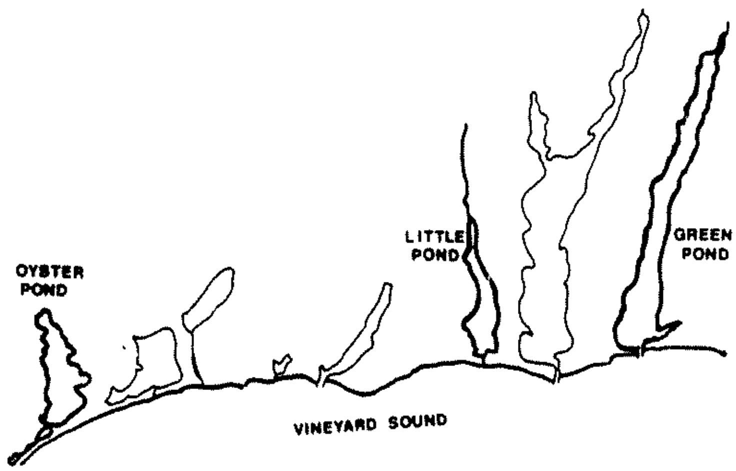
FINAL REPORT ON CITIZEN VOLUNTEER MONITORING OF WATER QUALITY IN FALMOUTH'S COASTAL PONDS



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This cooperative project is conducted with funding from the Woods Hole Oceanographic Institution Sea Grant Program and the Town of Falmouth Planning Office.

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EXECUTIVE SUMMARY

In 1987 a cooperative effort was initiated between the Town of Falmouth and the WHOI Sea Grant Program to address the matter of deteriorating water quality in Falmouth's coastal ponds. This initiative led to the development and implementation of a more comprehensive project in 1988 and 1989 based on the active participation of citizen volunteers in water quality observations and sampling of Oyster, Little and Green Ponds and additional WHOI Sea Grant sponsored projects on coastal ponds being initiated.

The objectives of this "Pond Watcher Project" were 1) to provide the Town with a documentation of the water quality status of the three ponds, 2) to provide information that would assist the Town Planning Office in interpreting the newly enacted Coastal Pond Nutrient Overlay Bylaw, and 3) to generate an increased awareness among the citizenry of Falmouth of the water quality problems facing coastal ponds.

More than 60 citizens volunteered and have taken part in this project. Over the two-year period about half of these people participated in sampling trips on the ponds using their own boats, or became involved in other projects such as oyster growing and rainfall recording. About 600 person-hours were spent by volunteers in connection with this project. Sampling equipment was provided to the "Pond Watchers" by WHOI Sea Grant and training sessions were held to teach sampling techniques. Pond Watchers made measurements in the ponds and prepared samples for nutrient analyses, conducted at WHOI. Sixteen complete sampling trips were conducted between September 1987 and October 1989, ten by Pond Watchers and six by WHOI personnel. The project proceeded very smoothly, largely because of the interest and dedication of the volunteers.

This project has generated a significant body of information about Oyster, Little and Green Ponds. In general terms, the data show pronounced nutrient loading of these ponds. Existing nitrogen levels in each of the ponds already exceed the threshold guideline of 0.5 mg total nitrogen per liter specified for these ponds in the Coastal Pond Nutrient Overlay Bylaw (although the seaward end of Green Pond averages slightly less than 0.5 mg total nitrogen per liter). Moreover, all of Oyster Pond and the upper reaches of Little and Green Ponds exceed 0.75 mg total nitrogen

per liter, the guideline specified for "intensive use areas." Consistent with these nutrient concentrations was our finding of periodic low oxygen conditions during the summer months throughout Little Pond, the upper reaches of Green Pond and seasonal anoxia in the mid and upper regions of Oyster pond -- significant oxygen depletion is the ultimate negative impact of high nutrient conditions -- placing the animal and plant communities in these areas under stress. All of these findings lead to the general recommendation that management options be considered to reduce nutrient inputs (or increase nutrient outputs) to these ponds during the critical summer months.

INTRODUCTION

Like many coastal ponds in Massachusetts, salt ponds in the Town of Falmouth are showing signs of diminished water quality and ecological stress. The causes, while not always clear, appear to involve nutrient loading which may be the result of increasing human pressures on the ponds and their associated watersheds. The population of Falmouth, as well as the other towns on the Cape and Islands, is growing rapidly, bringing intense demand for the desirable properties surrounding coastal ponds. The increased multiple uses of these ponds and their drainage areas are causing nutrient enrichment of these systems. The nutrients derive from a variety of sources including septic systems, lawn fertilizers, road run-off, and other activities associated with residential and commercial developments. The significance of these development-related nutrient inputs depends in part on the relative natural loading and cycling of nutrients in the recipient pond.

Coastal salt ponds, by their nature, are highly productive, nutrient-rich environments, frequently providing areas rich in shellfish. These ecosystems are generally able to tolerate high nutrient loads but, due to their high productivity and low flushing rates, run the risk of suffering from the extremely negative impacts of over-fertilization. Three ponds in particular, Oyster, Little and Green Ponds, presently show signs of advanced eutrophication: dense algal blooms, heavy growth of bottom vegetation, unsightly algal mats, odor production, shellfish contamination and occasional fish kills. Before this present study, most of our environmental assessment of these ponds was based on visual impressions with some quantitative data on water column nutrient levels collected mainly in association with environmental impact studies for commercial and residential developments. However, the data are too few and the sampling too unstructured to provide a sufficient understanding of the nutrient status of these ponds for use in planning and management.

The Town of Falmouth, like many other towns in Massachusetts, faces the difficult questions of when and how to deal with coastal pond water quality deterioration. While it is at present unclear how much of the current nutrient loading problem in Falmouth's coastal ponds is due to development, it is certain that in most situations increased loading will accelerate the decline in water quality and the deterioration of these environments. Management options include enlarging and improving the ponds' outlets to the sea, increased sewerage, restrictions on lawn fertilization, installation of denitrification systems, rezoning, building moratoria, etc. The Town is in need of water quality data and information on these ponds in order to enact management schemes and development policies which will not compromise these outstanding natural assets.

BACKGROUND

In April, 1987, the concern over the increasing eutrophication of Oyster, Little and Green Ponds was raised at the Falmouth Town Meeting. Dr. William Kerfoot, Chairman of the Salt Pond Planning Committee for the Town of Falmouth, requested that $60,000 be appropriated to have a diagnostic study of the ponds conducted. The Town was very interested in the problems of these ponds, but was unable to provide the required funding. The Town did, however, approve $5,000 as "seed" money (under the auspices of the Town Planning Board) to help initiate a water quality study of the ponds.

Recognizing the deterioration in the water quality of these ponds, Dr. David Ross, Coordinator of the Woods Hole Oceanographic Institution Sea Grant Program as well as a Town Meeting Member, indicated that WHOI Sea Grant would try to help the Town in this regard.

During the summer of 1987, Dr. Alan White, Marine Science Advisor with WHOI Sea Grant, and Dr. Brian Howes, Assistant Scientist, and Ms. Dale Goehringer, Research Associate in the Biology Department at WHOI, developed plans for a water quality study of Oyster, Little, and Green Ponds (Fig. 1). The project consisted of two parts, a preliminary survey followed by a comprehensive two-year water quality monitoring study in 1988 and 1989 involving the participation of citizen volunteers.

The purpose of the project was to provide the Town with comprehensive documentation of present water quality conditions in the ponds. The Town requires

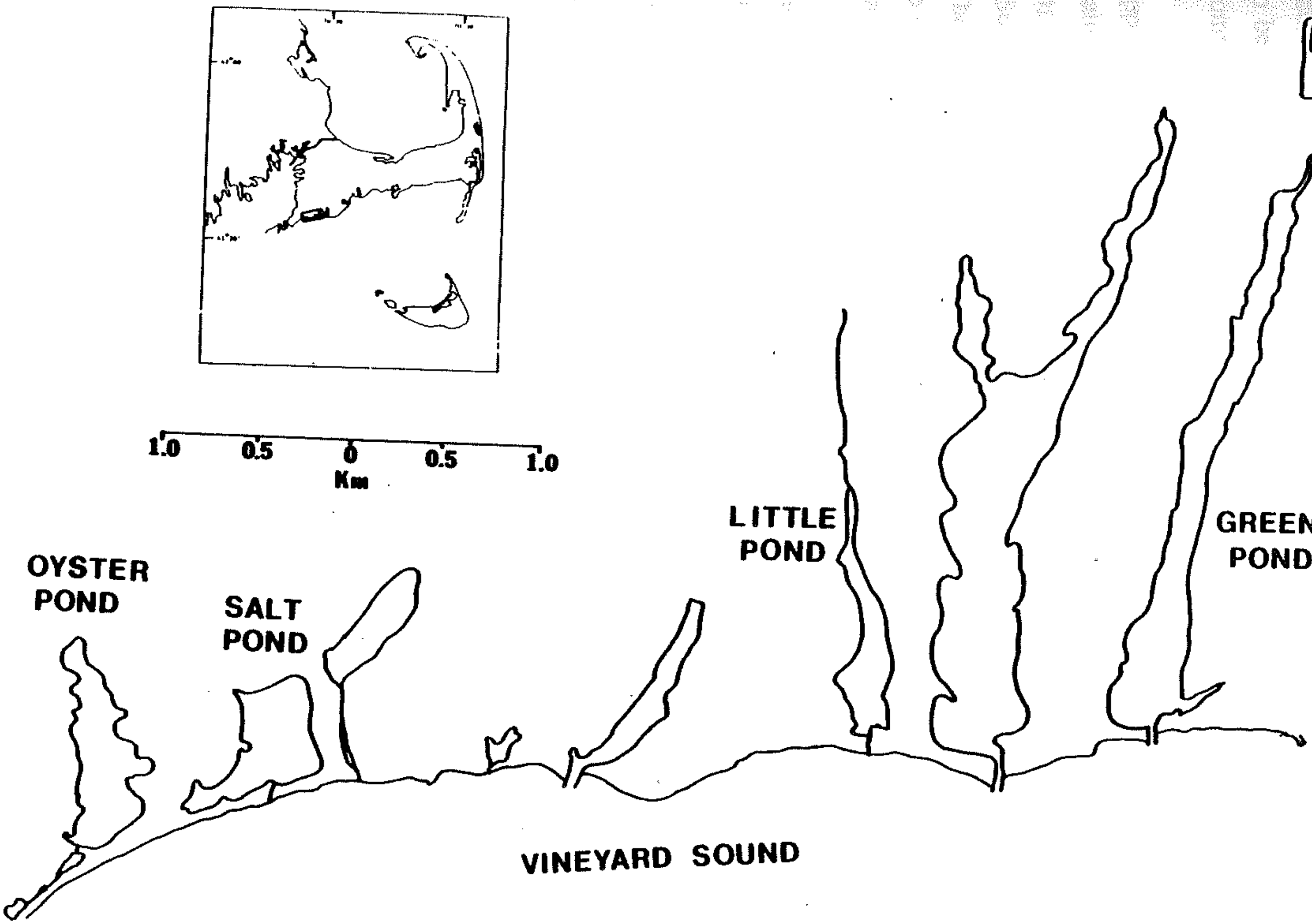


Figure 1. Relative location of the coastal salt ponds, Falmouth, MA. Little, Green and Oyster Ponds have been identified as areas of environmental concern by the Town of Falmouth.

the data for planning and for assessing the effectiveness of future management actions. Further, the project was designed to give concerned citizens an opportunity to become directly involved in the future of Falmouth's coastal ponds and to draw community attention to the increasing human pressures on these coastal resources.

At the Town Meeting in April, 1988, a Coastal Pond Overlay Bylaw was approved to preserve water quality. The Bylaw specified annual mean threshold values for total nitrogen concentrations in Falmouth's coastal ponds as follows: 0.32 mg total nitrogen per liter for "High Quality Areas," 0.50 mg per liter for "Stabilization Areas," and 0.75 mg per liter for "Intensive Water Activity Areas." Therefore, as this citizen-based water quality study developed, a further objective was to provide information to the Planning Board to assist it in assessing and interpreting the new Bylaw.

Funding for the preliminary survey and the first and second years of citizen monitoring has been provided jointly by the Woods Hole Oceanographic Institution Sea Grant Program and the Town of Falmouth Planning Office.

Preliminary surveys were conducted in the fall of 1987 and the spring of 1988. These surveys provided an initial data base and set the stage for the citizen volunteer component of the project in terms of developing sampling protocol (station locations, sampling depths, equipment needs, parameters to be measured, etc.). The citizens' monitoring effort began in the late spring of 1988. Through the enthusiasm, interest and selfless dedication of citizen volunteers ("Pond Watchers") we have very successfully completed the sampling program in 1988 and 1989 and have generated a substantial data set.

VOLUNTEERS

Requests for volunteers for this project were made in May and June, 1988 through newspaper articles (see Appendix 1) and radio and TV announcements. We explained that we were looking for people to perform either of two tasks. First, we needed volunteers who own, or have access to, a small boat and who would be willing to go to certain locations in the ponds once a month to make measurements and take samples -- in mid-July through mid-October, 1988 and mid-May through mid-October in 1989. Second, we needed volunteers who live close to the ponds to serve as the "eyes, ears, and noses" of the ponds and promptly report to us unusual occurrences, such as fish kills, algae mats, strange colors, bad odors, etc. It was stressed that a scientific background was not required for either task, only willingness to contribute.

The response from the community was swift and positive. Within just a few weeks, 55 people (of all ages and all walks of life) volunteered to help with the project. Since then the number of volunteers has increased to 65. A listing of these volunteers, henceforth referred to as "Pond Watchers," is given in Appendix 2.

ORGANIZATION AND TRAINING

An initial organizational meeting of the Pond Watchers was held on June 30, 1988 at Town Hall to explain the project, its overall goals, and what we expected of the volunteers. At that time, "Pond Captains" were appointed to help coordinate participation and performance for their ponds. These volunteer Pond Captains are as follows:

Oyster Pond	- John Dowling
	- Julie Rankin
Little Pond	- Jack Shohayda
Upper Green Pond	- Frank Souza
Lower Green Pond	- Edmund Wessling
	- Armand Ortins

Training sessions were held at the Woods Hole Oceanographic Institution on the evenings of July 12 and 15, 1988, in preparation for our first volunteer sampling effort on Sunday, July 17. Pond Watchers were shown the various pieces of equipment and participated in a hands-on demonstration of the techniques involved. The sampling protocol (Appendix 3) was explained step-by-step. It consisted of taking temperature, oxygen and light measurements at selected locations at the surface and at various depths and then collecting water samples, some of which were filtered for subsequent nutrient assays. A retraining session was held on May 10, 1989, in preparation for the 1989 sampling season.

EQUIPMENT

Equipment and supplies for Pond Watchers were purchased or fabricated during the spring and early summer of 1988. Eleven sets of sampling equipment and supplies were distributed among the Pond Captains. Each tool box contained a Secchi disc fastened on a fiberglass measuring tape, color wheel, thermometer, filters, filter holders, filtering syringe, forceps, oxygen kit, maps, data sheets, instruction sheets, waste reagent container, pens and pencils, etc. In addition, we provided a cooler for transporting and storing samples, and an instrument for water sampling - Niskin samplers were used for Oyster Pond, pole samplers with bottles attached at fixed locations were used for the shallower Little and Green Ponds.

Electronic (battery-operated) rain gauges were purchased and installed at Pond Watchers' homes at four locations - Oyster Pond, Bob Livingstone; Siders Pond, Alan White; Little Pond, Robert Roy; and Green Pond, Edmund Wessling. Beginning in August, 1988, rainfall amount was recorded on a daily basis by those Pond Watchers. In addition, tide gauge (Joe Johnson) and water column light transmission (Robert Roy) stations were established in Little Pond in May 1989.

SAMPLE LOCATIONS

Based on hydrographic and bathymetric data from the preliminary phase of the project, 15 sampling station locations were chosen as depicted on the maps in Appendix 4. There were four stations in Oyster Pond, four in Little Pond, six in Green Pond, and one at Buoy #2 in Vineyard Sound. Landmarks indicated on the maps enabled Pond Watchers to collect samples and take measurements at the same spot, or close to it, each month.

The depths at which samples were taken are listed in Appendix 5. Again, based on the hydrographic and bathymetric information from the preliminary study, these depths were chosen so as to provide data from the different strata (layers) of the pond.

In total, 33 sets of nutrient and particulate samples were taken and 33 sets of measurements were made by Pond Watchers per month.

SAMPLING LOGISTICS

As funding for the first year of the Pond Watcher project did not begin until July 1, 1988, the study was designed to have WHOI personnel collect samples from May through July of 1988 and Pond Watchers from July through October. Upon consensus of the Pond Watchers, the time of sampling was agreed to be Sunday mornings between 9 am and 12 noon. Prior to sampling days, Pond Captains ensured that teams of Pond Watchers (at least two per boat) were prepared to make the trip and were aware of their station designations, had adequate supplies, etc. Early in the morning on sampling days, Alan White telephoned Pond Captains to give them the "go" or "no go" for sampling, depending upon the weather and pond conditions. Fortunately, the weather was suitable for sampling on all 10 occasions in 1988 and 1989; no postponements were necessary.

Following sampling, Pond Watchers returned their samples (in coolers) and data sheets to their Pond Captains. Pond Captains kept the samples cold until Monday morning, when the samples and data sheets were collected by WHOI project personnel and returned to Brian Howes' laboratory for processing and analysis.

The dates of sampling are as follows:

September 16, 1987 (WHOI)
October 19, 1987 "
May 27, 1988 "
July 6, 1988 "
July 17, 1988 (Pond Watchers)
August 14, 1988 "
September 11, 1988 "
October 16, 1988 "
January 18, 1989 (WHOI)

March 7, 1989 "
May 21, 1989 (Pond Watchers)
June 11, 1989 "
July 16, 1989 "
August 13, 1989 "
September 10, 1989 "
October 15, 1989 "

POND WATCHER MEASUREMENTS AND ASSAYS

Following the protocol specified in Appendix 3, Pond Watchers obtained the following information for each sample location and entered it on their data forms:

total depth
temperature
light penetration (Secchi disc reading)
water color
oxygen content (using Hach kit)
comments on pond state, weather, etc.

In addition, Pond Watchers collected water samples and filtered portions of each. These water samples were kept in coolers with ice packs until they reached the laboratory where salinity and nutrient analyses were conducted as described below.

LABORATORY ASSAYS

In Brian Howes' laboratory at the Woods Hole Oceanographic Institution, a research team processed the water samples and conducted analyses to determine concentrations of the following nutrients:

nitrate plus nitrite
ammonium
dissolved organic nitrogen
particulate organic nitrogen

particulate organic carbon
dissolved organic phosphorus
phosphate
chloride

Salinity was determined by refractometer. For some samples taken during the preliminary survey phase of the project, sulfide and chlorophyll analyses were also conducted.

In total, more than 5,200 analytical determinations were made in the laboratory, coupled with more than 1,600 readings made in the field (depth, temperature, light, color, oxygen).

The results of the laboratory analyses and field measurements of oxygen and temperature are combined to produce an overall assessment of water quality conditions in the three ponds.

OYSTERS

In 1989 the Pond Watchers conducted an ancillary water quality project aimed at assessing the degree to which the ponds would support the growth of oysters.

In June oyster seed (certified disease-free) were obtained through the courtesy of Ocean Pond Corporation, Fishers Island, NY with the assistance of the Cotuit Oyster Company. On June 21 a team of volunteers weighed, measured, and numbered 600, thumbnail-size oysters. One hundred oysters were placed in each of six lantern net cages and suspended off the bottom at the six sites shown on the maps in Appendix 4 (two in Oyster Pond, one in Little Pond, two in Green Pond, and one in Vineyard Sound near the WHOI Shore Lab dock as a control).

The oysters were checked and cleaned at about weekly intervals by the following Pond Watchers:

Oyster Pond - Robert Livingstone and Barry Norris;
Little Pond - Robert Roy;
Green Pond - Stephen Molyneaux, Michael Kinney, and
John Quinn;
Vineyard Sound - Alan White.

The oysters were harvested on December 10 and total weight, shell length and displacement volume were measured on December 11 to determine growth. The oysters were then frozen and two months later the weights of the oyster meats (ash-free dry weights) were determined.

COMMUNICATIONS

One of the goals of this project is to have the project serve as a vehicle for public involvement, awareness, and education concerning Falmouth's coastal ponds and the problems confronting them. The key to opening this opportunity has been the initial group of citizen volunteers who were interested and concerned enough to step forward and offer their time and assistance to help make the project succeed.

During the project we have encouraged a free flow of information between Pond Watchers and project personnel at WHOI. We maintained an "open-phone" policy with Pond Watchers, trying to be of assistance with questions and problems whenever possible. Further, through correspondence with all Pond Watchers on a regular basis we kept them informed of project progress and developments, along with summaries and explanations of certain phenomena in the ponds. On February 7, 1989 and March 23, 1990 WHOI Sea Grant sponsored "science parties" with presentations to inform Pond Watchers of the progress and results of the project as well as demonstrate our appreciation of their volunteer efforts.

We reached many other people in Falmouth, on Cape Cod, and even across the country with information about the concept of citizens' involvement in environmental monitoring and about the Pond Watcher project in Falmouth. News of the project appeared in newspaper articles (Appendix 6), on a number of radio interviews, on a taping for national television (CBN, 700 Club), at presentations given for Falmouth Garden Club's Environment Day and for Buzzards Bay Day, at national meetings on citizens monitoring of the environment held in Rhode Island and New Orleans, and in a nationally distributed directory of citizen volunteer monitoring programs resulting from those meetings.

RESULTS AND DISCUSSION

The sampling program in 1988 and 1989 went extremely well. The field, laboratory, and coordination components all proceeded better than was anticipated when the project was initially proposed. The major factor in the success of the project has been the enthusiastic and conscientious participation and cooperation of the volunteer Pond Watchers. Even the weather cooperated; all sampling trips were held as scheduled. In addition, having a large team of samplers enabled collection of data from all three ponds "simultaneously", which greatly enhances the interpond comparisons and strength of the results.

On all sampling occasions, secchi disk readings in Little Pond and Green Pond indicated that light was available at the bottom of the ponds, at 1% of surface light levels at minimum. Thus macroalgal growth on the bottom might also be a nutrient related concern for these ponds.

Physical/Chemical Processes

Falmouth's coastal salt ponds are relatively shallow, enclosed brackish water bodies that are structured ecologically by high nutrient conditions and relatively low flushing rates. Large variations in physical and chemical parameters exist both from pond to pond and from site to site within ponds. Even so, the basic relationships of nutrients, plant production, oxygen conditions and water exchange are the same as in all coastal salt ponds.

