and orthophosphate from 0.093 to 0.189 ppm.

Only preliminary sampling has been performed at the Orleans Yacht Club transect. No permanent wells have yet been established. Ammonium values ranged from a low of 0.013 to a high of 0.406 ppm, nitrate from 0.032 to 11.144 ppm, and orthophosphate from 0 to 0.37 ppm. It is readily apparent that maximum nitrate values are much higher at this location in Town Cove than at Salt Pond Bay. Moreover, nitrate values are not as uniform as seen at Salt Pond Bay. Between 25 and 30 m transect stations, nitrate concentrations decrease from a high of 11.144 ppm to less than 0.1 ppm. Such variability may detract from this site's potential as a permanent sampling station; however, high spatial variability of groundwater-nitrate concentrations is typical of highly developed shorelines.

III. MACROALGAE

Cladophora gracilis has been reported to be a useful indicator of the trophic status of shallow embayments. By periodically quantifying its biomass over the course of a summer and comparing these production estimates over time, nutrient availability may be indicated.

MATERIALS AND METHODS

The biomass of green algae (primarily Cladophora gracilis) was determined on eight days during the summer from 7 June to 9 August. The site chosen was the same as in 1990 (Jones et al., 1990), an intertidal mud flat located in Salt Pond Bay, east of the Salt Pond inlet. A canoe was used for transportation to the site. At low tide, 20 random samples (chosen by throwing a marker over one's head) were harvested by placing a bottomless five gallon bucket over the sampling site and removing all of the algae 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 individual plastic bags.

In the lab, 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 bottom area), the biomass of algae (g/m^2) could be calculated.

Because the distribution of macroalgal mats were highly clumped in Salt Pond Bay, an alternate procedure was explored. To reduce the variability and obtain a better representation of

the green algae actually present, it was decided to map the locations of green algae present in Salt Pond Bay and then determine the production within each mappable unit. The feasibility of such an effort was examined. The intertidal flats of Salt Pond Bay were mapped using a 1987 aerial photograph of Salt Pond Bay as a base map. On 16 July, the biomass of the algae on each of the individual flats was measured. Initially, a subset of the largest mudflat (Figure 18) was randomly sampled. Samples were chosen by pacing off the dimensions of the area and then using a random number generator to establish coordinates for 20 samples. All other procedures were similar to the previously described protocol.

In another attempt to reduce variability, the sample area was increased approximately 180 times, from a bucket to a 10' x 10' quadrat. Again, a coordinate system was established and sample coordinates were randomly chosen. At each of 18 sample locations, a 10' x 10' frame made from four 10' sections of 1/2" PVC pipe and 4 90° elbows was similarly oriented and all of the algae from within this area were collected. As before, all samples were cleaned, dried at 60°C, and weighed.

Ground-checking the production was attempted on intertidal flat #5. This mud flat contained a plethora of mussels covered with green algae (Ulva, Enteromorpha, and Cladophora),

filamentous brown algae (e.g. Ectocarpus and Pylaeella), and a few red algae.

RESULTS AND DISCUSSION

It became immediately apparent that there was much less C. gracilis, and all green algae for that matter, on the flat than in 1990. As depicted in Table 2, the maximum recorded green algae production was on August 2, when there was slightly more than 46 g/m². This consisted of Ulva, Enteromorpha, and Cladophora. This contrasted strongly with values obtained the previous year, when more than 350 g/m² of green algae was present on the mud flat (Jones et al., 1990).

Table 2. Results of green algae biomass sampling, Salt Pond Bay, Eastham, Massachusetts.

<u>Date</u>	<u>Quadrat Size (m²)</u>	<u>N</u>	<u>Mean Biomass (g/m²)</u>	<u>S.D.</u>	<u>C.V.</u>
07-Jun	0.053	10	9.95	30.66	3.08
14-Jun	0.053	10	44.07	139.37	3.16
21-Jun	0.053	10	11.41	18.53	1.62
28-Jun	0.053	20	4.04	14.18	3.51
05-Jul	0.053	20	8.83	18.61	2.11
18-Jul	0.053	20	31.13	57.37	1.84
31-Jul	0.053	81	46.31	66.53	1.44
02-Aug					
09-Aug	9.290	17	33.84	17.39	0.51

Of the twenty samples collected, frequently half contained no algae. As a result, the variability was quite high. At the same time, there was a substantial amount of green algae observed

in Salt Pond Bay, that could not be accounted for by sampling the same mud flat as the previous year.

Using the sampling bucket, a productivity estimate of 31.1 g/m² with a standard deviation of 57.4 (n = 20) was obtained on July 18. To attempt to reduce the variability, the number of samples was increased. On July 31 and August 2, this flat was resampled; the average biomass was determined to be 46.3 g/m² with little decrease in standard deviation over the 18 July sampling despite the quadrupled sample size (n = 81).

On the next attempt (9 August), the sample area was increased approximately 180 times to a rectangular quadrat 10' x 10' (9.29 m²) in an effort to reduce variability. Seventeen samples were collected with an average biomass of 33.84 +/- 17.39 g/m². Thus, by using the larger sampling unit, the coefficient of variation was reduced from 1.44 to 0.51.

IV. EELGRASS

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.

MATERIALS AND METHODS

Ten eelgrass plants were randomly collected monthly from each of two locations, Mill Pond and Snow Shore Landing, both in Orleans. The protocol used in 1990 was continued through 2 July and the samples were shipped to Dr. Fred Short at the Jackson Estuarine Lab via overnight mail. A wasting disease index is used to evaluate the health of eelgrass populations by determining the extent to which individual plants are infected.

RESULTS AND DISCUSSION

Short and Wolf (1992) reported on the data obtained from eelgrass sampling. Samples were collected monthly between 10 July 1990 and 2 July 1991 and indicated that average wasting index (AWI) peaked during the winter (14% on 18 December 1990 at Snow Shore Landing and 23.5% on 7 February 1991 at Mill Pond). Maximum wasting index showed a similar trend (44.5% on 18 December 1990 at Snow Shore). Large maximum wasting indices were also observed on 1 April 1991 (43.5% at Snow Shore and 44.0% at Mill Pond). The prevalence of the disease at the two sampling sites within Cape Cod National Seashore was higher than other East Coast sites evaluated by Short. Only North Carolina had an AWI greater than Nauset Harbor (8.9 vs. 8.0). Great Bay, NH, Narragansett Bay, RI, and Waquoit Bay, MA all had AWI of less than 4.0.

Since Great Bay, NH experienced dramatic declines in its eelgrass population over the past ten years due to the wasting disease, it has been surmised that a similar die-off may occur in Nauset Harbor where the indices are greater than Great Bay. High disease rates have been correlated with high salinity and decreased water clarity, the latter attributed to nutrient loading and/or suspended sediments. Short and Wolf (1992) made several recommendations to improve water quality, including controlling surface run-off, regulating boat traffic, and restricting fish and shellfish harvest.

Long-term monitoring of the disease in Nauset Harbor is warranted, especially if Seashore staff could be trained to determine the wasting disease index. Combining this monitoring with the overall goal of determining nutrient inputs and understanding the degree of eutrophication of Nauset Marsh would provide for the continued success of Z. marina in this location.

IV. SALT POND STRATIFICATION AND MIXING

Dissolved oxygen monitoring (see I. Water Quality) indicated that water column stratification and hypolimnetic anoxia were the common summer condition at Salt Pond. However, rapid mixing (apparently overnight) was also observed on several occasions. Mixing occurred during calm weather, therefore wind did not appear to be an important factor. It was alternately

hypothesized that episodic destratification was due either to 1) a sudden drop in air temperature cooling surface water and increasing surface water density (atmospheric mixing) or 2) tidally-induced advection of cold ocean water (advective mixing).

It was reasoned that a water column profile of minimum temperatures during a period of destratification would reflect the mechanism of mixing as follows:

In the absence of high winds, atmospherically-induced mixing is caused by a sudden fall in air temperature, and thus surface water temperature, increasing surface water density. With little observed change in salinity with depth, density is almost exclusively dependent on temperature. Once density of surface water exceeds that of hypolimnetic water, the pond turns over. A profile of minimum temperatures attained during the destabilization period would show lowest temperatures at the surface. A minimum temperature profile during an advective profile should have lowest values at or near the bottom.

Temperature profiling was conducted in 1991 to attempt to describe the physical causes of observed mixing.

MATERIALS AND METHODS

A series of maximum/minimum thermometers were set out to distinguish advective vs. atmospheric cooling as the cause of the seemingly rapid turnover in Salt Pond. On a 10-m length of polypropylene line attached to a 20 lb. mushroom anchor, max-min thermometers were placed at 2, 3, 4, 5, 6, 7, and 8 m from the bottom. To ensure that the line remained vertical in the water column, a gillnet float was placed below each thermometer, a plastic gallon jug was tied in at 7.5 m, and a lobster buoy was placed at the surface. This buoy was deployed approximately 10-15 m southeast of the mooring. Max-min thermometers were also located at the surface buoy, in the inlet to Salt Pond, and in the air on the side of the Eastham clam shack. The inlet thermometer was tied to a one meter length of rebar sunk into the bottom sediments approximately 75 m from the entrance to Salt Pond on the north side of the channel. Every other day (Monday, Wednesday, and Friday), the minimum temperature recorded on all nine thermometers was noted and the thermometers were reset.

RESULTS AND DISCUSSION

It was anticipated that advective and atmospheric cooling could be discriminated from the temperature data. Figure 10 is a presentation of the minimum temperatures recorded in the inlet to

Salt Pond. Temperatures should represent nocturnal flood tide temperatures; incoming seawater should be much colder than water which has had time to warm on the flats during the day. Temperatures ranged from a low of 8°C between 22-24 July to a high of 18.5°C between July 3-5, demonstrating the strong oceanic influences on the Nauset system. The low temperature of 8°C, almost 7°C colder than usually recorded, may have resulted from a cold water eddy passing down the coast and entering at Nauset Inlet. Minimum air temperatures were also recorded (Figure 11). These varied from a high temperature of 22.2°C on 29 June to a low of 12.1°C on 8-10 July.

