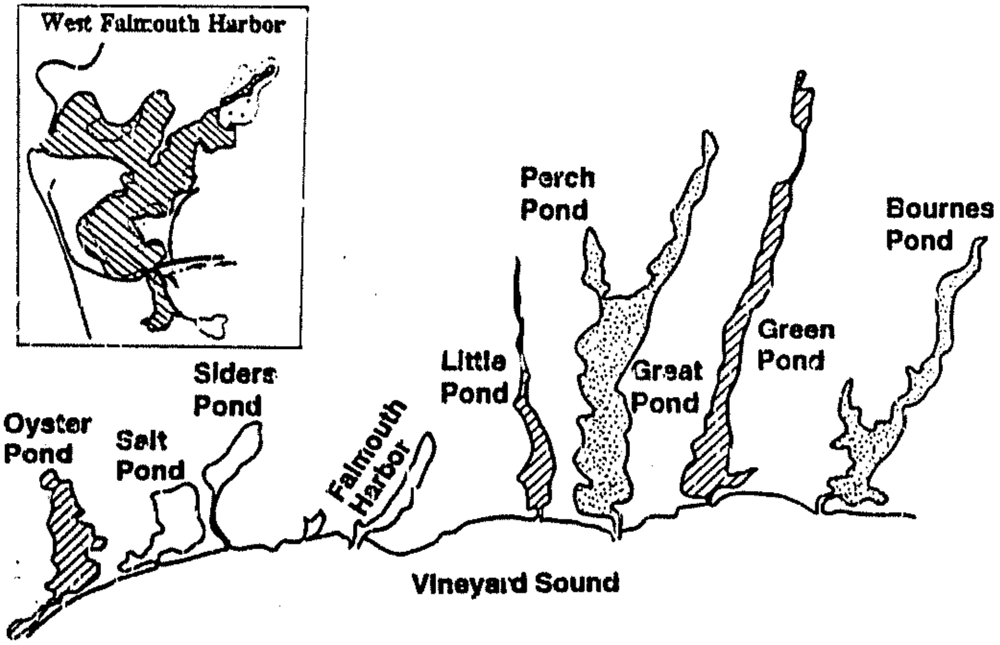
FALMOUTH POND WATCHERS

WATER QUALITY MONITORING
OF FALMOUTH'S COASTAL PONDS
REPORT FROM THE 1992 SEASON



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EXECUTIVE SUMMARY

Since 1987, the Falmouth Pond Watchers have given their time and energies to collect the baseline water quality data necessary for developing ecologically based environmental management strategies for Falmouth's coastal salt ponds and harbors. Starting with the three original ponds, Oyster, Little and Green, the project grew to incorporate two additional ponds, Bournes and Great, in 1990. Further expansion of the project to include West Falmouth Harbor in 1992 will provide baseline data in anticipation of evaluating any potential impact from the nutrient plume generated by the Falmouth Wastewater Treatment Facility. The project has met with great success since its inception, and the data base continues to grow. 1992 was no exception with all samplings conducted as scheduled.

1992 has seen a significant expansion in the focus of the Pond Watchers program. The long-term, high quality data base for the ponds is now enabling more emphasis on the ecological management and remediation aspects of the study, the ultimate goal of the program. Our initial efforts in this direction have been aimed at the two most eutrophic systems, Oyster and Little Ponds, both currently undergoing consideration by the Town for various remediation measures to improve water quality.

Overall, 1992 saw only slight variation in the water quality conditions of Oyster, Little, Green, Great and Bournes Ponds from previous years, with a declining trend for Green Pond

and small improvements in lower Great and Bournes Ponds. However, Oyster Pond showed a potentially significant improvement in bottom water oxygen conditions which suggests a new management direction for this system. All of the ponds continue to exhibit high nutrient levels and periodic bottom water oxygen depletion, especially in their upper reaches, and all stations exceed the nutrient levels specified by the Nutrient Overlay Bylaw. In contrast, the first year measurements in West Falmouth Harbor indicate high levels of water quality, although the inner reaches of the harbor do exceed those levels specified by the Bylaw. Our "Coastal Salt Pond Report Card" (Figure 1) indicates there is certainly "room for improvement" in the ponds on the southeastern shore of Falmouth, but we are confident through the continued efforts of the Pond Watchers and the close collaboration with the Town that we will soon be heading in this direction.

COASTAL SALT POND REPORT CARD

Pond	Ability To Make Bylaw Limit	Overall Water Quality	Status
Green Pond			
Upper	Fail	Poor	Same
Lower	Fail	Moderate	Declining
Great Pond			
Upper	Fail	Poor	Same
Lower	Fail	Good	Improving
Bournes Pond			
Upper	Fail	Moderate-Poor	Same
Lower	Fail	Moderate	Improving
West Falmouth Harbor			
Upper	Fail	Good	?
Lower	Pass	Good	?
Little Pond			
Upper	Fail	Poor	Same
Lower	Fail	Moderate-Poor	Same
Oyster Pond			
Shallow Basin	Fail	Poor	Improving (?)
Deep Basin	Fail	Poor	Same

Figure 1.

INTRODUCTION

The Citizen Volunteer Monitoring Effort for Falmouth's Coastal Ponds (better known as the "Pond Watchers"), was initiated in 1987 in response to concern over the apparently deteriorating water quality of Falmouth's circulation restricted coastal salt ponds. Beginning with three ponds (Little, Oyster and Green), the program expanded in 1990 to include two additional ponds (Bournes and Great), and most recently incorporated West Falmouth Harbor which saw its first sampling effort in 1992 (Figure 2). The fundamental purpose of the program is to provide much needed water quality data for the development of management plans established on the firm footing of quantitative, high quality environmental data. The project is jointly sponsored by the Town of Falmouth and the Woods Hole Oceanographic Institution Sea Grant Program, providing support for sampling equipment and analyses as well as avenues for direct application of results from the study. The backbone of the Pond Watchers program, however, is the effort and enthusiasm of the citizen volunteers who donate their time, boats and energies to collect environmental data on six of Falmouth's coastal ponds. These quantitative measures are crucial for developing management plans but often out of the reach of most coastal communities. The effectiveness of the program lies both in the enthusiasm and dedication of the Pond Watchers and the unique partnership which has developed between the citizens, local government and scientists whereby information gained from the research can be swiftly and directly applied toward effective management decisions for these fragile coastal environments.

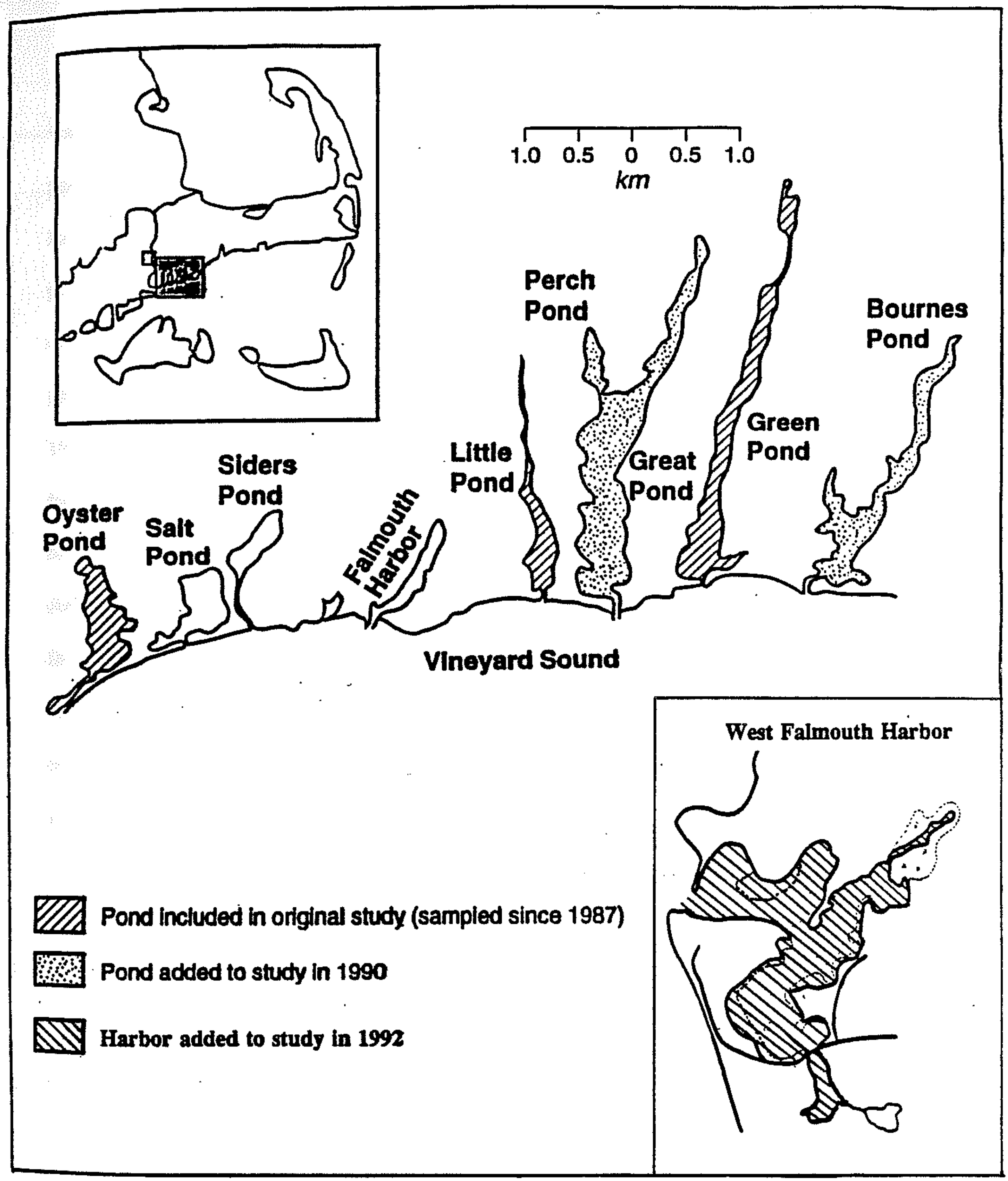


Figure 2. Relative locations of the study sites for the Falmouth Pond Watchers.

The overall goals of the study are to provide the Town with information on current water quality conditions in the ponds, both to help plan watershed land use and to help guide potential remediation plans where possible. In addition, the project was designed to involve local citizens directly in determining the present and future ecological health of their coastal ponds and harbors, as well as to draw community attention to the increasing human pressures on our fragile coastal resources. The need for the information and an involved citizenry is particularly important relative to the Coastal Pond Overlay Bylaw, enacted by Falmouth in 1988 to guide land use decisions around the ponds by specifying annual mean threshold values for total nitrogen concentrations in Falmouth's pond waters. 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 was designed to provide the nutrient information far too expensive to be provided wholly by already strained Town budgets to verify the validity of these threshold values as well as provide the Planning Board with additional ecological information to interpret the Bylaw.

To magnify the applicability of the monitoring data as well as assist in its interpretation, a parallel detailed scientific investigation of one of the monitoring ponds, Little Pond, was undertaken 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.

The importance of long-term data sets in evaluating trends in coastal water quality cannot be understated. Without year to year comparisons of ecological conditions it is impossible to evaluate apparent changes in water quality relative to natural processes (such as storms or natural shoreline changes) or anthropogenic (development or remediation related) impacts. The consistent and high quality data provided by the Pond Watchers is now enabling evaluation of various potential management directions for each individual system relative to both cost and ecological effectiveness. As well, the addition of West Falmouth Harbor to the suite of monitoring ponds provides a unique opportunity to obtain crucial "before" data with which to evaluate any potential future impact of the nutrient plume originating from the new Falmouth Wastewater Treatment Facility currently on a predicted course toward the Harbor.

The primary objectives 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,;

5) to provide baseline water quality data for evaluation of potential impacts to West Falmouth Harbor of the nutrient plume from the Falmouth Wastewater Treatment Facility;

6) 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.

With each subsequent year of monitoring, the value of the data base expands tremendously. These long term data sets enable the evaluation of trends in water quality conditions and provide the ability to identify what represents a short term, periodic event (such as periodic low oxygen events due to natural processes) and what is part of longer term trends in environmental health. With this data set, we are more able to evaluate not only the health of Falmouth's coastal salt ponds but also to more confidently make predictions on the potential effectiveness of various remediation measures. The unique partnership approach to addressing ecological and economic consequences of coastal eutrophication (scientists-citizens-local government) has proven to be extremely valuable toward the rapid implementation of results from the study. The direct application of data to management through close communication with the Town is especially effective in providing a data base for the Town to evaluate and implement its Coastal Pond Nutrient Overlay Bylaw. The effectiveness of this land use management plan is important both locally and regionally as it is now under consideration for adoption by many coastal communities. Interestingly, data generated by the Pond Watchers has shown that nutrient conditions in some of the ponds already exceed these threshold levels, an important discovery in evaluating management decisions for these systems.

A valuable advantage of the Pond Watchers program over other types of monitoring programs revolves around sampling methodology. Because of the large number of citizen volunteers, simultaneous sampling is conducted at all 34 stations on each sampling date. This provides data collected under the same conditions of weather and tide which is critical to making any system to system or station to station comparisons. This approach, although vital to providing the tools with which to make educated and effective management decisions for these complex systems, is frequently lacking in monitoring programs primarily due to the extensive labor requirements and associated costs. The joint effort between scientists and the community has the additional advantage of rapid implementation of new approaches to the monitoring plan based on the data collected, for instance "rapid response" efforts to provide more detailed information should unusual conditions be identified such as fish kills, algal blooms or low oxygen events. This cooperation has also served to keep costs low and provide for immediate transfer of information not only to the citizen volunteers but local and regional governments and the community as a whole. Most of all, the partnership has served to increase interest and understanding of the fragile nature of these valuable coastal resources.

Another important aspect of the Falmouth Pond Watcher's program is its wide ranging applicability to other types of coastal systems. 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. The success of the program is reflected in its adoption as a model for the EPA Bays Program/Buzzards Bay Project Citizen's Monitoring Program for the embayments of Buzzards Bay, and the number of other communities which are currently exploring mechanisms to establish similar Pond Watcher programs for their own harbors and ponds. National recognition of the Pond Watcher program was gained in 1991 when the National Environmental Awards Council cited the program for a National Environmental Achievement Award; recognition was again given to the program by Renew America as an innovative model for grassroots environmental protection programs, with a citation in their Environmental Success Index for 1992.

STATEMENT OF THE PROBLEM

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 over-fertilization (or "eutrophication") of these waters. Most all of Falmouth's coastal salt ponds presently show some signs of nutrient over-enrichment. 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.

