

Appendix 3.2: Shellfish Aquaculture

- Little Pond Year 3 Oyster Monitoring Tech Memo



The School for Marine Science and Technology

University of Massachusetts Dartmouth



Technical Memorandum

Shellfish Aquaculture Demonstration Project Little Pond Year 3 Monitoring Summer/Fall 2015 Oyster Deployment

To:

Town of Falmouth
Wastewater Division / Department of Public Works
Water Quality Management Committee

From:

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The monitoring results of the Oyster Aquaculture Demonstration Project in Little Pond have been described in annual Technical Memoranda to the Town to provide on-going guidance as to the effects of the annual oyster deployments. Due to budget constraints in Year 3, a reduced program was implemented compared to Years 1 and 2. However, key metrics monitored in prior years were continued this past year in order to yield multi-year assessments. What follows in this Technical Memorandum is a summary of the data collection undertaken during the summer 2015 field season with brief comparison to prior years. Data collection in 2015 was limited to the following:

- Water quality sampling at ten stations from May-October + December + April 2016
- Dissolved Oxygen / Chlorophyll-a mooring deployments
- Benthic Infaunal Community Assessment

This technical memorandum is limited to providing the essential past results from the Year 1 (2013) and Year 2 (2014) monitoring in addition to the findings from Year 3 (2015). In this manner it will be easier for the reader to cross compare the results of all three years without having to refer to the past reports. Results will be presented in the same order as the bullets above.

Background: Estuarine water quality in towns throughout southern Massachusetts, inclusive of the Town of Falmouth, is impaired due to excessive nitrogen inputs from development within their watershed and needs to be improved in order to meet State Water Quality Standards. Towns like Falmouth who have undergone assessment under the programmatic umbrella of the Massachusetts Estuaries project (MEP) are currently working on planning and implementing pilot studies to lower nitrogen levels within these impaired estuaries and are seeking lowest cost alternatives (aka. soft solutions) for improving estuarine water quality before turning to more expensive infrastructure based solutions for water quality management.

Over the past 5-8 years, one of the more intriguing "soft" solutions that has emerged as a potential approach for improving water quality in estuarine receiving waters has been the use of filter feeders as a form of in-estuary treatment (others are to lower watershed loads). The filter feeders generally considered are quahogs and oysters, as they grow well in the shallow warm estuaries of southeastern Massachusetts and the mechanics of seeding and aquaculture are well established regionally. Oyster culture has been specifically deployed for lowering nitrogen levels in nearby Mashpee River, within the Popponesset Bay Estuary by both the Town of Mashpee and the Mashpee Wampanoag Tribe. SMAST staff has been supportive of these efforts from the beginning and have been working to quantify nitrogen removals for the past several years in the Towns of Mashpee and Barnstable estuaries as well as in Falmouth, specifically Little Pond.

In 2012, the Town of Falmouth selected the upper portion of Little Pond to examine its in-estuary nitrogen mitigation approach for improving water quality and habitat health. As agreed to by the Town of Falmouth and the SMAST-Coastal Systems Program (CSP) Science Team at the outset of the three (3) year Shellfish Demonstration Monitoring Project, the primary mission of the Town's Demonstration was to lay the foundation for establishing TMDL-nitrogen removal credit for oyster aquaculture.

The upper estuary of Little Pond was selected for the following reasons:

- Nitrogen removal within the upper reaches of an estuary provides both local improvement, as well as lower nitrogen levels in down gradient basins. This distributes

any beneficial effects over a larger area of estuarine habitat;

- Eelgrass restoration in Little Pond is primarily restricted to the lower main basin, placing culture gear in the lower basin would have to take into account shading of the bottom and other actions that would impede potential restoration of eelgrass habitat;
- Access to the water is readily available through Narragansett Street.

It should be noted that the assessment of the effects of the moderate scale oyster deployment in Little Pond (2013, 2014 and 2015) builds on foundational work undertaken by CSP-SMAST scientists over the past two decades, specifically for Little Pond:

1. PondWatch – this program coordinated by CSP-SMAST staff since 1987 collects water quality data on Little Pond each summer in July and August on 4 dates. This data supported the basis for the Massachusetts Estuaries Project water quality modeling and nitrogen loading assessment. In addition, early PondWatch experiments on oyster growth in Little Pond were provided to the Town to assist its oyster pilot project planning. All data collected by CSP-SMAST for post-oyster deployment assessment will be directly comparable to the PondWatch results.
2. Massachusetts Estuaries Project – technical leadership by CSP-SMAST. The MEP conducted embayment specific habitat assessment, hydrodynamic and water quality modeling that serves as the underpinning of the Little Pond TMDL. The water quality and moored instrumentation approaches used by CSP-SMAST for the MEP analysis of Little Pond will be directly comparable to the CSP-SMAST post-oyster deployment assessment data.
3. Pre-oyster – The CSP-SMAST scientific team on the present project also conducted detailed summer 2012 monitoring data collection from Little Pond at 9 sites (seven of which were continued in 2013-2015) and 12 dates (biweekly). This data forms the basis for the pre-oyster deployment baseline and also demonstrated the ability to collect samples within the necessary time-window to give a true-snapshot of the nitrogen related water quality gradient (TN, chlorophyll-a, particulate N, etc) along the long axis of Little Pond. This data was used by the Town for its permitting of the pilot project and the data directly comparable to the CSP-SMAST post-oyster deployment assessment data, both in sampling approach and laboratory assay.
4. Preparation for post-oyster assessment – Prior to the finalization of water quality sampling plans, CSP-SMAST scientists collected water quality samples in May-October + December + April from Little Pond at each of 9 stations and depths (2). These samples were assayed and yielded directly comparable results for summers 2013, 2014 and 2015. These samples were collected in concert with other programs conducted by SMAST throughout the upper Cape.

Specific characteristics of Little Pond, its function and its response to the initiation of oyster aquaculture in this system have been further evaluated in the context of additional work undertaken by CSP scientists across the estuaries of southeastern Massachusetts, specifically:

1. Scientific analysis of TN levels and eelgrass habitat quality, documenting TN reduction to restore habitat. A full assessment of the relationship of TN level to eelgrass habitat has been conducted by CSP-SMAST scientists to support

management, where nitrogen reductions to reduce water column nitrogen levels are needed for restoration.

2. Scientific analysis of TN levels and benthic animal habitat quality, documenting TN reduction for restoration. A full assessment of the relationship of TN level to infaunal habitat has been conducted by CSP-SMAST scientists to support management, where nitrogen reductions to reduce water column nitrogen levels are needed for restoration.
3. Scientific analysis of TN levels and accumulation of macroalgae, documenting at what levels and under what geomorphological conditions accumulation occurs. Much of this analysis was conducted in Falmouth estuaries and was conducted to support predictions of the impacts on macroalgal accumulations of lower nitrogen levels in estuarine waters.
4. Review of scientific analysis of oyster filtration and water clarity, on-going review of effects of nitrogen processing by bivalves on natural and artificial systems.
5. Assessment of over 65 estuaries under the MEP project including measurement and evaluation of benthic communities, sediment dynamics, surface water and stormwater inputs, water quality analysis, tidal dynamics, watershed delineation, watershed nitrogen loading, water quality modeling, and ecosystem assessments.

All of the information noted above directly relates to Little Pond nitrogen dynamics and the efficacy of the oyster monitoring project.

What follows is the summary of work that was undertaken in Year 3 of the oyster aquaculture demonstration in Little Pond. Field data collection was focused on the summer 2015 oyster deployment with water quality sampling that mirrored the 2013 and 2014 sampling program as well as dissolved oxygen / CHLA mooring deployments and benthic infaunal community characterization. Due to budget constraints in 2015, tidal flux characterizations and denitrification analyses for nitrogen cycling were not undertaken. Each sampling event was undertaken consistent with techniques and protocols utilized by the Coastal Systems Program in past years such that data collected in 2015 would be directly comparable to historical data from the Falmouth PondWatch Program, the Massachusetts Estuaries Project, summer 2012, summer 2013 and summer 2014 sampling.

For the convenience of the reader, results from the Year 1 (2013) and Year 2 (2014) Oyster Monitoring Report have been included in this report. Doing so provides continuity with the Year 3 monitoring work (2015) and allows the reader to be able to quickly refer back to the results from previous years for comparative purposes. The CSP Technical Team agreed that including the pre-2013 water quality summary would make the current (2015) synopsis too cumbersome so that was removed for the purpose of this Technical Memorandum as it has been presented previously.