Salinity

Variations in salinity within and between ponds reflect the relative mixing of fresh (stream flow, groundwater inputs, runoff, precipitation) and salt water (specifically, exchange with Vineyard Sound) inputs. All three ponds studied, Green, Little, and Oyster Ponds, have salinities throughout the year that are significantly less than Vineyard Sound. Salinity differences between ponds appears to be directly related to the degree of exchange with Vineyard Sound (the source of salt water). All three ponds exhibit decreasing salinities with increasing distance from their inlets to Vineyard Sound (Figure 2). Green Pond exhibits a strong salinity gradient with salinity increasing from the head toward Vineyard Sound. This is not surprising

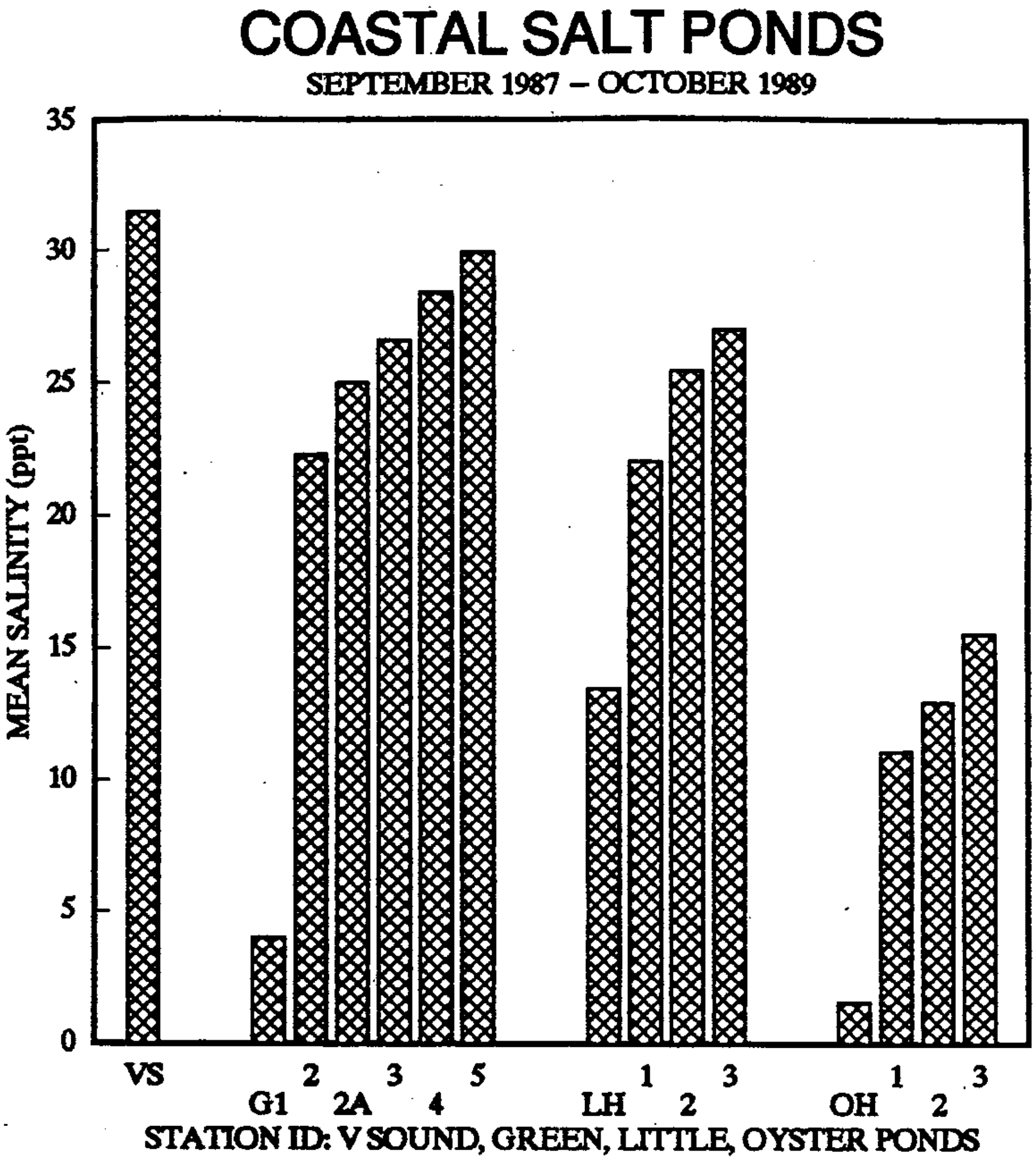


Figure 2. Average salinities for each sampling station within Green, Little and Oyster Ponds. As no strong seasonal trends in salinity were observed, the data from all 16 sampling collections has been combined.

considering the pond length and the surface, freshwater inputs at the head, groundwater discharges along its length, and increasing tidal exchange toward the mouth of the pond. The gradient for Little Pond is similar but less pronounced with the general pond salinities less than Green Pond, primarily because of its smaller size and more limited tidal exchange with Vineyard Sound. Oyster Pond is farther along the continuum and is the "freshest" of the three ponds because of its very restricted exchange with Vineyard Sound. The surface water salinities of Oyster Pond were typically around 10 ppt while water in the deep basin (Station 3) was in excess of 25 ppt. However, the interaction of the bathymetry of Oyster Pond (with its deep basins) and limited tidal exchange has resulted in an historic anoxia of its basins in summer related in part to the strong stratification caused by high salinity (dense) water settling in the basins.

Rainfall

Given the importance of direct nutrient and water inputs from rainfall and groundwater and the large variation in local rainfall which can occur in coastal areas, we are maintaining rain gauges on each of the ponds and on Siders Pond. Investigation of rainfall patterns has emphasized the importance of maintaining site-specific rain collection stations. The ponds show significant variation among them in terms of rainfall; therefore, using any single point (such as the Long Pond station) for measurement of this parameter masks the small-scale spatial variation in precipitation inputs to these ponds. Also, not unexpectedly, comparisons with data collected from Long Pond Station indicate that monthly total rainfall can be significantly different (three to four-fold) from the ten-year average frequently used in models to correlate rainfall to other environmental parameters. By keying each of our pond gauges to the Long Pond Station for several years we hope to determine a correction factor for each pond relative to Long Pond.

Temperature

Coastal ponds differ from adjacent coastal waters in another ecologically important, yet frequently overlooked way. The summer water temperature of the ponds can be more than 5 degrees Celcius (9 degrees Fahrenheit) warmer than

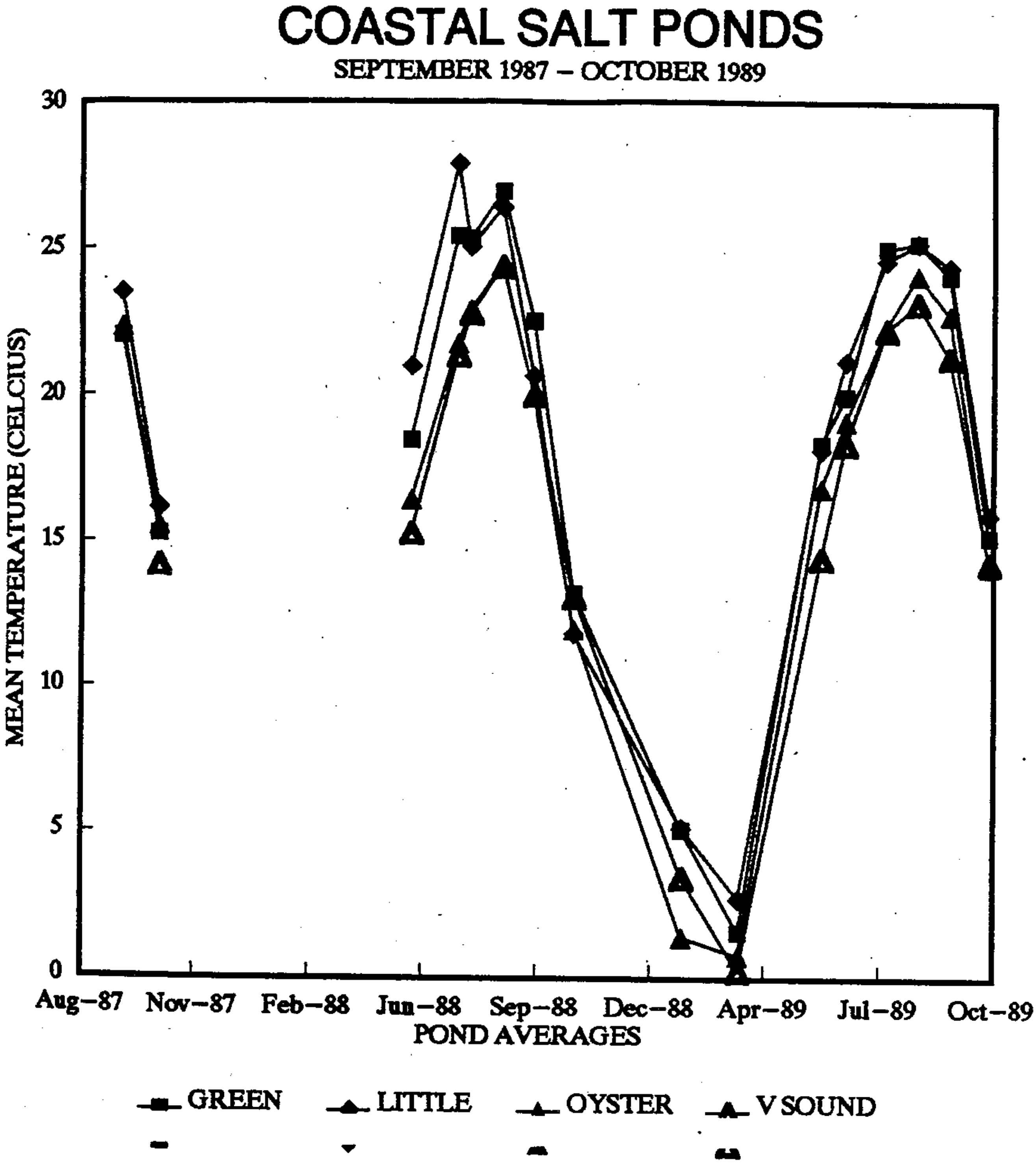


Figure 3. Average temperature of all stations within each pond for each sampling period. Oyster Pond temperatures on average are much closer to Vineyard Sound than Green and Little Ponds due to its much greater depth.

Vineyard Sound (Figure 3). This has biological significance in that increased temperature stimulates respiration, hence oxygen consumption, in these systems. The ponds generally show a gradient from higher to lower temperature from the head toward Vineyard Sound. Some of this temperature variation is due to the shallower nature of the upper regions, some due to increased mixing with cooler Vineyard Sound waters near the pond entrance. Unfortunately, these conditions place the greatest temperature "stress" on the least well flushed and highest impact areas of the ponds.

Water Column Stratification

Since each of the ponds exhibits some level of estuarine circulation, freshwater flowing toward the Sound over more dense saline water flowing in, the potential for significant water column stratification exists. Stratification has important ecological effects on nutrient rich coastal environments where production of organic matter by plants and phytoplankton is high. The high rates of organic matter production almost inevitably result in high rates of oxygen uptake at night (when photosynthesis ceases) or when the organic matter decays. In a well mixed system oxygen can be replenished from the atmosphere, but in a stratified water column bottom waters become isolated and oxygen concentrations decline.

The existence of water column stratification can be determined from profiles of temperature and salinity. Simply put, cold water is more "dense" (heavier) than warm water and more saline water is more dense than less saline water. Coupling the effects of temperature and salinity we can determine the density of water at a given depth and compare that density with other depths in the water column. If a strong vertical gradient exists, the water column is stratified. For each sampling station within each pond on each sampling time we have determined stratification based on the ratio of the density of the surface (10 cm) versus bottom waters (Figure 4a,b,c,d). Ratios above approximately 1.2 indicate strong stratification and the higher the ratio, the more likely for the situation to persist.

Using this simplified technique, the Vineyard Sound station, as expected, never showed stratification. This results from the strong tidal currents and the small

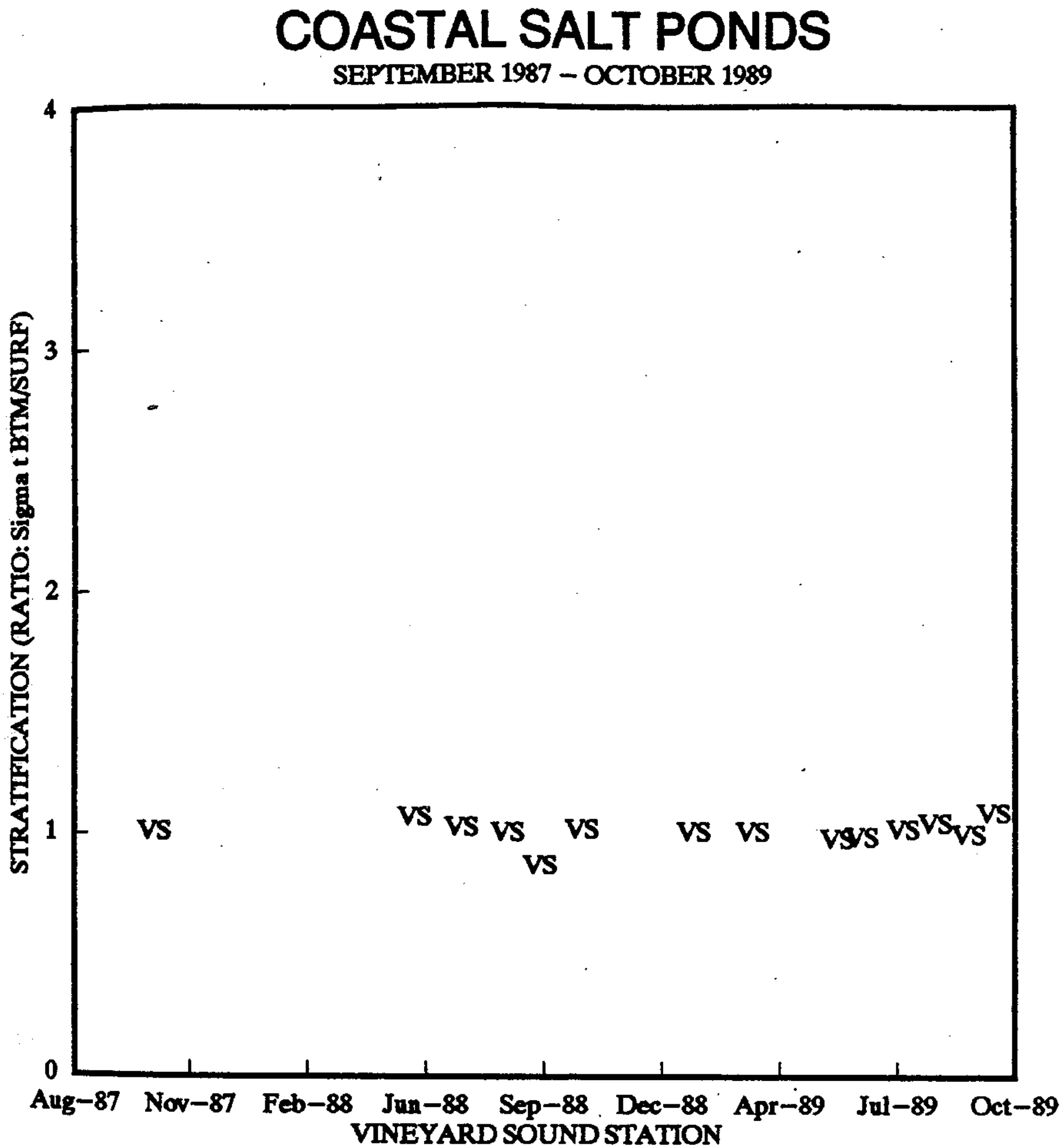


Figure 4 a,b,c,d. Ratio of Bottom to Surface water density for each sampling station and time. Symbols represent sampling station i.d.'s (See Appendix 4). Values greater than about 1.2 represent stratification.

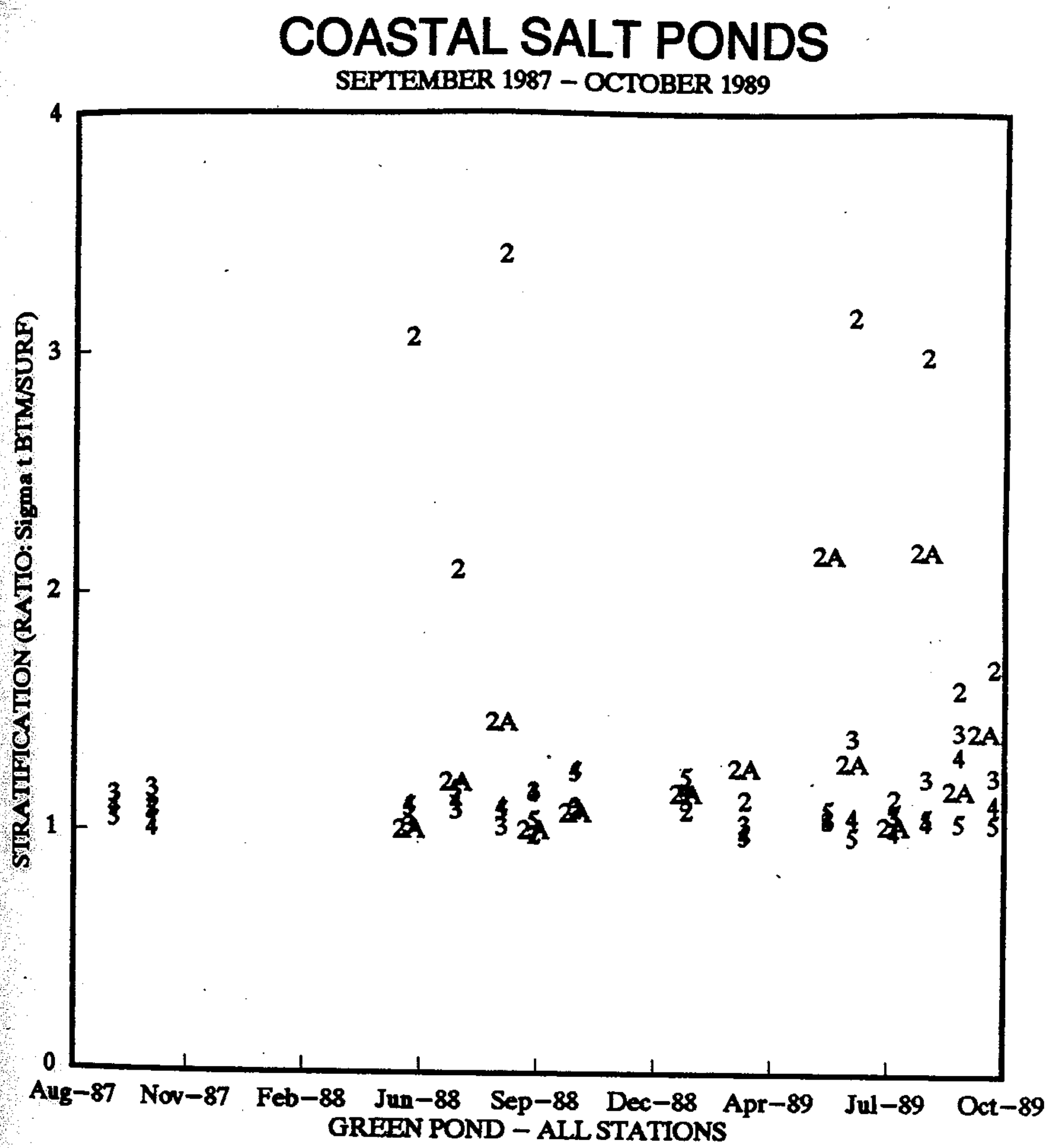

COASTAL SALT PONDS
SEPTEMBER 1987 – OCTOBER 1989
STRATIFICATION (RATIO: Sigma t BTM/SURF)
0
1
2
3
4
Aug–87
Nov–87
Feb–88
Jun–88
Sep–88
Dec–88
Apr–89
Jul–89
Oct–89
GREEN POND – ALL STATIONS

Figure 4 b.

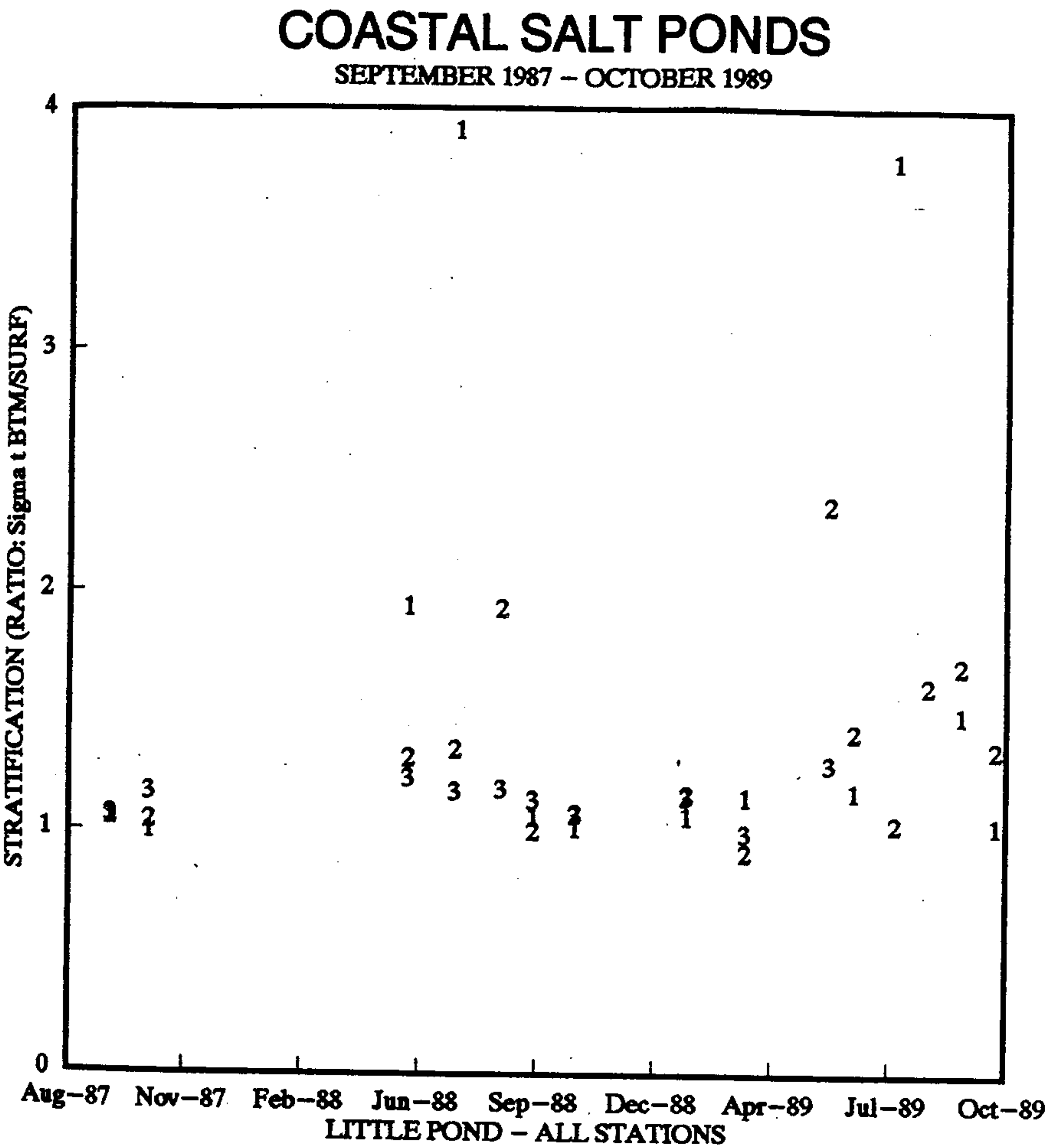
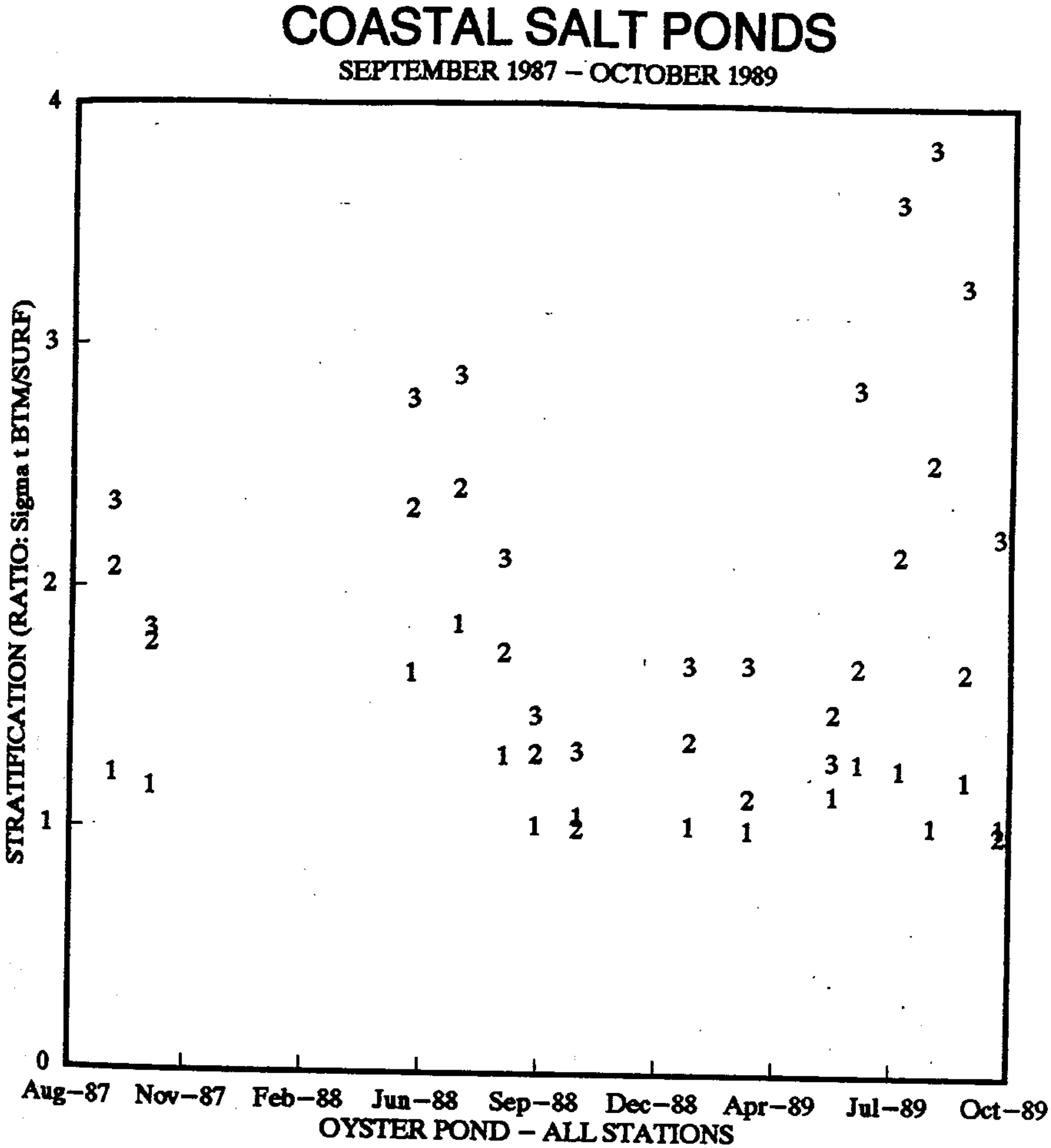