Eutrophication is the natural response of coastal aquatic systems to excessive nutrient loading. At the highest levels of nutrient inputs into coastal waters the environmental health of coastal systems is severely impacted, 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. 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 nitrogen compounds enter the water column of coastal water bodies, the extent of their impact is determined by the rate at which they are lost through tidal exchange or burial in the sediments. Readily available nitrogen (nitrate or ammonia) can be taken up by algae and phytoplankton. These plants may fall to the bottom upon dying, or may be eaten and "processed" digestively by zooplankton (microscopic animals), fish or shellfish. Subsequent microbial activity in the sediments can re-release the nitrogen bound in such decaying organic matter to the overlying water column, where it once again becomes available as a nutrient for plant growth. Thus the harbor sediments act as sort of a "storage battery", 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. Each cycle magnifies the impacts of a one-time input. Since sediments store large amounts of nitrogen, the extent of recycling determines how long nutrient-related problems persist after the original sources from groundwater or surface runoff from land are stopped. Evidence for this magnification of impact and the significance of biological transformations which occur in these systems, especially in the finger ponds, is represented from observed changes in the dominant form of nitrogen which occurs in different segments of the ponds. In the upper reaches of the finger ponds, readily available dissolved forms of nitrogen such as nitrate and ammonium dominate, however moving down the ponds toward Vineyard Sound the dominant nitrogen species shifts toward the particulate form, reflecting transformation and uptake by phytoplankton in the water column as the nitrogen is transported toward open coastal waters. Separate benthic flux measurements show that a portion of the nitrogen the particulate form which has fallen to the sediments does indeed become re-released as inorganic nitrogen from the sediments, providing once again a readily available source of nitrogen for plant production in the water column. The significance of this finding revolves around the fact that with each round of particulate-dissolved transformation which occurs in the sediments, oxygen is consumed. In addition, with each new bloom of phytoplankton, night-time respiration by these plants increases the demand for oxygen in the water column when light is not available for photosynthesis. It appears from the data that nitrogen is actively transformed and recycled within the ponds as it moves from headwaters until it is eventially flushed out of the pond and therefore the one time input of nitrogen can impact the system many times until it is eventually lost to open coastal waters.

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. 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. It is this oxygen depletion that is directly responsible for most of the detrimental effects of excessive nutrient loading in coastal ecosystems. 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.

MANAGEMENT

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 and the value of real estate properties on or near these systems, thus potentially impacting important economic resources for many coastal 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.

Increasing our understanding of these coastal salt ponds, as well as the relative success or failure of remediative measures to improve their water quality, allows us to better predict the potential impacts which may result from alteration of one or more of the dominant processes which structure them such as nutrient inputs or losses. This project provides the 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. In addition, many of the coastal ponds are linked hydrologically, with potential hydrologic alteration of one causing secondary effects in watershed-pond nutrient delivery rates to adjacent systems. Even more direct secondary impacts are created when nutrient removal by sewering a watershed is performed, nutrients removed from one watershed usually being merely transferred to a different embayment after treatment. By better understanding these ecosystems and their linkages 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. In addition, 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.

SUMMARY OF PREVIOUS RESULTS: 1987 - 1991

The results of previous samplings (1987-1991) have provided significant insights into the ecological health of Falmouth's coastal salt ponds, and we are now in a position to begin evaluation of potential future trends in water quality conditions for these systems. In the initial stages of this study, measurements were conducted over annual cycles, providing information on the seasonal variability in nutrient and oxygen conditions in the ponds. It has become clear that both of these major determinants to ecological health are highly variable both spacially and temporally, emphasizing the importance of multiple samplings and long-term data sets for assessing nutrient related water quality in these systems. Further study, with additional emphasis on the importance of natural physical processes such as wind driven mixing and water temperature on the fate and transformations of nutrients and oxygen, resulted in the focussing of field sampling effort to summer months when the systems are most biologically active and sensitive to nutrient inputs. 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 the stream samples). The result is that summer sampling gives a good average view of nutrient levels and is the critical period for low oxygen events. In addition, the ability to concentrate samplings during the more productive summer months without impacting the data yield permitted more efficient use of volunteers and resources and allowed more frequent samplings during the period when the ponds were most likely to experience the lowest water quality conditions. However, without the initial annual sampling program, it would not be possible to rely on the more focused effort and be confident that the important ecological questions were actually being addressed.

The most significant finding from previous work was that almost every region of every pond exhibits total nitrogen concentrations above the allowable levels as specified by the Falmouth Coastal Pond Overlay Bylaw, and that the levels were fairly stable from year to year. In fact, many of the areas exceed the highest level of 0.75 mg/l specified for intensive use areas; some designated as "high quality" or "stabilization" areas would need reductions of more than 50% to reach the currently specified levels according to the Bylaw. In addition, the results show that the high nitrogen areas are indeed associated with low water quality as defined by low dissolved oxygen levels (especially in bottom waters), and frequently macroalgal blooms as well. This is most well demonstrated by the longer data sets on Little, Green and Oyster Ponds, all nutrient rich and eutrophic systems. Bournes and Great Ponds also exhibit periodic low oxygen conditions (less than 4 mg/l, generally considered to be stressful to benthic and bottom dwelling organisms) at most stations. Although apparently more periodic for these ponds, it is not possible at present to assess the duration and extent of low oxygen conditions over the entire summer for these two systems without a more intensive sampling regime such as has been conducted in Little Pond. Additional data from subsequent years, however, will be valuable in providing information to answer this question. In simplest terms, the higher nutrient levels in the Bylaw do reflect poor water quality and all areas with total nitrogen levels below 0.32 mg/l are indicative of healthy, productive systems, eg. Vineyard Sound and Buzzards Bay. It appears that, if anything, the specified nutrient levels are a little too low to achieve stated ecological standards. In other words, low oxygen conditions and impoverished animal communities are found at lower nitrogen levels than anticipated.

A major finding of the study reflects the importance of differentiating natural processes from anthropogenic impacts in evaluating those factors responsible for water quality conditions in these systems. For instance, the physical structure of Oyster Pond with its deep anaerobic basin is a good example of a naturally eutrophic system. The very structure of this pond, with its deep basin, virtually eliminates any wind driven mixing of oxygen into the deeper regions of the water column. In addition, light attenuation in the deeper depths of the water column minimizes photosynthetically derived oxygen at the same time decomposition processes consume oxygen. Although nutrient additions to Oyster Pond are impacting the system, the natural processes effecting the deep basin would occur regardless of additional nitrogen inputs and therefore by the standards of the Bylaw (as well as most ecological standards) would be considered to have eutrophic, oxygen depleted bottom waters regardless of human activities around the pond. Nevertheless, additional nutrient loading to this system without parallel increases in nutrient loss (i.e. via flushing) has the potential to seriously impact the ecological health of the shallow areas of this type of system once the assimilative capacity for new nutrients has been exceeded.

Results from the project so far also indicate that rainfall plays an important role in contributing to observed variations in nutrients and oxygen. Significant rain events appear to be frequently associated with low oxygen events, and ponds with very limited flushing such as Oyster Pond may reflect changes in salinity related partially to annual rainfall. Not all rain events lead to low oxygen in the ponds, however, and we are focusing on developing methods to predict the meteorological conditions which result in low oxygen events in the various salt pond areas. So far we have observed long-term changes due to Hurricane Bob and moderate changes due to interannual rainfall variations as well as short-term effects of individual rain events. These results underscore the need for long-term monitoring of these dynamic coastal systems.

Since our concern with high nutrient levels and low oxygen conditions is primarily due to its severe negative impacts on animals and plants living in the ponds, special projects were undertaken by the Pond Watchers focusing on evaluating the comparative health and growth of animal species living in the different ponds. These projects involved oyster growth experiments, and fish and invertebrate surveys. Oysters were found to grow best with very low mortality at sites in Little Pond (LP3) and Green Pond (GP4, GP2); oysters located in Oyster Pond, however, exhibited poor growth and about 15 percent mortality. The low success in Oyster Pond may be potentially due to the reduced salinity of the pond, or the form of phytoplankton species may have been unpalatable or indigestible by the oysters as there were high levels of particulate organic nitrogen suggesting plenty of organic matter in the water column. The data suggests that shellfish can survive in all of the ponds, however it is important to note that oysters in these experiments were suspended in nets above the bottom and therefore do not reflect survivorship of infaunal animals.

Fish and invertebrate censuses were conducted in each of five ponds (prior to the inclusion of West Falmouth Harbor) with both an upper and lower site within each pond. Fish species were collected using both "minnow" and larger commercial box traps at each stations, with collections in concert with the four watercolumn samplings to enable comparison of oxygen and nutrient conditions to species population and distribution. Although traps do not provide perfect quantitative results since some species may avoid entering traps, the results of the census were consistent between all sites: areas with low bottom water oxygen had a lower number of species present than higher oxygen areas. This result is independent of which species were found and whether one considers fish or invertebrates. This finding is supported by basic ecological theory where high stress habitats generally have a lower species diversity. The lowest diversity was generally found in Oyster, Little and Upper Green Ponds, and in the less eutrophic ponds (Bournes, Great and Lower Green) there was a tendency for a lower diversity in the upper versus lower sites. These results support the contention that low oxygen and high nutrient areas are of low ecological health.

Previous results from the program also indicate that the eutrophic nature of the ponds is resulting in the limitation of light penetration through the water column, even in the relatively shallow systems. By mid-summer, the water columns of most of the stations are supporting large phytoplankton populations consistent with the high measured concentrations of particulate organic carbon and nitrogen. This increased production resulting from the nutrient rich nature of the waters is most likely the cause of the decrease in light penetration. We are currently investigating in more detail the relationship between light penetration, eelgrass and macroalgal growth as eelgrass provides very valuable habitat, however overproduction, especially of some macroalgal species, can have deliterious ecological consequences to coastal pond systems.

SAMPLING LOGISTICS AND EQUIPMENT

Prior to the commencement of field sampling each year, the Pond Watchers take part in a refresher course on sampling procedures and receive information on any "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 for 1992 were:

Oyster Pond -	John Dowling
	Julie Rankin
Little Pond -	Bobby Rogers
Upper Green Pond -	Matt Adamczyk
Lower Green Pond -	Edmund Wessling
	Armand Ortins
Upper Bournes Pond -	Steve Molyneaux
Lower Bournes Pond -	John Soderberg
Great Pond -	Chuck Olive
West Falmouth Harbor -	Paul Bansbach

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

RESULTS AND DISCUSSION

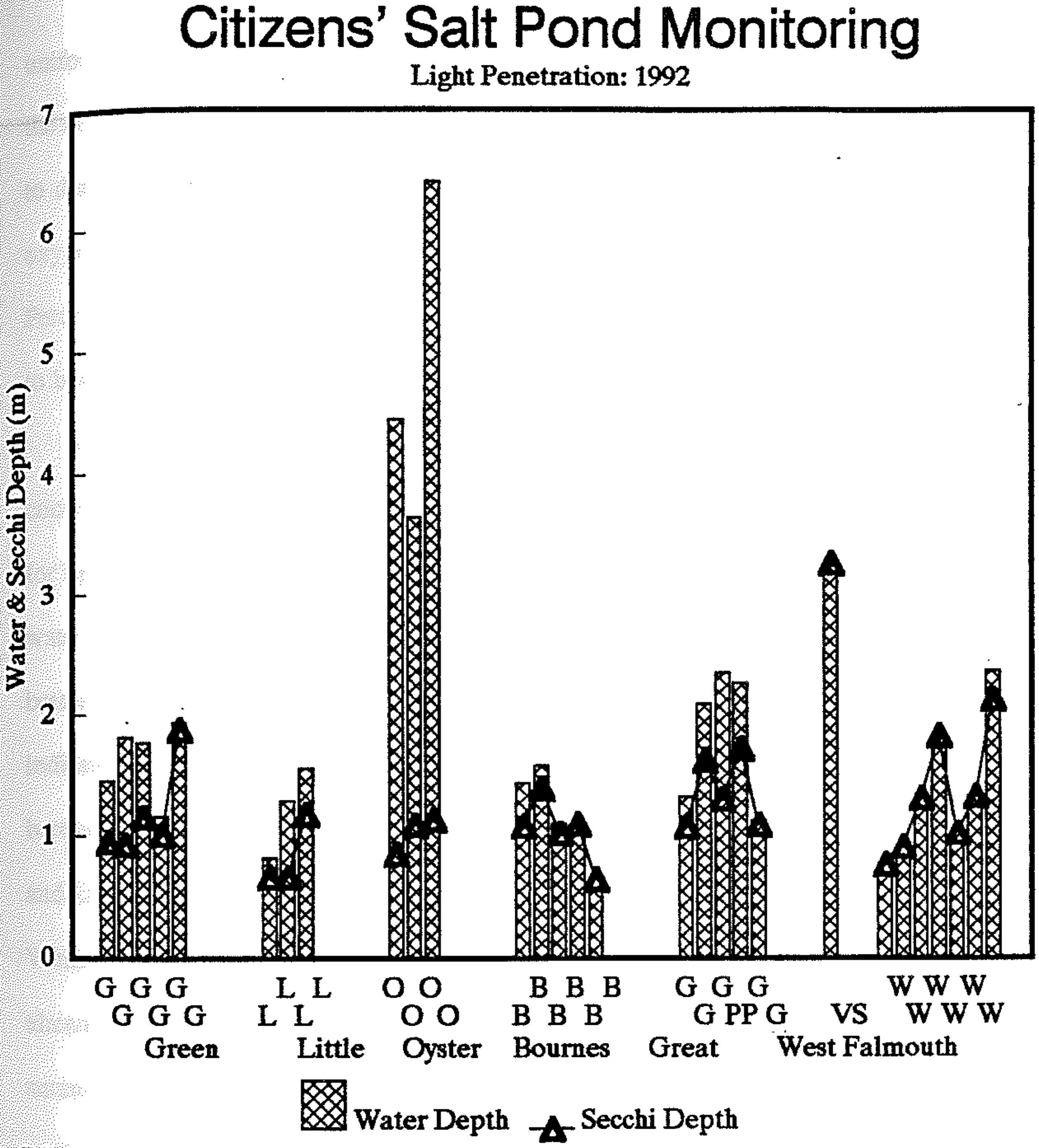
The past year, 1992, has seen a significant expansion in the focus of the Falmouth Citizens Salt Pond Monitoring Program. In 1992 we began to place more emphasis upon management and remediation in addition to the continuing long-term mission of acquiring quantitative nutrient data relative to the Nutrient Bylaw and providing current water quality status of the salt ponds. With this in mind the analysis of the 1992 results is divided into two parts: 1) a presentation of long-term trends and current ecological health of each of the embayments including the first information on West Falmouth Harbor and 2) suggested management options for two of the more impacted systems, Oyster and Little Ponds.

Overall, taken as whole ecosystem units, the status of Green, Little, Great/Perch, Bournes, and Oyster Ponds remains as in previous samplings at almost all stations. These five ponds continue to exhibit high nutrient levels and periodic oxygen depletion in their upper reaches and all exceed nutrient levels specified by the Nutrient Overlay Bylaw. However, the ponds do not function as single units but rather as linked upper and lower pond components forming the whole. Assessing individual stations within each pond gives a different view with the declining trend in water quality in Green Pond now apparently confirmed and small improvements in lower Great and Bournes ponds possibly due to increased circulation. However, the greatest potential change involves the first indication of improving conditions in Oyster Pond and also suggests that a remedy for that system may be possible.

Ecological Health: Status

Approximately 2500 chemical assays (each in duplicate) and almost 1000 physical measurements were conducted throughout the six embayments (Figure 2) monitored by the Falmouth Pond Watchers in 1992. Consistent with previous years, variations of almost two fold in nitrogen or oxygen levels were frequently observed at individual sites between samplings. However, at four of the twenty seven stations monitored in 1992, significant changes in either oxygen or nitrogen were found from previous years. These changes stress the importance of multiple samplings and longer-term data collection for assessing nutrient related water quality in these dynamic coastal systems.