The Water Quality Monitoring Program: The Town of Falmouth initiated the oyster aquaculture pilot project (Oyster Monitoring Project) in Little Pond for the summer 2013 growing season (Year 1). Year 2 of the monitoring project encompassed the summer 2014 growing season and commenced in May, 2014 and included sampling in December 2014 as well as sampling in April 2015. Year 3 monitoring mirrored sampling completed in 2013 and 2014. Sampling commenced in May-December 2015 with an event in December 2015 and one to be

completed in April 2016. As in previous years, the UMD-Coastal Systems Program performed all sampling and chemical analyses as well as data synthesis. The sampling and chemical analyses has remained the same for Years 1, 2 and 3 as well as being consistent with sampling performed for the Falmouth Pond Watch Program, the MEP and most importantly, for the 2012 pre-oyster baseline analysis that was conducted in advance of the Year 1 and 2 data collection efforts.

The 2012 Little Pond Pre-Oyster Water Quality Monitoring Program was established to:

- Develop the foundation (and context), a pre-oyster deployment baseline, for evaluating in-estuary nitrogen management by oysters and,
- Work out the details of obtaining an adequate snapshot of the nutrient gradient in Little Pond.

2012 Sampling was conducted at nominal weekly intervals from July 8, 2012 to October 24, 2012. The sampling program was built around the existing PondWatch Water Quality Monitoring Program, which continues to be under SMAST technical oversight. Additional sampling stations expanded on the historical 4 PondWatch Stations to add refined spatial coverage of the main nitrogen gradient within Little Pond (Figure 1). Stations were located by GPS and coordinates (LAT/LON) were obtained for each of the 9 stations sampled (Table 1).