Also depicted on Figures 10 and 11 are hypoxic/anoxic events. A precursor to these events was warm air and inlet temperatures. Minimum temperatures at Salt Pond inlet before all three events were at least 17°C for at least one day. Before the 1 July anoxia and the 23 July hypoxia, minimum air temperatures were quite warm, nearly 22°C. It thus seems that Salt Pond summertime anoxia is due to both warm air and incoming waters.

To separate advective and atmospheric cooling as stimuli for destratification, the same figures can be examined. For advective cooling to be effective, post-anoxic event inlet temperatures should be substantially less than those during the event. Similarly, atmospheric cooling could be responsible for destratification when minimum air temperatures are less after the

event than during or before it. Following the anoxia of 1 July, inlet temperatures slightly rose (Figure 10); minimum air temperatures, however, decreased slightly and remained relatively low for approximately 7 days (Figure 11). The recovery from anoxia occurred gradually, as indicated by the slow increase in 7 meter DO concentrations (Figure 5). This recovery was indicated by a slow erosion of stratification and not the influx of a cold, dense parcel of water. Atmospheric cooling is thus a plausible explanation for this destratification event.

The hypoxic event of 23 July (7 meter DO = 1.3 ppm) ended after a large decrease in both inlet and air temperature (Figures 10 and 11). Figure 8 also indicates how the temperature of incoming waters in the inlet is much colder than any of the water in Salt Pond. Moreover, the hypoxic event was quickly terminated by 24 July when the 7 meter DO was recorded as 6.6 ppm. With such a rapid recovery from hypoxia, it seems likely that advective cooling, the episodic intrusion of cold oceanic water, was the primary stimulus responsible for this destratification, though atmospheric cooling may have played a minor role.

The final anoxic event observed during the summer of 1991 was detected on 29 July. Its resolution is more difficult to explain. The graphs depicting general changes in inlet and air minimum temperatures provide little help. Minimum inlet temperatures remained fairly constant (Figure 10), while minimum

air temperatures actually increased (Figure 11). The erosion of the anoxic layer occurred over the course of several days, suggestive of a gradual process (Figure 5). The profile representing the minimum temperatures between 29-31 July (Figure 9) demonstrated a marked stratification. Between 4 and 7 meters from the bottom, the temperature increased, from 15.5°C to 18.3°C. The surface waters of Salt Pond, as well as the waters 8 meters from the bottom, were cooler than the waters 7 meters from the bottom, indicative of the influence of low air temperatures. Both this and the gradual erosion of the anoxic layer suggests that atmospheric cooling was probably responsible for the destratification observed.

It should be remembered that these interpretations are based upon indirect measures of density. Though salinity did not appear to vary substantially with depth (see above), future work should include combined salinity and temperature monitoring of Salt Pond and its inlet so that density can be computed.

RECOMMENDATIONS

The following recommendations for future monitoring are provided to assist in developing a monitoring plan for Nauset Marsh.

Water Quality. A methodology for sampling water quality in the Nauset Marsh water column is currently being developed by Dr. Charles Roman (pers. comm.).

Groundwater. Several permanent groundwater transects should be established along the seaward edge of Spartina, with well points driven to a 10cm depth. A refractometer should be used to distinguish between fresh and brackish water. More specific methods for groundwater sampling may be developed and should be incorporated into future monitoring (Portnoy and Roman, 1991).

Macroalgae. To reduce the variability inherent in green algae sampling, an alternative sampling design should be used that incorporates a long, thin rectangular quadrat. Salzer (pers. comm.) has recommended replacing 2 x 2 meter quadrats with 0.4 x 10 meter quadrats for plants with a clumped distribution. In a computer simulation, these thin quadrats demonstrated an improved sampling distribution with decreased variance. An appropriately-sized quadrat for macroalgae will have to be developed that will demonstrate a similar decrease in error.

Eelgrass. Short & Wolf (1992) recommend a long-term eelgrass sampling strategy for Nauset Marsh including mapping (annually or biannually) and monthly monitoring of wasting disease. Due to high year to year variability in eelgrass wasting disease indices, monthly sampling is warranted on an annual basis.

Biannual mapping should be sufficient to track changes in the spatial extent of eelgrass beds.

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: Importance of diel vertical migration and surface avoidance. *Marine Ecology - Progress Series* 25:39-50.
- Doering, Peter. Pers. comm. University of Rhode Island, Kingston, RI.
- Jones, L. Kyle, Kenneth R. Vander Have and Geremea P. Fioravanti. 1990. Nauset Marsh monitoring report. Cape Cod National Seashore, South Wellfleet, MA. 56pp.
- Lind, Henry. Pers. comm. Eastham Natural Resource Officer, Eastham, MA.
- Portnoy, John and Charles T. Roman. 1991. Research proposal: An assessment of nutrient loading in Nauset Marsh, Cape Cod National Seashore. Cape Cod National Seashore, South Wellfleet, MA. 15pp.
- 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.
- Salzer, Daniel W. Pers. comm. Stewardship Ecologist, The Nature Conservancy, Oregon Field Office, Portland, Oregon.
- Short, Frederick and Jamie Wolf. 1992. Wasting disease in eelgrass at Nauset Harbor, Massachusetts. Jackson Estuarine Laboratory, University of New Hampshire, Durham, NH. 5pp.
- Valiela, I., J. Costa, K. Foreman, J. M. Teal, B. Howes and D. Aubrey. 1990. Transport of groundwater-bourne nutrients from watersheds and their effects on coastal waters. *Biogeochemistry* 10:177-197.

Salt Pond Temperature Profile

July 12, 1991

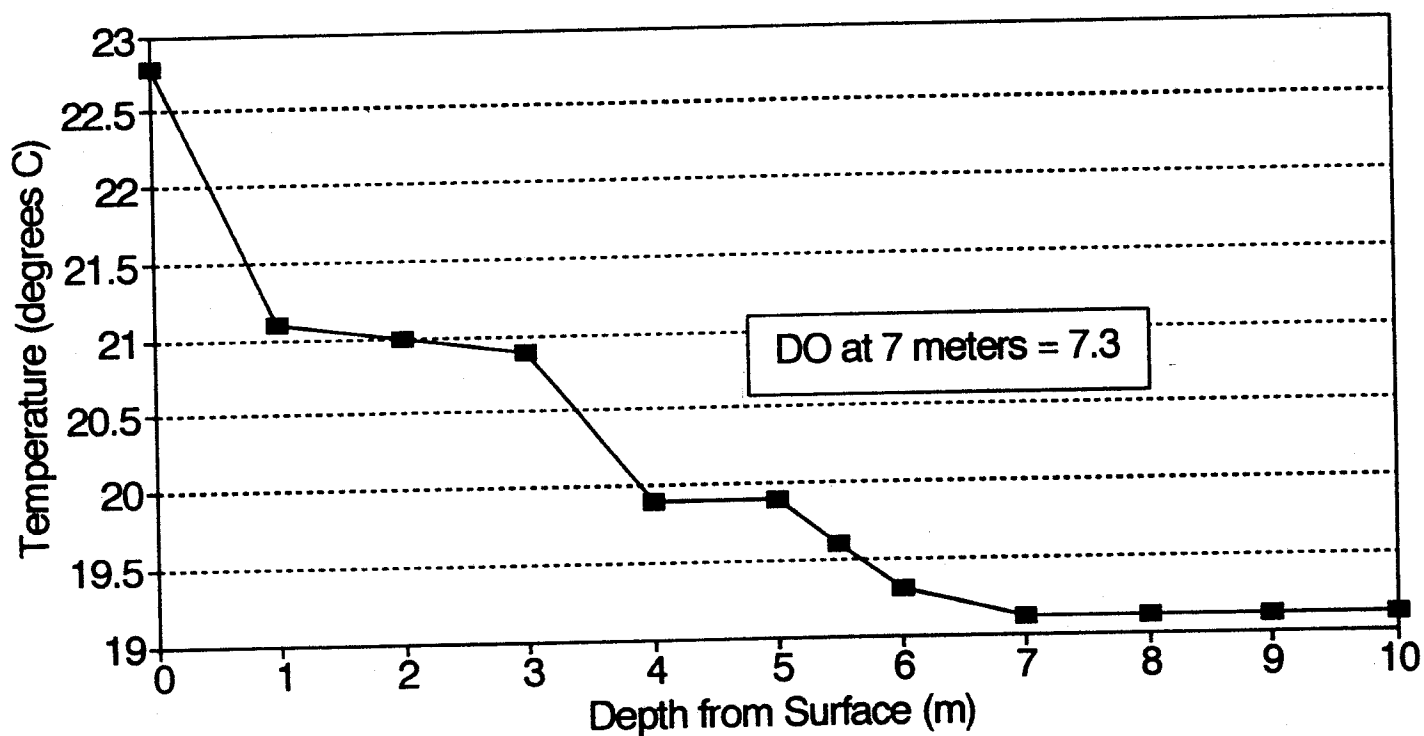


Figure 1. Temperature profile in Salt Pond, Eastham on July 12, 1991.