The physical structure, shape and depth, of each of the embayments appears to play a major role in their susceptibliy to ecological impacts from nutrient loading. The bathymetries of each of the five salt ponds are in keeping with their modes of formation: Green, Little, Bournes and Great Ponds by groundwater sapping of glacial outwash versus Oyster Pond (and Perch and Salt Ponds) from drowning of 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, 6m). West Falmouth Harbor is intermediate in these respects functioning much like the main basins of Great and Bournes Ponds but without the long narrow upper portions (Figures 2 & 3). Shape and depth effect water quality as a function of the decreasing exchange with lower nutrient offshore waters as distance from the inlet increases, hence the more elongated portions tend to be more susceptible to nutrient related impacts. The role of water depth is linked more to oxygen status than nutrient levels in that the deeper the water, the less likely that the watercolumn will be



Citizens' Salt Pond Monitoring

Light Penetration: 1992

B.L. Howes, WHOI Sea Grant

When Secchi Depth = Water Depth: the potential for macroalgal blooms exists.

Figure 3.

uniformly mixed from top to bottom. Since the ponds frequently require oxygen inputs from the atmosphere to surface waters and subsequent physical mixing to bring oxygenated waters to depth to maintain oxygen balence, deeper waters are more likely to experience periodic oxygen depletions when vertical mixing doesn't reach the bottom (stratification). Oyster and Perch (because of its isolated basin) Ponds are the most susceptible to negative impacts due to basin depth.

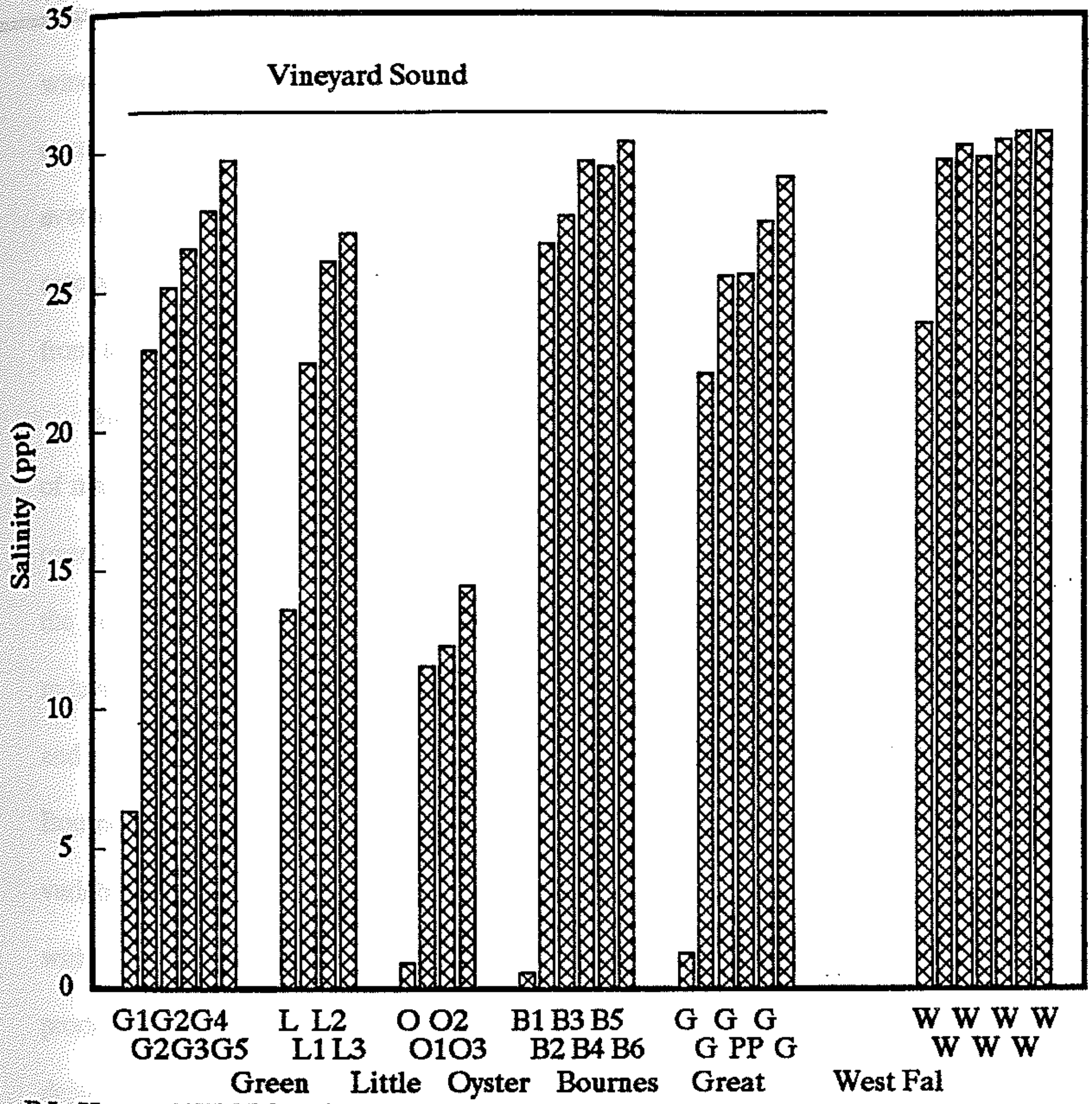
In addition to its relation to potential stratification, basin depth coupled with the particle concentration in the pond waters (primarily plankton and macroalgae) determines the potential for light to reach the bottom sediments. An important consequence of the eutrophic state and water depth of the ponds is that light is generally attenuated in summer before reaching the bottom where it could support benthic algae (Figure 3). The importance of water clarity is indicated by comparing pond stations with Vineyard Sound which had light reaching the bottom at over 3 meters depth. In contrast, most of even the relatively shallow Green, Great and Little Ponds and the deep basins (4 & 6m) of Oyster Pond had limited light penetration. While this may reduce the susceptibility to benthic blooms, the low water clarity is due to the already eutrophic conditions. It appears that the watercolumns at most of the stations by mid-summer are supporting large phytoplankton populations consistent with the measured high particulate organic nitrogen and carbon concentrations. West Falmouth Harbor, at all stations, was similar to the lower, more well flushed regions of Green, Great and Bournes Ponds and Vineyard Sound in both depth and water clarity. The result is that throughout the Harbor, bottom sediments can support benthic algae and rooted plants eg. eelgrass.

A major ecosystem structuring parameter in these circulation restricted coastal embayments is salinity (Figure 4). The animal and plant communities within any embayment are able to tolerate a moderate range of salinities but not the full spectrum from fresh to seawater. The result is that major changes in salinity can result in the replacement of whole communities independent of water quality issues. At present all of the six systems contain salt water, and except for Oyster Pond, almost all stations were above 25ppt with fresher headwaters where groundwater and streamflows are greatest and highest salinities near the seawater source at the inlet. These high salinities will support most estuarine species including most shellfish. A relative indicator of the efficiency of tidal exchange in each of the six systems can be derived from the magnitude of the salinity gradient from the inlet inland. Oyster Pond's fresher water is directly the result of its restricted inlet which limits tidal inflow. As might be expected from morphology and water clarity (Figures 2 & 3) the lower portions of Green, Great, Bournes Ponds and most of West Falmouth Harbor all had salinities approaching the source waters consistent with their good tidal exchange. Little Pond, due to the restriction of its inlet by sedimentation over the last several years, is experiencing a gradual freshening of its waters due to its diminishing tidal flux. The upper regions of Green, Great and Bournes Ponds are most similar to Little Pond except that the diminished flushing of their waters (relative to the lower regions) is due to their distance from the inlet more than changing inlet structure.

One of the environmental factors contributing to the observed variation in nutrients and oxygen levels is the frequency and magnitude of storms/rainfall. Rain events appear to be frequently associated with low oxygen events; relatively unflushed ponds like Oyster Pond may exhibit salinity fluctuations related in part to annual rainfall. Pond sampling each year is

Citizens' Salt Pond Monitoring

Summary Watercolumn Salinity: 1987 – 1992

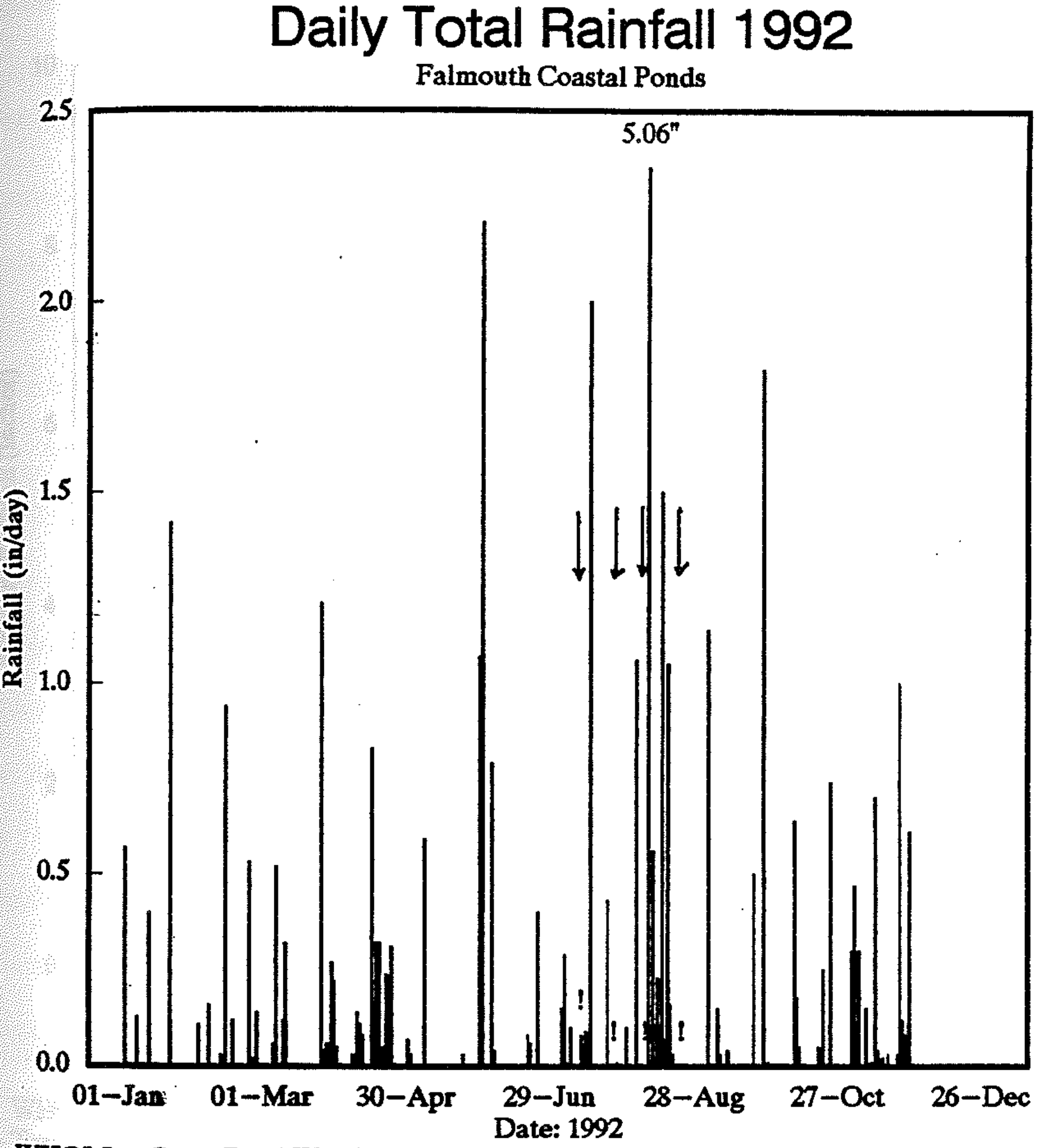


B.L. Howes, WHOI Sea Grant
Watercolumn averages, all data.

Figure 4.

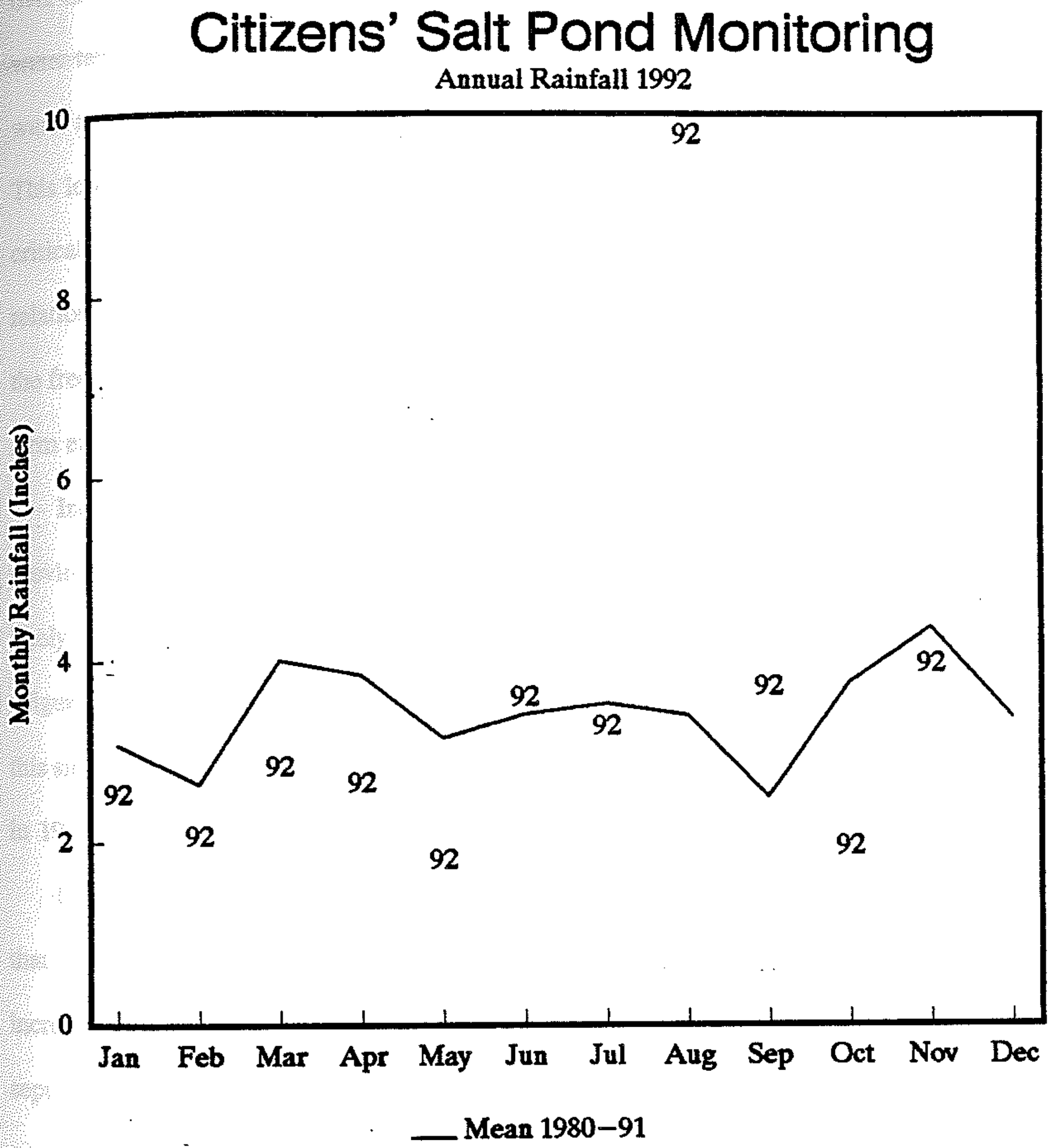
generally conducted relative to high and low rainfall periods as was true for 1992 (Figure 5). At present, the relative importance of rainfall versus the extent of low light conditions and low wind speeds (low vertical mixing) which co-occur with rain events in triggering low oxygen events is unclear. However, in 1990 and 1991 in all five salt ponds the major low oxygen events appeared to be associated with these conditions. Not all such weather patterns had associated low oxygen events and the magnitude of the rainfall may play a role as suggested from the 1992 data.