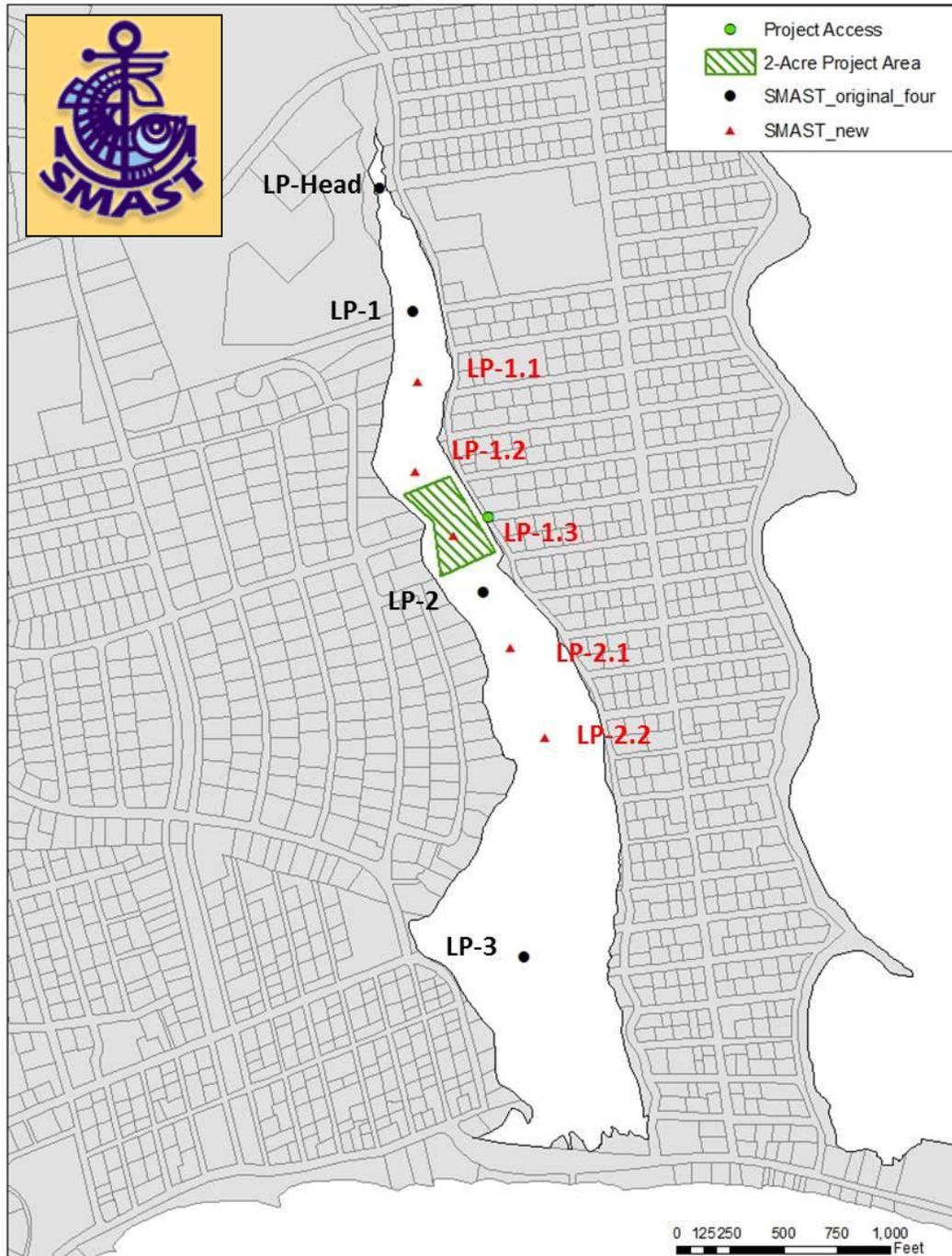


Figure 1. Sampling locations and proposed growing area in Little Pond as sampled during 2012 for development of the pre-oyster deployment base line. Total number of stations is 9 in order to quantify the "local" effect of the aquaculture pilot project. Four stations were traditional PondWatch stations shown as black dots (LP-Head, LP-1, LP-2, LP-3) and five stations are additional sampling sites shown as red triangles to quantify more localized effects of oyster aquaculture (LP-1.1, LP-1.2, LP-1.3, LP-2.1, LP-2.2). The proposed footprint of the oyster deployment is shown by the green polygon.

Table 1. Coordinates of the pre-oyster deployment sampling in 2012. Station I.D.'s correspond to Figure II-1 and figures and data tables provided electronically. Note the tidal inlet is used as a reference.

LITTLE POND PILOT STATION COORDINATES 2012

STATION	COORDINATES *
LP HEAD	041° 33.4576' N, 070° 35.4993' W
LP 1	041° 33.4078' N, 070° 35.4925' W
LP 1.1	041° 33.3404' N, 070° 35.4856' W
LP 1.2	041° 33.2865' N, 070° 35.4856' W
LP 1.3	041° 33.2315' N, 070° 35.4472' W
LP 2	041° 33.1797' N, 070° 35.4101' W
LP 2.1	041° 33.1258' N, 070° 35.3758' W
LP 2.2	041° 33.0781' N, 070° 35.3565' W
LP 3	041° 32.9071' N, 070° 35.3579' W
Inlet	041° 32.6540' N, 070° 35.3402' W
* coordinates are in WGS 84	
"Inlet" does not have a WQ station , it is for reference	

The sampling locations established for the pre-oyster deployment monitoring in 2012 and the Year 1 (2013) oyster monitoring project were based upon the existing PondWatch monitoring stations for data collection ("LP" in Figure 1) utilized by the Massachusetts Estuaries Project (MEP), but the 2013 monitoring was to be a down-sampling from the pre-deployment baseline conducted in 2012. CSP staff decided that down-sampling would cause difficulties in interpretation, especially if some 2012 stations were not sampled in 2013 or their locations were moved. As a result CSP maintained the sampling program from 2012 in 2013 allowing the full suite of sampling locations for comparative analysis to be performed. The pre-oyster deployment sampling in 2012 demonstrated that a higher station density (9 stations) allowed detection of smaller differences than coarser scale sampling. In the 2012 sampling, stations were situated to give 3 near-field stations both up-gradient and down-gradient of the oyster deployment area. This configuration yielded a more robust assessment of changes in gradient due to passage of water through the oyster deployment area. Also, three stations is the minimum to detect trends, which is why 3 stations (up-gradient and down-gradient) were sampled in 2012 and 2013.

Year 2 monitoring commenced in May, 2014. As in previous years, the Coastal Systems Program at UMD-SMAST performed all sampling and chemical analyses as well as data synthesis. The sampling and chemical analyses were the same as performed for Pond Watch, the MEP and most importantly, for the 2012 pre-oyster/baseline analysis and 2013 Year 1

sampling and analysis. The sampling locations during the 2014 sampling season built upon the sampling conducted in 2012 and 2013. The two additional stations (LP-1.3 and LP-2.2) that were sampled throughout the 2012 and 2013 monitoring season to increase the accuracy of the quantification of mass nitrogen removal by the oyster deployment were also sampled in 2014. Additionally, analysis of 2013 data showed that the addition of one more station between LP-2 and LP-2.1 (to be labeled LP-2.1A) should enable more robust determination of oyster impacts down-gradient and improve overall gradient resolution. This station became part of the 2014 sampling program (Figure 2).