Salt Pond Profiles

July 22, 1991

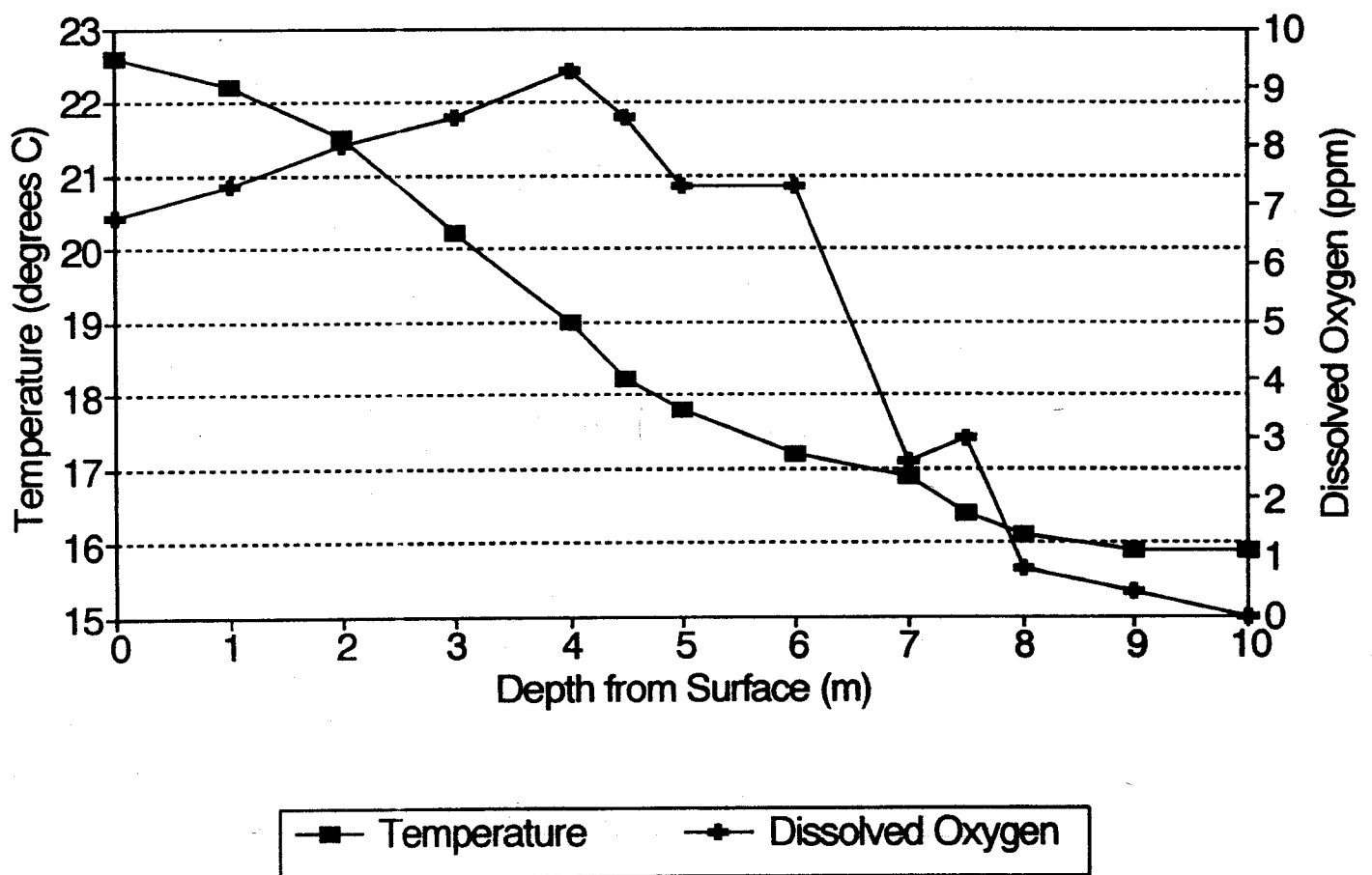


Figure 2. Temperature and dissolved oxygen profiles in Salt Pond, Eastham on July 22, 1991.

Salt Pond Profiles

July 24, 1991

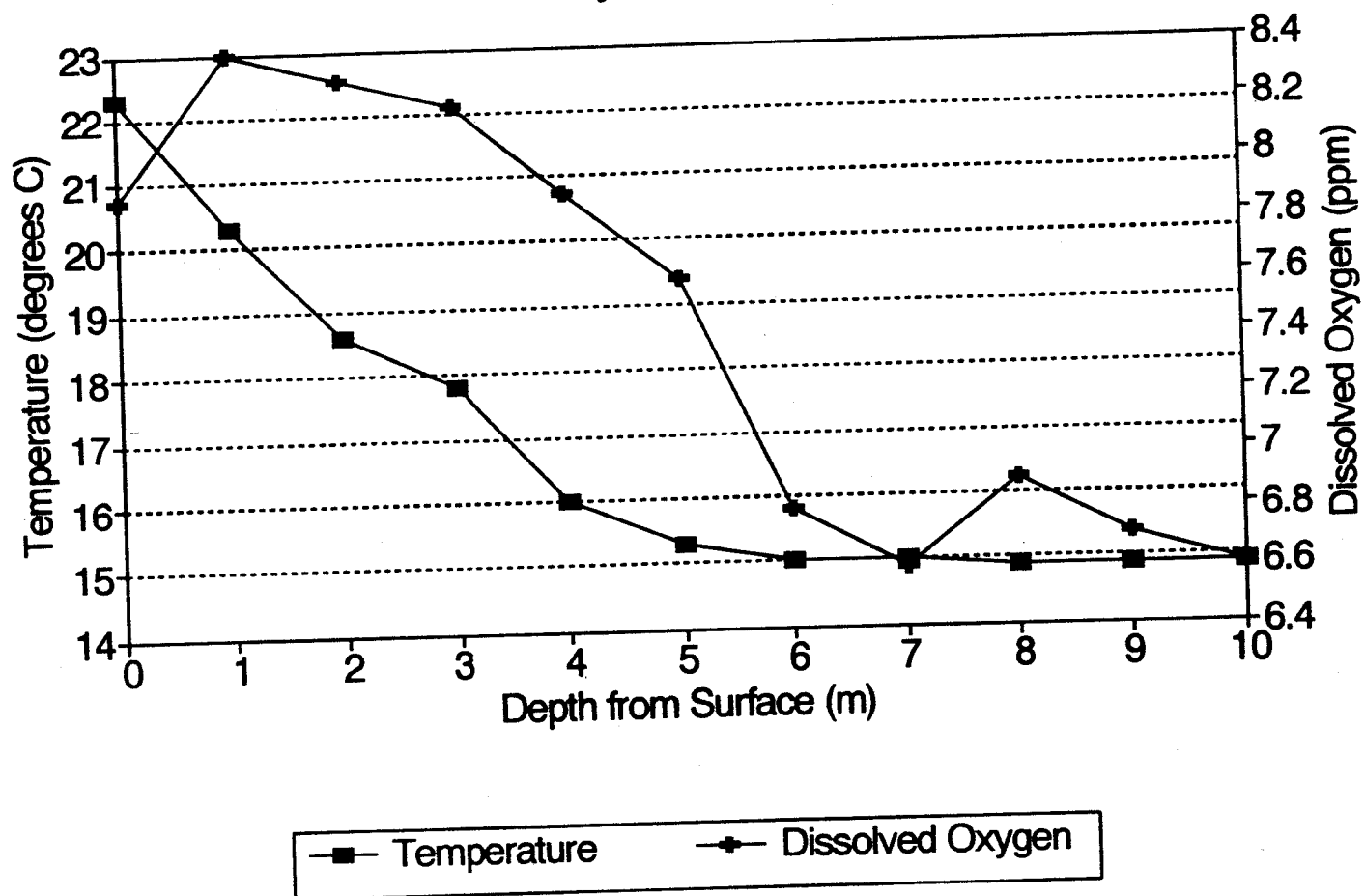


Figure 3. Temperature and dissolved oxygen profiles in Salt Pond, Eastham on July 24, 1991.

Salt Pond Profiles

July 29, 1991

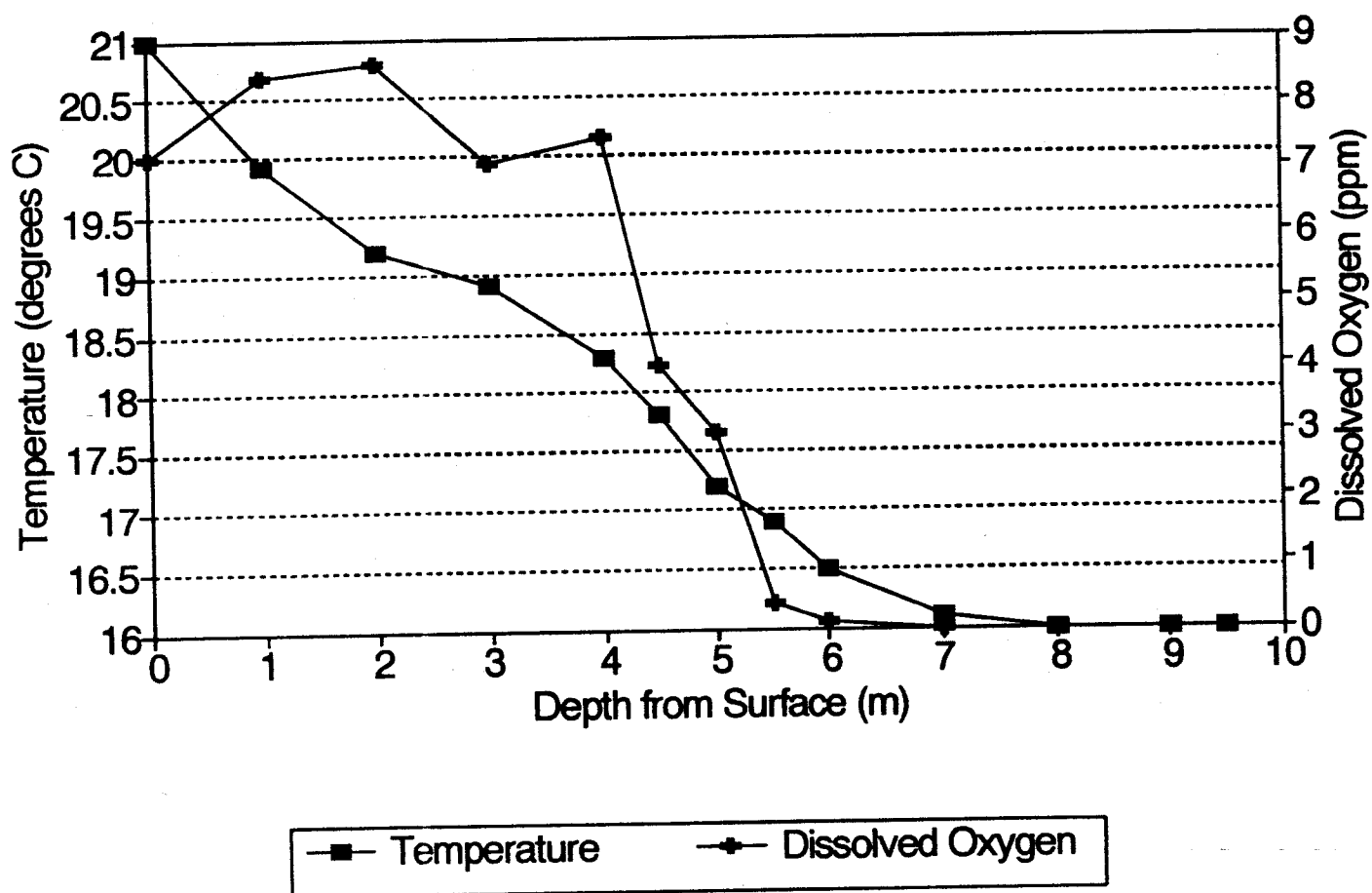


Figure 4. Temperature and dissolved oxygen profiles in Salt Pond, Eastham on July 29, 1991.