COASTAL SALT PONDS
SEPTEMBER 1987 – OCTOBER 1989
STRATIFICATION (RATIO: Sigma t BTM/SURF)
0
1
2
3
4
Aug–87
Nov–87
Feb–88
Jun–88
Sep–88
Dec–88
Apr–89
Jul–89
Oct–89
LITTLE POND – ALL STATIONS

Figure 4 c.



COASTAL SALT PONDS
SEPTEMBER 1987 – OCTOBER 1989
STRATIFICATION (RATIO: Sigma t BTM/SURF)
Aug–87
Nov–87
Feb–88
Jun–88
Sep–88
Dec–88
Apr–89
Jul–89
Oct–89
OYSTER POND – ALL STATIONS

Figure 4 d.

freshwater input relative to the volume. In contrast, parts of all of the ponds exhibited periods of strong stratification, notably Upper Green Pond (Stations 2, 2a, 3), Little Pond (Stations 1, 2, 3) and Oyster Pond (Stations 1, 2, 3). Oyster Pond Station 3 (near barrier beach) was always strongly stratified due to the 15 ppt difference in salinity between surface and bottom waters.

The most significant ecological factor after the presence of stratification itself was that stratification was a summer phenomenon and in winter (except for one station in Oyster Pond) the water column in all of the ponds was well mixed. This is most likely due to temperature effects and the velocity and direction of winter versus summer wind patterns.

Oxygen

Measurements of water column oxygen concentrations show interesting correlations among water temperature, water column stratification, and oxygen concentrations, and some background information here may be useful to the understanding of their relationships. At high temperatures, the solubility (and therefore concentration) of oxygen in water is low; when water is cooled, oxygen content increases independent of biological activity (cold water holds more dissolved gas than does warm water). This is evident in the measurements conducted in Vineyard Sound, where a decrease in oxygen concentration was found with increased temperature from spring to summer. In this case, the decrease could be accounted for solely by physical processes influencing the solubility of the gas. In the ponds, however, biological factors are much more prominent and frequently obscure the purely physical effects. When water temperatures in the ponds increase, biological activities also increase which consume oxygen. Oxygen depletion occurs when the rate of consumption exceeds the rate of delivery to the water either from the atmosphere or from photosynthesis. In waters that are vertically well mixed, oxygen exchange with the atmosphere can maintain oxygenated conditions even at high rates of consumption. However, as we have seen (Figure 4), even though the coastal ponds are shallow, they are not vertically well mixed. In summer they can become significantly stratified, potentially leading to severe oxygen depletion. Since the amount of oxygen in water changes with temperature due to physical factors, it is more relevant to gauge oxygen conditions based on percentage of saturation. In this way, samples from a variety of temperatures and salinities can be directly compared and water quality concerns directly addressed. Values of 100% of saturation represent a water column in equilibrium with the atmosphere. Although there is currently much scientific debate over acceptable oxygen values, it is certain that evidence of oxygen concentration below 80% of saturation indicate a system experiencing ecological stress. Vineyard Sound showed no significant oxygen depletion. This is expected from the well mixed nature and high water quality of Vineyard Sound waters (Figure 5a). Consistent with the summer occurence of water column stratification at Upper Green Pond (Station 2, 2a, 3; Figure 4b), Little Pond (Station 1, 2, 3; Figure 4c) and Oyster Pond (Station 1, 2, 3; Figure 4d), these stations all exhibited significant oxygen depletions in their bottom waters (Figure 5b, c, d). Oxygen depletion at these stations were frequently about 40% below atmospheric equilibrium and represent stressful conditions to both animal and plant communities. However, periods of oxygen depletion were not always correlated with stratification. This suggests that the high levels of oxygen uptake within pond sediments and water column are sufficient to deplete oxygen even under mixed conditions and indicates that periodic anoxia (absence of oxygen) may be occurring at these sites.

As large as they were, the oxygen depletions measured in this study must be regarded as minimum depletions. This is due to the fact that the measurements were made in late morning after photosynthesis had resumed, hence oxygen production by plants was underway. Our work in other coastal salt ponds and specifically in Little Pond indicates minimum oxygen conditions occur near dawn after the maximum period of darkness, with a return above 80% of saturation by late afternoon. The oxygen conditions are the best evidence that the existing nutrient conditions are in a range incompatible with the maintenance of stable animal communities. More information on the oxygen concentrations in the ponds in relation to nutrient and

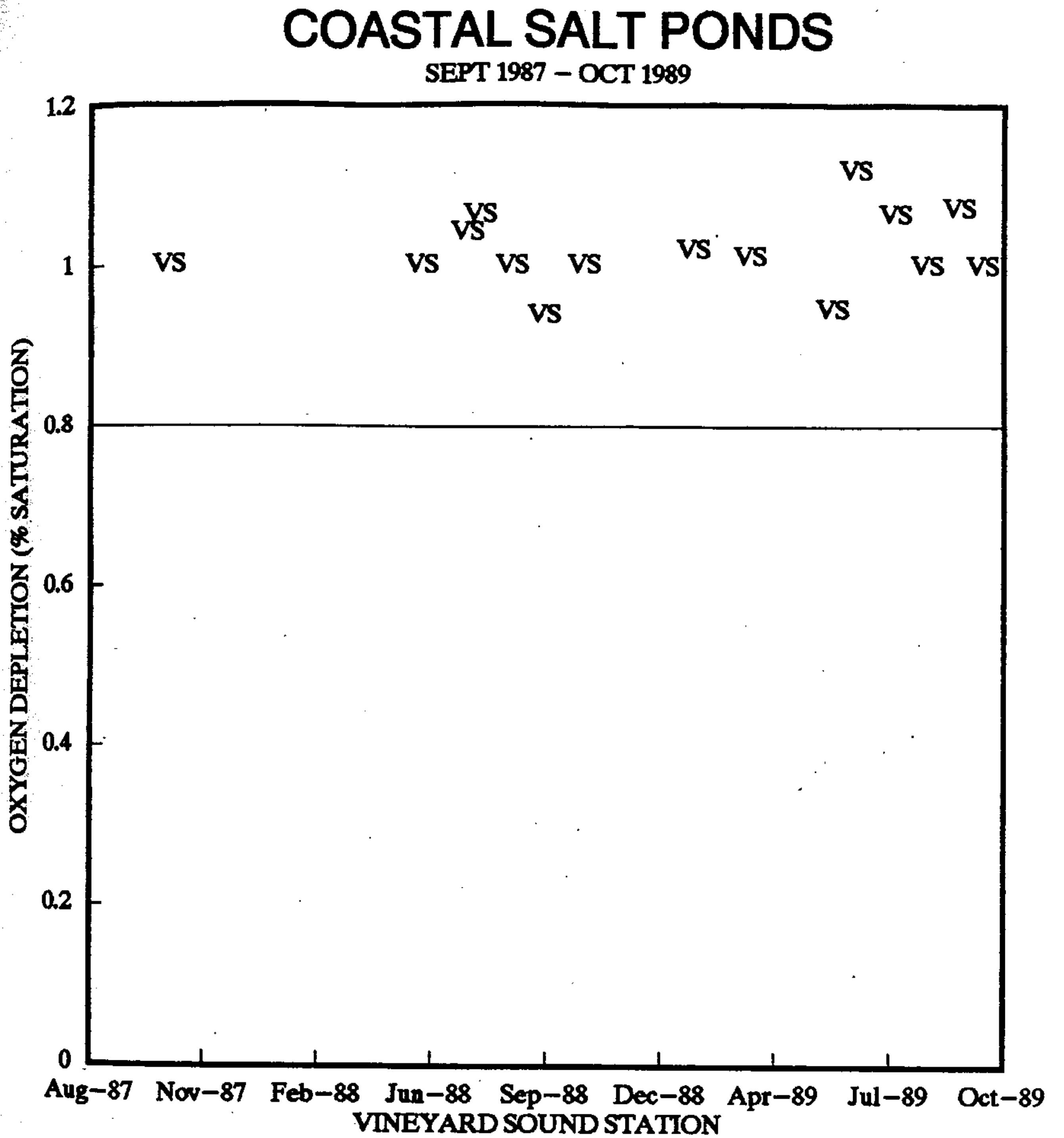


Figure 5 a,b,c,d. Oxygen concentration in bottom waters over stations and times as % of atmospheric equilibration. Values below 80% indicate potentially stressful conditions.

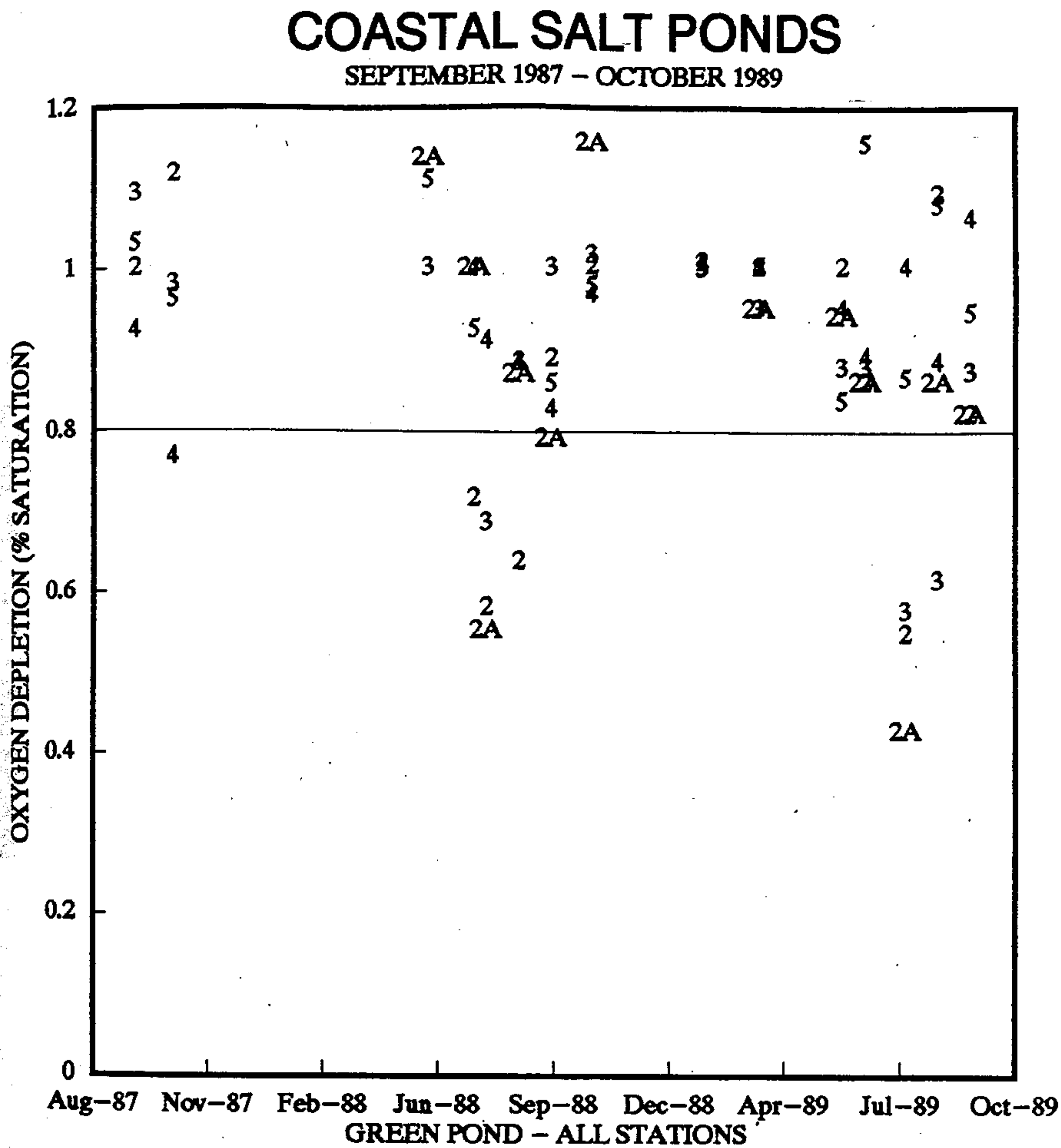
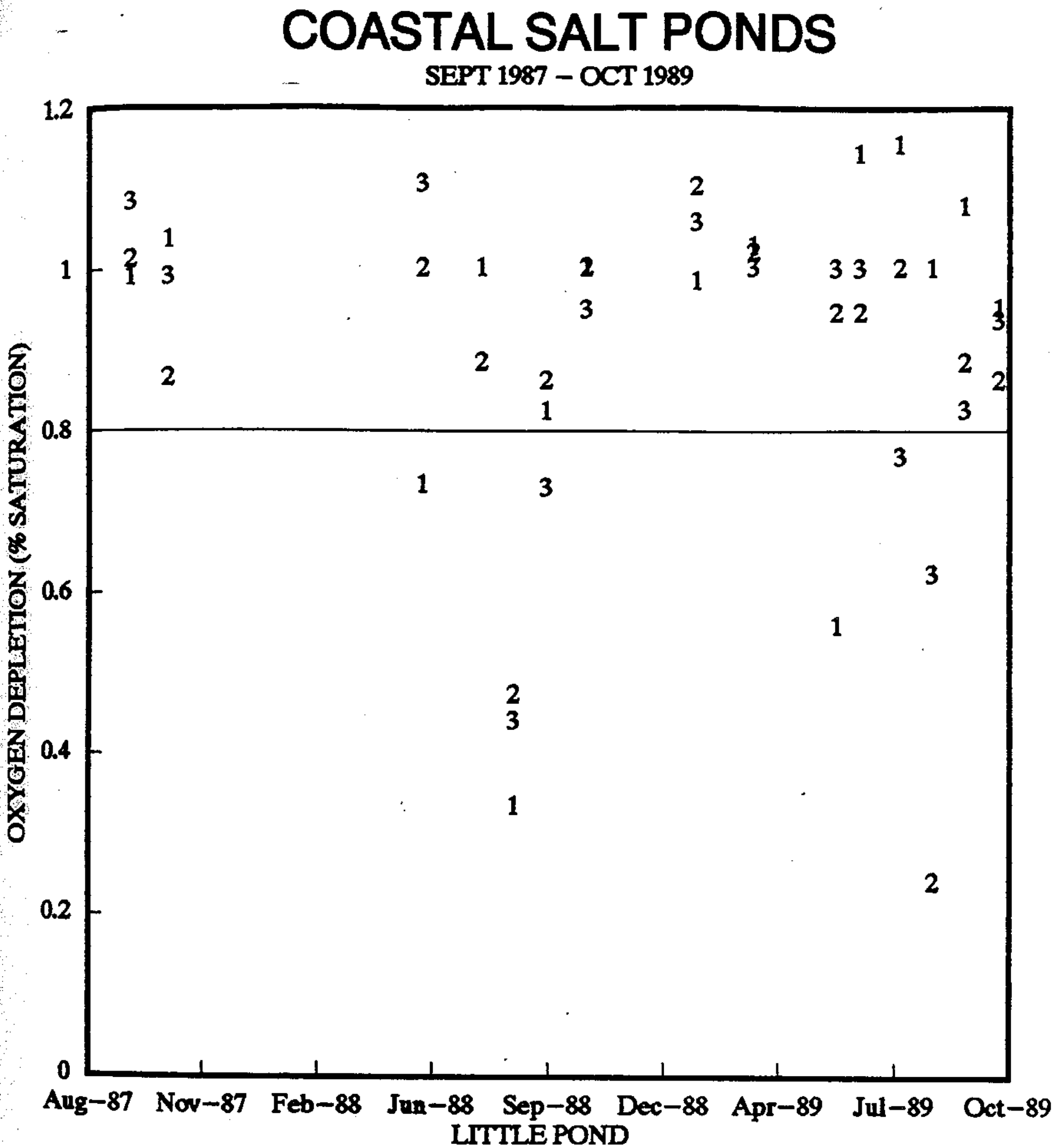

COASTAL SALT PONDS
SEPTEMBER 1987 – OCTOBER 1989
OXYGEN DEPLETION (% SATURATION)
1.2
1
0.8
0.6
0.4
0.2
0
Aug–87
Nov–87
Feb–88
Jun–88
Sep–88
Dec–88
Apr–89
Jul–89
Oct–89
GREEN POND – ALL STATIONS

Figure 5 b.



COASTAL SALT PONDS
SEPT 1987 – OCT 1989
OXYGEN DEPLETION (% SATURATION)
1.2
1
0.8
0.6
0.4
0.2
0
Aug–87
Nov–87
Feb–88
Jun–88
Sep–88
Dec–88
Apr–89
Jul–89
Oct–89
LITTLE POND

Figure 5 c.

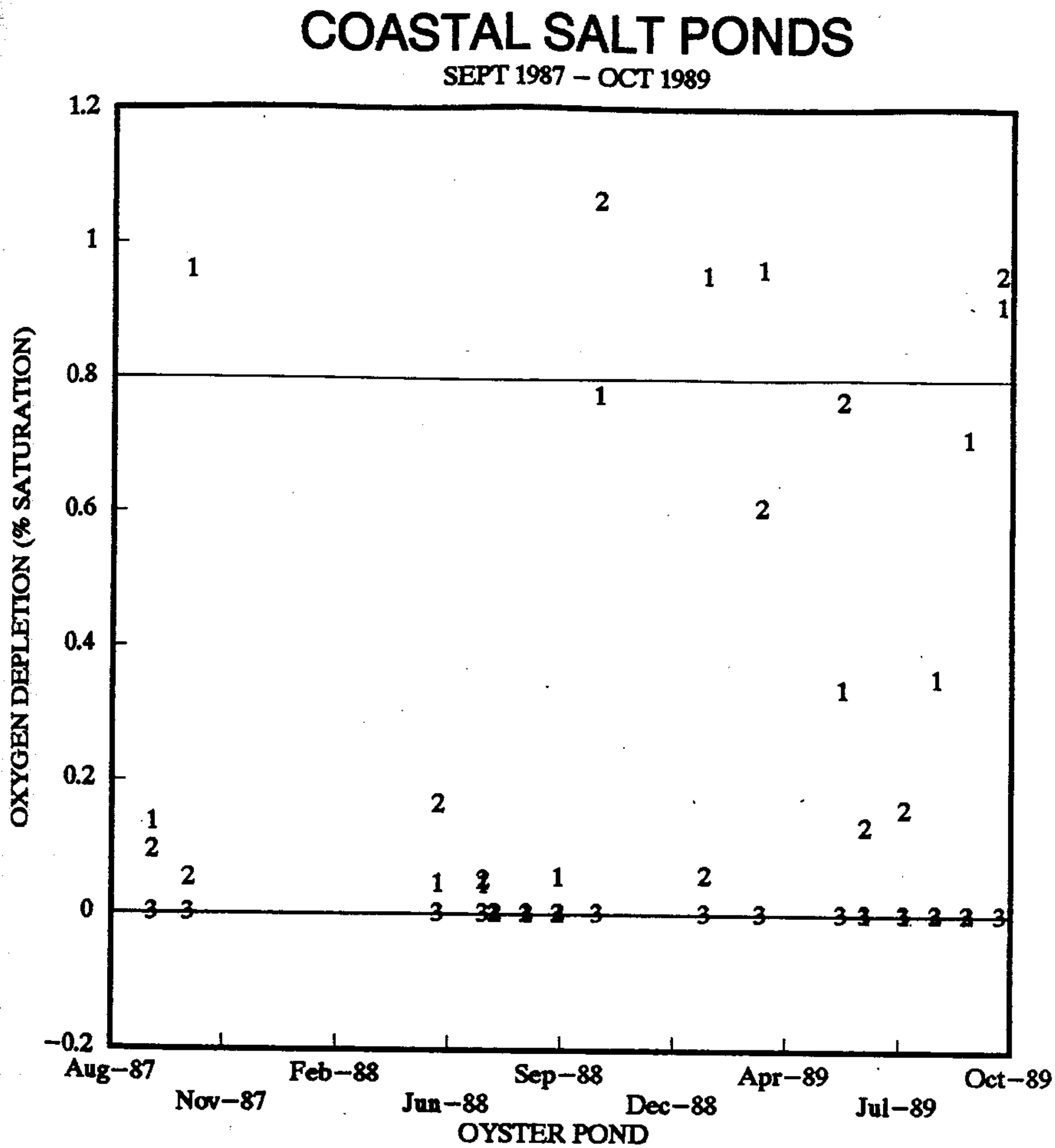

COASTAL SALT PONDS
SEPT 1987 – OCT 1989
OXYGEN DEPLETION (% SATURATION)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
Aug-87
Nov-87
Feb-88
Jun-88
Sep-88
Dec-88
Apr-89
Jul-89
Oct-89
OYSTER POND

Figure 5 d.

physical parameters is critical to determining the overall environmental health of these systems.