Summer rainfall in 1992 was exceptionally high especially in August, generally the month of maximum low oxygen events. A single rain event in August delivered 5.06 inches of rain over 24 hrs and overall almost 2.5 times more rain fell in August 1992 than the average for the previous 12 years (Figure 6). This exceptional weather appears to have resulted in a reduction in low oxygen events rather than an increase. The direct mechanism is not yet clear and is partially confounded by the potentially increased flushing of some ponds (Great and Bournes) over previous years due to inlet scouring post Hurricane Bob (August 1991). The variable effects of storms on oxygen conditions may be related to the magnitude of the event with: 1) moderate storm/rainfall events serving to briefly reduce photosynthesis (oxygen production) and stratify the pond (via freshwater inflow) causing bottom water oxygen depletions; and 2) high and prolonged storm and rain activity improving oxygen balance by increased flushing of ponds due to massive freshwater inflows coupled with lower water temperatures from the decreased insolation causing a reduction in the rate of oxygen uptake. Support for the effect of moderate storm effects and low oxygen conditions has been found in previous years. Partial support for the latter mechanism is seen in the daily water temperatures



WHOI Sea Grant Pond Watchers
Arrows indicate 1992 pond samplings, 4th wettest August past 27 yrs.

Figure 5.



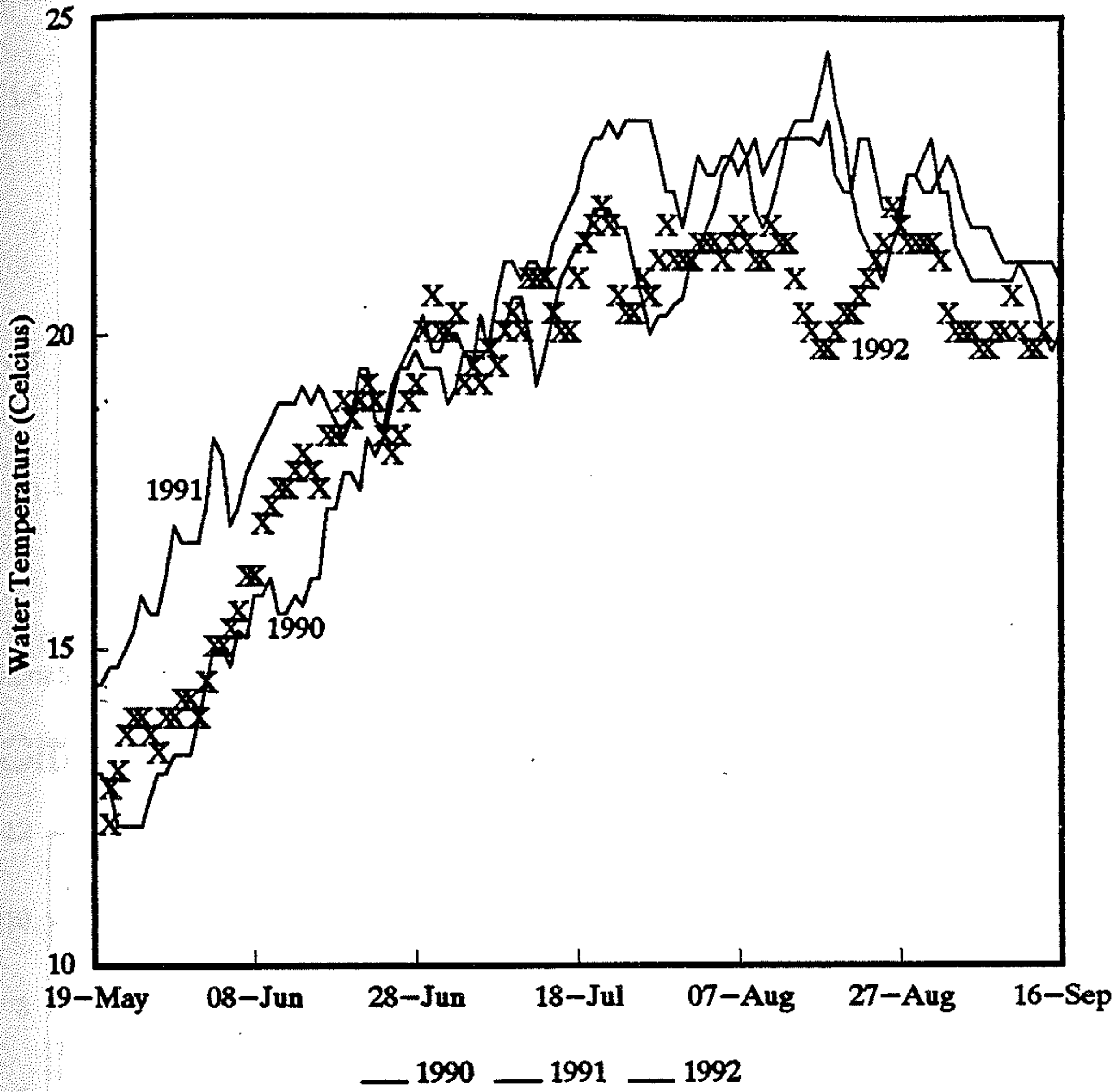
WHOI Sea Grant
Total annual rainfall about 12 yr average.

Figure 6.

over the past three summers (Figure 7). Throughout June, July and August in 1990 and 1991 water temperatures were variable but similar in pattern. In contrast, throughout August 1992 water temperatures were depressed presumably due to the lower insolation during this period. This lower temperature would have a significant effect upon oxygen uptake during the most critical period for pond oxygen depletion. We will continue our investigation of the relationships between meteorological events and pond water quality to better understand both the frequency of low oxygen events and to facilitate water quality evaluations in light of short-term effects of stochastic events.

Indeed, the 1992 sampling found minimum oxygen levels higher in most ponds than in previous years. While this was true for most of Green Pond, the apparent "improvement" is likely to be short lived as it was not associated with significant reductions in nitrogen levels (Figure 8) which exert the long-term control on oxygen depletion. However, it is possible that this single season improvement may result in small increases in secondary production (animals) in 1993 due to increased survival in the areas of moderate water quality.

Green Pond was one of the initial three ponds selected for study in 1987 due to concerns that its water quality was declining from increasing nutrient loading to its watershed, the increased loading being the result of expansion of the developed land area and use of on-site septic disposal of wastewater within the pond's zone of contribution. We have been following a possible decline in oxygen minima and increasing nitrogen levels to gage this effect. The upper reaches of Green pond have exhibited high nitrogen levels, exceeding 0.75 mg/l and low oxygen events, less than 4 mg/l for several years, similar to the upper portions of most of the ponds. In contrast, the lower reaches of the Green Pond, closest to the inlet, have maintained



Daily Summer Water Temperature

Woods Hole: 1990 – 1992

B.L. Howes, WHOI Sea Grant
Data: Woods Hole Oceanographic Institution

Figure 7.

relatively good water quality. The concern over potential declines in ecological health of Green Pond did not focus on further declines in the uppermost (already stressed) regions but on the mid-region (Station 4). It is the mid-region where the transition from low to high water quality occurs. Increased nutrient loading causes the low water quality region to expand with the effect that the zone of high impact appears to move down the pond. Since the level of nutrient loading has been increasing, partially due to the long travel time for groundwater to discharge new nutrient sources to the pond waters, the effects may not yet be fully developed. Another factor is the possible sedimentation of the inlet which, to the extent that tidal exchange has become increasingly restricted (yet undocumented), would cause increases in pond nitrogen levels. For the past few years it appeared that Green Pond Station 4 (above the bridge) was transiting from the water quality of the lower pond to be more like the upper pond system. The difference now appears to be "real" with this area of the pond experiencing low oxygen events and an upshifting of mean nitrogen levels from the 0.32-0.5 mg/l designation to the 0.5-0.75 mg/l level (Figure 9). The lower temperatures in 1992 may be responsible for the overall improvement in oxygen levels; if other longer lived causes are responsible the effect should be found in the coming year. If the apparent decline in Green Pond continues potential management options will be explored.

The Great/Perch Pond system, like Green Pond, exhibited much higher oxygen levels in 1992. In fact, no low oxygen events were sampled. The positive effect (if any) on 1993 fisheries is yet to be determined. Also like Green Pond, the mid-region of Great Pond (Station 3) showed a single season change in nitrogen levels, however this change being an improvement (Figure 10). The longevity of this lower nitrogen level and its cause is not yet relatively good water quality. The concern over potential declines in ecological health of Green Pond did not focus on further declines in the uppermost (already stressed) regions but on the mid-region (Station 4). It is the mid-region where the transition from low to high water quality occurs. Increased nutrient loading causes the low water quality region to expand with the effect that the zone of high impact appears to move down the pond. Since the level of nutrient loading has been increasing, partially due to the long travel time for groundwater to discharge new nutrient sources to the pond waters, the effects may not yet be fully developed. Another factor is the possible sedimentation of the inlet which, to the extent that tidal exchange has become increasingly restricted (yet undocumented), would cause increases in pond nitrogen levels. For the past few years it appeared that Green Pond Station 4 (above the bridge) was transiting from the water quality of the lower pond to be more like the upper pond system. The difference now appears to be "real" with this area of the pond experiencing low oxygen events and an upshifting of mean nitrogen levels from the 0.32-0.5 mg/l designation to the 0.5-0.75 mg/l level (Figure 9). The lower temperatures in 1992 may be responsible for the overall improvement in oxygen levels; if other longer lived causes are responsible the effect should be found in the coming year. If the apparent decline in Green Pond continues potential management options will be explored.

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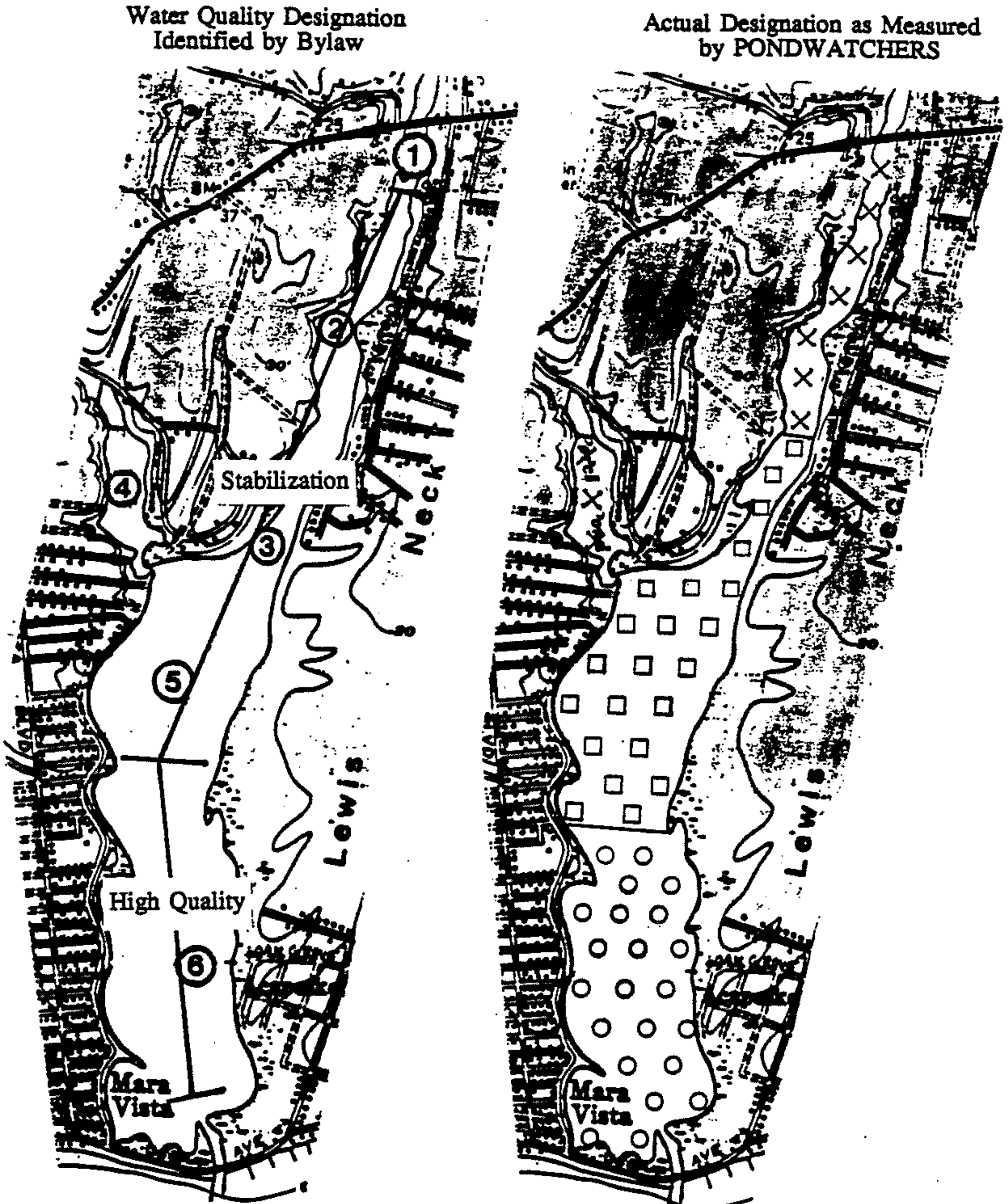
While the 1992 nitrogen levels suggested an improvement at the mid pond station, all of the Great/Perch Pond system is above the levels specified in the Nutrient Bylaw. As in Green Pond the upper reaches had total nitrogen levels in excess of 0.75 mg/l and almost 2/3 of the pond area was above 0.5 mg/l (Figure 11).

Bournes Pond showed trends almost identical to Great Pond both in 1992 and earlier years. As in Great Pond the mid-pond station exhibited lower total nitrogen levels and an improvement in the three year average for that zone (Figure 12). Oxygen levels were improved over the previous two years but not quite as well as for Great Pond, with some low oxygen (4 mg/l) values being recorded in the upper reaches. It appears that the upper reaches of Bournes, Great and Green Ponds function as similar systems, all experience high nutrient levels and low oxygen events (in some years); the key factor determining the extent of low water quality appears to be related to the distance from a main water body. For Green Pond the main high quality water source is Vineyard Sound, while for the upper reaches of Great and Bournes Ponds it appears to be the main pond basin. The increased distance is related to the ability of water exchange in the upper reaches to transport the nutrient load to open waters.

Great Pond station locations and Water Quality Designation as identified by Coastal Pond Overlay Bylaw (adopted by Falmouth Town Meeting, April 1988) and actual designations according to the Bylaw as measured by Falmouth Pondwatchers.