Salt Pond Dissolved Oxygen 7 Meter Depth

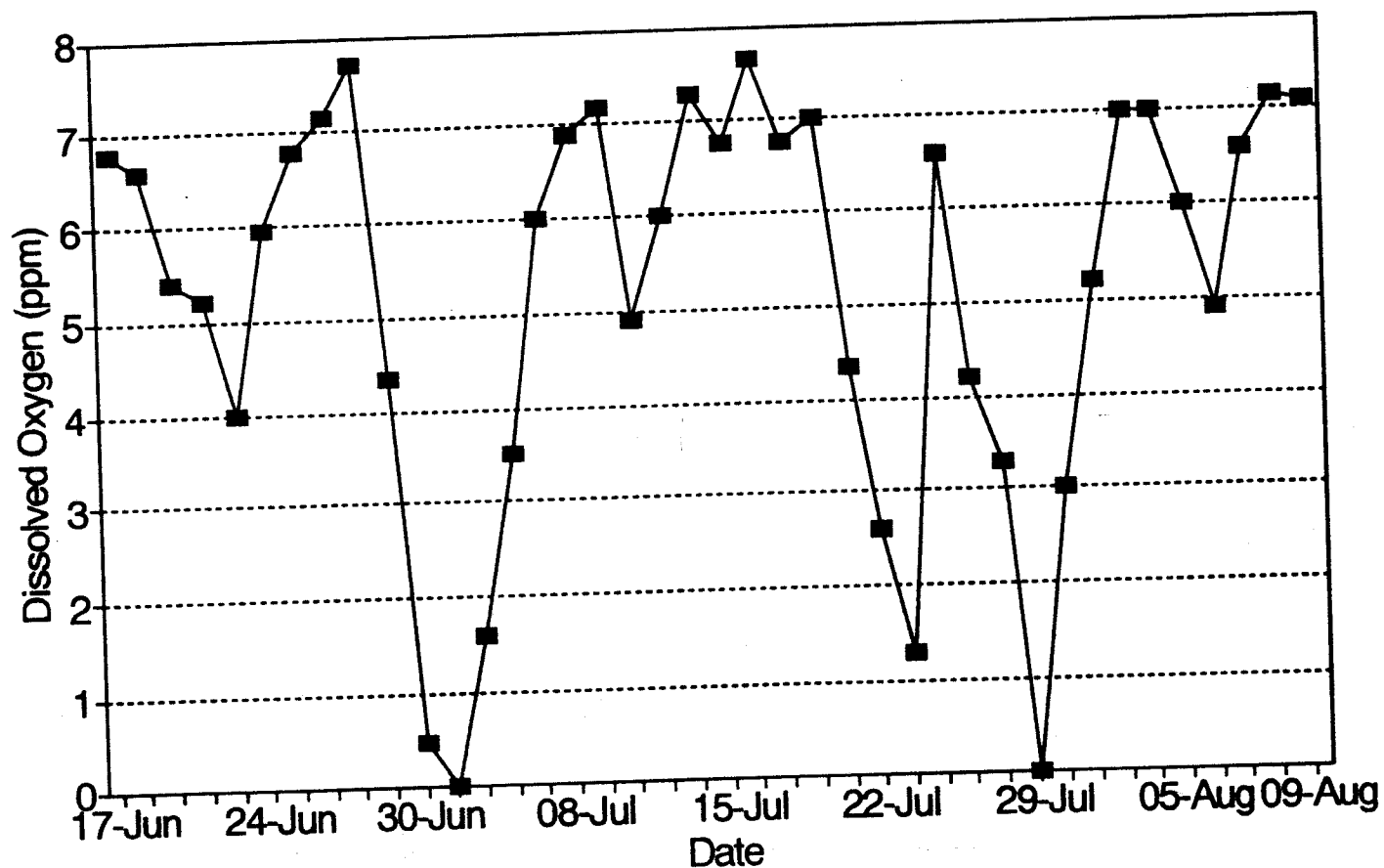


Figure 5. Dissolved oxygen concentrations in Salt Pond, Eastham from June 17 - August 9, 1991.

Salt Pond Dissolved Oxygen Profile

July 1, 1991

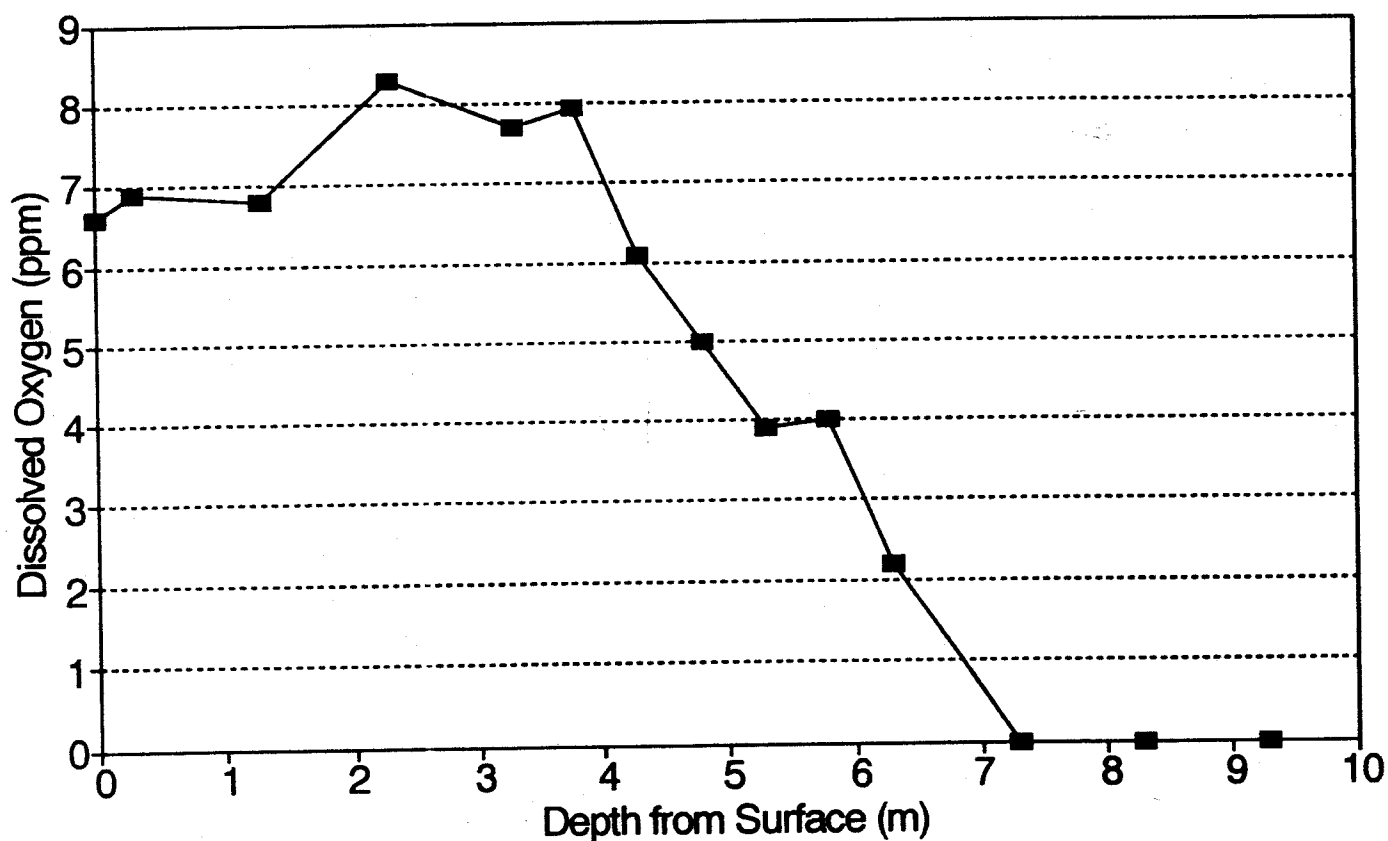


Figure 6. Dissolved oxygen profile in Salt Pond, Eastham on July 1, 1991.