The sampling locations for the Year 2 (2014) and Year 3 (2015) monitoring of the oyster demonstration project were the same as sampling stations for Year 1 with the exception of the addition of one station (LP-2.1A) by mutual consent between the Town of Falmouth and CSP scientists. As was the case in Year 1, CSP staff decided that down-sampling would cause difficulties in interpretation of data, especially if some stations were not sampled or their locations were moved. As a result CSP maintained the sampling program from 2012 and 2013 into 2014 and 2015 thereby allowing the full suite of sampling locations for comparative analysis to be performed. Sites for sampling included: LP-1.1, LP-1.2, LP-2.1 and were located specifically for the purposes of the oyster demonstration project. The 2 additional stations (LP-1.3 and LP-2.2) were sampled throughout the 2012-2015 monitoring program, to increase the accuracy of the results and LP-2.1A was added in 2014 and 2015 as well based on needs determined from the evaluation of the 2013 water quality data. LAT/ LON coordinates for each station sampled were determined by GPS and are provided in Table 2 (same LAT/LON 2014 and 2015). Every attempt was made to precisely occupy the same locations of the stations sampled in 2013 and prior years.

For 2013, 2014 and 2015 sampling, the number of sampling dates was also increased above the typical Pond Watch sampling frequency (4 per summer) to capture a total of 12 events (minimum). Sampling was undertaken bi-weekly, "May-October" (duration of growing season), with two additional sampling events in the colder months, 1 in December (early winter) and 1 in April (late spring) to comply with the Conservation Commission Order of Conditions for this project. Sampling dates for Year 1, 2 and 3 are provided in Tables 3, 4 and 5 respectively.



Figure 2. Sampling locations and growing area in Little Pond sampled during the Year 1 (2013) growing season with the addition of LP-2.1A in Year 2 (2014). Same stations sampled in Year 3 (2015). Four stations are PondWatch stations (LP-Head, LP-1, LP-2, LP-3) and six stations are additional sampling sites to quantify more localized effects of oyster aquaculture (LP-1.1, LP-1.2, LP-1.3, LP-2.1, LP-2.1A, LP-2.2).

Per the water quality monitoring program protocols, all samples collected in 2013, 2014 and 2015 were analyzed at the Coastal Systems Analytical Facility at SMAST for the following parameters: temperature, total nitrogen (nitrate + nitrite, ammonia, dissolved organic nitrogen, particulate organic nitrogen, dissolved organic nitrogen), chlorophyll-a, pheophytin-a, orthophosphate, salinity, temperature, dissolved oxygen, transparency (secchi depth), alkalinity. As is done during all water quality sampling, weather and tide-status were documented to assist in the interpretation of results. Additionally, sampling was completed synoptically during a narrow (~2 hr.) window to minimize the effects of a changing tide (ebb tide sampling) as well as weather-related effects on samples (e.g. significant precipitation events). Salinity measurements were correlated to rainfall and other relevant parameters.

Water Quality in Little Pond

Results from Year 1 (2013) Sampling: The major question to be addressed in 2013 related to whether the oysters affected a discernible change in the water column nitrogen related constituents in Little Pond. Since oysters were introduced to the surface waters of the pond on July 10, 2013 and removed in late October of the same year, this was the primary period for evaluation. The analytical approach involved comparing the gradients in water quality parameters both during the oyster deployment (2013) and during the same period in 2012 when no oysters were deployed. Since the oysters were deployed in floating bags, initially as small spat, their effect over the first month in the pond was expected to be negligible. Therefore, the period for gauging the effect of the ~1.25 million oysters deployed was July 31, 2013 through the end of October 2013, while the oysters were larger and actively feeding. Analysis using the entire dataset (May 2013 - December 2013) was also performed, but the results were confounded by high rainfall in May and June and very cold temperatures (low activity) in December, coupled with the absence of the oysters in May, June and December.

Stratification of Little Pond:

In both 2013 and 2012, the Little Pond water column showed moderate stratification¹ (Figure 3). Stratification of an estuarine water column is most commonly the result of salinity differences from the surface to the bottom waters. This salinity difference results from fresh waters entering from the watershed and differentially freshening the surface water, and marine waters entering from the tidal inlet differentially increasing the salinity of bottom waters. A secondary factor in the density difference is the occurrence of colder bottom waters overlain by warmer surface waters. The salinity difference is clear in both 2012 and 2013 results (Figure 3). The salinity differences exist at all stations, but diminish moving away from the major freshwater inflows in the pond's upper reaches. While the pond was periodically hypoxic, periodic mixing did occur which aerated the bottom waters. Although it is difficult to quantify, it appears that stratification focused the effects of the oysters on the surface layer, since the oysters were deployed in floating bags at the pond surface. From the water quality sampling it is clear that the surface and bottom layers of the pond water column are not tightly coupled through the warmest months of the study when the oysters were having their greatest effect (see below).