Water Quality Designation Identified by Bylaw

Actual Designation as Measured by PONDWATCHERS

"Critical Eutrophic Levels" as designated by Coastal Pond Overlay Bylaw
(Total Nitrogen as Average Over Year)

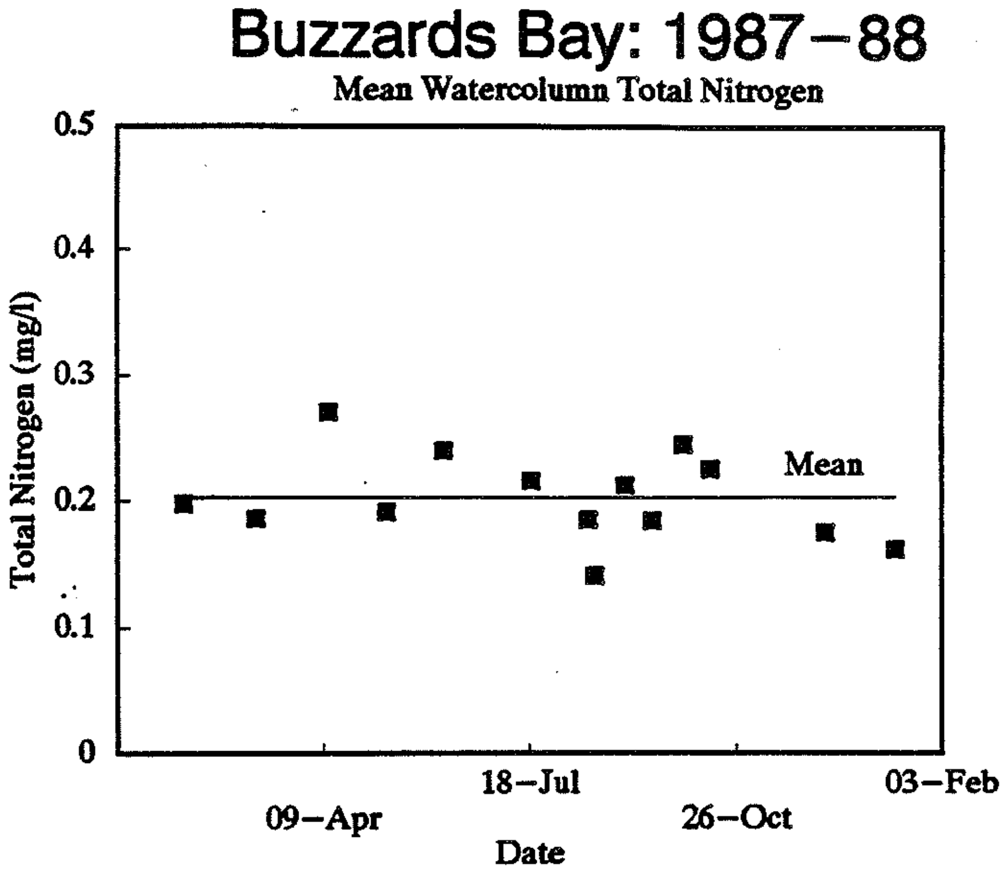
> 0.75 mg/l	= Above Highest "Critical Eutrophic Levels"	×
0.5 - 0.75 mg/l	= Intensive Water Activity Area	☐
0.32 - 0.5 mg/l	= Stabilization Area	○
< 0.32 mg/l	= High Quality Area	

Figure 11.

Nutrient loading remains the ultimate source of water quality problems with circulation determining the magnitude of the impact.

As in Great Pond, all of Bournes Pond is above the nitrogen levels specified by the Nutrient Bylaw (Figure 13). Similarly, the mid-pond station showed a net reduction in nitrogen levels, changing the designation from 0.5-0.75 mg/l to 0.32-0.5 mg/l. The duration and causes of this improvement are probably the same as stated above for Great Pond.

West Falmouth Harbor was included in the Citizens' Monitoring Program for the first time in 1992. The harbor is an embayment of Buzzards Bay (See map in Appendix I). Buzzards Bay has a high level of water quality similar to Vineyard Sound with low total nitrogen and high oxygen levels found in previous studies (Figure 14). Buzzards Bay also has a much greater tide range than Vineyard Sound which increases the potential water exchanges with its embayments enhancing their water quality. The high salinities found throughout West Falmouth Harbor are partially due to this high rate of water exchange with Buzzards Bay waters (Figure 4). West Falmouth Harbor currently exhibits high quality waters and a heathly ecosystem. The low nutrient levels (Figure 15) and low level of eutrophication allow light pentration to the bottom allowing eelgrass beds to persist (Figure 3). At present there is no indication of periodic low oxygen in the harbor (Figure 15). Unlike the other five embayments in our study, most of West Falmouth Harbor meets the levels specified by the Nutrient Bylaw and the areas which exceed the limits are still in the 0.32-05. mg/l range (Figure 16). We caution that this is a limited data set in an apparent low enviromental stress year. We will continue to monitor this system as it is the likely receipient of the nutrient plume from the Falmouth Wastewater Treatment Facility. This plume, if it discharges to the harbor, will



B.L. Howes, WHOI Sea Grant
Source water for West Falmouth Harbor

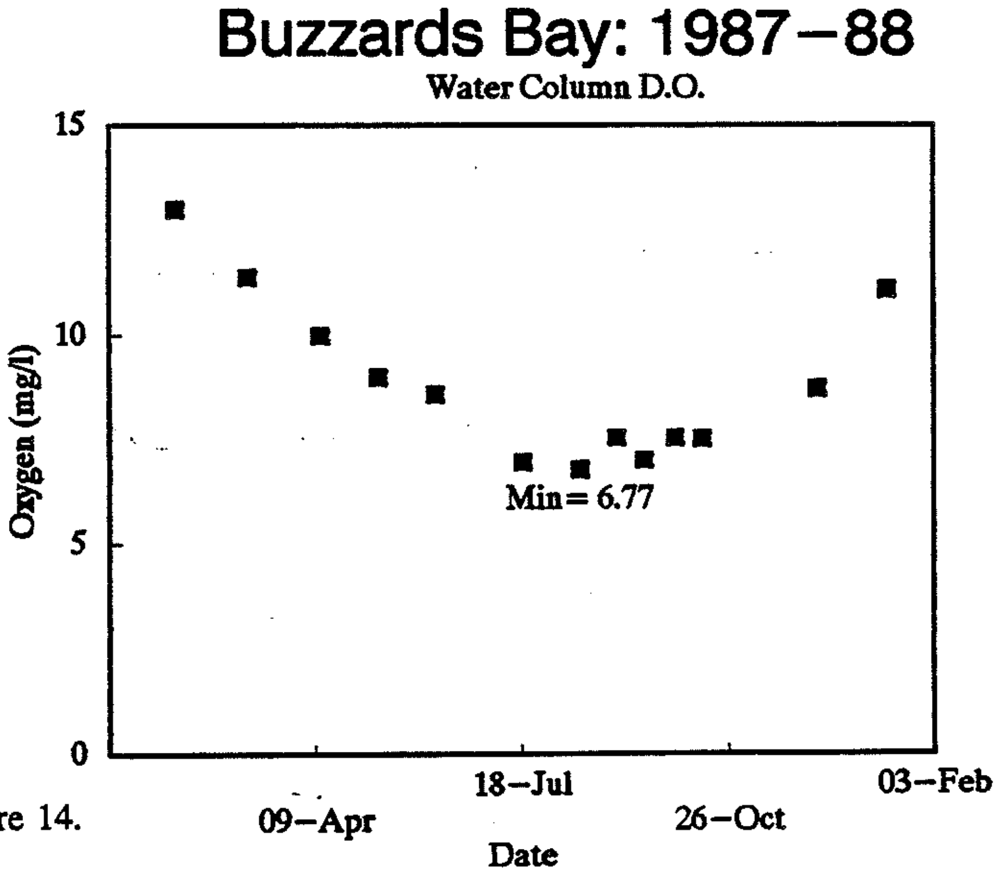
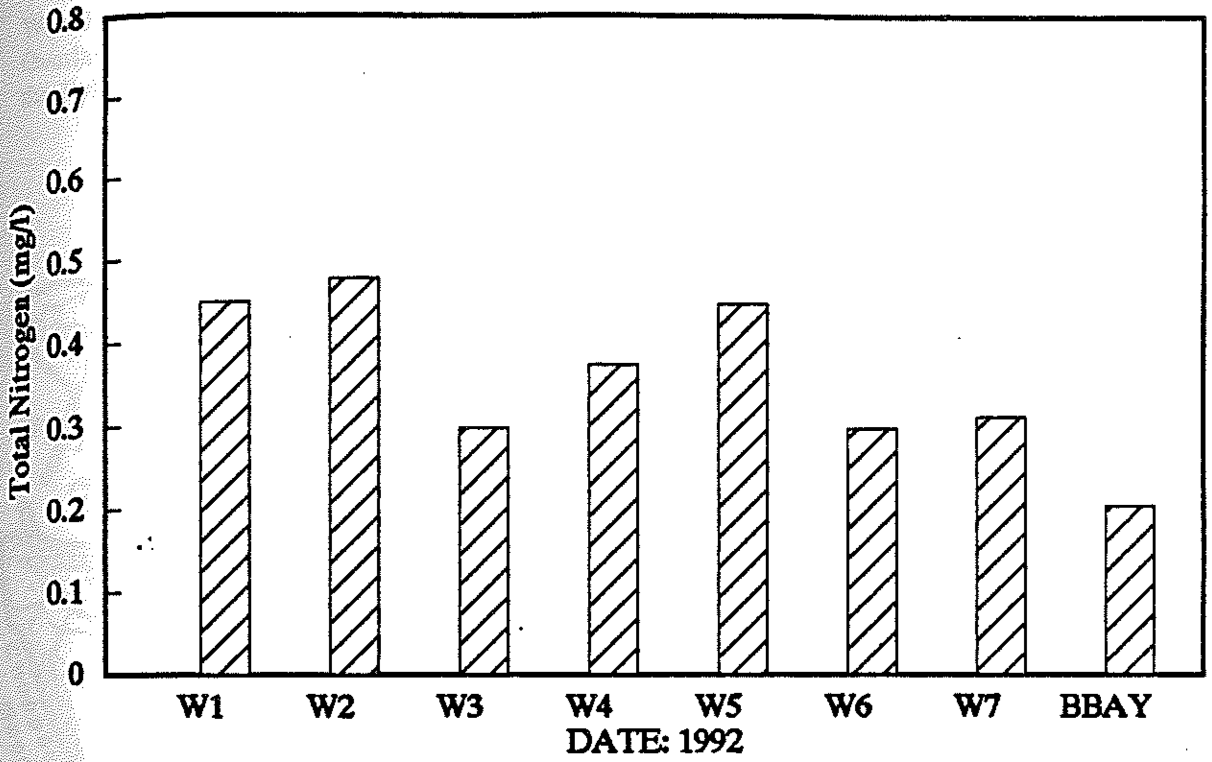


Figure 14.

B.L. Howes, WHOI Sea Grant
Source water for West Falmouth Harbor

Citizens' Salt Pond Monitoring: 1987 – 92

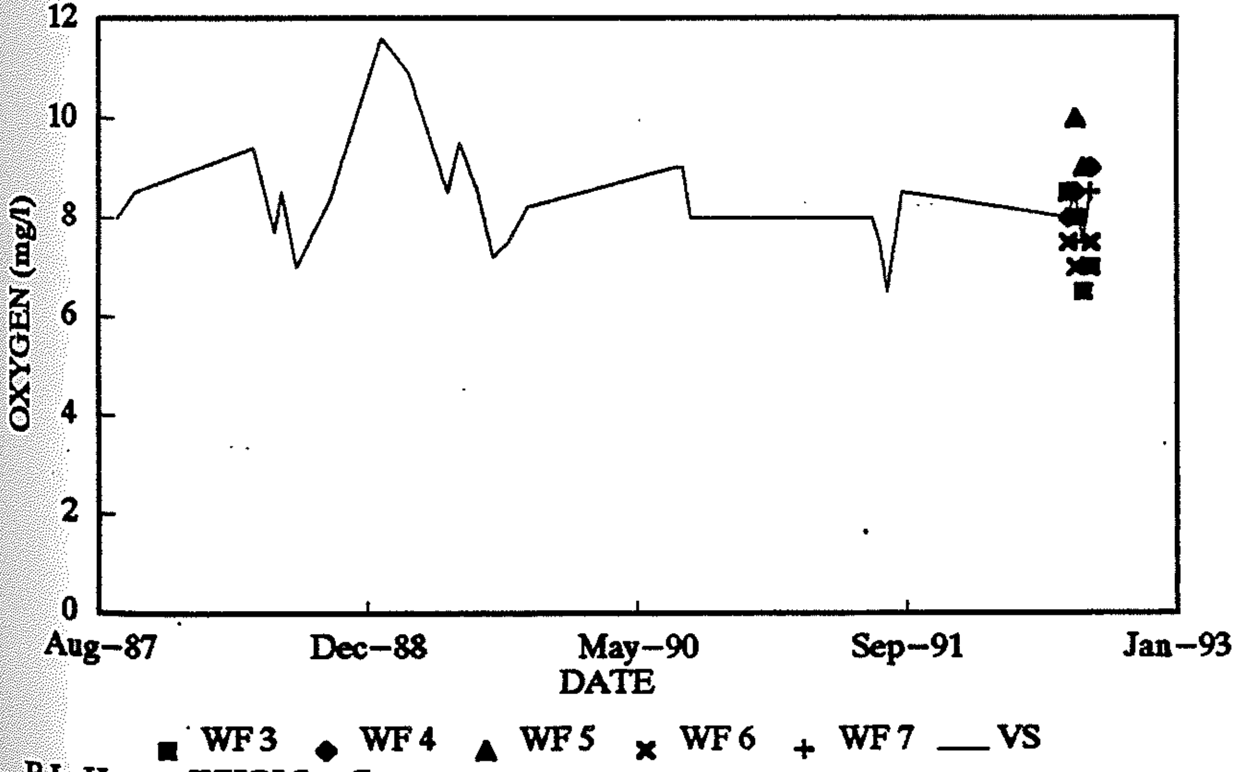
West Falmouth Harbor: Total Nitrogen



B.L. Howes, WHOI Sea Grant
Major Storms in August 1992.

Citizens' Salt Pond Monitoring: 1987 – 92

West Falmouth Harbor: Bottom Water D.O.



B.L. Howes, WHOI Sea Grant
Major Storms in August 1992.

Figure 15.

effectively double the current nutrient loading to the system with a yet to be determined level of impact. The detailed circulation study presently being contracted by the Town should help us to better predict the level of nutrient related stress expected from the interception of this plume. For now, however, West Falmouth Harbor remains a healthly coastal embayment.

Little and Oyster Ponds are extremely eutrophic and have relatively poor water quality throughout. Both ponds have restricted tidal exchange with resulting fresher waters than the other four embayments (Figure 4). These ponds were selected for the initial study due their obvious water quality problems. Little Pond continues to have high nitrogen levels and periodic very low oxygen events (Figure 17). The effect is that benthic animal communities within the pond are impoverished or non-existent by the end of each summer season. The same was true in 1992. Nitrogen levels remain above the limits of the Nutrient Bylaw throughout the pond with levels exceeding 1 mg/l in the upper reaches and 0.5-0.75 mg/l in the main basin (Figure 18). In addition to the loss of animal comunities, eelgrass beds have all but disappeared and macroalgal blooms cause floating mats, resulting in further declines in oxygen conditions. The ultimate cause of this poor water quality is the high nutrient loading due to development in the Little Pond watershed. The proximate cause is the recent (since 1989) high rate of sedimentation at the inlet causing very reduced flows and even a freshening of pond waters.

Oyster Pond is the most eutrophic of the six embayments, has the highest nitrogen and lowest oxygen levels. The pond has the most restricted inlet which has resulted in its relatively fresh surface waters (<10 ppt) and retention of plant nutrients. As a result of its inlet, for the past century Oyster Pond has been functioning more like a salt lake than a tidal embayment.