Minimum Temperatures in Salt Pond

July 1-3, 1991

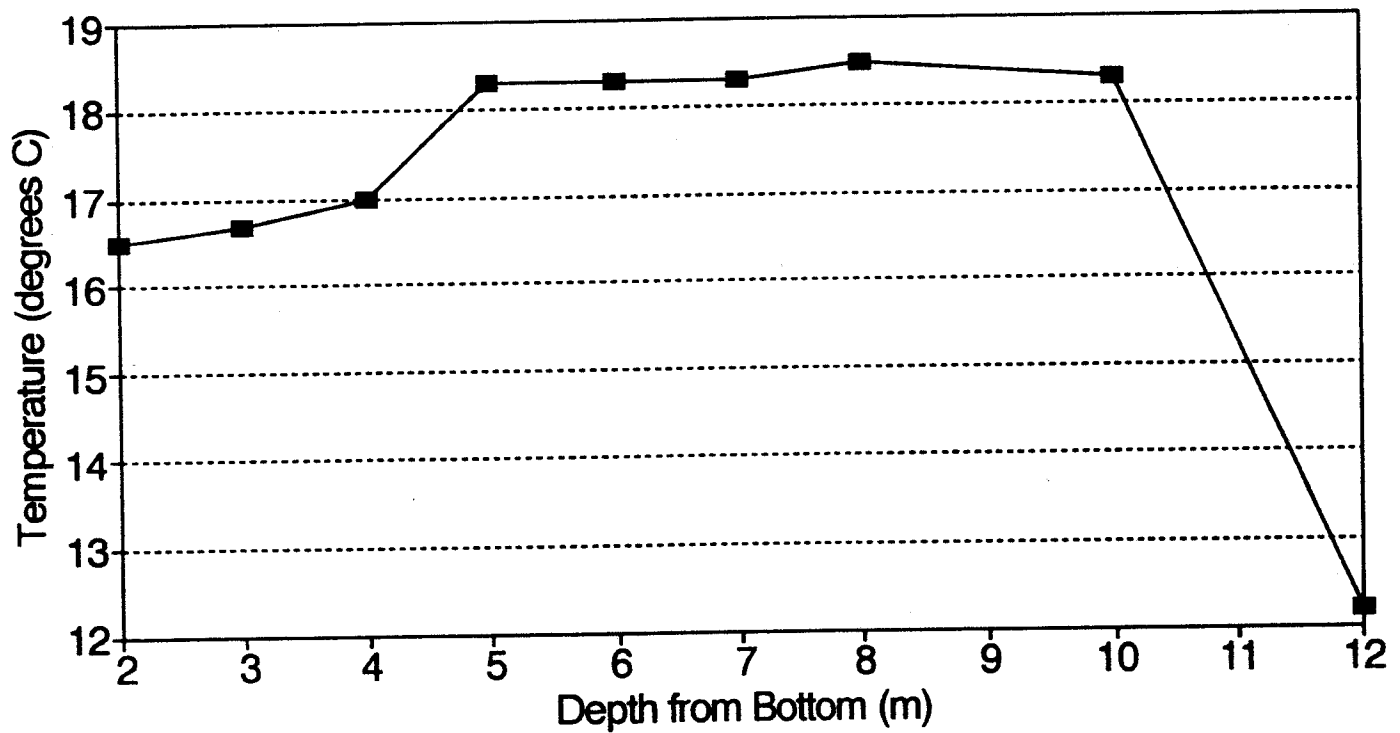


Figure 7. Minimum temperature in Salt Pond, Eastham from July 1-3, 1991.

Minimum Temperatures in Salt Pond

July 22-24, 1991

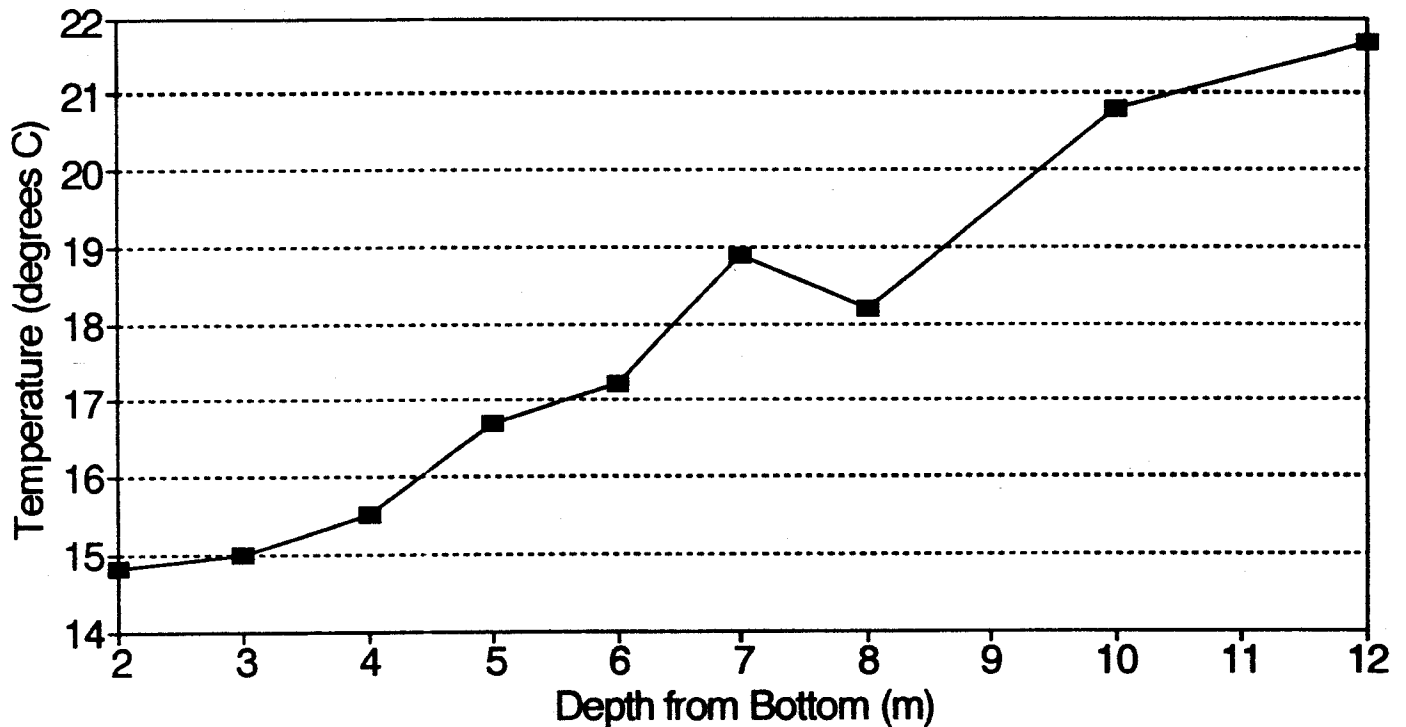


Figure 8. Minimum temperature profile in Salt Pond, Eastham from July 22-24, 1991.

Minimum Temperatures in Salt Pond

July 29-31, 1991

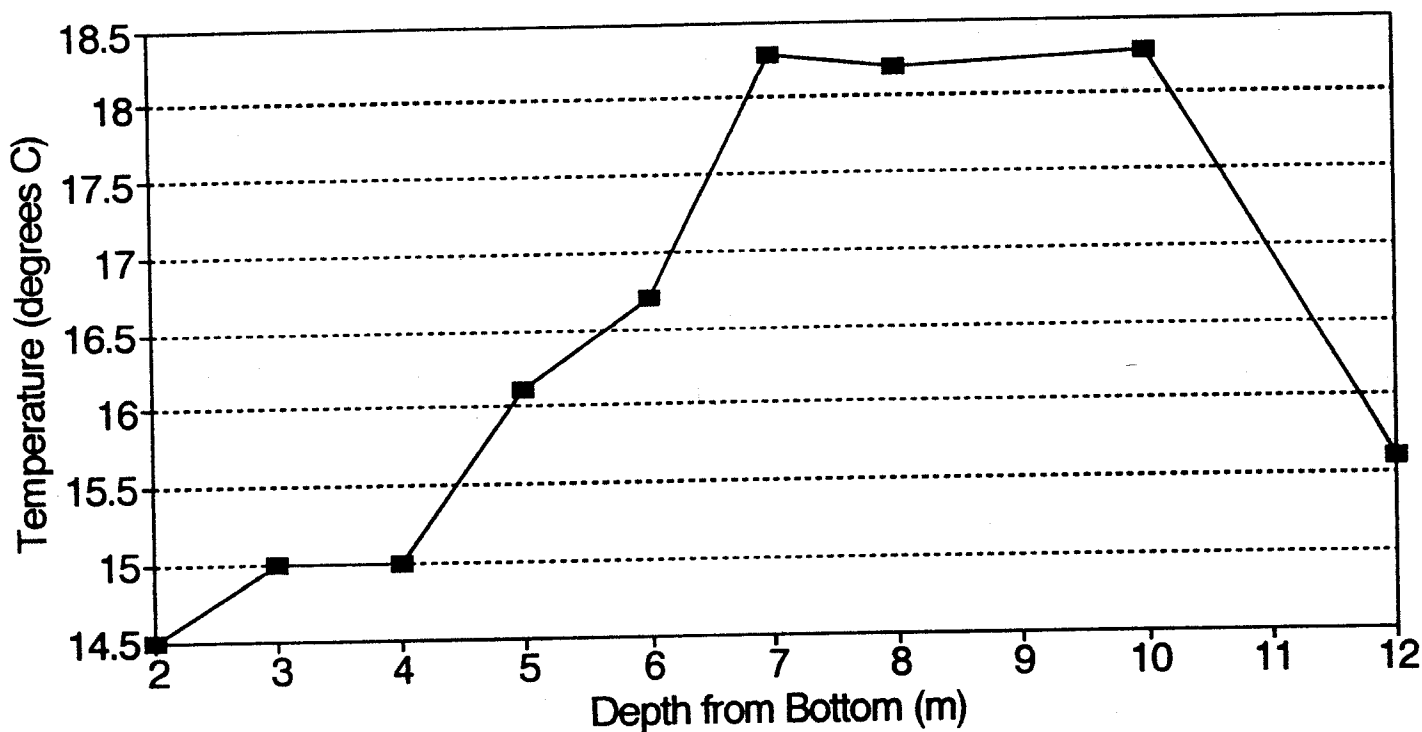


Figure 9. Minimum temperature profile in Salt Pond Inlet, Eastham from July 29-31, 1991.