Oyster Pond was the only pond to have sites of seasonal anoxia, i.e. no oxygen all summer and oxygen all winter. Both inland basins (Stations 1 and 2, Figure 5d) showed significant oxygenation during winter months. However, the summer anoxia will prevent the establishment of benthic communities at these sites. It is clear that the basins have experienced summer oxygen depletion for many years, likely a result, at least in part, of the physical configuration of the pond.

NUTRIENTS

Nutrient loading, primarily via groundwater inputs, affects each pond differently depending upon the variety of physical parameters to which each is subject. Primary factors that modify the ecological impacts of nutrient loading are flushing rates, stratification, temperature (oxygen consumption) and the form of nitrogen involved (inorganic/organic). Nitrogen is generally the limiting factor for plant growth in saltwater systems. It is for this reason that we have focussed primarily on nitrogen concentrations. In this study, total nitrogen was fractionated into inorganic (ammonium and nitrate) and organic (dissolved and particulate) pools. It is the inorganic forms which directly stimulate plant growth and lead to eutrophic conditions, but due to biological processes the form of nitrogen can cycle rapidly through all the pools. Knowing both the amount and form of nitrogen at any location helps to identify its source as well as its potential impact. A good way to evaluate how an ecosystem is responding or how it is processing nutrient inputs is to follow the changing fractionation of the total nitrogen as it moves through the system. Since the Coastal Zone Overlay uses water column integrated nutrient conditions, we have integrated our station depth profiles to depth weighted averages.

Green Pond experiences high nitrate inputs especially at the head of the pond, with a decrease in nitrate concentration moving toward Vineyard Sound (Figure 6a). The source of this nitrate entering the headwaters is probably groundwater and the nitrate is rapidly taken up by algae and phytoplankton living on the bottom and in

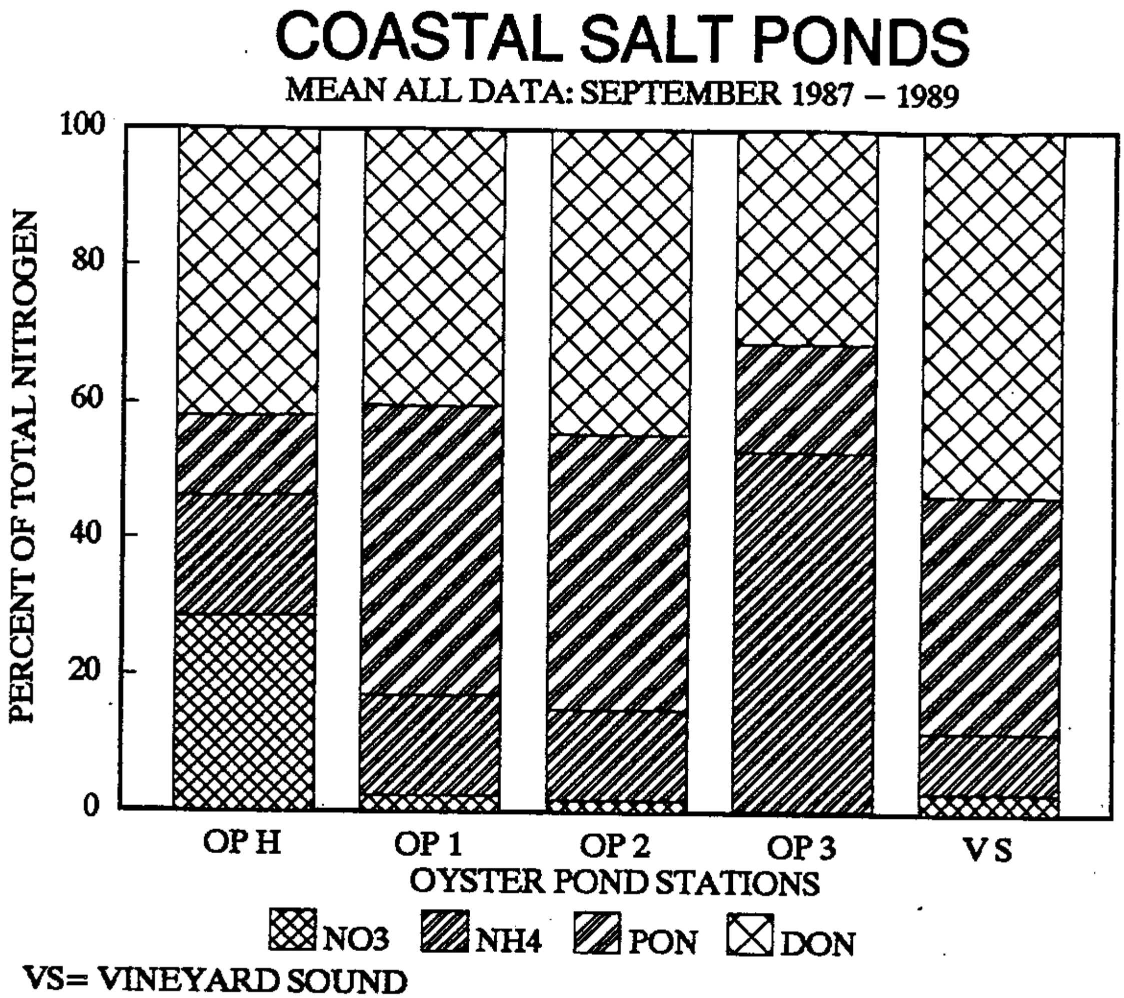


Figure 6 a,b,c. The mean percentage (n=16) of the total nitrogen at each station that consists of nitrate, ammonium, dissolved organic nitrogen (DON), or particulate oragnic nitrogen (PON). All of the ponds transform inorganic nitrogen to organic forms.

the water. Moving toward the Sound we concurrently see a decrease in inorganic forms of nitrogen (nitrate and ammonium) which are directly available for plant growth, and an increase in organic forms (particulate and dissolved organic nitrogen). This is indicative of high rates of plant production, the death and decay of which consumes oxygen. It is important to note that nitrogen at this stage has not been removed from the system, merely transformed into another form. There exists, therefore, a transformation gradient of nutrient forms along the pond, with primarily inorganic nitrogen (nitrate) at the head, and most of the nitrogen at Stations 2, 2A and 3 (Appendix 4) as particulate organic nitrogen (in phytoplankton and zooplankton). It is interesting to note the lowest oxygen concentrations occur where the particulate nitrogen form predominates, and vice versa as observed in Vineyard Sound waters.

The limited flushing experienced by Little Pond results in similar nutrient conditions at all stations in the basin. Preliminary results indicate high levels of nitrate enter the inland pond stations (Figure 6b). This pond exhibits high levels of organic nitrogen (dissolved and particulate) and ecologically stressful oxygen concentrations during part of the summer season. The changing fractionation is much like in Green Pond (Figure 6a). The relative importance of nitrogen transformations within Little Pond versus "new" nitrogen entering in groundwater is the subject of a companion ongoing WHOI Sea Grant project.

While Oyster Pond also acts to transform incoming inorganic nitrogen from the watershed to organic forms, the oxygen conditions of the pond adds an additional feature to the nitrogen distribution (Figure 6c). Due to the deep salinity-stratified basins and minimal flushing, the organic matter produced which falls to the bottom and decays consumes oxygen faster than oxygen can be supplied by mixing, with the result that Station 3 is "permanently" anoxic and Stations 1 and 2 seasonally anoxic. Although there is no oxygen present, additional organic matter falling into these anoxic zones still decays except the released inorganic nitrogen remains as ammonium in the water column (Figure 6c) until it is mixed into the surface waters. Just as stratification "keeps oxygen out", it serves to "keep ammonium in". The result is the accumulation of exceedingly high levels of ammonium (18 mg N/l) especially at Station 3 which is not seasonally mixed. This condition is typical of all anoxic marine basins from Oyster Pond and Salt Pond to the Black Sea. The combination of inputs of "new" nitrogen with "old" nitrogen compounded by high (ammonium) concentrations from the anaerobic bottom waters maintains the nitrogen concentrations at the highest levels found in any of the ponds. Oyster Pond has higher nitrogen concentrations than any of the other stations in either Little or Green Pond. Although the streams entering all three ponds have fairly high levels of nitrogen as nitrate, the original source is as yet unclear and it is not possible with the available data to distinguish between natural and man-induced inputs.

Total nitrogen concentration determined as the sum of nitrate, ammonium, dissolved organic nitrogen and particulate organic nitrogen was calculated for each pond station and sampling period and for the Vineyard Sound station (Table 1). No strong seasonal trends were observed for any stations during this study (Figure 7, 8, 9, 10), although large differences were found between sampling dates due primarily to periodic algal blooms. Vineyard Sound, as expected, had the lowest observed total nitrogen and was consistently less than 0.32 mg N/l and averaged 0.267 mg N/l over the study period (Figure 7). The Upper Green Pond stations (1, 2, 2A, 3) were consistently above 0.5 mg N/l and frequently greater than 0.75 mg N/l; in fact, of these stations, only Station 3 (0.66 mg N/l) had an average total nitrogen value below 0.75 mg N/l (Figure 8 a,b,c,d). Lower Green Pond (Station 4 and 5) exhibited significantly lower total nitrogen levels due primarily to exchange with the low nitrogen Vineyard Sound water, with average values of 0.444 and 0.440 mg N/l, respectively (Figure 8 e,f).

Consistent with its reduced flushing relative to Green Pond, all stations in Little Pond exhibited total nitrogen values approaching or in excess of 0.75 mg N/l (Figure 9 a,b,c,d). In addition, an extensive macroalgal bloom occurred in June and July 1989 which impacted almost all of the pond. Oyster Pond, as discussed above, had the highest levels of total nitrogen with no single pond station having a depth averaged mean concentration of less than 1 mg N/l (Figure 10 a,b,c,d), and in the

SUMMARY DATA CITIZENS MONITORING STUDY
WOODS HOLE OCEANOGRAPHIC INSTITUTION/TOWN OF FALMOUTH
DR. A. WHITE & DR. B. HOWES

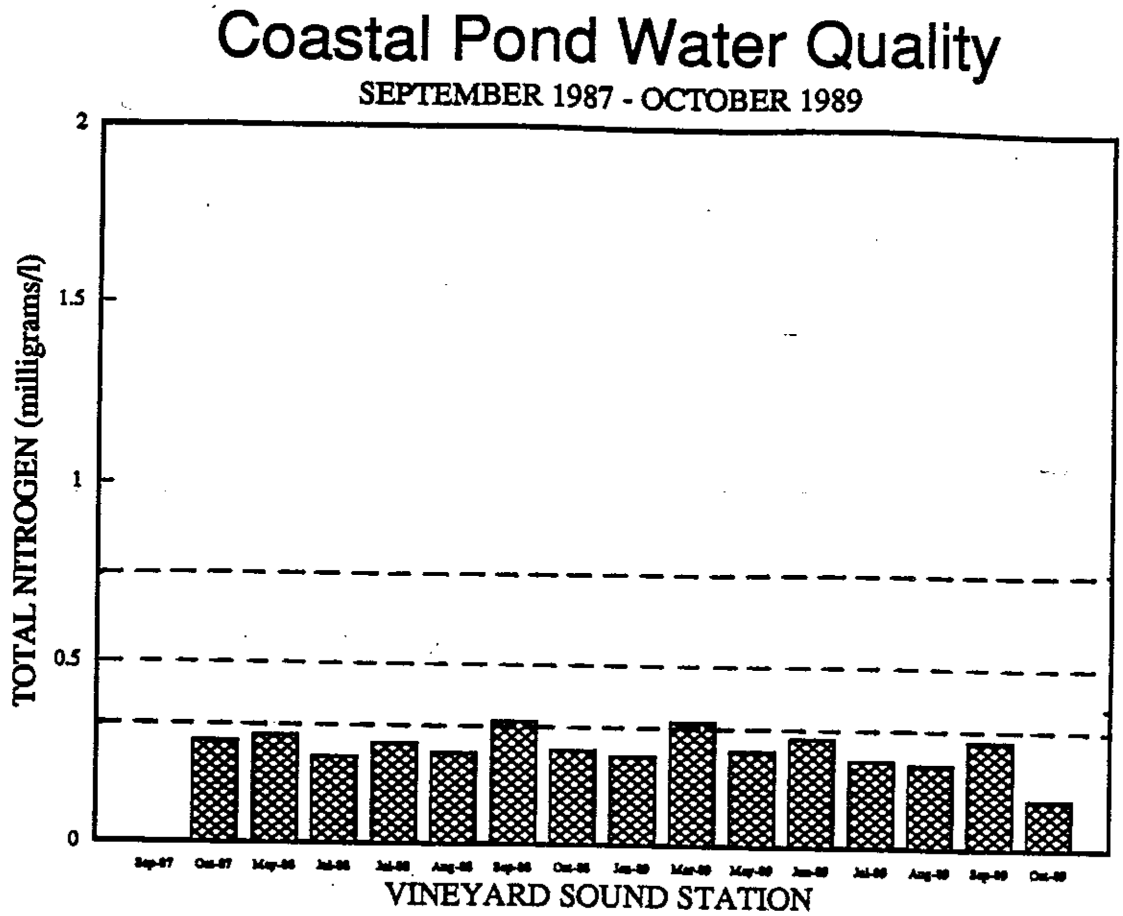
TABLE 1.

******************** TOTAL NITROGEN (MILLIGRAMS PER LITER): WATERCOLUMN AVERAGES BY STATION ********************************

Station	Sep-87	Oct-87	May-88	Jun-88	Jul-88	Aug-88	Sep-88	Oct-88	Jan-89	Mar-89	May-89	Jun-89	Jul-89	Aug-89	Sep-89	Oct-89
GREEN POND																
GP 1	0.847	1.180	1.250	1.507	0.952	1.637	1.656	0.791	1.658	0.593	0.984	1.459	1.113	1.146	1.008	0.841
GP 2	0.954	0.664	1.200	0.644	0.818	1.586	0.837	0.693	1.133	0.430	0.906	0.795	0.884	0.774	0.659	0.733
GP 2A	NA	NA	1.719	0.509	0.546	0.968	0.773	0.498	1.056	0.316	0.839	1.014	0.734	0.763	0.611	0.588
GP 3	0.421	0.786	0.931	0.480	0.451	1.703	0.596	0.824	0.598	0.295	0.614	0.974	0.373	0.525	0.500	0.513
GP 4	0.429	0.395	0.660	0.500	0.431	0.412	0.465	0.389	0.289	0.226	0.558	0.678	0.336	0.550	0.459	0.331
GP 5	0.379	0.436	0.369	0.355	0.312	0.557	0.435	0.283	0.283	0.217	0.428	0.377	0.761	0.511	0.632	0.702
LITTLE POND																
LP Head	3.729	1.154	2.399	2.162	2.351	2.167	0.761	1.047	0.412	1.222	2.651	0.995	1.939	2.976	2.593	1.381
LP 1	0.703	0.847	0.935	1.157	0.910	2.135	0.708	0.991	0.541	0.917	1.758	0.982	1.300	2.244	1.231	1.391
LP 2	0.650	0.670	0.648	0.618	0.753	1.108	0.614	0.452	0.700	0.923	1.224	0.864	0.519	0.680	0.831	0.594
LP 3	0.506	0.808	0.578	0.498	0.580	1.139	0.751	0.609	0.609	0.805	0.678	0.817	0.438	0.376	0.642	1.529
OYSTER POND																
OP Head	NA	NA	NA	NA	2.038	1.644	1.759	1.026	0.972	1.242	0.931	2.053	1.872	2.122	1.922	1.564
OP 1	1.384	1.233	2.028	2.298	2.606	2.927	4.058	2.157	2.465	2.301	1.931	3.863	1.419	1.383	1.445	2.284
OP 2	1.699	2.929	2.845	3.203	2.145	3.389	2.666	2.141	2.428	2.276	2.284	2.148	1.995	1.466	1.588	2.060
OP 3	32.737	30.409	9.512	6.773	5.707	8.402	7.633	11.680	11.118	10.509	7.427	8.503	9.858	7.570	8.942	5.223
VINEYARD SOUND																
VS	NA	0.282	0.299	0.239	0.277	0.251	0.341	0.262	0.246	0.341	0.265	0.299	0.240	0.232	0.296	0.135

************************ STATION AVERAGES (SEPTEMBER 1987 - OCTOBER 1989 ********************************

Station	NITRATE/NITRITE MEAN (uM)	SE	AMMONIUM MEAN (uM)	SE	PARTICULATE N MEAN (uM)	SE	DISSOLVED ORG N MEAN (uM)	SE	TOTAL NITROGEN MEAN (uM)	SE	TOTAL NITROGEN MEAN (milligram/l)	SE
GREEN POND												
GP 1	51.24	6.40	2.64	0.39	14.83	2.23	14.4	2.1	83.1	5.8	1.164	0.081
GP 2	11.80	2.02	2.46	0.42	25.57	4.68	21.4	2.2	61.2	4.7	0.857	0.065
GP 2A	5.85	1.78	1.88	0.34	30.75	6.18	17.3	1.0	55.8	5.9	0.781	0.083
GP 3	3.24	0.88	2.17	0.33	26.45	5.96	15.4	1.1	47.2	5.9	0.661	0.082
GP 4	1.54	0.39	2.27	0.34	12.60	1.62	15.3	1.2	31.7	2.2	0.444	0.030
GP 5	1.35	0.41	2.23	0.32	9.00	0.92	18.4	2.8	31.4	2.7	0.440	0.038
LITTLE POND												
LP Head	60.62	9.63	35.36	5.97	17.90	2.91	19.8	6.9	133.7	15.8	1.871	0.221
LP 1	22.77	4.52	15.01	2.85	21.34	2.86	24.6	4.0	83.7	8.6	1.172	0.120
LP 2	11.84	3.08	5.84	1.39	19.03	2.53	16.2	1.5	52.9	3.6	0.740	0.050
LP 3	6.62	1.96	4.11	0.79	19.17	3.01	20.8	3.4	50.7	4.9	0.710	0.069
OYSTER POND												
OP Head	32.42	5.12	20.29	4.05	13.48	2.82	47.8	6.2	114.0	7.6	1.595	0.106
OP 1	3.71	1.03	23.24	5.11	67.94	8.35	64.4	7.7	159.7	14.5	2.236	0.203
OP 2	2.82	0.91	21.94	5.85	67.35	6.81	74.2	6.6	166.3	9.6	2.329	0.134
OP 3	2.92	0.80	427.60	55.55	128.46	9.96	253.5	88.9	812.5	140.0	11.375	1.960
VINEYARD SOUND												
VS	0.56	0.13	1.71	0.26	6.62	0.94	10.2	1.1	19.1	0.9	0.267	0.012



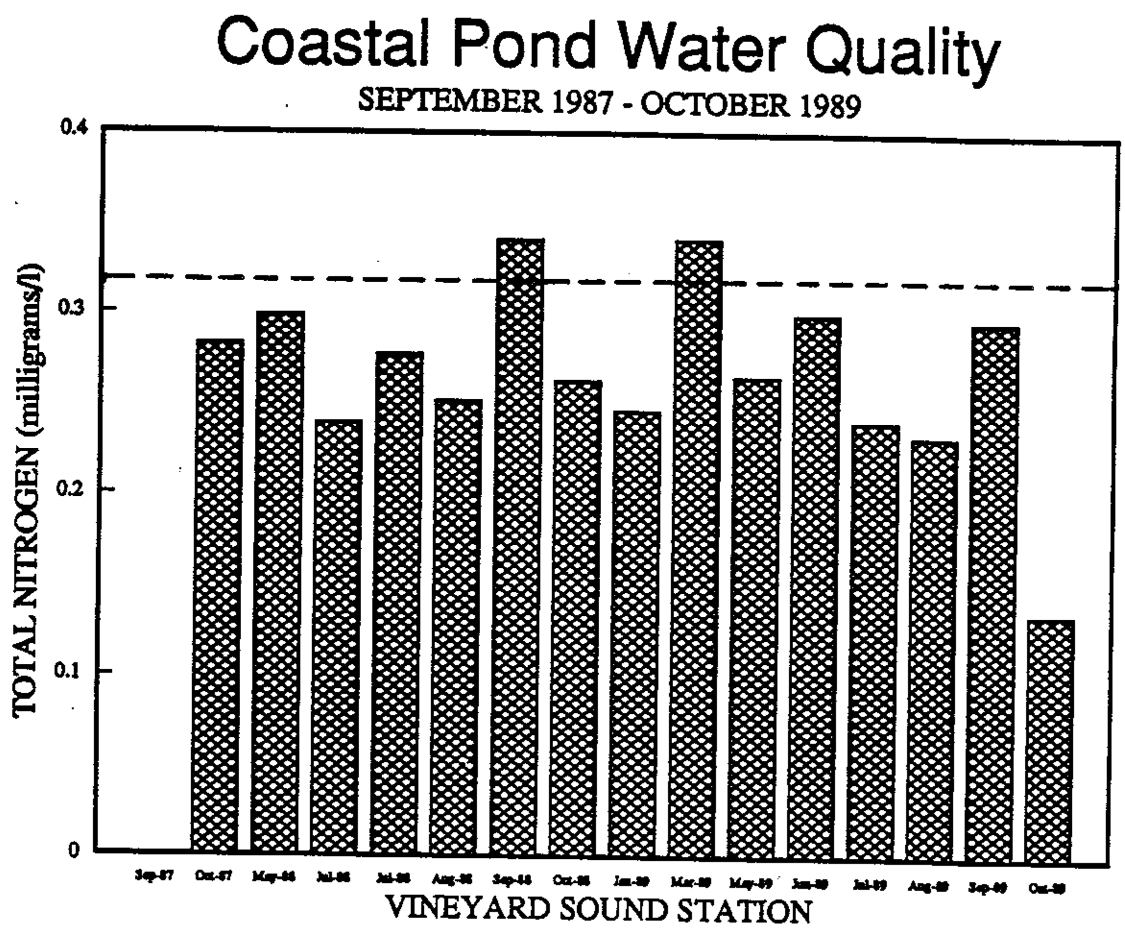


Figure 7. Total Nitrogen for Vineyard Sound Station; depth averaged values for each sampling period.