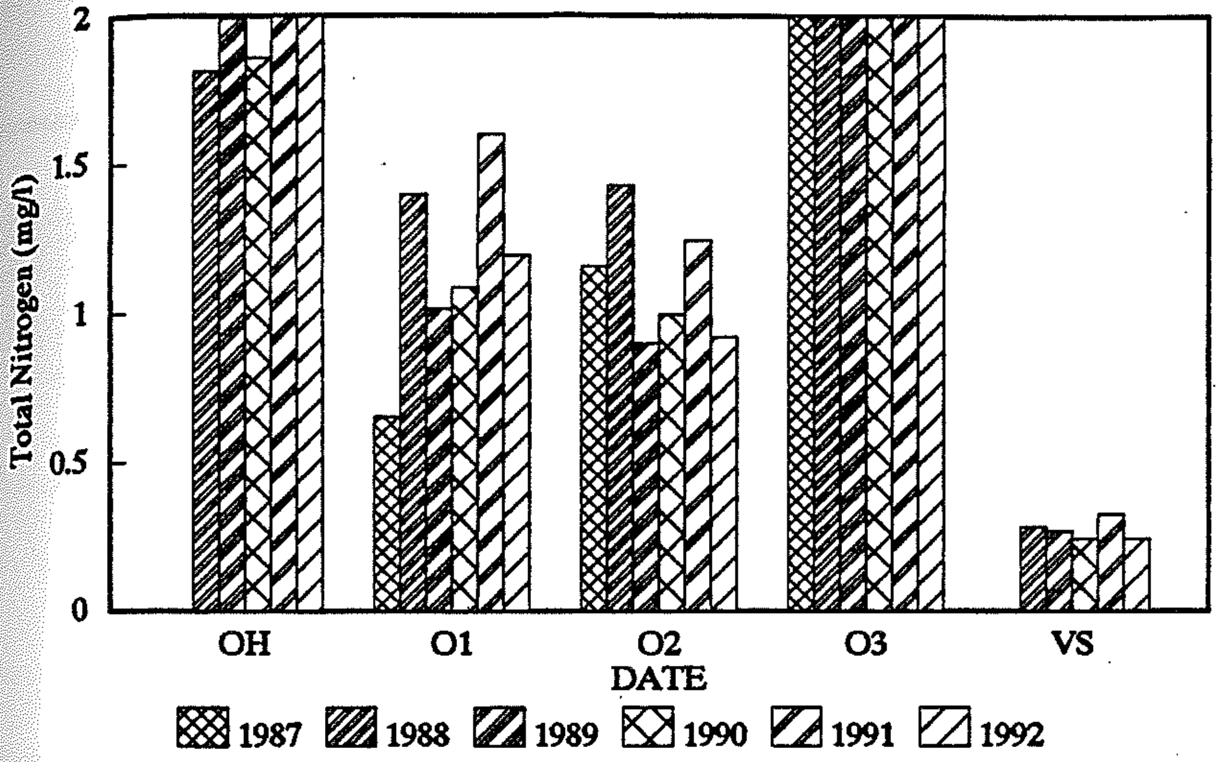
All stations in Oyster Pond have mean watercolumn nutrient concentrations above 1 mg/l (Figure 19), well above the bylaw limits (Figure 20). For the first time since 1987, oxygen levels in one of the basins did not drop to zero through the summer, however in previous years all three basins, or more than 50% of the pond bottom, was anoxic (no oxygen) for much of the summer season. The main basin (Station 3) has had continuously anoxic bottom waters at least for several decades. The factors underlying the periodic anoxia are related to basin geometry discussed below. The effect of current water quality conditions in Oyster Pond is that almost 60% of the bottom is typically devoid of animal communities. Application of the monitoring results to potential water quality improvements for Little and Oyster Ponds is in the following section of the discussion.

Ecological Management: Oyster and Little Ponds

Oyster Pond: As stated above, Oyster Pond has summertime oxygen depletions throughout much of its bottom preventing the establishment and growth of animal communities. The effect is that more than half of the pond area is unsuitable for animal and plant habitat. Oyster Pond's current water quality stems from its current nutrient loading, its restricted inlet, and its deep basins. However, most of Oyster Pond's present ecological "problems" result from "natural" processes with nutrient loading being a lesser factor. Simply stated, it is the inability to vertically mix the watercolumn that is the proximate cause of the low oxygen conditions. Oyster Pond has the deepest basins of all of the coastal systems studied (Figure 3). The configuration of these basins make vertical mixing to the bottom difficult (Figure 21). The salinity record of the pond indicates that occasional massive salinity intrusions like Hurricane

Citizens' Salt Pond Monitoring: 1987 – 92

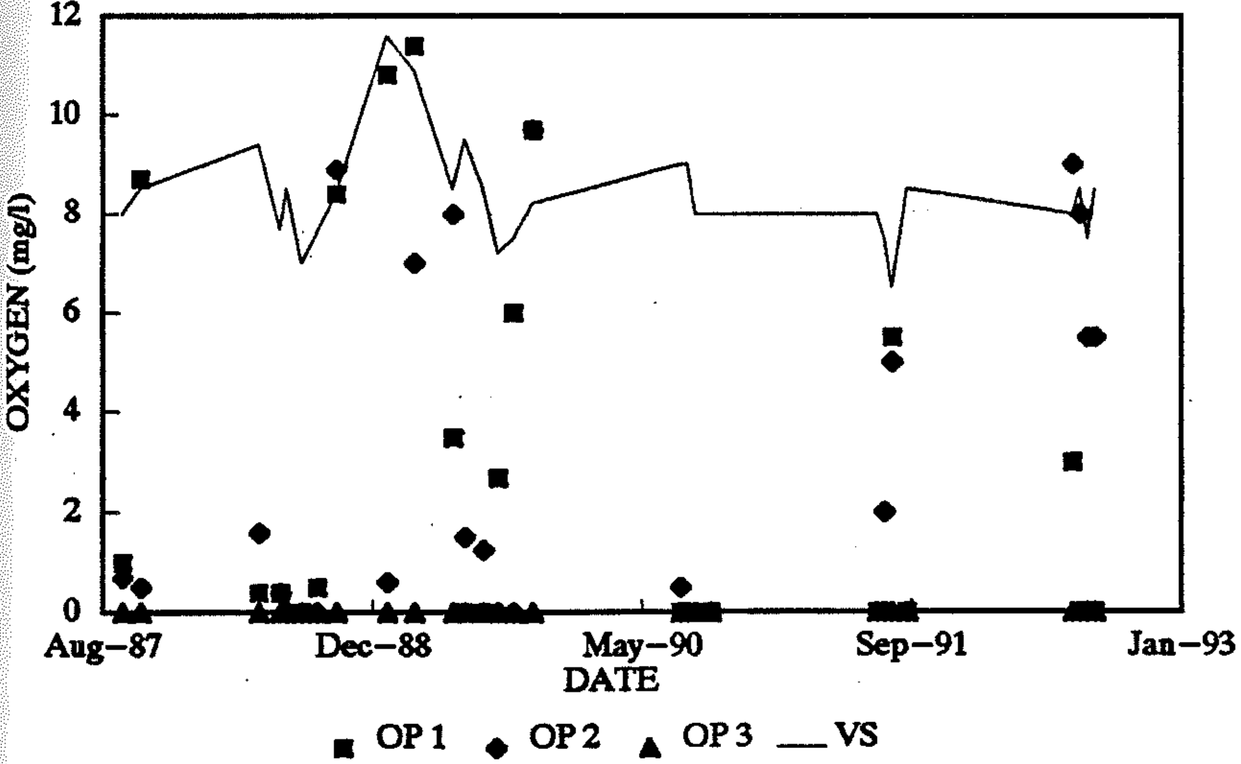
Oyster Pond: Total Nitrogen (mg/l)



B.L. Howes, WHOI Sea Grant
Major Storms in August 1992.

Citizens' Salt Pond Monitoring: 1987 – 92

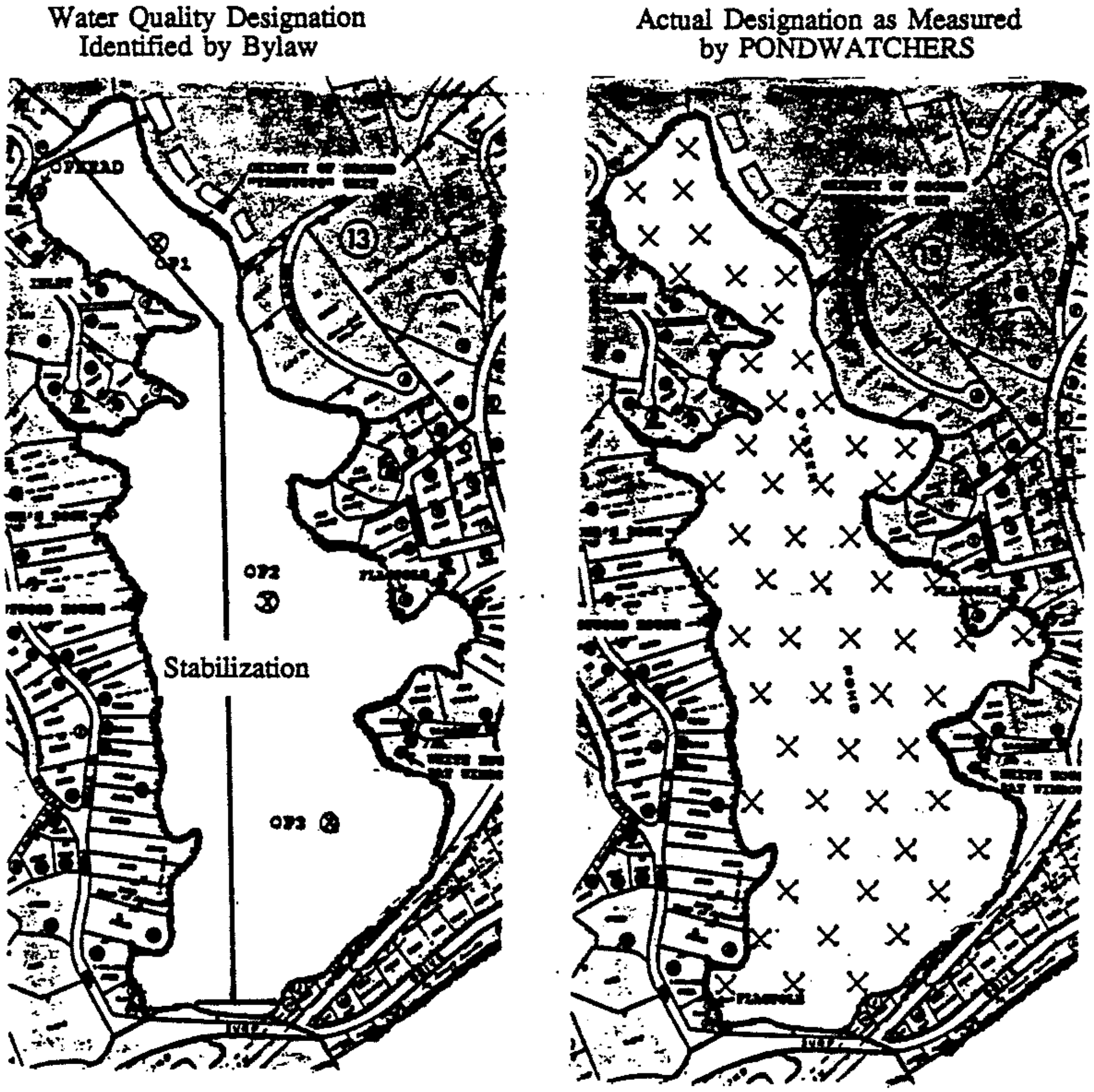
Oyster Pond: Bottom Water D.O.



B.L. Howes, WHOI Sea Grant
Major Storms in August 1992.

Figure 19.

Oyster Pond station locations and Water Quality Designation as identified by Coastal Pond Overlay Bylaw (adopted by Falmouth Town Meeting, April 1988) and actual designations according to the Bylaw as measured by Falmouth Pondwatchers.



Water Quality Designation Identified by Bylaw

Actual Designation as Measured by PONDWATCHERS

"Critical Eutrophic Levels" as designated by Coastal Pond Overlay Bylaw
(Total Nitrogen as Average Over Year)

> 0.75 mg/l = Above Highest "Critical Eutrophic Levels" ✕
0.5 - 0.75 mg/l = Intensive Water Activity Area ☐
0.32 - 0.5 mg/l = Stabilization Area ○
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Figure 20.