Minimum Temperatures

Salt Pond Inlet

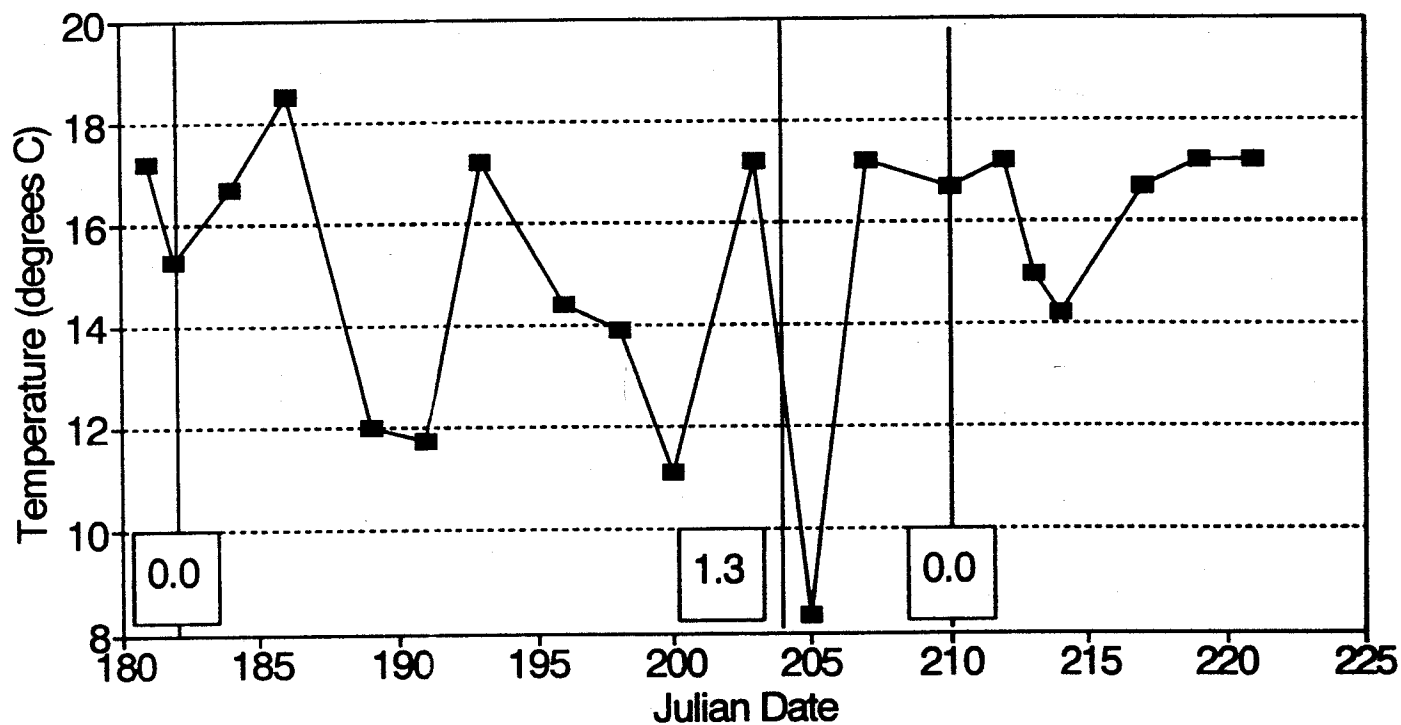


Figure 10. Minimum temperature profile in Salt Pond Inlet, Eastham from June 29 - August 13, 1991.

Minimum Air Temperatures Salt Pond

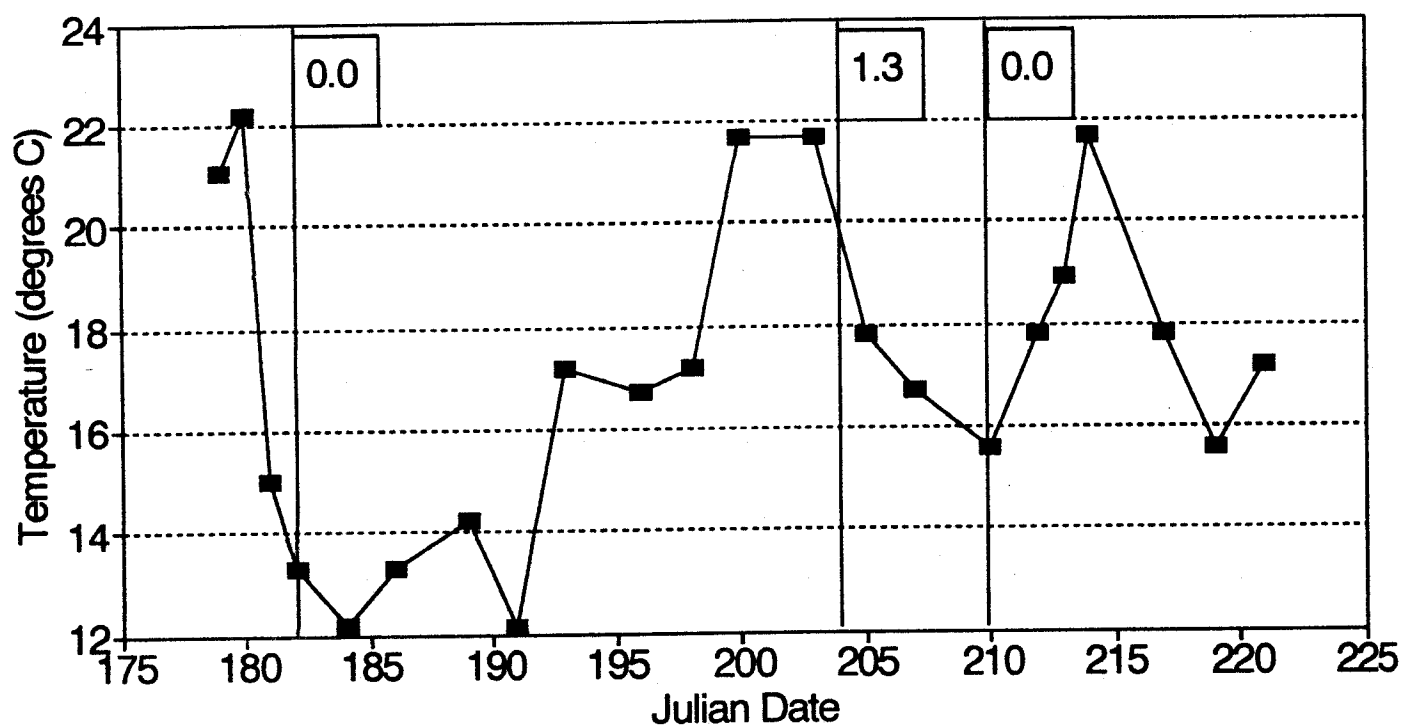


Figure 11. Minimum air temperatures in Salt Pond, Eastham from June 24 - August 13, 1991.

Salt Pond Salinity Profile

July 12, 1991

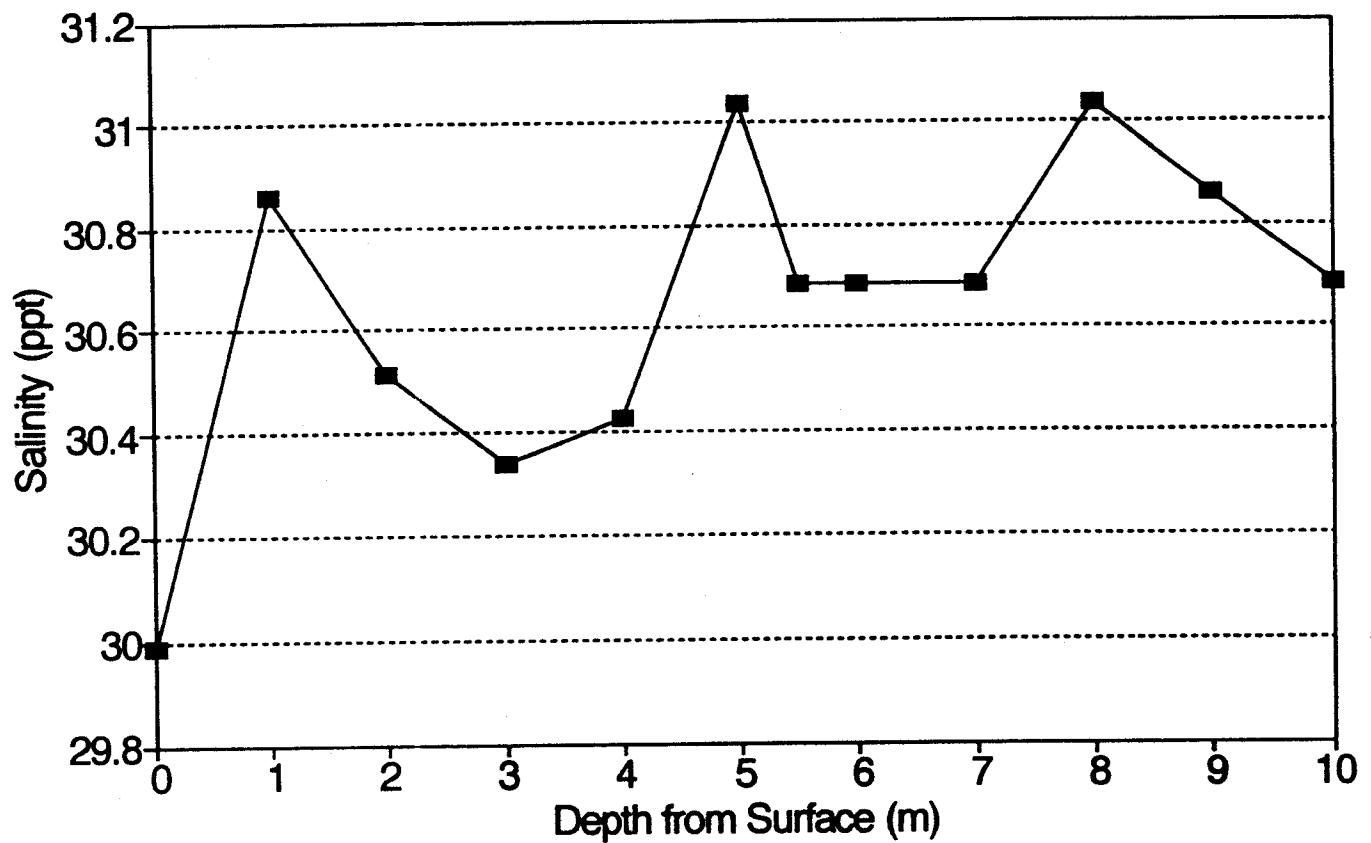


Figure 12. Salinity profile in Salt Pond, Eastham on July 12, 1991.