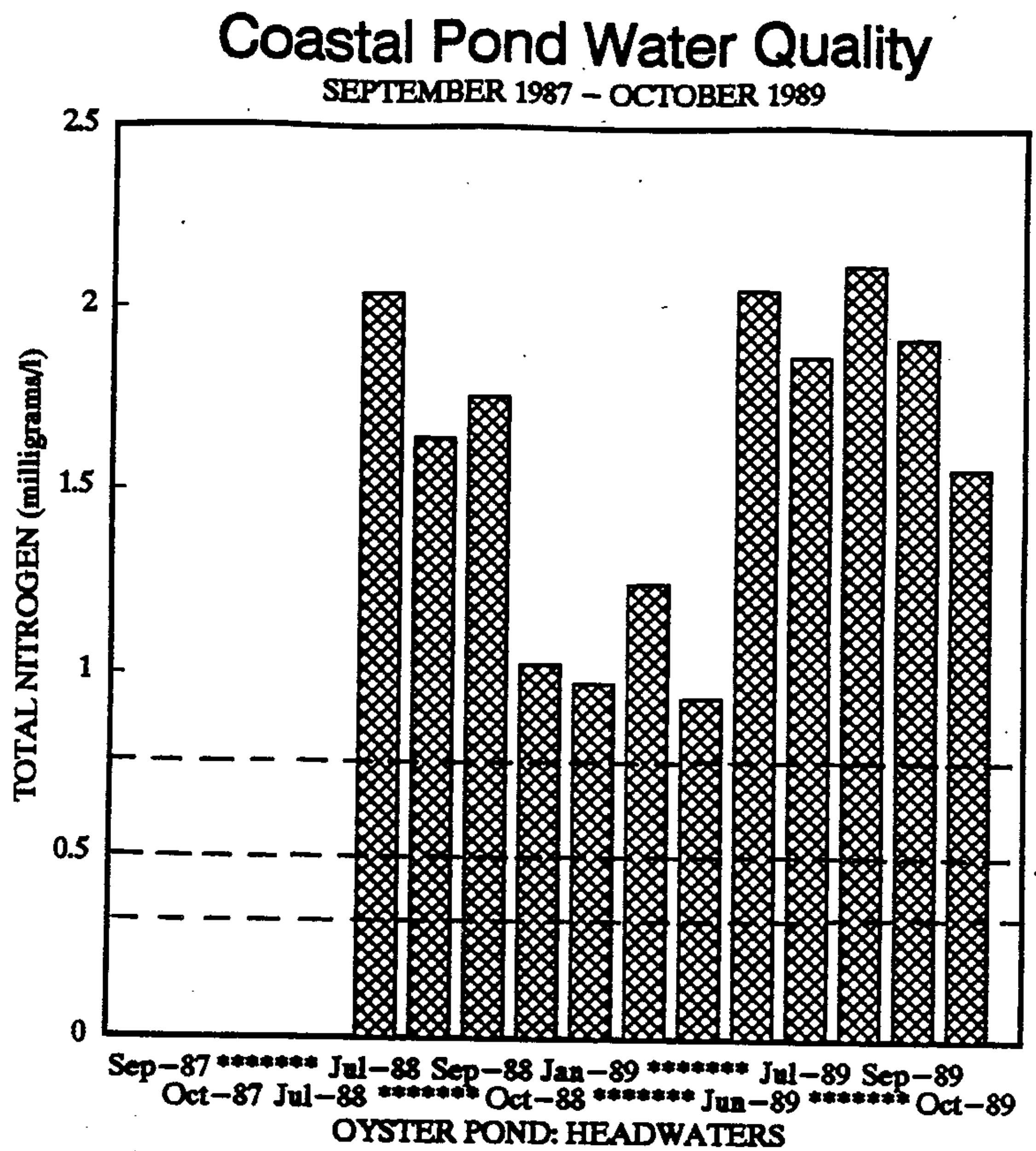


Figure 10 a,b,c,d. Total Nitrogen for Oyster Pond Stations; depth averaged values for each sampling period.

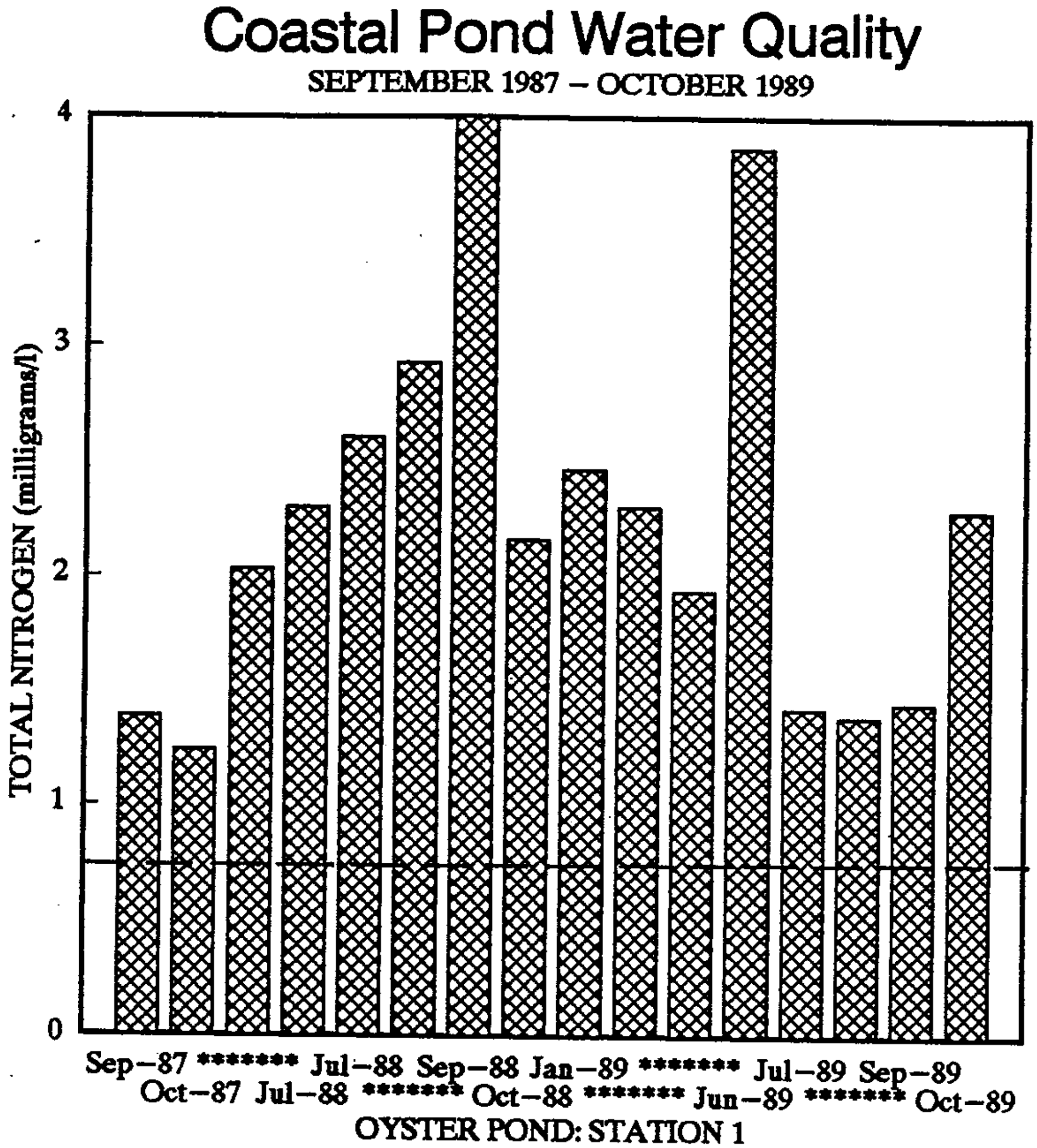

Coastal Pond Water Quality
SEPTEMBER 1987 – OCTOBER 1989
TOTAL NITROGEN (milligrams/l)
0
1
2
3
4
Sep–87
Oct–87
****
Jul–88
Jul–88
****
Sep–88
Oct–88
Jan–89
****
****
Jun–89
Jul–89
****
Sep–89
Oct–89
OYSTER POND: STATION 1

Figure 10 b.

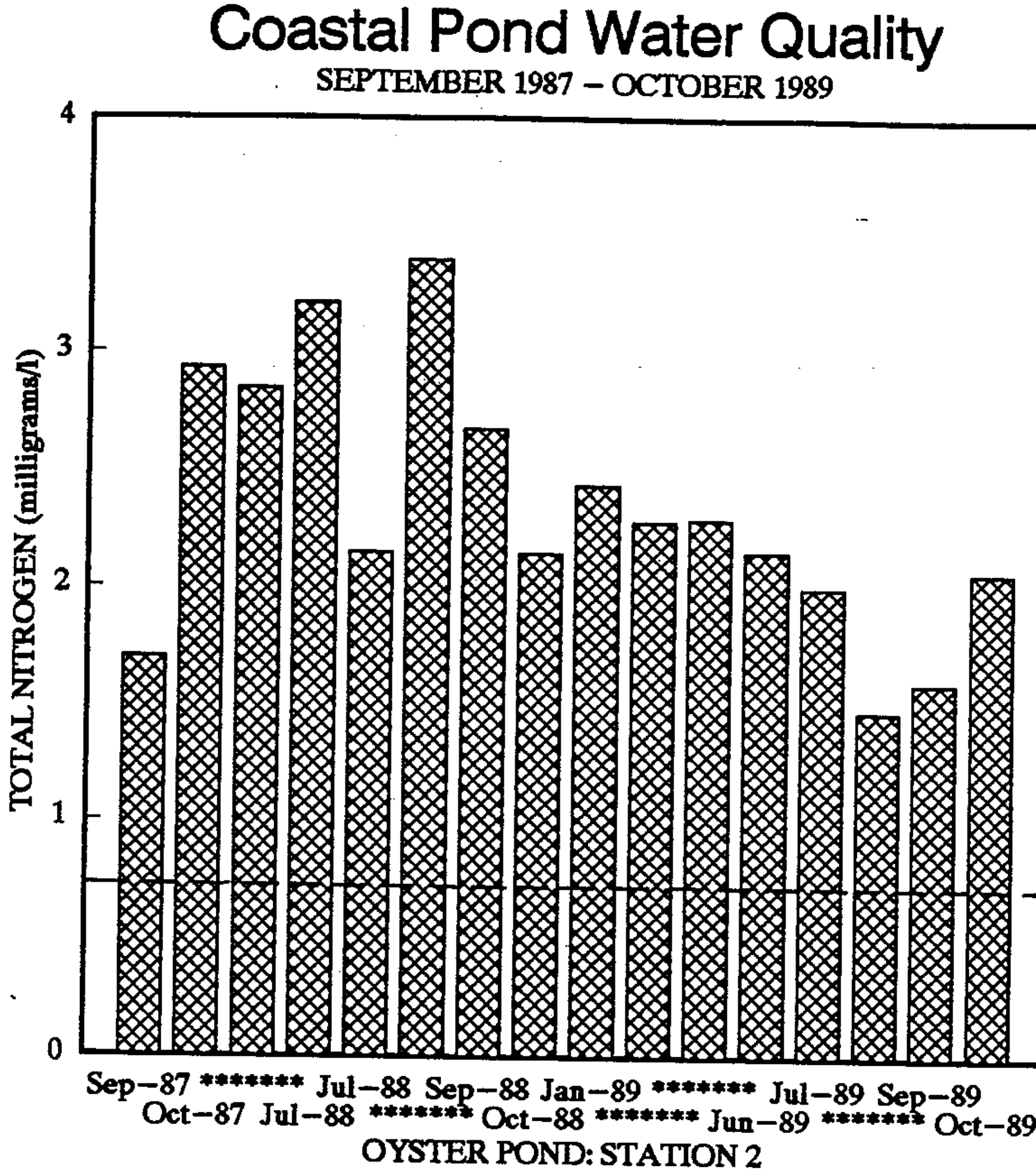

Coastal Pond Water Quality
SEPTEMBER 1987 – OCTOBER 1989
TOTAL NITROGEN (milligrams/l)
0
1
2
3
4
Sep–87 ******* Jul–88 Sep–88 Jan–89 ******* Jul–89 Sep–89
Oct–87 Jul–88 ******* Oct–88 ******* Jun–89 ******* Oct–89
OYSTER POND: STATION 2

Figure 10 c.

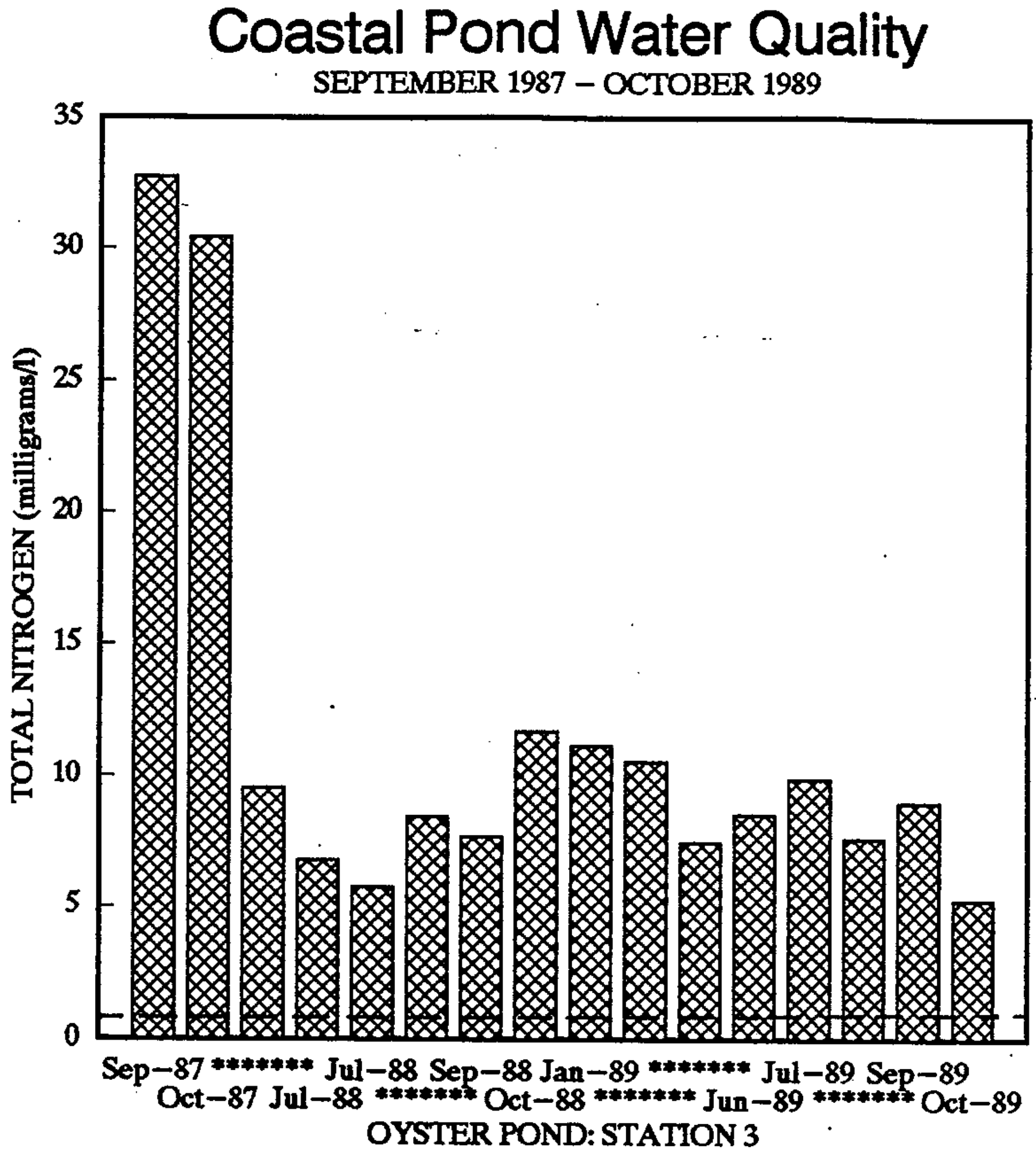

Coastal Pond Water Quality
SEPTEMBER 1987 – OCTOBER 1989
TOTAL NITROGEN (milligrams/l)
35
30
25
20
15
10
5
0
Sep–87 ******* Jul–88 Sep–88 Jan–89 ******* Jul–89 Sep–89
Oct–87 Jul–88 ******* Oct–88 ******* Jun–89 ******* Oct–89
OYSTER POND: STATION 3

Figure 10 d.

"permanently" anoxic Station 3 total nitrogen reached values in excess of 30 mg N/l. The large variability in the total nitrogen measured at Station 3 results primarily from the steep gradient in total nitrogen from lower values at the surface to extremely high values near the bottom. The effect of this steep gradient is that small differences in the depth of water collection results in large differences in measured nitrogen concentrations with resultant effects on the water column averages.

The total nitrogen distributions in the ponds are consistent with the areas of measured oxygen depletion. Upper Green Pond, Little Pond and Oyster Pond stations with total nitrogen values in excess of 0.75 mg N/l are the areas showing significant oxygen depletion hence diminished water quality. Only Lower Green Pond stations (Stations 4 and 5) which are well mixed, well flushed systems with lower total nitrogen concentrations, are not yet experiencing significant oxygen depletion.

Unfortunately, the oxygen and nutrient conditions measured in this study must be evaluated as a "best case", in other words the conditions are better than reality. The reason for this caveat is that as stated above, oxygen conditions were measured in late morning, while lowest oxygen concentrations occur near dawn and generally improve during the day. More importantly, in some regions of the watersheds of the ponds recent additional nutrient loading to the groundwater has not yet impacted the ponds due to the long time lag imposed by the slow rate of groundwater flow. In simple terms, the nutrient conditions in the ponds are not yet in steady state with the inputs to the watershed. In addition, particularly in Green Pond, additional loading to either the lower or upper pond will likely lower water quality throughout the whole pond given the bi-directional tidal driven flow.

OYSTERS

Oysters grew best at the site in Little Pond near Station LP3 (see map in Appendix 4) whether considered on the basis of total volume, total weight or ash-free dry weight (Figures 11 a,b,c). Oysters grew nearly as well at the seaward site in Green Pond near Station GP4 (again see map in Appendix 4). At each of these sites only one oyster died during the grow-out experiment. Oyster growth was also

COASTAL SALT PONDS

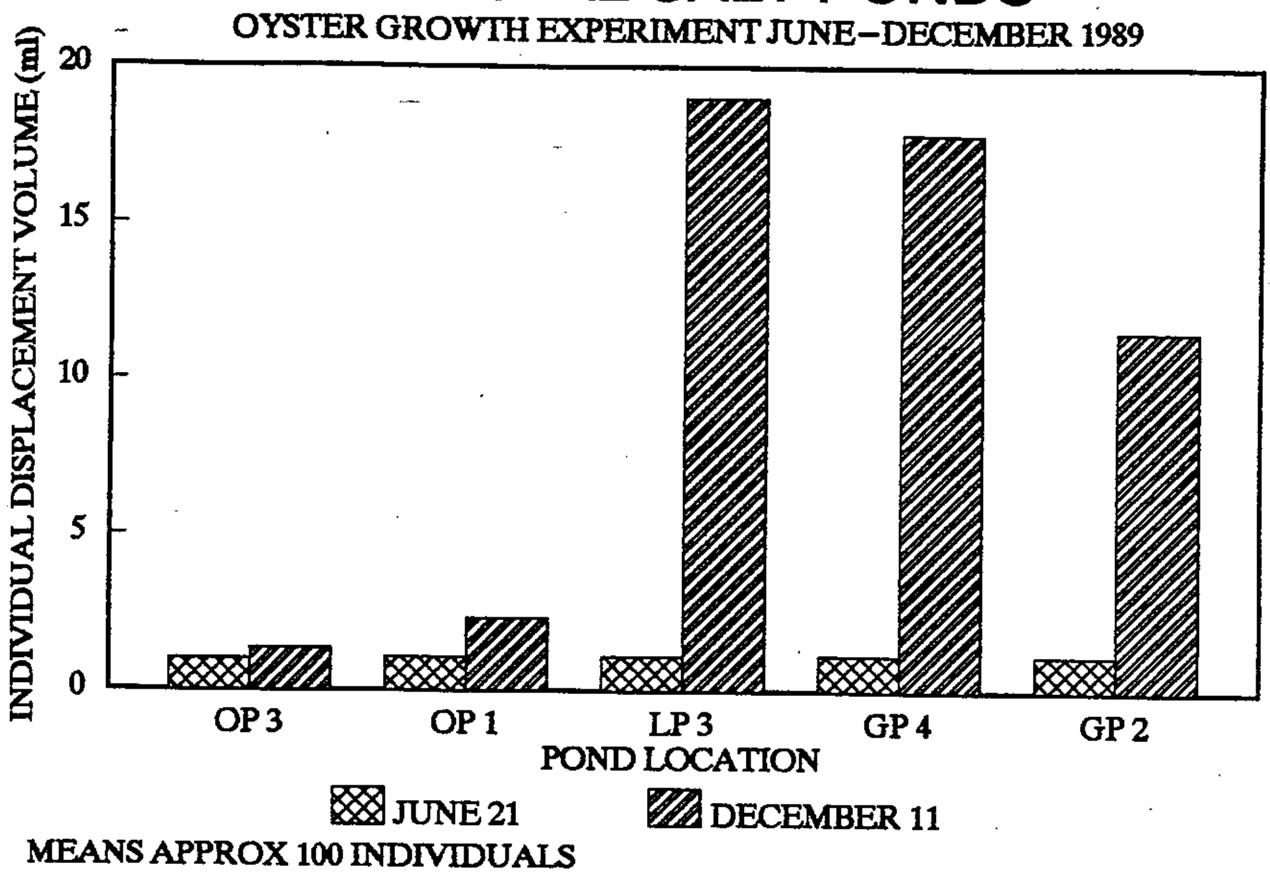


Figure 11 a. Mean displacement volume of oysters set out in Oyster, Little and Green Ponds.