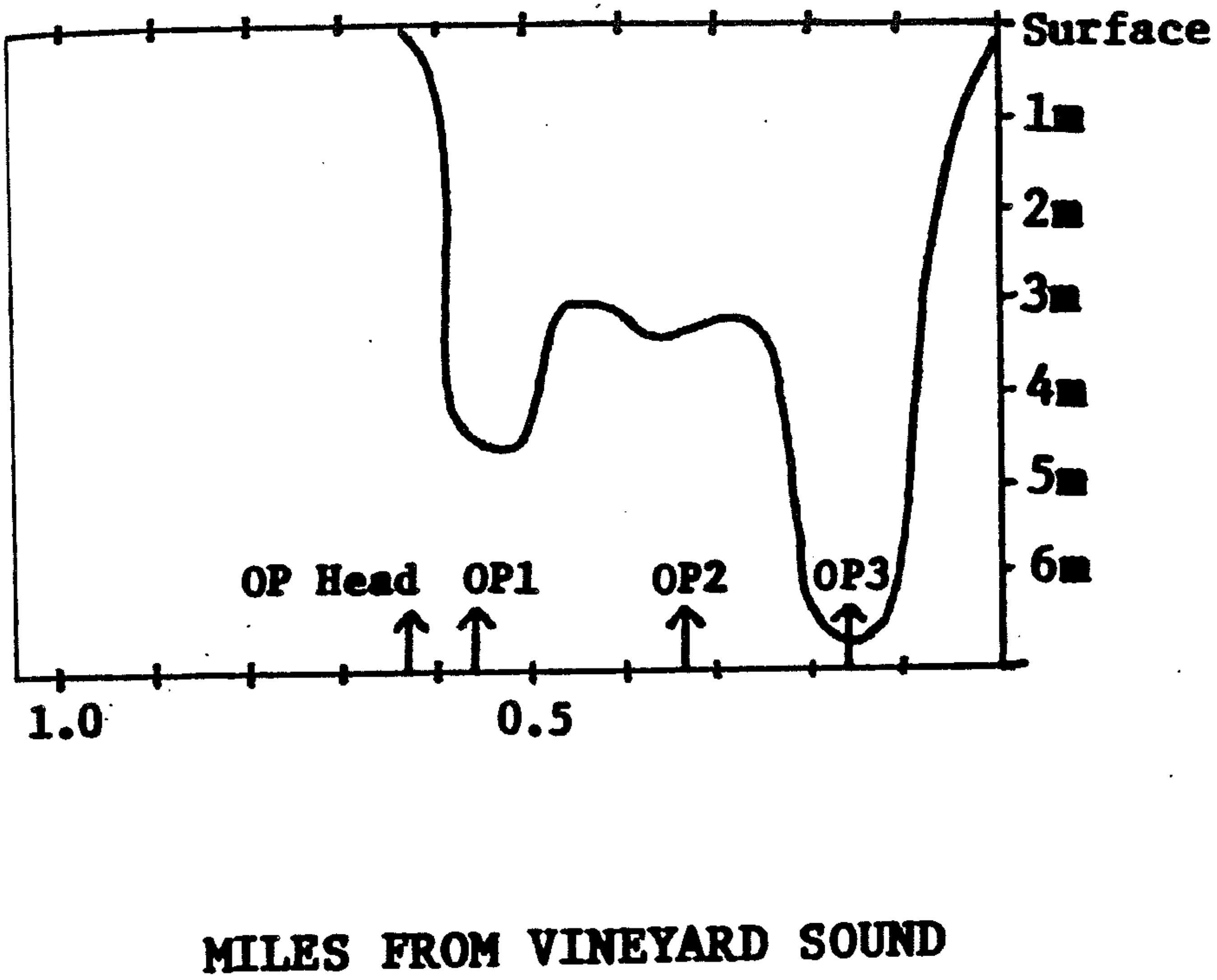
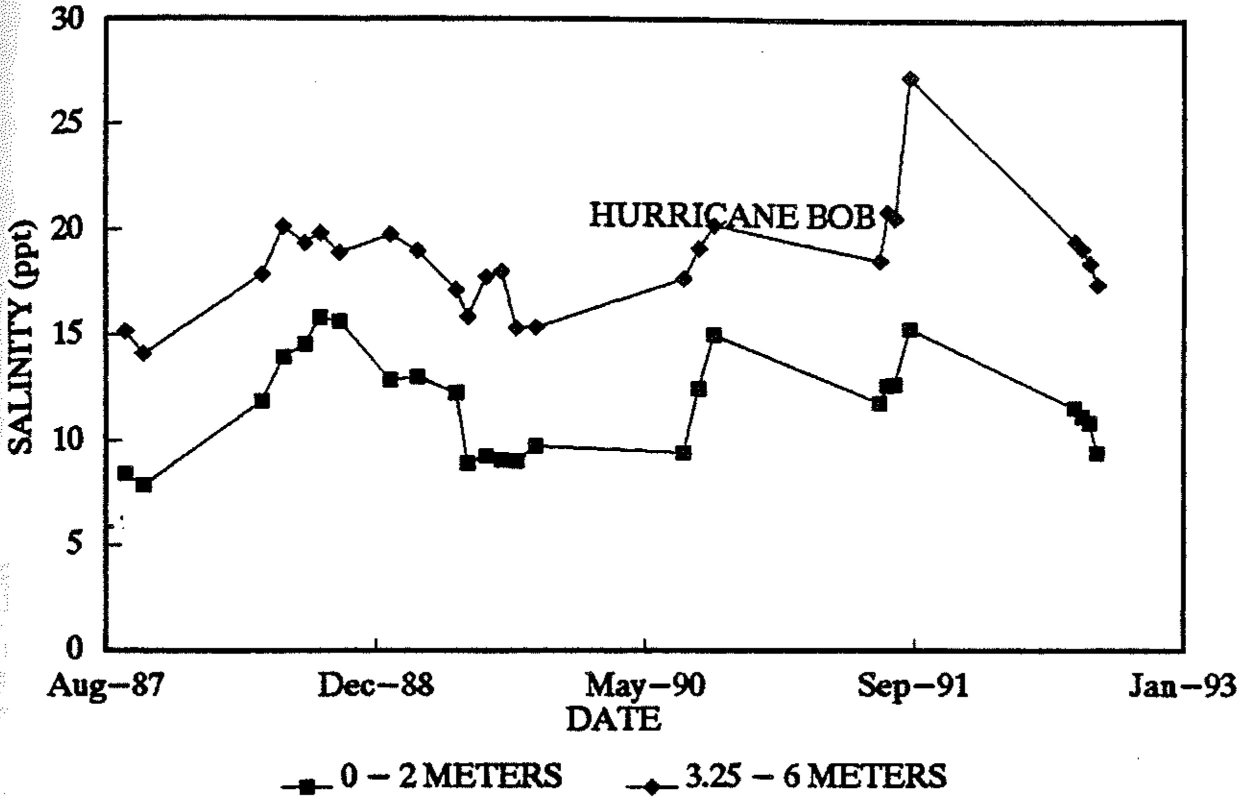

Surface
1m
2m
3m
4m
5m
6m
OP Head
OP1
OP2
OP3
1.0
0.5
MILES FROM VINEYARD SOUND

Figure 21.

Bob and during the 1938 hurricane occur. These periodic events and the small daily salt inputs through the inlet coupled with the freshwater inflows have maintained salinity stratification (top less salty-lighter, bottom more salty- heavier) throughout our study (Figure 22 Top). The potential solution to Oyster Pond's oxygen problem must include a mechanism to breakdown the summer salinity-based stratification.

While there is some debate over when the tidal exchange between Oyster Pond and Vineyard Sound first became restricted, it is clear that with the construction of the railroad embankment in 1872 that the current era began. Oyster Pond receives its daily exchange with the Sound via a culvert to the Trunk River. This corridor was altered in the mid 1980's and the culvert replaced with a larger unit prior to the summer of 1990. The current convoluted path forms a natural sediment trap which continually becomes restricted even with continual maintainence. The possibility to open a new entrance to Oyster Pond to increase tidal mixing and potentially make the water column uniform salinity (breaking down salinity stratification) has been proposed. However, in addition to being very costly its success is uncertain given the deep basins and the freshwater flows to the inner regions of the pond. A more cautious approach with much lower costs and one which could be easily altered would be to build a herring run into Oyster Pond and allow the Trunk River/culvert path to revert to the mid-1980 configuration. The effect would be to create a further freshening of the pond waters which our monitoring data suggests should reduce the oxygen problems throughout most of the pond.

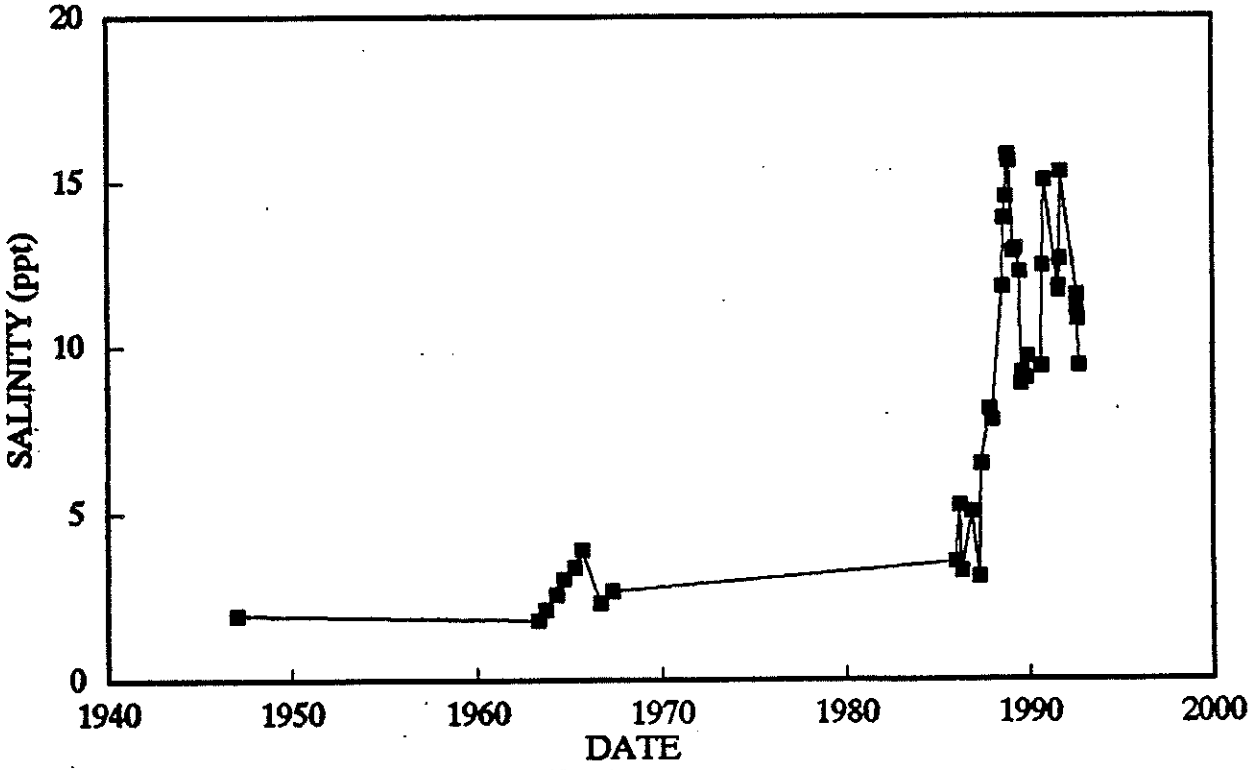
Our conclusion that much of the oxygen problem for Oyster Pond would be removed stems from a re-analysis of our oxygen and salinity data for Station 2 from 1987-1992 (Figure 23). It appears that there is a near perfect relationship between the salinity difference from top



SALINITY: OYSTER POND 1987–1992

Mean 3 Stations

CITIZEN'S MONITORING PROJECT – WHOI SEA GRANT

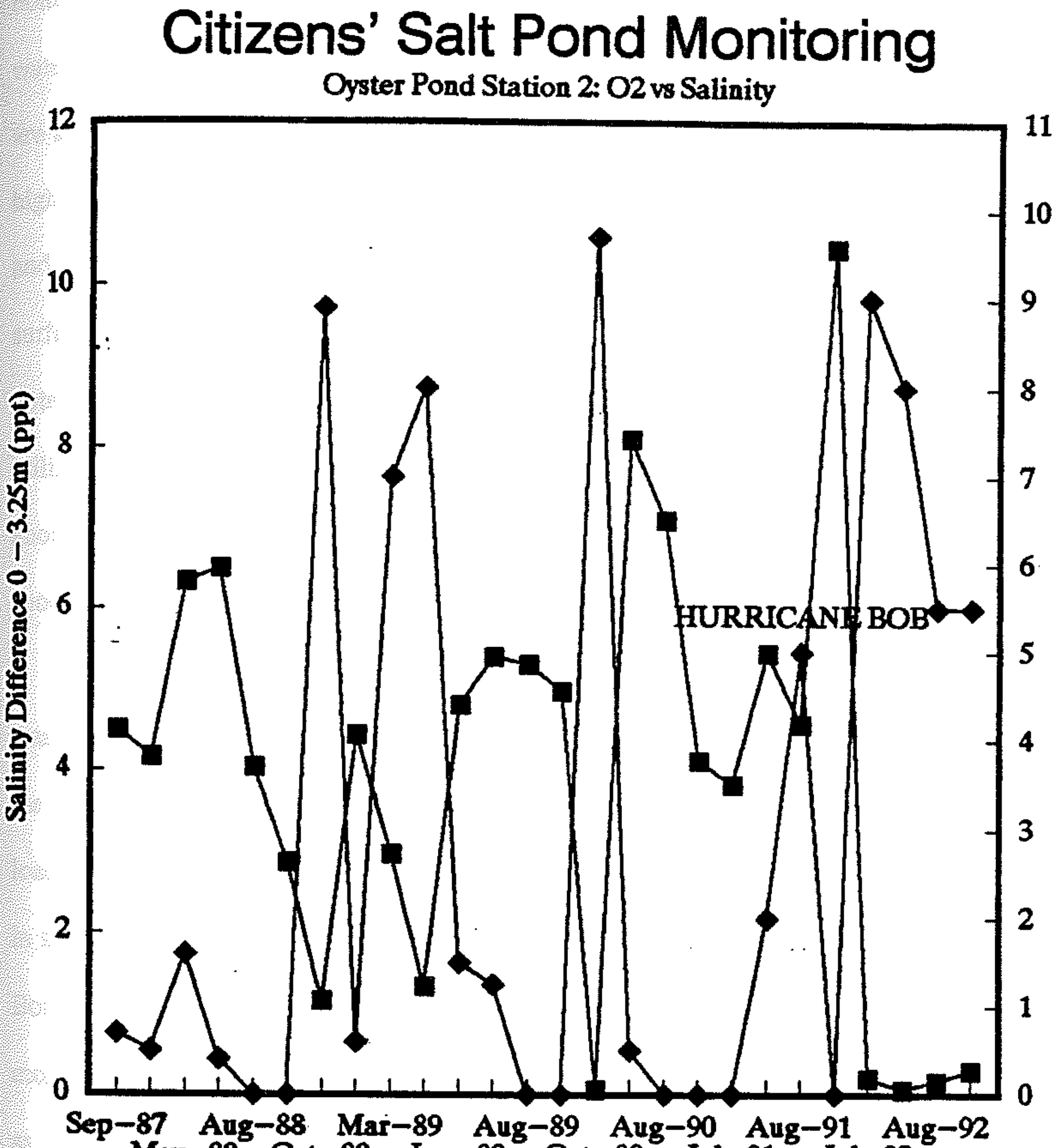


HISTORICAL OYSTER POND SALINITY

MIXED LAYER (0–2m) AVERAGES

K.O. EMERY, MASS DMF & Pond Watch
B.L. Howes, WHOI Sea Grant

Figure 22.



B.L. Howes, WHOI Sea Grant
Hurricane Bob: 19 Aug 1991

Figure 23.

to bottom of the water column (bottom>top) and the presence or absence of oxygen in the bottom waters. Figure 23 shows that when the salinity difference is small or absent bottom water oxygen levels are generally high, but when the difference is large (>2ppt) bottom waters are anoxic. Equally important was the finding that this past summer oxygen levels remained high above 3.25 meters in the pond and coincidentally the surface 0-3.5 meters had freshened and become uniform at about 9 - 10 ppt. It is our prediction that with further freshening the surface 3.5 to 4 meters may reach 2-4 ppt within a few years, greatly reducing the stratification potential and encouraging a predominantly oxygenated system. The dramatic difference in utilizable bottom area if this occurs can be gaged by comparing the 1987-1991 summertime anoxic area to that in 1992 (Figure 24). If this can be maintained the availible benthic habitat should about double over previous years.

In our study of Oyster Pond it has become clear that much of the concern that the system was changing and that traditional fish populations were disappearing was confirmed. Indeed the pond has changed in recent years, the reason however does not appear to be nutrient loading and too little flushing but too much flushing. Prior to alterations to the tidal pathway in the mid-1980's, Oyster Pond was fairly fresh with surface salinities of 2-4 ppt (Figure 22, Bottom). With the increase in tidal exchange the salinity rose rapidly to present levels. It is most likely the salinity change which is responsible for the changing fish and plant populations as most species living at 2 ppt cannot survive or spawn at 15 to 16 ppt. It was also the enhancement of the salt stratification which most likely resulted in the probable expansion of the summertime anoxic area. The main basin has been anoxic throughout the record most likely due to occasional massive salt intrusions (overwash).