Salt Pond Salinity Profile

July 22, 1991

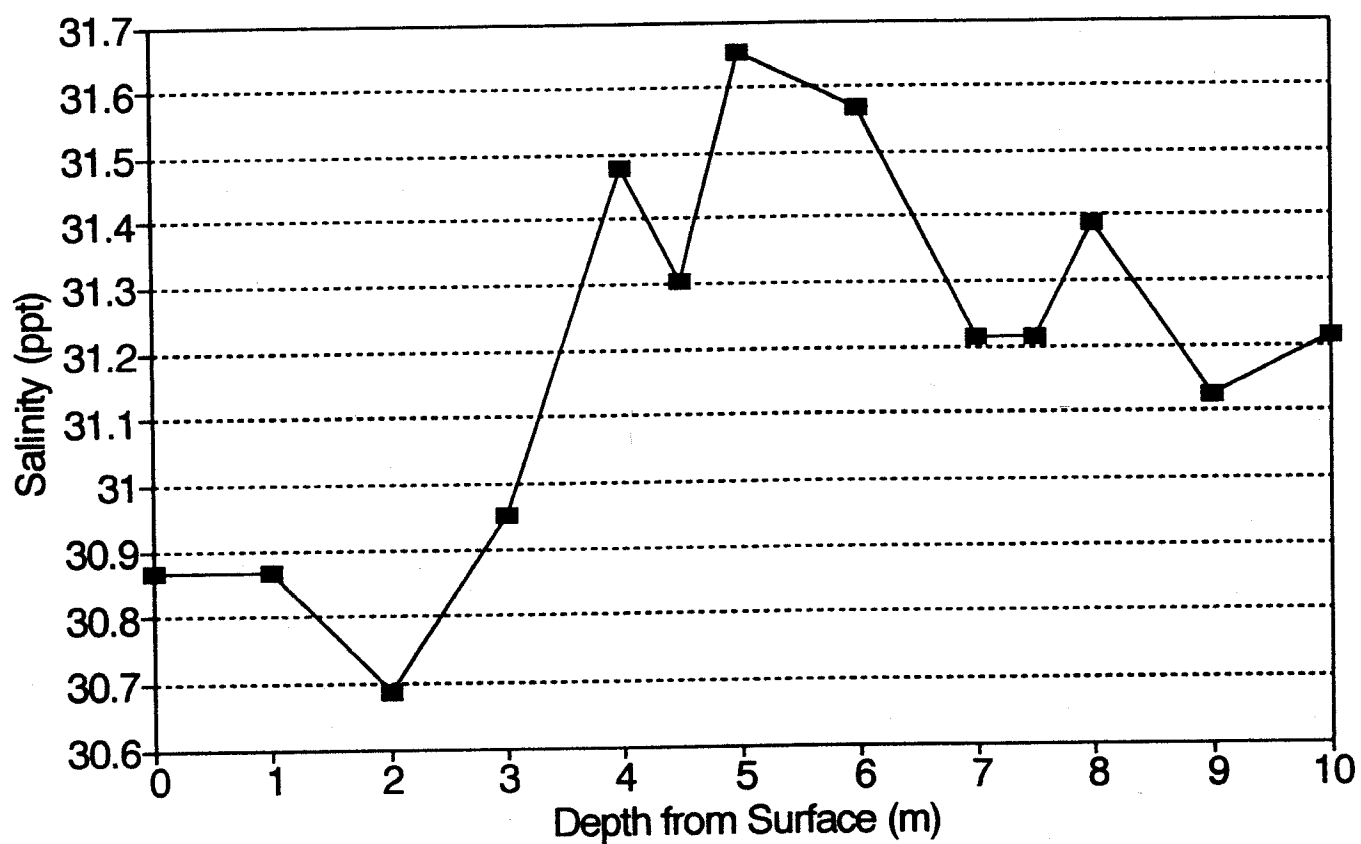


Figure 13. Salinity profile in Salt Pond, Eastham on July 22, 1991.

Salt Pond Density Profile

July 12, 1991

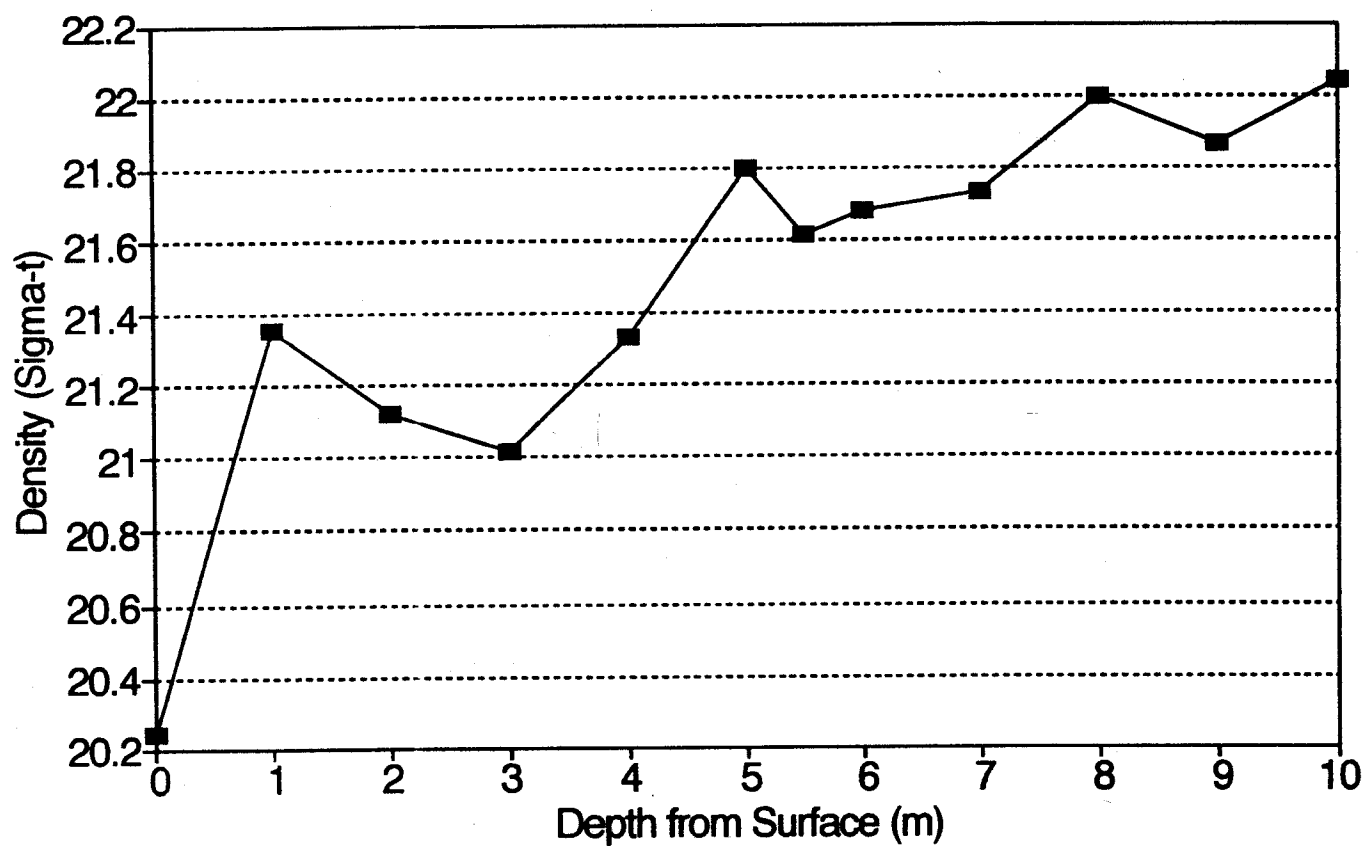


Figure 14. Density profile in Salt Pond, Eastham on July 12, 1991.

Salt Pond Density Profile

July 22, 1991

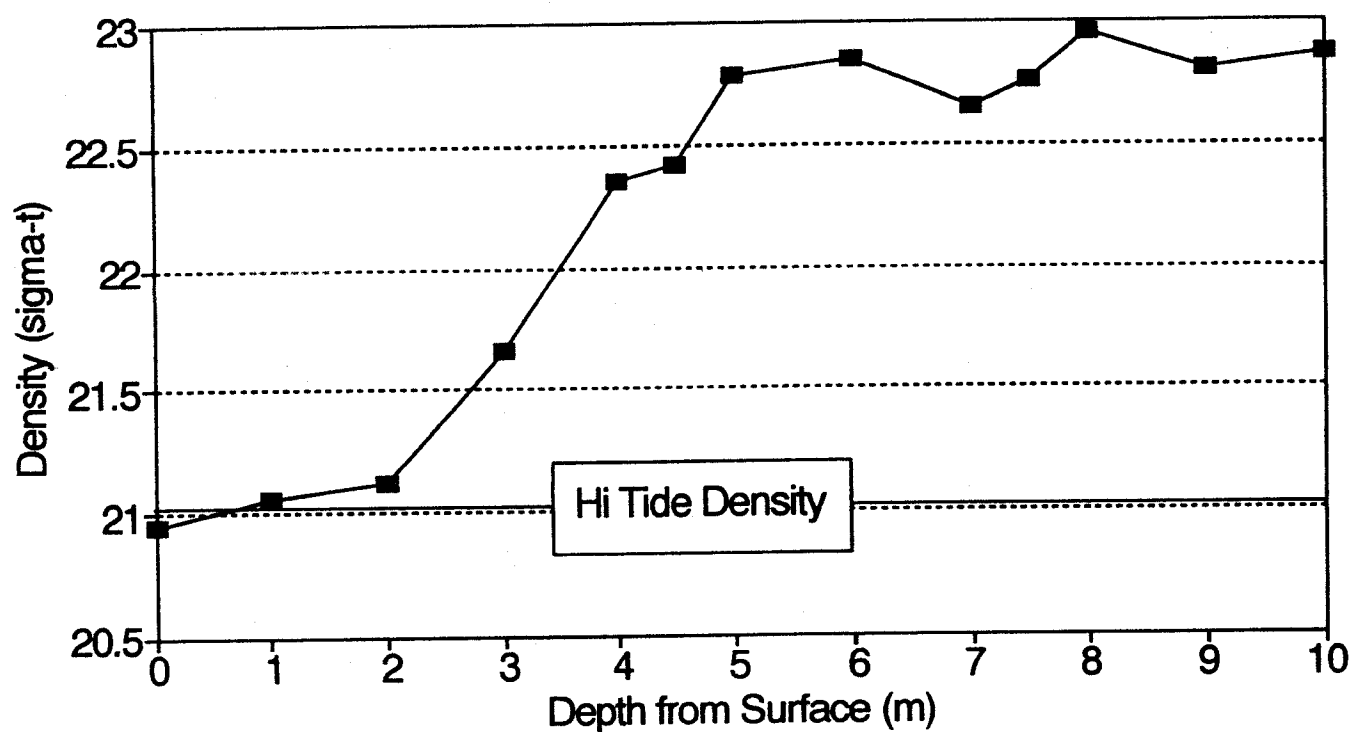


Figure 15. Density profile in Salt Pond, Eastham on July 22, 1991.