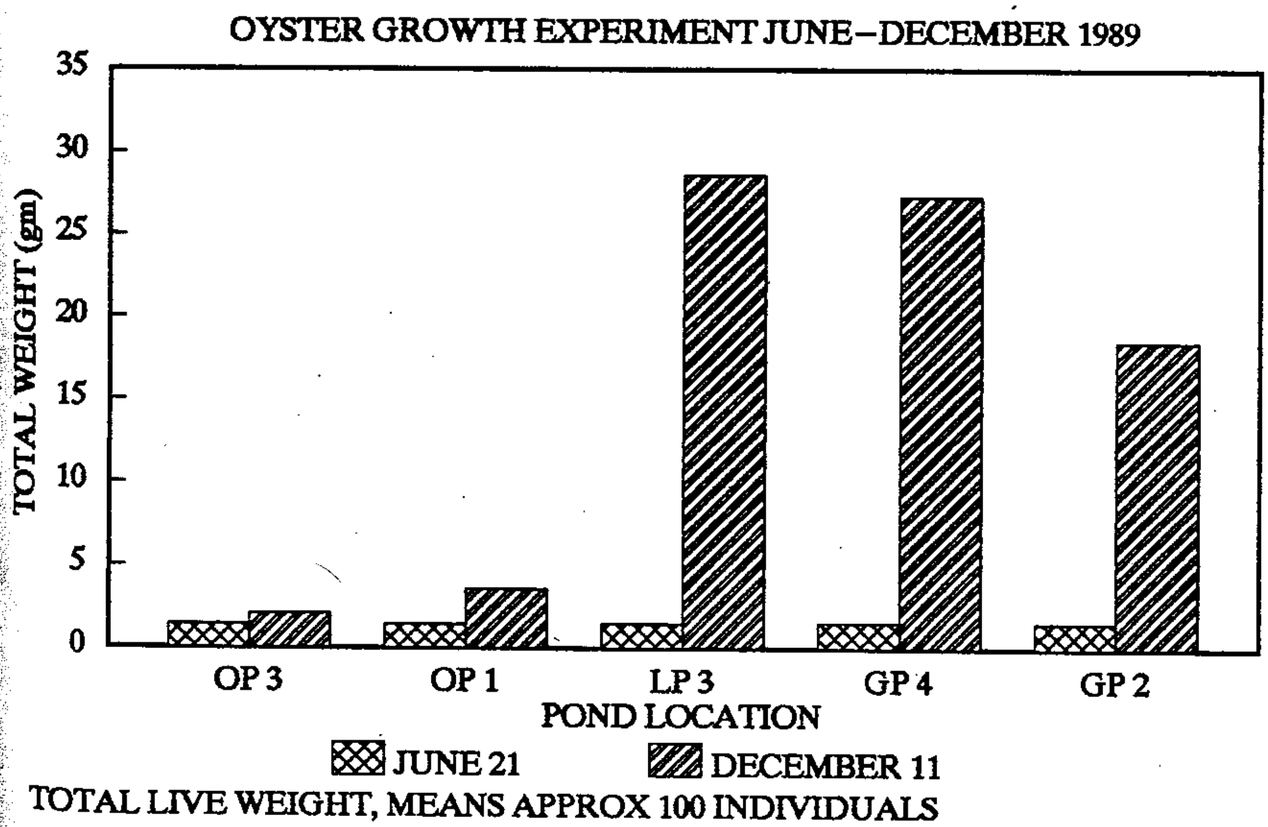


Figure 11 b. Mean individual total weight of oysters.

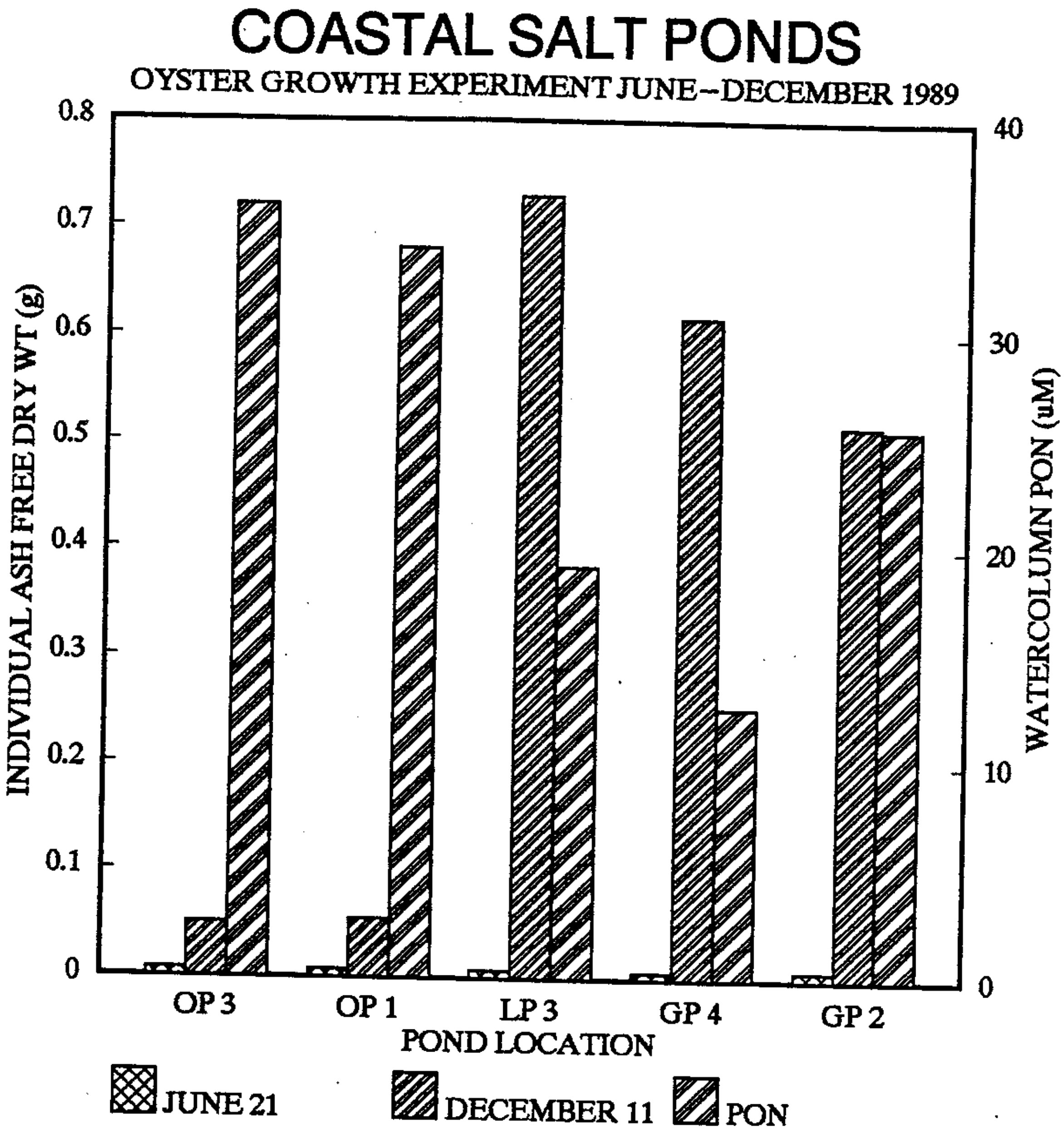


Figure 11 c. Mean ash-free dry weight of oyster tissue along with the mean concentration of particulate organic nitrogen (PON) in the water column at each site during the oyster grow-out period.

excellent at the control site in Vineyard Sound (WHOI dock near the Shore Laboratory on the bike path), but these oysters were lost during a fall storm so their growth could not be quantified. Oysters grew moderately well at the landward site in Green Pond near Station GP2 and mortality there was also minimal.

In Oyster Pond, however, the oysters grew poorly at both sites, in the vicinity of Stations OP1 and OP3. The level of mortality at these sites was about 15 percent, occurring during the summer months. The inability of oysters to grow in Oyster Pond may be related to the reduced salinity of the pond, to the composition of phytoplankton available as food, or to a combination of these. Figure 11 c shows there was plenty of organic matter in the water in Oyster Pond, as indicated by the high levels of particulate organic nitrogen (PON) during the course of the experiment. Of course, this organic matter may have been in the form of phytoplankton species unpalatable to or indigestible by the oysters.

These data seem to suggest that shellfish can survive in all of the ponds. However, it is important to note that the oysters were suspended in nets above the bottom and therefore do not reflect infaunal animal survival.

NITROGEN BUDGET FOR LITTLE POND

In collaboration with the research conducted through the Pond Watcher project on Oyster, Little, and Green Ponds, a more detailed investigation of the nitrogen budget for a coastal salt pond is being conducted concurrently on Little Pond, also with WHOI Sea Grant funding. The focus of this project is to quantify nutrient inputs due to human impacts versus those from natural processes and the degree to which these interact. The study is designed to determine the processes which control the nutrient and oxygen conditions, hence the water quality of a coastal salt pond. Only by determining the controlling factors can we make rational decisions as to which environmental processes we need to target in a management program. Of major importance to the determination of current and potential impacts of this nutrient loading is understanding the extent to which the system is self sustaining as a result of nutrients incorporated into and stored within the sediments. This "battery effect" may continue to supply nutrients to overlying waters even if the original inputs are diminished. Understanding the relative importance of the sources and sinks of nutrients, primarily in the form of nitrogen, requires the construction of a nutrient budget for the entire system.

For a coastal pond ecosystem, the major nutrient inputs come from the entire watershed via groundwater, with additional but less significant input from terrestrial runoff and precipitation. The major losses occur primarily through tidal exchange with associated waters, sediment denitrification (whereby nitrate is transformed into harmless nitrogen gas), and burial into the sediments as particulate nitrogen. The most significant of these processes, which as yet remain poorly understood, are groundwater contributions and denitrification. The extent to which the input is partitioned between these fates determines the importance of each of the major inputs to potential eutrophication.

The construction of a nitrogen budget for Little Pond requires measurements of: groundwater transported nutrients, benthic regeneration of inorganic nitrogen, import and export through tidal exchange, denitrification, rainfall, streamflow and nitrogen burial in the bottom sediments. Emphasis is being placed on 1) the potential importance of benthic sediments in maintaining high levels of nutrient loading to the water column relative to alterations in the contribution of other sources, 2) the importance of groundwater transported nutrients and the loss of nitrogen to denitrification processes as it moves via groundwater flow to the pond water column, and 3) the significance of residential on-site sewage disposal and fertilizer use to the overall nutrient economy of the adjacent coastal salt pond.

The next phase of work requires delineation of the watershed contributing groundwater to the pond. The major effort of acquiring permission from land owners and installation of monitoring wells for measurement of groundwater flow and sample collection is complete and we are now in the initial stages of experimentation.

A permanent tide gauge station has been established for the monitoring of tidal range over the course of the study. A stream gauge recorder has been placed at the head of the pond to measure flow from the major stream input source. These data, when coupled with groundwater input estimates and detailed bathymetry of the pond, will give us an accurate assessment of water turnover in the pond.

Groundwater nutrient concentrations will be measured using multilevel wells to allow determination of the potential groundwater nutrient load to the pond. The extent to which these nutrients reach the pond water column will be determined from measurements of benthic nutrient exchange, sediment nutrient profiles, and groundwater seepage and denitrification measurements. Rainfall data are being collected by the Pond Watcher gauges in the area.

Finally, a census is being conducted in the watershed area to determine population, fertilizer use, age of houses, and number of bedrooms to help quantify human nutrient inputs. With this information we will be able to model the nitrogen budget for the pond and determine the relative importance of natural inputs versus human activities to pond eutrophication and the potential effects of altering the inputs to or losses from the system.

CONCLUSIONS

1) Basically, Oyster, Little and Green Ponds are more sensitive to nutrient loading than adjacent coastal waters because of similar underlying processes. Each pond displays estuarine characteristics, the waters of each pond exhibit elevated temperatures in summer, and each pond shows stratification, thus setting the stage for oxygen reduction or depletion and the ensuing ecological stress to animal and plant communities.

2) All of Little Pond, the upper reaches of Green Pond, and the mid and upper sections of Oyster Pond show periodic reduction or depletion of oxygen. The seaward basin of Oyster Pond shows persistent anoxia resulting in a high concentrations of hydrogen sulfide in the deeper waters.

3) In simple terms, the three ponds act as factories for transforming inorganic nitrogen to particulate organic nitrogen. Nitrates enter the ponds primarily at the landward sites, are taken up by the micro and macroalgal communities as they progress down the pond, and are converted into particulate nitrogen, which, as a

consequence of its decay, leads to the oxygen depletion mentioned above.

4) Although there was significant variability in nutrient levels between sampling dates, no obvious seasonal trends in nutrient levels were apparent.

5) Total nitrogen concentrations in all three ponds currently exceed 0.5 mg per liter, with the exception of the seaward region of Green Pond which averages slightly less than 0.5 mg per liter.

RECOMMENDATIONS

1) Because the nutrient data show variability through time, it is important for the purposes of assessing existing nutrient levels relative to the Coastal Pond Nutrient Overlay Bylaw that measurements be conducted on a number of occasions.

2) The lack of a strong pattern of seasonal variability in nitrogen levels allows for less intensive sample collection during the winter months meaning that more intensive sampling of nutrient conditions during warmer summer months is appropriate.

3) Because the ponds are most sensitive to oxygen depletion during the warmer months (April through November), nutrient conditions during this period are the critical values for assessing the impacts of additional nutrient loading.

4) Biologically active nitrogen pools (nitrate, ammonium and particulate organic nitrogen) may be more useful for gauging the susceptibility of ponds to nutrient loading than is total nitrogen.

5) Environmental planners should recognize that the health of coastal ponds is more directly indexed by oxygen conditions (periodic anoxia) and by the status of existing animal and plant communities than by total nitrogen conditions. In other words, low total nitrogen levels may not mean that pond water quality is satisfactory, although our results indicate that high levels of total nitrogen do seem to be related to oxygen depletion and poor water quality.

6) At present data are not available to be able to assess the relative contributions of man's activities versus natural events in the nitrogen loading of the ponds. Nevertheless, the data obtained during this study indicate that these ponds have poor water quality during the summer months. The ponds appear to be poised for more severe and widespread environmental problems if nutrient loading continues to increase above present levels. Therefore, it is recommended that management options be considered and adopted to reduce nutrient inputs (or increase nutrient outputs) to the ponds, particularly during the critical summer months.

It is intended that these recommendations be updated and expanded as more information becomes available from continuing phases of the Pond Watcher project and other WHOI Sea Grant-supported coastal salt pond projects.

PLANS FOR 1990

This Pond Watcher project was initially intended to be conducted over a two-year period, 1988 and 1989. However, the project has developed and proceeded so smoothly and productively that there are good reasons for encouraging its continuation in 1990. Now that the Pond Watcher volunteers have been trained and mobilized to be an enthusiastic and responsive group of "research assistants," it would be a shame to see a loss of the community service momentum that has been built around a common interest in the health and welfare of Falmouth's coastal ponds.

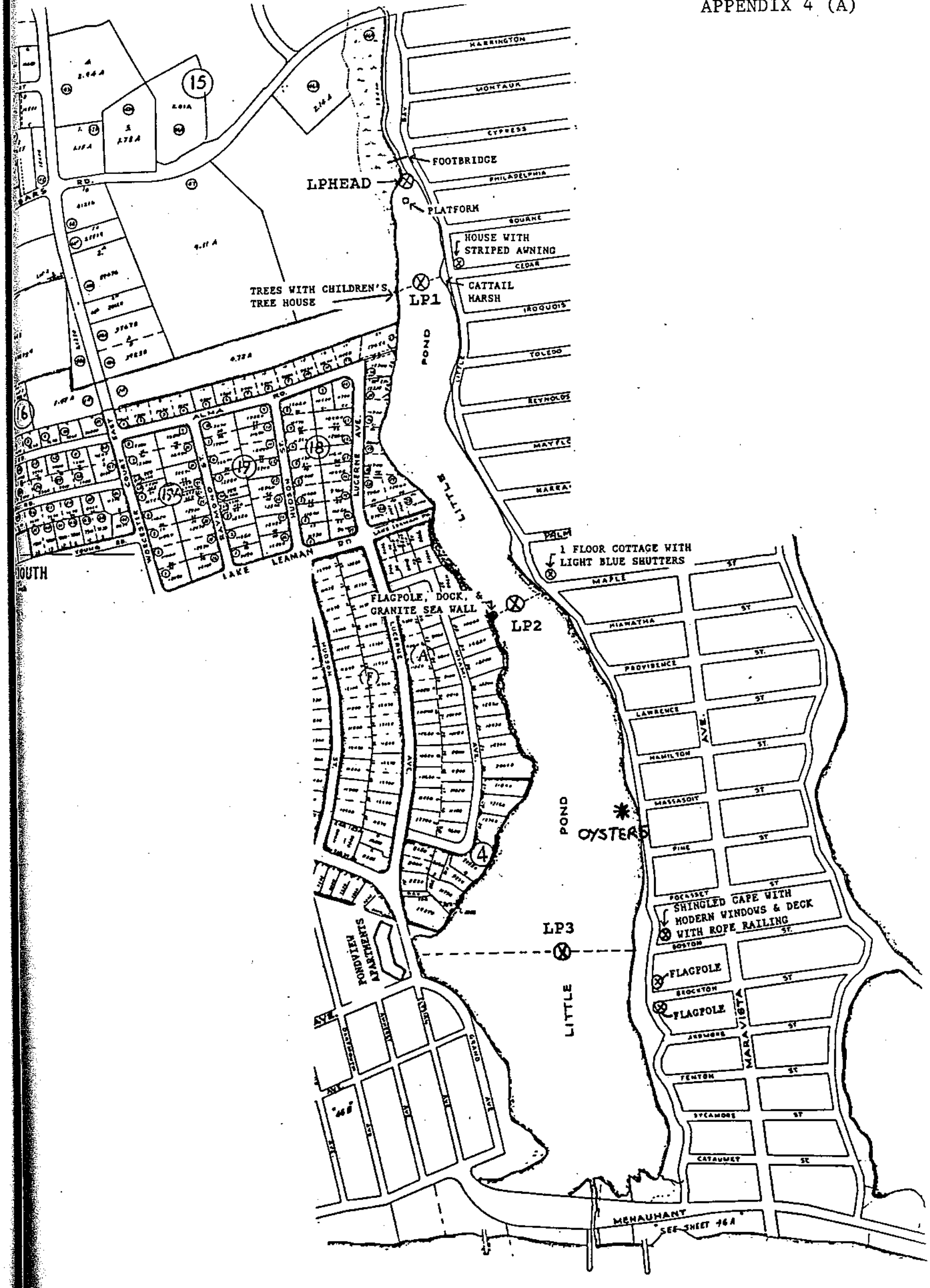
Further, a productive synergism has developed between this project and other WHOI Sea Grant-supported projects focussing on Falmouth's coastal ponds. As a result of this joint effort, substantial headway is being made in understanding the water quality status of the ponds, the detailed mechanisms involved in eutrophication of the ponds, and the links between nutrient loading and resulting ecological consequences. All of this has a significant bearing on how the Town plans and manages development around its coastal ponds. As well, these projects provide much-needed information necessary for fuller interpretation of the recently enacted Coastal Pond Nutrient Overlay Bylaw.

Accordingly, we propose to continue the Pond Watcher project in 1990, shifting emphasis toward a more intensive examination of the three ponds in mid-summer when the ponds are the most vulnerable to the effects of water quality degradation, along with a general nutrient and oxygen survey of other coastal ponds in Falmouth (such as Great Pond and Bourne's Pond) to be able to rank them relative to the ponds for which we already have information.

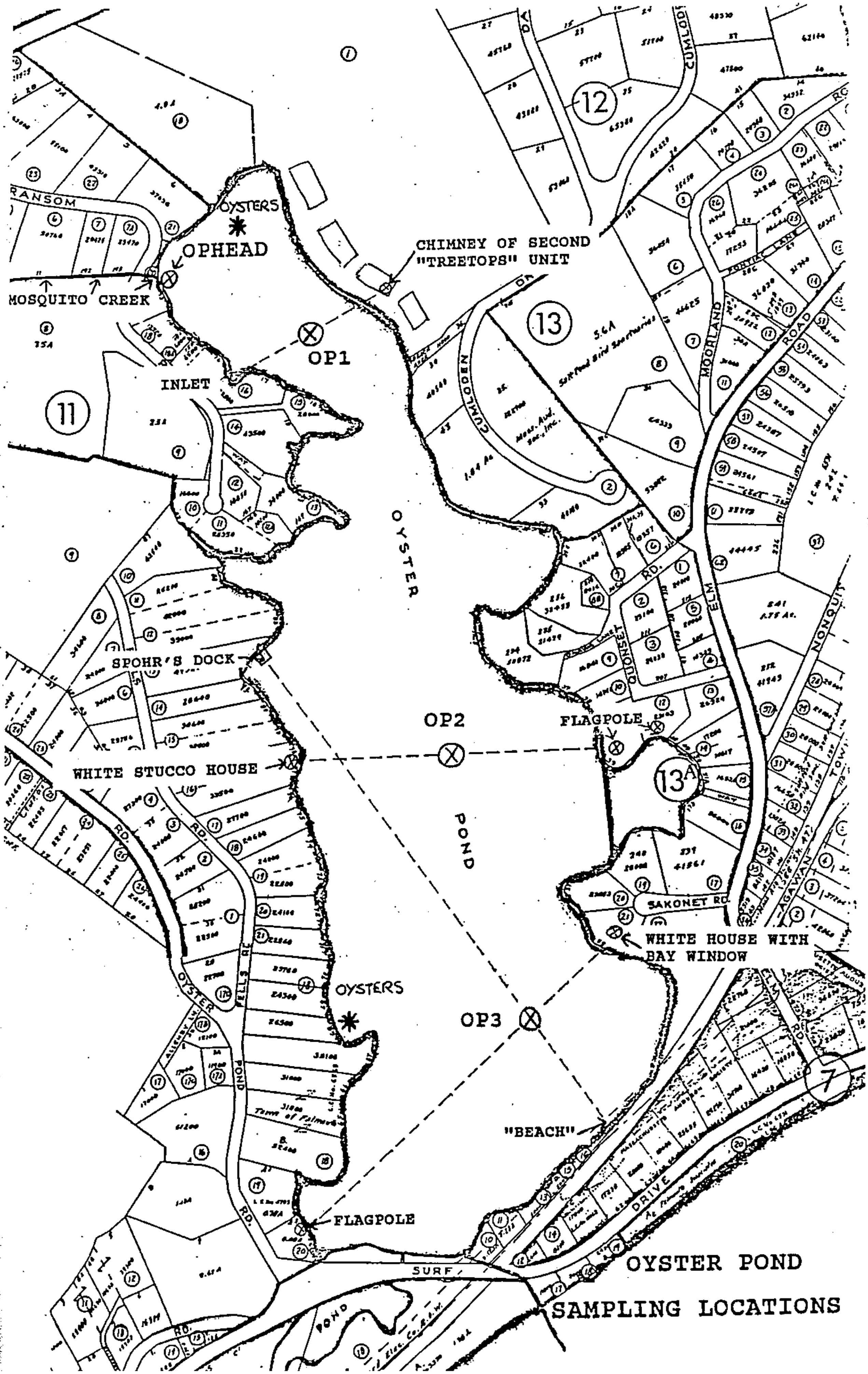
During the year we also intend to explore opportunities with Pond Watchers and with local, state, and federal agencies for 1) perpetuation of citizens monitoring of coastal ponds in Falmouth as a self-run effort and 2) linking such an effort with local, state, and federal funding and to the environmental regulatory infrastructure.

ACKNOWLEDGEMENTS

We wish to express our sincere thanks to all Pond Watchers for their interest in and support for this project. We are especially grateful to Pond Captains and those Pond Watchers who played a role in the sampling aspects of the project for giving freely of their time and expenses (boats, gas, ice, etc.). We thank Richard van Etten, Tony Millham, Andrea Arenovski, David Schlezinger, and David White for research support, and Lee Anne Campbell and Nanci Pacheco for their assistance with project coordination and outreach.