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OYSTER POND, FALMOUTH

Summer Oxygen Distribution

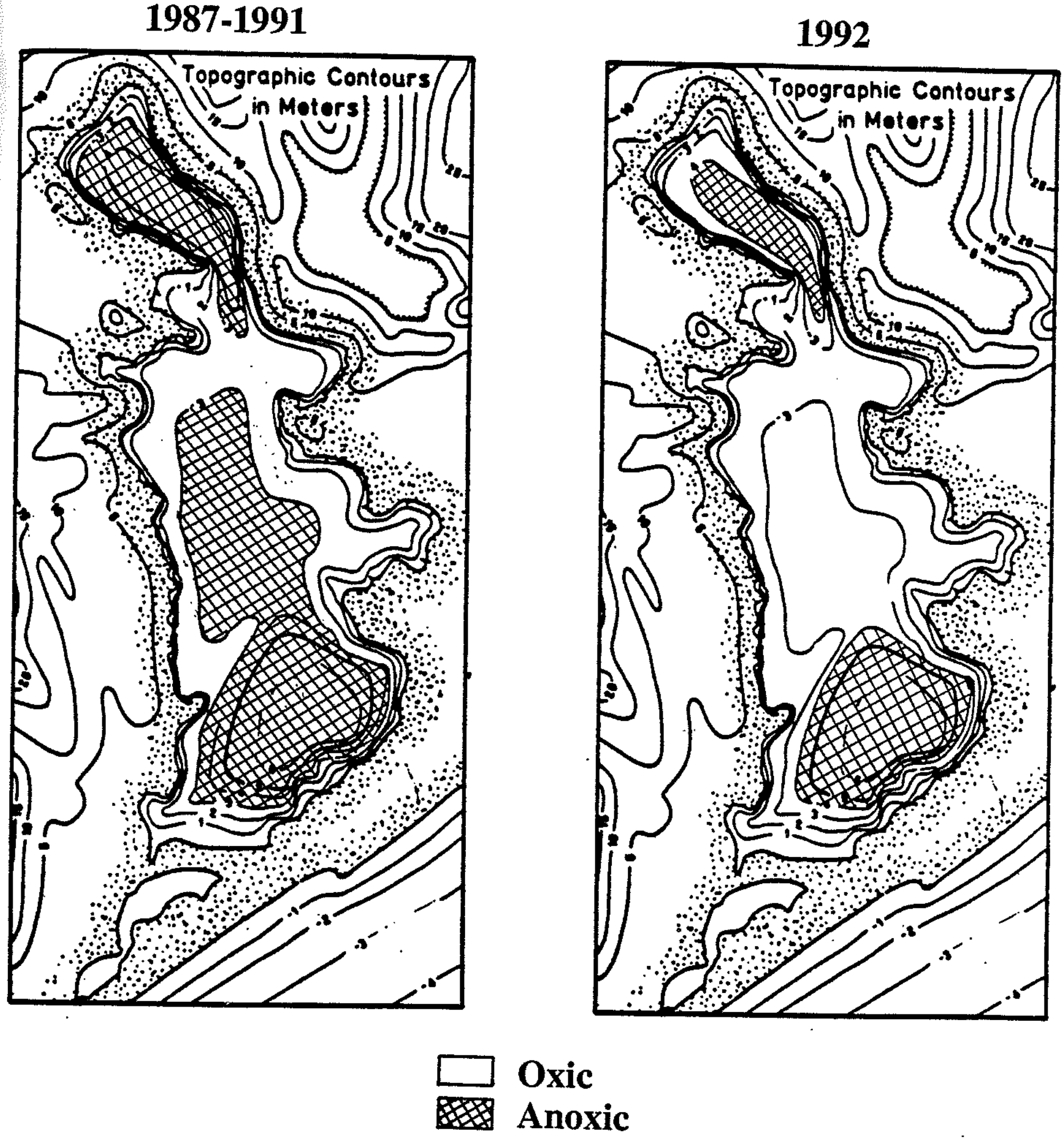
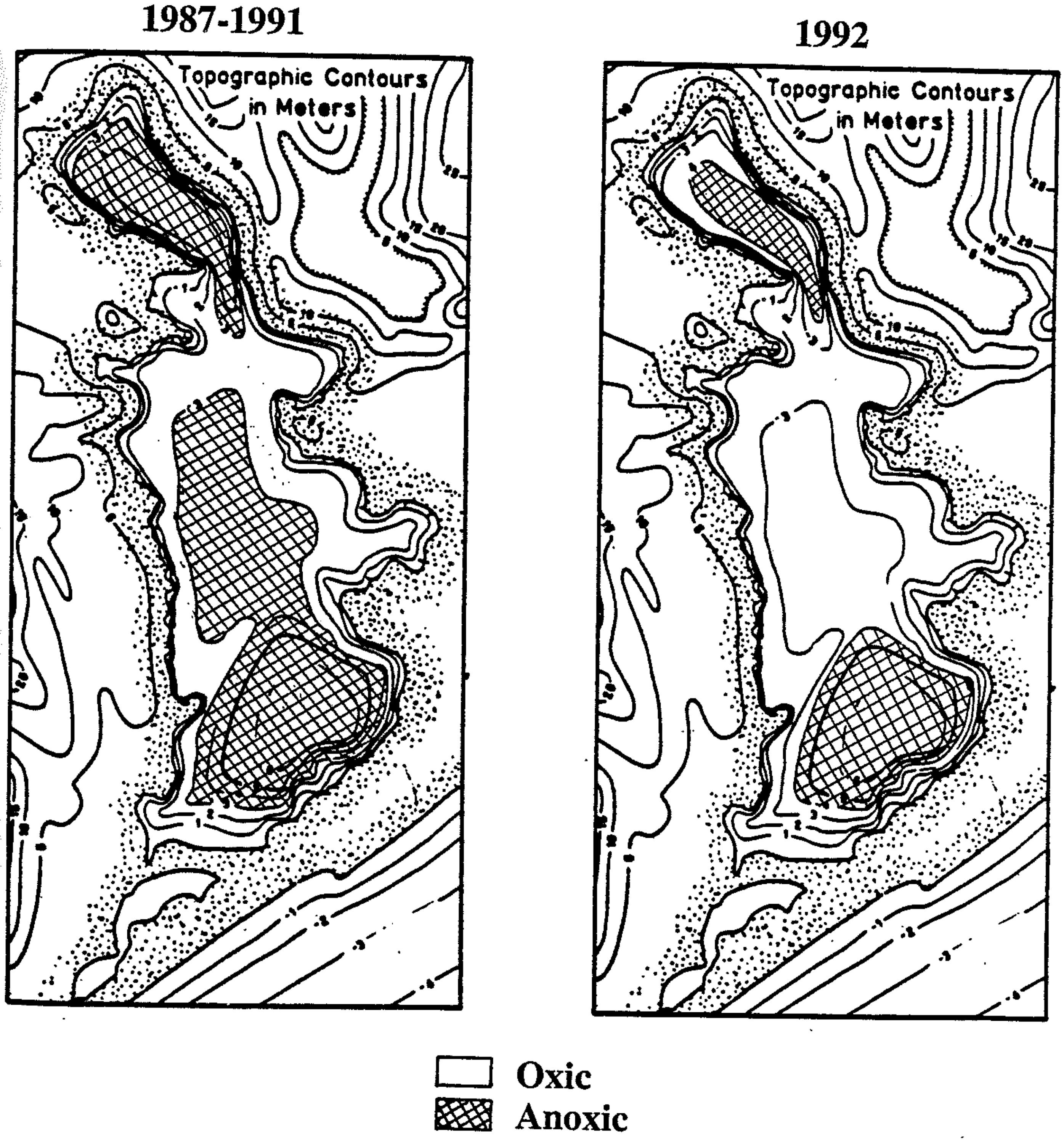


Figure 24.

OYSTER POND, FALMOUTH

Summer Oxygen Distribution



1987-1991

1992

Figure 24.

Since most of the citizens abutting Oyster Pond cite the conditions prior to 1980 as a goal for remediation, it seems that the return to the pre-inlet manipulation configuration should accomodate this desire as well. Opening the inlet further would not. The inlet is now naturally reverting, but a herring run should be constructed to maintain low flows and to allow utilization of this traditional natural resource. It is important to note that this is a summary, not the entire data base relating to the management of Oyster Pond, and more details will be made available to the Town as we progress.

Little Pond: While Little Pond and Oyster Pond show similar types of ecological stress the causes and solutions are very different. This underscores the problems with managing these systems which appear to have site specific problems and solutions.

Little Pond has the lowest water quality of the shallow embayments studied. Summertime low oxygen events are frequent and severe with the effect that benthic animal populations are almost completely absent by September each year even though there is a large and diverse set of young animals each Spring. Little Pond's ecological problems stem from too high nutrient inputs almost entirely from development and restricted exchange with Vineyard Sound. Phase II of Falmouth's WWTP plan is to sewer the Maravista pennisula reducing nutrient flow to Little Pond. However, a more certain and less costly approach involves improving the circulation of Little Pond. In the late 1800's Little Pond had a natural inlet to Vineyard Sound permitting free tidal exchange. With the construction of Menauhant Road the inlet was channelized and entry to the pond restricted. The man-made inlet has been altered many times and the pond was even fresh water for a brief period. The current problem is not that the

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Since the real problem is not the inlet structure but the sedimentation of the inlet this problem needs to be addressed or no improvement will be seen. When the current jetty and groin system was built on the barrier to Little Pond, the beach was much narrower than at present (Figure 26). In fact, the groin was constructed to build a beach and it has operated well as such. But now the sand has filled both the area behind the western jetty and the eastern groin with the effect that storms drive sand into the Little Pond inlet blocking its flow. One solution is to extend the jetties, but this also reduces the water flow into Little Pond and while the inlet may be kept open the level of ecological improvement would potentially be reduced. Equally important is that if the mean tide level of Little Pond is raised, secondary hydrologic effects will result in a greater area of the Maravista septic systems discharging to Great Pond. In essence transfering Little Pond's nutrient problem to Great Pond. In addition, extending the jetties diverts (and basically loses) a valuable sand supply to deeper waters with no guaranteed effect.

Another plan would be to simply dig back the beach a small amount. This would prevent the sedimentation of the inlet without effecting the inlet structures. While it is true that sand removal would have to be performed every 3-5 years it is also true that the sand is a resource with value for the nourishment of other Town beaches and protection of coastal structures. Sand nourishment is commonly a component of the Town's expenditures. Of course the initial clean out would also require removal of the extensive sand bar now inside the inlet in Little Pond, however this would also be required if the jetties were extended. There is an additional potential cost savings in that if the inlet is kept clean and open the nutrient discharge from Maravista pennisula should continue to be into Little Pond but at a level accomodated by the pond system. If this proves to be true, the additional cost of sewering to decrease nutrient loading to this system may be unnecessary. We will continue to assess the efficacy of these managament options if and as they are implemented. As for Oyster Pond, this is a summary of the data and the management plans themselves in a more expanded form will be developed as required.

Appendix IV. Sampling Protocol for the Falmouth Pond Watchers

SAMPLING PROTOCOL

General:

The goals of the sampling program are to:

1) collect water column samples without disturbing the bottom sediments (this is very important, especially if you are standing nearby in the water);

2) process oxygen samples as quickly as possible and with the minimum chance of introducing atmospheric oxygen into the sample before the reagents are added.

The order of sampling is:

1) Collect Surface Samples
    a) process for oxygen
    b) temperature
    c) salinity
    d) nutrients

2) Collect Deeper Samples
    a) oxygen
    b) temperature
    c) nutrients

3) Physical Measurements
    a) Secchi depth
    b) total depth

You will need sampling kit (with data sheets and protocol), and sampling pole (provided) or Niskin Bottle (Oyster Pond). You will need to bring an oxygen waste container; a one quart wide mouth juice container should last all season.

Procedures:

Note: For simplicity we use the sampling pole for both surface and deep water collection. If you like, you can fill the surface 1 liter nutrient bottle by hand; try not to suck in water directly from the surface.
Oyster Pond deep stations use a Niskin bottle.

1) Put stopper in pre-labelled (with date, pond, station & depth) 1 liter nutrient/salinity bottle and in the 0.5 liter oxygen bottle. Make sure the side tube on the 0.5 liter bottle is placed upwards.

2) Lower the bottle to the appropriate depth: 0.1 meter, 1 meter, 1.5 meter, etc. depending on your station.

REPEAT FOR EACH DEPTH SAMPLE

3) a) Pull oxygen bottle stopper (0.5 liter).
    b) then pull nutrient bottle stopper (1 liter).

4) Keeping the pole vertical, bring the samples on deck. Remember to support the bottles as they will be heavier out of water.
    a) Remove nutrient (1 liter) bottle, put in thermometer, record temperature, cap and set aside.
    b) **OXYGEN:** lower tube from oxygen bottle on pole to the bottom of the glass bottle (with glass stopper) from the blue oxygen kit. Drain about 3/4 of the 0.5 liter bottle (bottle with hose) through the glass bottle, overflowing the glass bottle. Tap glass bottle if bubbles stick to sides.
    c) As volume reaches 3/4 of the 0.5 liter bottle, slowly remove the side tubing from the glass bottle and carefully insert the glass stopper (drop) so as not to trap any bubbles.

d) 1. Using the clippers in the blue oxygen kit open Reagent pillow 1;
   2. remove glass stopper from glass oxygen bottle;
   3. pour Reagent 1 into bottle;
   4. open Reagent pillow 2 and add to bottle.
   5. Replace glass stopper, careful not to trap bubbles.
   6. Shake bottle vigorously holding bottle and stopper (some reagent may stick to bottom of bottle...this is O.K.). Shake for 45 seconds turning bottle upside-down and rightside-up several times.
   7. Let stand 2 minutes, shake again.
   8. After a total of 5 minutes, open Reagent pillow 3, remove glass stopper, add powder to bottle, replace stopper, shake vigorously until water in bottle becomes clear (no particles but may be color). A dark yellow color indicates high oxygen.
   9. Remove glass stopper and, rinse first with sample and fill small plastic tube to top TWICE (two volumes) pouring each time into the square glass bottle in the kit.
   10. You are now ready to determine the oxygen content.
   Take the eyedropper and fill with solution in the brown plastic bottle in kit (do not get on hands). Now the tricky part: add 1 drop to the square bottle and swirl. continue to add drop by drop (about 10 seconds between drops) and swirl; continue to add drop by drop and swirl until the yellow color goes away. At the point you think color is gone, add one more drop to check; often the eye is fooled by the color. Record the number of drops to turn clear; don't count the extra drop added as a check (1 drop = 0.5 mg O_2/liter). Surface samples usually takes 14-15 drops to turn clear.
   11. Collect and save oxygen waste in juice container or the like; we will collect these at end of season for disposal.
   12. Rinse glass bottles, plastic tube and dropper with distilled or tap water and let dry.

5) **Nutrients:** (Make sure all bottles are pre-labelled with station I.D., date & depth)
   a) Remove bottle from pole.
   b) Place filter in clear plastic filter holder; align steps in top and bottom of holder and screw on clamp to hold together.
   c) Shake 1 liter bottle, and rinse and fill 60cc syringe with water from bottle by removing plunger and pouring in (cover hole on end so water doesn't get lost while you're pouring in), replace plunger.
   d) Attach filter to syringe and discard first approx. 15-30 cc of water.
   e) Push next 20-30 cc of water into the small sample bottle provided, replace cap, shake and discard water.
   f) Now refill syringe and collect all water in the now rinsed bottle until bottle is full to shoulder, cap and put on ice.
   g) Cap 1 liter bottle, check label and put on ice.

6) **Physical measurements:** - Light, color & depth:
   1. Lower Secchi disk into water slowly from shady side of boat until it just disappears from view. Record depth of dissapearance as 1st Secchi depth from where tape meets water. Lower below view, raise until comes into view and record second secchi depth (these numbers should be very close).
   2. Bring up to half of the disappearance depth and compare color of disk to color wheel, if available, and record.
   3. Lower disk slowly until it touches bottom, record depth.
   Note: Sometimes the disk will hit the bottom before it disappears --- record as bottom and the depth from the tape.

After sampling, hose down sampling poles, Secchi disk and clippers to minimize rusting.
Note any unique or unusual characteristics of station -- presence of algae, smell or anything that may appear unique. When finished, keep samples cold and in the dark (on ice or in refrigerator, NOT freezer).