Salt Pond Chemistry Profiles

July 22, 1991

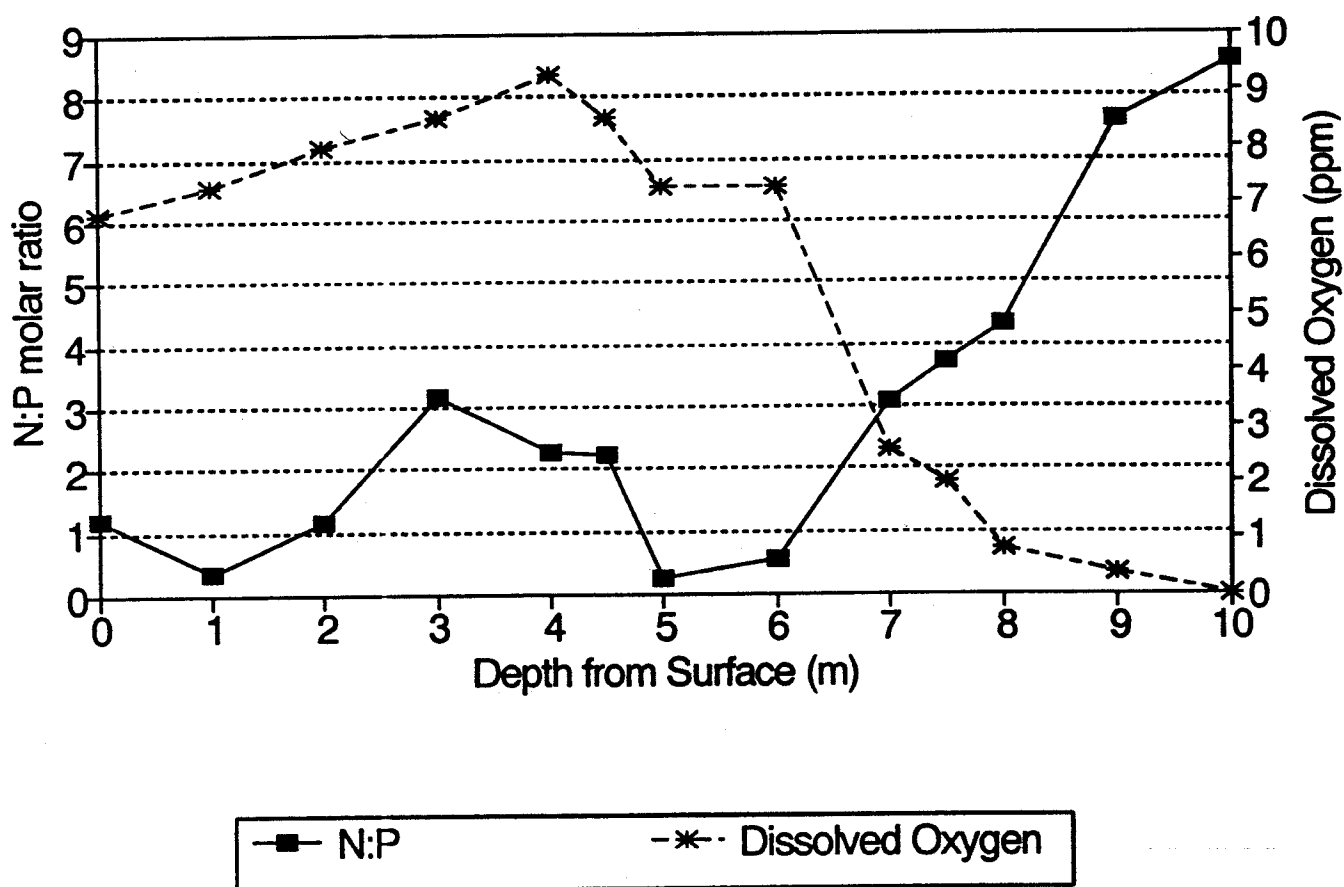


Figure 16. N:P and dissolved oxygen profiles in Salt Pond, Eastham on July 22, 1991.

Salt Pond Chemistry Profiles

July 22, 1991

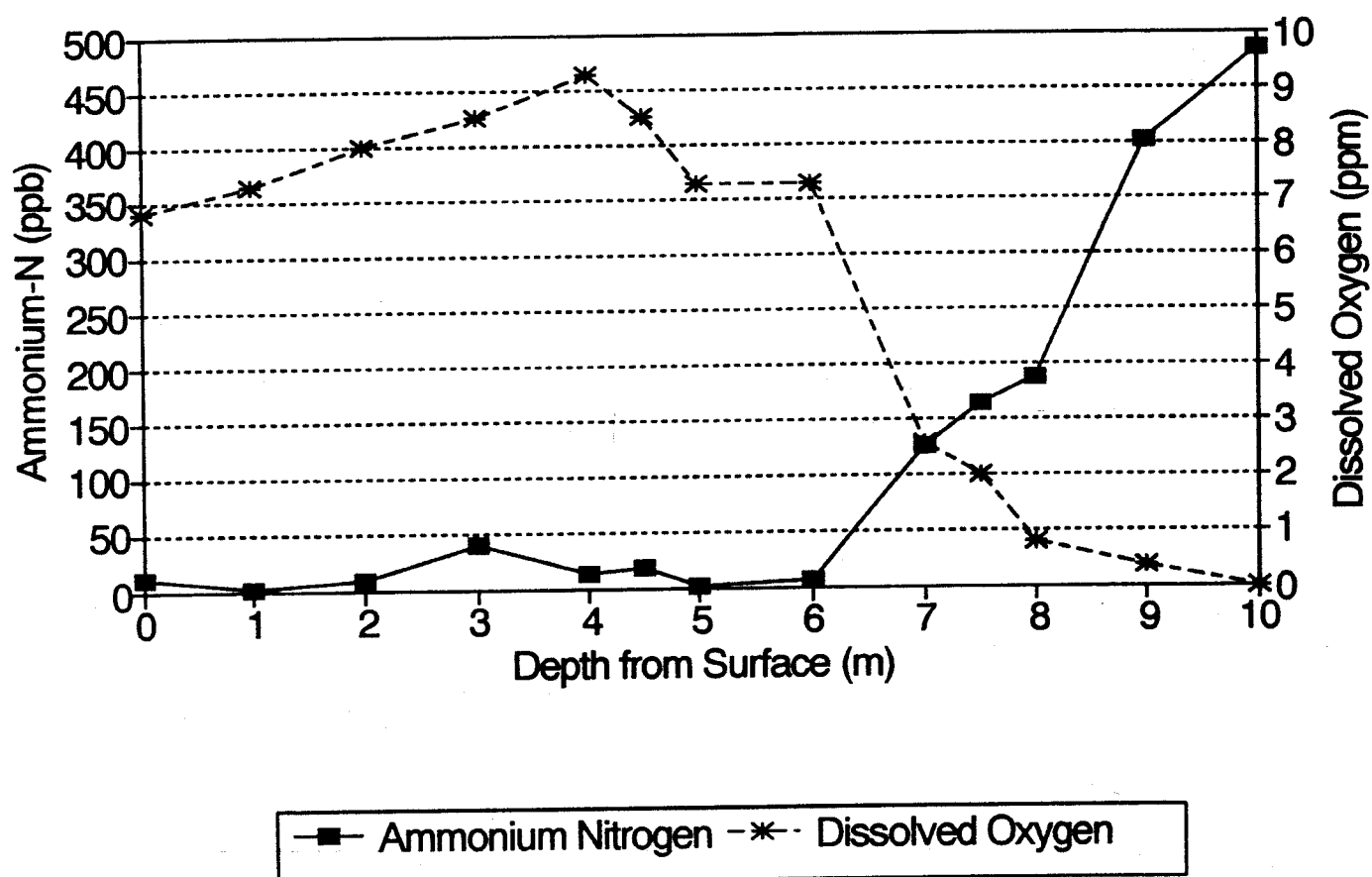


Figure 17. Ammonium-nitrogen and dissolved oxygen profile in Salt Pond, Eastham on July 22, 1991.

KEY TO CLADOPHORA MAP

<u>Intertidal Flat</u>	<u>Description</u>
#1	Mudflat; algae is patchy, but concentrated near the eastern edge. It thins as one moves west. The algae is found on small mud hillocks. Most of the green algae is Cladophora, but there is a little Ulva. Some brown was also apparent.
#2	Sandflat; green algae predominant (Cladophora), although there are some browns. All algae is concentrated in a small patch (in red) on the northeast side of this flat. Here immature mussels were found emerging from the bar. The rest of the sandflat was empty.
#3	Mudflat; the eastern portion contains very sparse Cladophora, but the western half is covered with mussels. On this portion, Cladophora, Enteromorpha, Ulva, and brown algae can be found.
#4	Mudflat; very similar to the description of #3 west.
#5	Mudflat; this is the flat where biomass estimates were attempted. The description for flat #3 west characterizes this flat as well.

Figure 18. *Cladophora* flats in Salt Pond Bay, Nauset Marsh, Eastham.