LITTLE POND SAMPLING LOCATIONS



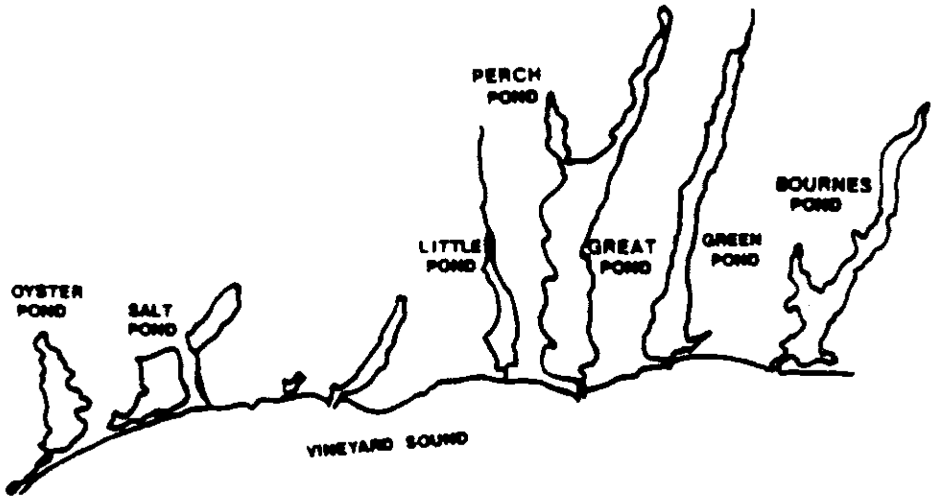
OYSTER POND SAMPLING LOCATIONS

Sampling Depths

Oyster Pond	
OPHead	Surface
OP1	Surface, 2 and 4 meters
OP2	Surface, 2 and 3.25 meters
OP3	Surface, 2, 4, and 6 meters
Little Pond	
LPHead	Surface
LP1	Surface and 1 meter
LP2	Surface and 1 meter
LP3	Surface and 1 meter
Green Pond	
GP1	Surface
GP2	Surface and 1 meter
GP2A	Surface and 1 meter
GP3	Surface and 1 meter
GP4	Surface and 1 meter
GP5	Surface, 1, and 1.5 meter
Vineyard Sound	
VS1	Surface, 1 and 2 meters

FALMOUTH POND WATCHERS

UPDATE ON 1991
CITIZEN VOLUNTEER MONITORING OF WATER QUALITY IN FALMOUTH'S COASTAL PONDS



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and

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April, 1992

This cooperative project is conducted with funding from the Town of Falmouth Planning Office and the Woods Hole Oceanographic Institution Sea Grant Program

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April, 1992

EXECUTIVE SUMMARY

The 1991 field season of the Citizen's Monitoring Project for Falmouth's Coastal Ponds was the most successful and productive to date, due primarily to the enthusiasm and dedication of Falmouth's Volunteer "Pond Watchers". Through their continued efforts, we now have five years of data on three of Falmouth's ecologically fragile coastal salt ponds (Oyster, Little and Green Ponds), and two summer's information on two additional ponds (Bournes and Great/Perch). This past year was a transition year in that the emphasis of the project is shifting to be more centered upon management and determining the effectiveness of management plans/projects as they are implemented. Also, 1991 was a "Special Projects" year in that in addition to the water quality sampling, fish sampling was conducted in each of the 5 main salt ponds. Another significant, although unplanned, special project was conducted as Hurricane Bob made his presence well known between our last two sampling dates.

The overall goals of the Pondwatch Project are:

1) to provide the Town of Falmouth with a data base of nutrient levels and nutrient related water quality of Falmouth's coastal ponds relative to the Coastal Overlay Bylaw;

2) to aid in evaluation of potential environmental management options for the ponds;

3) to provide a high quality independent evaluation of the impacts of both natural and man induced alterations (ex. changes to nutrient inputs or circulation) to the water quality of Falmouth's salt ponds;

4) to evaluate the effectiveness of implemented management programs aimed at protecting or improving nutrient related water quality, and;

5) to develop heightened public awareness of the cumulative impact of human activities on these ponds with the ultimate objective of fostering interactive partnerships between citizens, scientists and resource managers for maintaining the ecological health of these fragile coastal ecosystems.

This report is an interim summary of ongoing work since the 1991 Interim Report on Citizen Volunteer Monitoring of Water Quality in Falmouth's Coastal Ponds and includes review of this year's data in context with results from the project since its inception. In addition, a brief overview of a cost-effective short term remediation approach for Little Pond is included. It is becoming increasingly clear that, because of the large degree of environmental variability, the multi-year component of this effort is critical in providing accurate information on nutrient and oxygen conditions in these ponds for the development of long-term management strategies.

It is clear from the data that portions of these five Falmouth coastal salt ponds are undergoing varying degrees of nutrient related stress. In each of several years, major portions of all five ponds exhibited periodic water column stratification and periodic low oxygen and/or anoxia (hypoxia) events. The sensitivity of these systems to periodic hypoxia results from their estuarine circulation patterns and the high rates of oxygen consumption resulting from the large amount of nutrient stimulated organic matter production from phytoplankton and macrophytes. In all of the "finger" ponds (Green, Little, Bournes and Great Ponds), nutrient and oxygen conditions as well as water clarity showed a gradient of increasing quality moving from the headwaters toward Vineyard Sound. Nutrient and oxygen levels in the three salt ponds with multi-year data were not statistically different from previous years. However, it appears that nutrient levels may be increasing in some areas, Particularly Green Pond.

Oyster Pond, which had its inlet enlarged in 1990, did not appear to be significantly affected by this action. The lack of a change in Oyster Pond nutrient or salinity levels is most likely due to the partial blockage of the inlet by sedimentation soon after installation and soon after each clearing. The two "new" ponds, Bournes and Great Ponds, were most similar to Green Pond in both nutrient and oxygen levels, depth, stratification and water clarity, but had some areas of better water quality. The nutrient levels in Bournes and Great Ponds, with the possible exception of the stations directly adjacent Vineyard Sound, were in excess of 0.5 mg total nitrogen per liter and most of the area of each ponds exceeds Coastal Overlay Bylaw levels. It is also becoming clear that the areas of high nutrient concentration in all ponds generally have periodic low oxygen in bottom waters and have low species diversity of fish and invertebrates as indicated by our trapping study this past year.

The relative contribution of natural versus anthropogenic causes of this stress is being evaluated as a part of our efforts to provide information necessary for determining the potential success of a variety of remediative actions. The results from the Pond Watcher's efforts in concert with parallel scientific studies of these ponds now being conducted by WHOI-Sea Grant researchers are now beginning to provide the basis for designing data based management schemes not only for the Town of Falmouth, but for other coastal pond systems as well.

We are proud that the Falmouth Citizen's Monitoring Project has been selected for inclusion in both the 1991 and 1992 Environmental Success Index of the Renew America Program, a "unique clearinghouse of information that will be made available to policy makers, citizens' groups, private and public organizations, the media and individuals interested in finding solutions to environmental problems...being part of the ESI means that this program will be promoted as a model for others." The Pondwatchers have also just (1992) received a National Environmental Achievement Award from the National Environmental Awards Council, an honor considering the relatively short history and localized scale of this program.

INTRODUCTION

Pondwatch:

Since 1987, the Citizen Volunteer Monitoring Effort for Falmouth's Coastal Ponds (better known as the "Pond Watchers") has been providing much needed water quality data for the development of data-based management plans for now five coastal ponds in Falmouth, Massachusetts. Jointly sponsored by the Town of Falmouth and the Woods Hole Oceanographic Institution Sea Grant Program, this project represents a unique partnership between local citizens, town government and WHOI scientists whereby scientific information generated through the efforts of citizen volunteers under the guidance of WHOI scientists is applied directly (and immediately) to planning decisions for the town. The success of this project depends largely upon the efforts of a group of private citizens with wide ranging backgrounds and educational pursuits, all sharing a common interest in maintaining the health of their nearshore coastal waters. Perceived deterioration of water quality in Falmouth's nearshore coastal salt ponds, the first indicators of nutrient pollution along the coast, has led this group of "activist volunteers" to, rather than complacently observe, put their concerns into action through active participation in identifying and monitoring the nutrient related water quality of these systems (Figure 1).

Through this interactive partnership, valuable data and information is collected annually from many of Falmouth's coastal salt ponds in order to evaluate the current health of these systems as well as to develop, implement and determine the effectiveness of management strategies to improve/protect long-term water quality. With five years of monitoring we are now able to assess longer-term trends in the ecological health of these fragile coastal ecosystems, and with the 1991 data set in place have been developing science based management plans for these environments. With our existing data base and continued

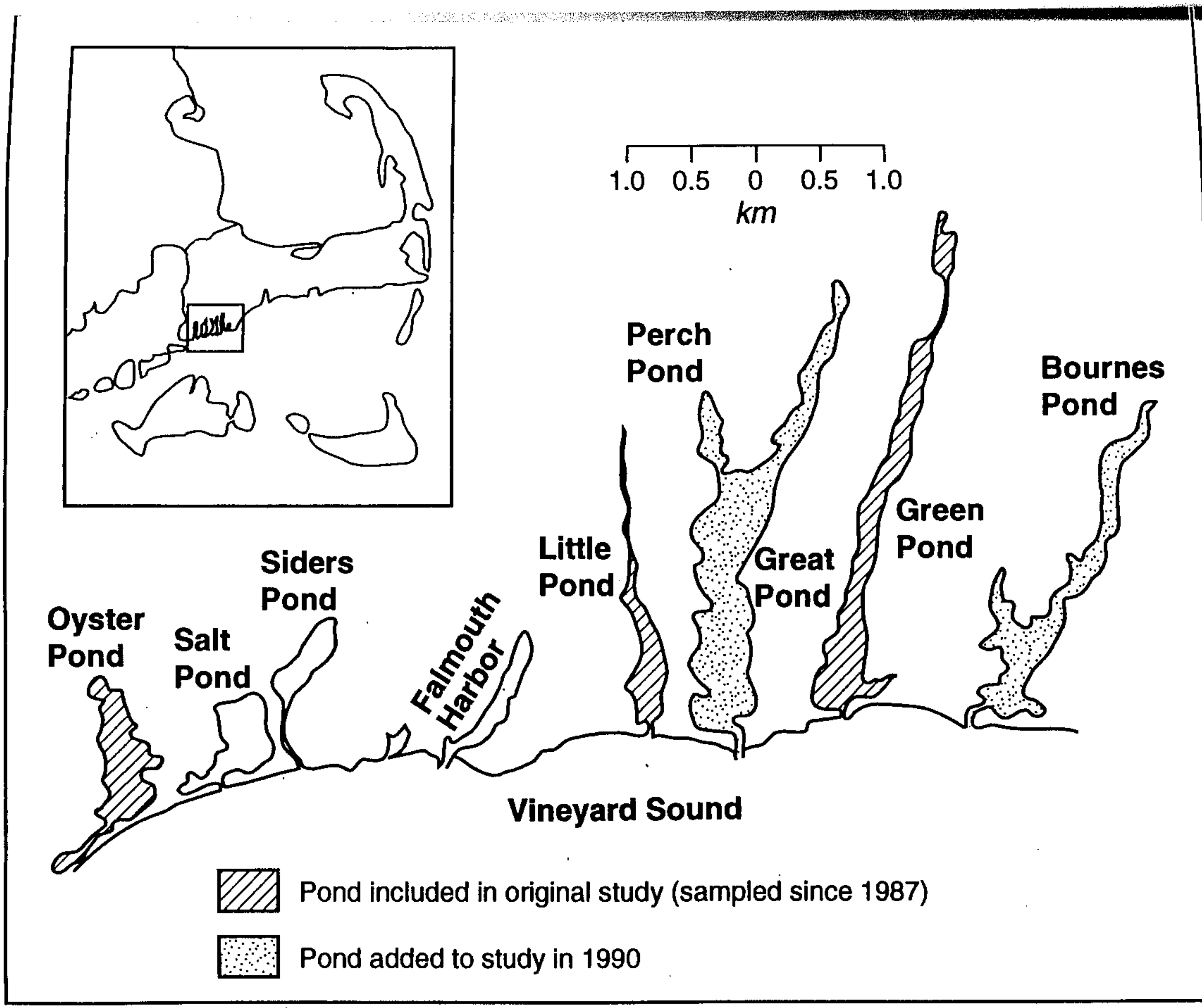


Figure 1. Relative locations of the coastal salt ponds in Falmouth, Massachusetts.

monitoring we are in a unique position both to detect continuing changes in the ecological health of these systems as a result of both long-term (chronic nutrient inputs) and short term (increased exchange with tidal waters via pond opening) alterations to the system. The value of these data bases cannot be understated in our efforts to understand and predict potential consequences of various sorts of management options for these sensitive nearshore environments. Equally significant, we are in a position to gauge the effectiveness of implemented management plans as we continue to monitor, a position nearly unique in any coastal area (Figure 2). The lack of comparable data for coastal embayments is underscored by the growing scientific interest in this project as one of the only long-term data sets available for these systems.

The goals of the project are:

1) to provide the Town of Falmouth with a data base of nutrient levels and nutrient related water quality of Falmouth's coastal ponds relative to the Coastal Overlay Bylaw;

2) to develop and evaluate various potential environmental management options for the ponds;

3) to provide a high quality independent evaluation of the impacts of both natural and man induced alterations (ex. changes to nutrient inputs or circulation) to the water quality of Falmouth's salt ponds;

4) to evaluate the effectiveness of implemented management programs aimed at protecting or improving nutrient related water quality, and;

5) to develop heightened public awareness of the cumulative impact of human activities on these ponds with the ultimate objective of fostering interactive partnerships between citizens, scientists and resource managers for maintaining the ecological health of these fragile coastal ecosystems.

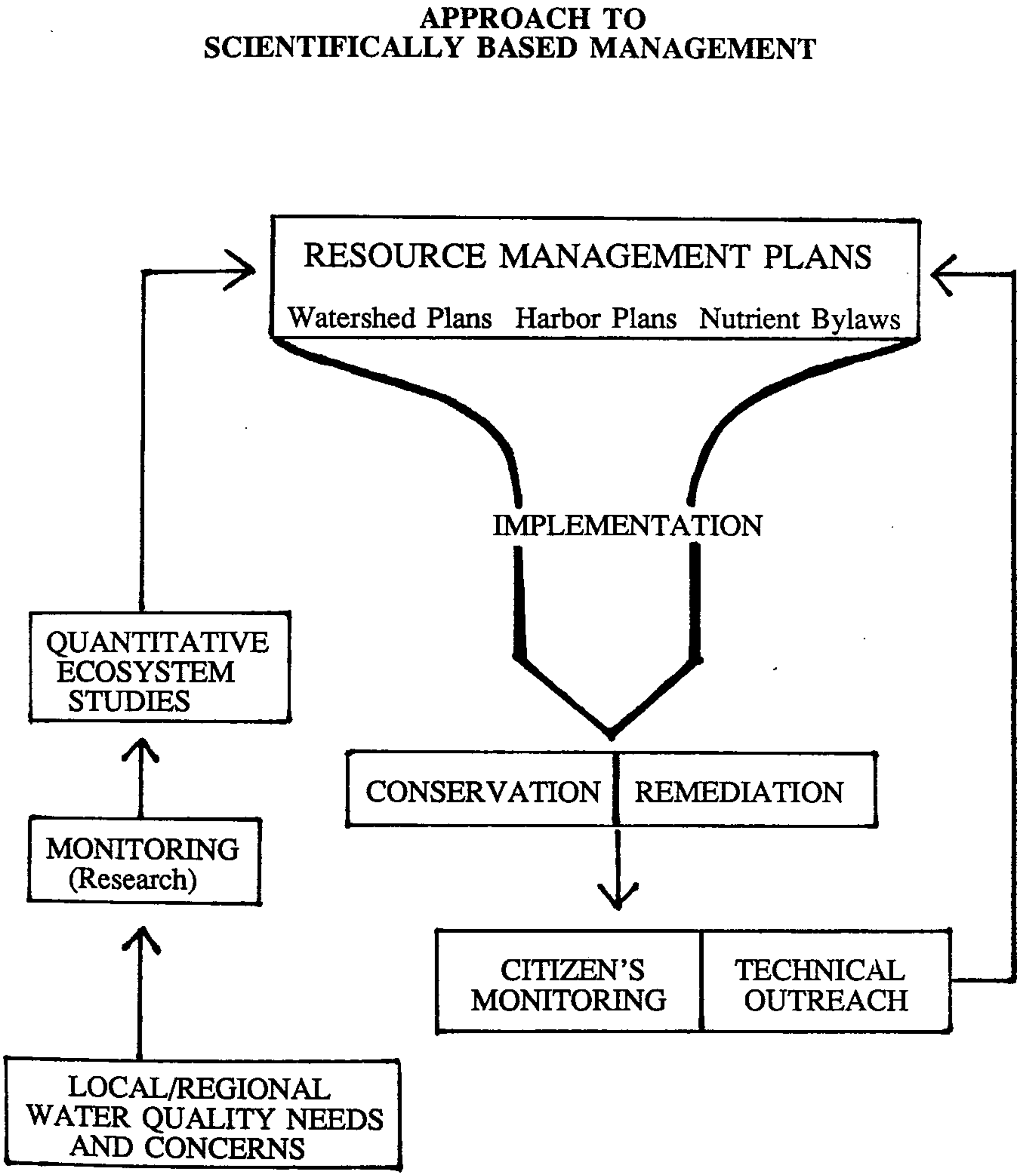


Figure 2. Schematic of scientifically based management for Falmouth's coastal ponds.

The Citizen's Monitoring Effort is unique in its partnership approach to addressing the ecological and economic consequences of coastal eutrophication. Techniques and methods used by the Pond Watchers have been specifically designed so that virtually any coastal community can undertake this type of effort efficiently but at low cost. This cooperative project has been cited by Renew America as an innovative model program, and this year received a National Environmental Achievement Award from the National Awards Council. In support of this concept, the Falmouth Pondwatch Project is being used as the model for the upcoming (1992) EPA Bays Program/Buzzards Bay Project citizen's monitoring program for the embayments of Buzzards Bay.

Steadily increasing nutrient inputs, resulting primarily from on-site septic systems, fertilizers and runoff associated with increased coastal development poses a serious long-term threat to the health of our coastal environments. Our limited understanding of the impact of nutrient overload to these systems, and of remediation measures to deal with the detrimental effects of overload, has created serious obstacles for the development of successful land management practices for these systems. Coastal salt ponds, because of their large shoreline area and generally restricted circulation and flushing, are usually the first indicators of nutrient pollution along the coast, especially for nutrients entering via groundwater such as nitrogen resulting from residential development with on-site septic disposal. These systems, by their nature, are highly productive, nutrient rich environments frequently providing suitable habitat for many species of commercially and recreationally valuable fish and shellfish. Although quite tolerant to high nutrient conditions, the delicate balance of these systems can be upset by excessive nutrient inputs resulting in the overfertilization (or "eutrophication") of these waters. Most all of Falmouth's coastal salt ponds presently show some signs of nutrient overenrichment. Portions of four in particular, Oyster, Little, Great and Green Ponds indicate signs of advanced eutrophication, with periodic dense algal blooms, malodorous conditions and occasional fish kills from low oxygen conditions resulting from nutrient related oxygen depletion in bottom waters. Although it is often difficult to separate the results of natural processes from those induced by man, increased nutrient conditions resulting from excessive loading due to human activities will certainly result in declining water quality in these sensitive coastal ecosystems.

This program has been extremely successful on several fronts. First, it has provided a data base for the Town of Falmouth that can be used to evaluate its newly enacted Coastal Pond Nutrient Overlay Bylaw, a plan which identifies nutrient threshold limits for each independent ecosystem. Information generated by the citizen volunteers has shown that some of the ponds currently exceed these threshold values, a finding needed for management decisions regarding these systems. Second, because of the large number of participants, the Pond Watchers can conduct simultaneous sampling at all sites under the same conditions of weather and tide, crucial to making site to site comparisons in these complex ecosystems. Third, the Pond Watchers provide physical data and samples for the ongoing scientific studies of coastal nutrient cycling at WHOI, an effort which would not otherwise be possible under the constraints of funding and available manpower. Equally significant, the nearly unique (multiple pond and multi-year) information generated by the program would not be generated if "experts" (researchers, State or Federal agencies) were to conduct all of the work because of the expense. The joint effort between scientists and the community has kept costs low and created a conduit for immediate transfer of environmental information to local government and an activist citizenry. The end result has been increased public awareness of the fragile nature of our coastal ecosystems not only among the Pond Watchers, but the local and regional community as well.

Management:

Increasing our understanding of these coastal salt ponds, as well as the relative success or failure of remediative measures to improve water quality in these systems, allows us to better predict the potential impacts which may result from alteration of one or more of the dominant processes which structure the system such as nutrient inputs or losses. The information resulting from this project is providing quantitative information for the development of site-specific management plans crucial to protecting the economic, aesthetic and recreational value of Falmouth's embayments and coastal salt ponds. Maintaining healthy ecological systems goes well beyond the economic benefits of harvest and recreation. The cost of remedial projects, such as those undertaken for Bournes Pond, New Bedford Harbor and Boston Harbor can be extremely expensive, ranging from multi-million to even billion dollar efforts. By better understanding these ecosystems as well as the impact of human activities on their environmental health, we may help to avert the need for expensive remediation measures before they become necessary, and if necessary, we will be able to recommend appropriate cost effective remediation options.

The role of the scientists in this study is to oversee the project in terms of sample collection and analysis, and to synthesize the data within the proper ecological context. The framework for this ecological context is based upon ongoing studies in Dr. Howes' laboratory which involve coastal nutrient cycling in systems ranging from larger more open coastal systems such as New Bedford and Nantucket Harbor to permanently ice covered stratified eutrophic marine lake systems in Antarctica. These associated projects are providing valuable information with which to better understand and interpret the results from the Citizen's Monitoring Project. One of the unexpected benefits of this program has been the cooperation and communication it has generated among research scientists, citizens and local government, demonstrating the wealth of untapped energy and dedication of private citizens to environmental conservation.

The direct application of data to management through close communication with the Town is especially effective in providing a data base for the Town from which to evaluate its newly enacted Coastal Pond Nutrient Overlay Bylaw. The Bylaw is a land use management plan which limits additional nutrient inputs beyond threshold levels for each embayment and a plan now being considered for implementation for many coastal communities (Bourne and Wareham). The project has stimulated interest in the local citizens for their ability to directly affect management decisions regarding the future preservation of their valuable coastal resources both through direct participation in sampling as well as public presentations to explain and present the data from the study, providing an educational medium as well as an avenue for dissemination of the results of this work. The information from this effort is reaching beyond the participants by presentations to community organizations, local and regional governments, as well as across the country through participation in national meetings on citizen's monitoring of the environment.

For a coastal community, water quality has both direct and indirect economic benefits. The health of valuable natural resources such as recreational and commercial fish and shellfish species depends on the environmental health of coastal ecosystems. Similarly, poor water quality conditions seriously affect the desirability of a coastal area for the tourist industry as well as the value of real estate properties on or near these systems, thus potentially impacting an important economic resource for many of these towns. The continuing partnership between citizens, managers, scientists and local government to monitor the health of Falmouth's salt ponds for the development, implementation and maintenance of environmental management plans is our best and most cost-effective method for maximizing the ecological and economic benefits of these important coastal resources. By better understanding these ecosystems as well as the impact of human activities on them, we may help avert the need for expensive remediation measures before they become necessary, and if necessary we will be able to recommend appropriate and effective remediation options.

STATEMENT OF THE PROBLEM

Eutrophication is the natural response of coastal aquatic systems to excessive nutrient loading. Eutrophic conditions are caused by high nutrient inputs into coastal waters which severely impact the environmental health of coastal systems, in some instances resulting in water column anoxia, fish kills, and loss of valuable eelgrass and shellfish beds. Nitrogen is generally the nutrient limiting phytoplankton and algal productivity in marine systems, and increasing the availability of nitrogen will stimulate production of these microscopic plants in these systems, much like fertilizer additions to a garden. The subsequent deterioration of coastal waters therefore is not directly the result of nutrient loading, but rather a secondary effect of the resulting overproduction of phytoplankton and submerged aquatic plants. As these plants respire at night and ultimately die and decay, oxygen is consumed and may become severely depleted in the bottom sediments and water column. It is this oxygen depletion that is ultimately responsible for the detrimental effects of excessive nutrient loading in coastal ecosystems.

Of the various forms of pollution that threaten coastal waters (nutrients, pathogens and toxics), nutrient inputs are the most insidious and difficult to control. This is especially true for nutrients originating from non-point sources, such as nitrogen transported in the groundwater from on-site septic treatment systems or lawn fertilizers. These introduce nitrogen to groundwater primarily as nitrate, which passes generally unaltered to the sediments underlying ponds and coastal waters. At the sediment/water interface at the bottom of a salt pond or harbor, the nitrate either passes up into the harbor (where it is available for plant uptake), or may be "detoxified" by a natural community of denitrifying bacteria which release the nitrogen as harmless nitrogen gas. How nitrate input is partitioned between these processes determines its effect on the biological activity and environmental health of a receiving water body. Once in the water column, the impact of a one-time input of nitrogen may be magnified many times over depending on how many times the nitrogen cycles between sediments and overlying waters column. The re-release of nitrogen after algae and phytoplankton (whose growth has been stimulated by the initial availability of nitrogen) die and decompose results in the nitrogen once again becoming available for production. Accumulated both organic and inorganic nitrogen within pond sediments may act as a "storage battery" for nutrients, continuing to provide a source of nitrogen for biological production even though the original inputs may have diminished or ceased. How many times the nitrogen cycles between sediments and the water column before being flushed out to the ocean or buried permanently in the sediments is directly related to the potential for eutrophication. Eutrophication resulting from overproduction of organic matter due to excessive nutrient loading ultimately impacts oxygen conditions. High nutrient levels are frequently associated with depletion of oxygen, potentially to the point of limiting or prohibiting survival of benthic infauna, shellfish and fish in these waters. Through the efforts of the Pond Watchers we now have several years of data on these parameters, enabling comparison of nutrient and oxygen conditions between ponds on time scales relevant to potential changes in development related inputs.

By providing a sustained data base on nutrient conditions in Falmouth's coastal salt ponds, the Citizen's Monitoring Project is enabling consolidation of several parallel investigations on nutrient cycling and water quality in these ecosystems, permitting application of new results from each effort to the range of environments found in each of the monitoring ponds and in effect multiplying the value of each project. Because the

Pondwatchers are currently monitoring a range of coastal pond systems encompassing a variety of nutrient loading conditions and flushing regimes, information gained from this effort can now be applied to a wide range of coastal pond ecosystems found in the region.

BRIEF HISTORY OF THE PROJECT

The Citizen's Monitoring Project was spawned from a cooperative effort begun in 1987 between the Town of Falmouth, The Woods Hole Oceanographic Institution (WHOI) Sea Grant Program and the research laboratory of Dr. Brian Howes in the Biology Department of WHOI. Concerned over the apparent continued degradation of water quality in its coastal salt ponds, the Town of Falmouth (through the Falmouth Planning Board) provided $5,000 as "seed money" toward initiating a water quality study of the ponds. These funds were then substantially augmented through the efforts of Dr. David Ross, coordinator of the Woods Hole Oceanographic Institution Sea Grant Program as well as a Town Meeting Member, with funding from the Sea Grant Program of NOAA, as well as with continued support from the Town.

The goals of the study were to provide the Town with information on current water quality conditions in the ponds, data critical to assessing and developing intelligent management actions to insure the protection of these fragile coastal ecosystems. In addition, the project was designed to involve local citizens directly in determining the present and future ecological health of these systems, as well as to draw community attention to the increasing human pressures on our fragile coastal resources. The value of this information became more important with the inception of a Coastal Pond Overlay Bylaw enacted by the Town in 1988, specifying annual mean threshold values for total nitrogen concentrations in Falmouth's coastal ponds. The Bylaw specified limitations of 0.32 mg total nitrogen per liter for "High Quality Areas," 0.50 mg per liter for "Stabilization Areas," and 0.75 mg per liter for "Intensive Water Activity Areas." Comprehensive data from the Citizen's Monitoring Effort would now provide crucial information far too expensive to be provided by limited Town budgets to verify the validity of these threshold values as well as provide the Planning Board with information to interpret this new Bylaw.

Parallel with the inception of the Citizen's Monitoring Project was the initiation of a more detailed scientific investigation of one of the monitoring ponds, Little Pond, by Dr. Howes' laboratory to provide in depth understanding of the processes controlling nutrient cycling and the impact of additional nutrient inputs on salt pond ecosystems. As this parallel study nears completion, we are now able to apply the information from this detailed study to management objectives for all of Falmouth's ponds. In addition, the consequences of pond management are being investigated as related to Falmouth's salt ponds in a WHOI Coastal Research Center/Sea Grant study of Sesachacha Pond, Nantucket. Sesachacha Pond is a eutrophic coastal salt pond historically opened one or two times per year to exchange with the sea, but which was left unaltered for 10 years and only recently been reopened. This pond is providing supplemental information on the efficacy of circulation management on improving salt pond environmental conditions. It has been our contention that given the great expense and limited financial resources available for remediation made necessary by excessive nutrient loading that a priori assessment of the potential efficacy of each management option is essential.

SAMPLING LOGISTICS AND EQUIPMENT

Prior to the commencement of field sampling each year, the Pond Watchers are given a refresher course on sampling procedures and information on additional "Special Projects" to be undertaken that year. Pond Captains for each pond are then responsible for distribution of sampling equipment to each of the sampling teams for the season. The individual Pond Captains are:

Oyster Pond -	John Dowling
	Julie Rankin
Little Pond -	Jack Shohayda
Upper Green Pond -	Frank Souza
Lower Green Pond -	Edmund Wessling
	Armand Ortins
Upper Bournes Pond -	Jim Begley
	Steve Molyneaux
Lower Bournes Pond -	John Soderberg
Upper Great Pond -	Herb Stern
Lower Great Pond -	Dick Erdman

Sampling equipment consists of a sampling kit with: Secchi disk fastened on a fiberglass measuring tape; color wheel for phytoplankton identification; thermometer; filters, syringes, filter forceps and in-line filter holders for field processing of nutrient samples; oxygen kit, maps, data sheets, instruction sheets, waste reagent container, pens and pencils; and other miscellaneous items of need such as clippers for opening reagent pillows, etc. Coolers for transporting and storing samples are provided as well as instruments for collection of water samples; because of the presence of deep basins in Oyster Pond, Niskin bottles were used there, pole samplers with bottles attached at fixed depths were used for the four other shallower ponds. For specific measurements such as rainfall, electronic rain gauges were purchased and installed at the homes of Bob Livingston (Oyster Pond), Robert Roy (Little Pond) and Ed Wessling (Green Pond). Rainfall amounts have been recorded on a daily basis by these conscientious Pond Watchers since August 1988 and are compiled with records maintained at a permanent weather station located at nearby Long Pond. In addition, tide gauge and water column light transmission stations were established on Little Pond at the homes of Joe Johnson and Robert Roy. The additional effort of these individuals above and beyond the routine collection of samples and physical measurements has provided ancillary data tremendously useful in interpreting the results of the monitoring effort.

Within each pond, sampling stations were located on the basis of a preliminary water quality survey, attempting to represent major ecological and physical zones within each pond. Samples are collected from each station with depth profiles made at stations deeper than 0.5 meters. These depth profiles are critical in identifying potential stratification events as well as in generating an overall understanding of the individual ecosystems. The number of stations at each pond are as follows: Oyster Pond - four; Little Pond - four; Green Pond - six; Bournes Pond - six; and Great Pond - six with an additional reference station in Vineyard Sound. On a given sampling, 27 stations must be sampled nearly simultaneously.

The selection of pre-determined sampling dates is based upon the compilation of the previous data. The sampling dates focus on periods potentially sensitive to eutrophication events. As in 1990, the 1991 sampling dates were chosen to more closely identify nutrient conditions during summer months when warmer weather results in increased biological activity and increased probability of low oxygen events. Results from previous samplings indicated that the annual variation in nutrient levels was within the range encountered during summer sampling alone and that for the 15 stations where two annual cycles were measured, the average summer total nitrogen values were the same as those in winter (with the exception of stream samples). The result is that summer sampling should give a good average view of nutrient levels and an estimate of the occurrence of low oxygen events. This is important because even periodic brief low oxygen events can significantly alter benthic animal populations so that knowing the lowest level of oxygen rather than the annual average is what is needed for environmental evaluation.

Four Pond Watcher samplings were conducted in 1991: July 14, July 28, August 11 and September 8. Cooperative weather conditions enabled sampling on the first three pre-scheduled dates, however the appearance of Hurricane Bob required (justifiably so) rescheduling of the last sampling. After early morning consultation between project coordinators and Pond Captains, the Pond Captains released their individual teams previously equipped for sampling. All teams sampled their stations nearly simultaneously ($\pm$ 2 hrs) to make sure samples were collected during the same conditions of weather and tide. Simultaneous sampling of all sites is crucial to enabling site to site and pond to pond comparisons and was made feasible only through the large volunteer effort of the Pond Watchers. After sampling, coolers containing samples and data sheets were turned in to the Pond Captains for transfer to the Woods Hole laboratories for subsequent chemical and data analyses.

The following measurements and assays were conducted on each sampling (O = On Site; L = Lab):

Physical Measurements:

- (O) Total Depth
- (O) Temperature
- (O) Light Penetration (Secchi disk)
- (O) Water Color
- (O) Rainfall

Chemical Measurements:

- (L) Nitrate + Nitrite
- (L) Ammonium
- (L) Dissolved Organic Nitrogen
- (L) Particulate Organic Nitrogen
- (L) Total Dissolved Nitrogen
- (L) Phosphate
- (L) Oxygen Content
- (L) Salinity
- (L) Chloride
- (O/L) Periodic Sulfide and Chlorophyll

In addition, Pond Watchers record observations of pond state, weather and wind conditions, and any other pertinent information which may later prove useful to interpretation of the data such as algal blooms or unusual odors.

SPECIAL PROJECTS

"Special Projects" are conducted each year to gather information of a non-routine monitoring nature but which are useful either to interpret monitoring data, or assess directly habitat quality for animals and plants within the ponds. The linkage of nutrient based studies with direct habitat assessments provides a powerful tool for refining the critical nutrient levels required for maintaining the plant and animal resources. In previous years, the Pondwatchers have conducted oyster growth experiments, detailed profiling of Oyster Pond, and continue to operate in a "rapid response" mode when fish kills or other low oxygen events trigger non-routine water sampling.

In 1991, several Pondwatchers participated in a fish survey as our major "Special Project" for that year in order to gain some insight into the populations of mobile aquatic species living within each one of the ponds. Each participant was responsible for two traps, a large baited box trap and a smaller minnow trap. Surveys were conducted four times in 1991 coinciding with the water quality sampling dates. Baited traps used squid for the first three samplings and herring for the fourth sampling. Traps were set 24 hours before collection, and catch was emptied into coolers (large trap) or bags (small trap) for return to the Woods Hole labs for sorting and identification.

The "Pond Trappers" were:

Oyster Pond 1	--	Barry Norris
Oyster Pond 3	--	Stan Hart
Little Pond 1	--	Bob Rogers
Little Pond 3	--	Jack Shohayda and Jane Carter
Green Pond 2	--	Matt Adamczyk
Green Pond 5	--	Armand Ortins
Bournes Pond 2	--	David Thomas and John-David Thomas
Bournes Pond 6	--	Jon Soderberg and Alicia Soderberg
Great Pond 2	--	Herb Stern
Great Pond 6	--	Dick Erdman and Jayne Hartnett

Identification and sorting of catch was conducted by Bob Livingston with assistance from John-David Thomas, Alicia Soderberg and Jason Fink.

RESULTS AND DISCUSSION

The sampling program in 1991 went exceedingly well, and undaunted as always, the Pondwatchers returned to sample their stations after Hurricane Bob. Approximately 2000 chemical assays (each in duplicate) and 1000 physical measurements were conducted in the monitoring effort in 1991 alone. In addition, individual rainfall records were kept for Oyster, Little, and Green Ponds, a tide gauge was maintained on Little Pond, and a fish trapping census of the upper and lower reaches of each pond conducted.

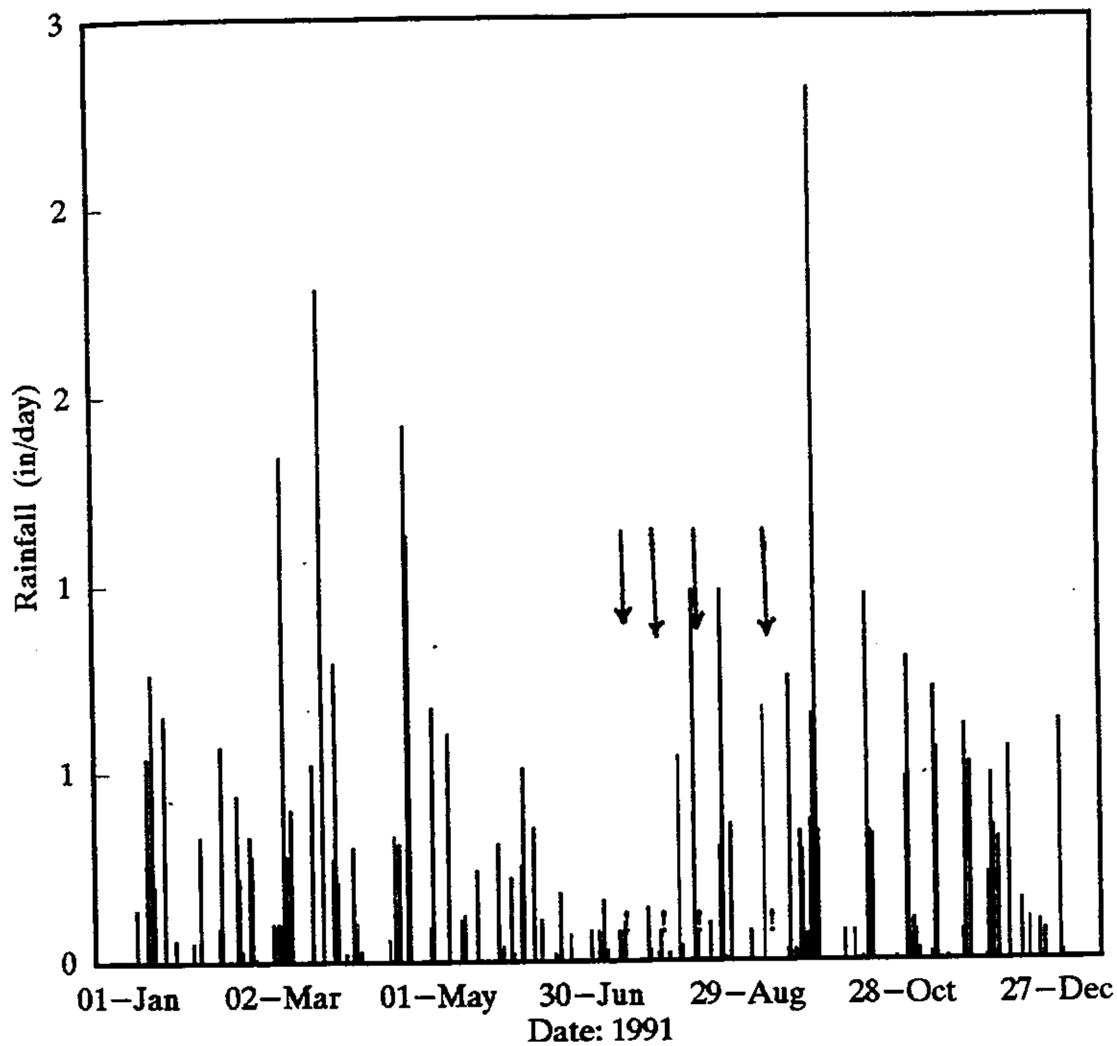
It is becoming increasingly clear that nutrient and oxygen levels within the ponds are highly variable both spatially and temporally. Our data from all five ponds indicate that a two-fold variation between samplings is not unusual. These results stress the importance of multiple samplings and longer-term data collection for assessing nutrient related water quality in these systems.

One of the environmental factors contributing to the observed variation in nutrients and oxygen levels is rainfall. Large rain events appear to be associated frequently with low oxygen events, and relatively unflushed ponds like Oyster Pond may exhibit salinity fluctuations related in part to annual rainfall. Pond sampling was by chance conducted both after periods of high and low rainfall (Figure 3). At present the relative importance of amount of rain versus extent of low light conditions (which co-occur with rainfall) in triggering low oxygen events is not clear, however comparing our five ponds in 1990 and 1991 the major low oxygen events in both years appear to be associated with these conditions. However, not all such weather events were associated with low oxygen. As more data accumulate, we continue to work toward developing methods to predict the meteorological conditions which result in low oxygen events in the various salt pond areas.

The bathymetries of the five ponds are in keeping with their different modes of formation: Green, Little, Bournes and Great Ponds by groundwater sapping of glacial outwash versus Oyster Pond (and Perch and Salt Ponds) from kettle holes. The "finger" ponds tend to be long, narrow and shallow with generally uniform depths of 1-2 m, while kettle ponds (freshwater ones as well) tend to be more circular and deeper (eg. Oyster Pond, 6 m).

Daily Total Rainfall 1991

Falmouth Coastal Ponds



WHOI Sea Grant Pond Watchers
Arrows indicate 1991 pond samplings.

Figure 3.

An important consequence of the eutrophic state and water depth of the ponds is that light is generally attenuated before reaching the bottom where it could support benthic algae (Figure 4). Given the depth of the Oyster Pond and Perch Pond (Great Pond Station #4) stations of greater than 3 m, it may seem reasonable that they have limited light penetration. However, at a similar depth the Vineyard Sound station (3.3 m) generally has light reaching the bottom. In fact, in general most of the relatively shallow Green, Great and Little Ponds also have similarly limited light penetration. It appears that the water column at most of the stations by mid-summer are supporting large phytoplankton populations consistent with the measured high particulate organic nitrogen and carbon concentrations. It is likely that it is this high plant productivity resulting from the nutrient rich waters which is causing the measured light attenuation. It may even be that the high phytoplankiton biomass partially inhibits macroalgal production in some areas, even in these generally shallow ponds. We will be investigating the phytoplankton-light-macroalgae interactions further since macroalgal production can have deleterious ecological consequences to coastal salt pond systems.

One consistent feature of all of the ponds is the increasing salinity moving from the inland headwaters toward Vineyard Sound (Figure 5). Green, Little, Bournes and Great Pond are for the most part saline ponds with average salinities above 25 ppt. The average summer salinity gradients from head to mouth in the ponds measured this past year are slightly less than in previous years due to the effects of Hurricane Bob. It appears that the very high tides and almost no rainfall associated with Bob increased the amount of salt water contribution to the upper regions of the ponds. This can be best seen when we compare the average chloride (sodium chloride) concentrations in pond waters before versus after the Hurricane (Figure 6). The stations below the 1:1 line have higher salinities days after Bob passed through. Oyster Pond (Figure 7) due to its restricted tidal exchange hence low salinity waters was the most sensitive indicator of this effect. The bottom waters of the pond

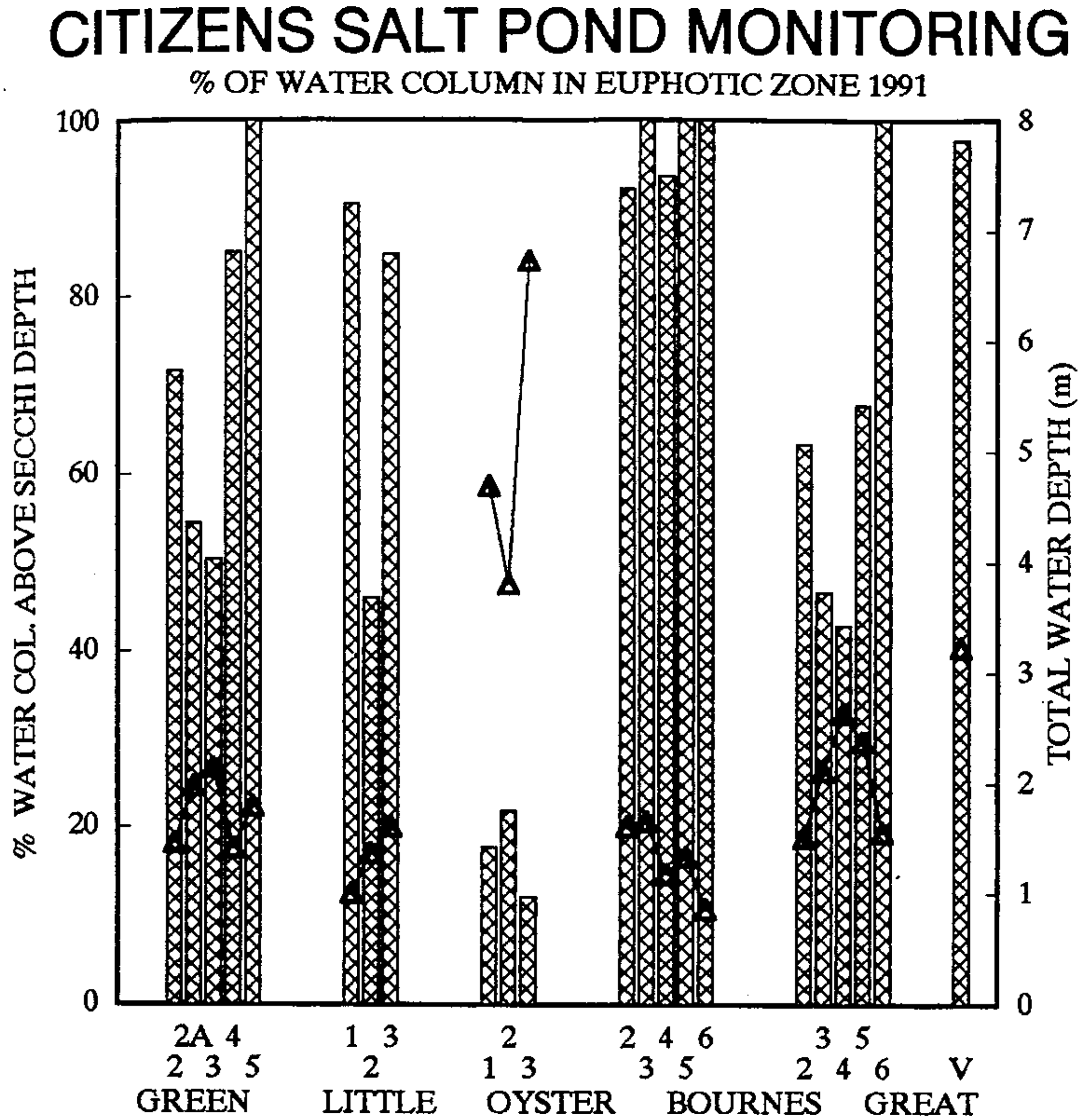


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Figure 4.