The stratification of surface and bottom waters can also be clearly seen in the key oyster food indicators of total chlorophyll a pigment and particulate organic carbon (Figure 4). In both cases

¹ Well mixed conditions show similar salinity and temperature at surface and bottom, while moderate stratification shows higher salinity (1-2 PSU) at bottom than surface.

the higher phytoplankton production in the surface layer, due to light availability, can be seen in the significantly higher concentrations in surface versus bottom waters at almost all sampling locations in 2013. The same effect was seen in 2012 over the same time period, but with smaller differences.

Chlorophyll, Particulate Organic Carbon (POC) and Fluorescence Data Analysis:

Particulate Organic Carbon and Total Pigment Data

Data for both total chlorophyll *a* and POC² shows higher phytoplankton concentrations in the stations upgradient (LP-1.2) of the deployment area (LP-1.3). Concentrations on the ebbing tide decrease measurably at LP-1.3, with a continued decline at LP-2, downgradient of the Demonstration Site. This was clearly seen in the surface waters where the decline from upper to lower station was 0.64 mg C/L for POC and 6.7 ug/L for Total Chlorophyll *a*. This decline was not seen across the bottom waters across these sites, further supporting the conclusion that the decline is due to the removal of particles by the oysters in the surface layer, with deposition likely downgradient as the particles settle. The decline occurred over the three “near-field” stations as would be expected as water flows downgradient through the oyster area on the ebbing tide.

Analysis of the 2012 water quality results from these same 3 sites, when there were no oysters deployed, shows no significant decline in POC or Total Chlorophyll *a*. This is consistent with the conclusion that the pattern in 2013 resulted from the addition of oysters and not from a natural gradient within the estuary (Figures 4 and 5).

Chlorophyll *a* and Pheophytin *a* Data

When oysters filter phytoplankton and process the particles, the chlorophyll *a* in the phytoplankton chloroplasts is typically degraded to pheophytin *a*. This can also occur when zooplankton graze on phytoplankton cells and is a well-documented effect of grazing.

Examining the chlorophyll *a* and pheophytin *a* gradients in the 2013 and 2012 monitoring indicates that there is intense “grazing” of phytoplankton in the surface layer in 2013, but not in 2012, and not in the bottom waters (Figures 6 and 7). In 2013 there is a decline in chlorophyll *a* concentration through the near-field, with concentrations upgradient > oyster site > downgradient station on the outgoing tide. The bottom layer did not show this pattern. The 2012 data showed the opposite, with chlorophyll *a* increasing to a peak at the site of the next year’s oyster deployment and the pheophytin *a* showing a continuing decline through the area. Of particular note in 2013, the pheophytin *a* “spiked” within the oyster deployment area, compared to upgradient and downgradient sites. These measurements are consistent with the oysters actively feeding (deployment area) where phytoplankton are observed to have been consumed (chlorophyll *a* declines) and “digested” (spike in pheophytin *a*) and that this activity is mainly seen in the surface layer due to water column stratification at the time of the measurements. That these patterns were not observed in 2012 when the oysters were not deployed is also consistent with the effect resulting from oysters rather than a natural gradient within the pond.

² There is a linear relationship between total chlorophyll *a* and POC in Little Pond water as in many other estuaries on Cape Cod. This was presented in the 2012 Pre-Oyster Deployment Monitoring Report [B.L. Howes, S.J. Sampieri and R.I. Samimy. 2013. Nutrient Related Water Quality Monitoring Baseline for Gauging Nitrogen Removal by Town of Falmouth Oyster Pilot Project in Little Pond Summer 2012, Technical Memorandum from the Coastal Systems Program-SMAST to the Town of Falmouth.].

These results related to oyster feeding through filtration of water column particles (phytoplankton) is supported by the time-series measurements of fluorescence and light attenuation.

Fluorescence Data

Although the mooring data varies considerably throughout the three month deployment, there were generally trends seen from the head of the pond down to the mouth. Highest chlorophyll was generally upgradient of the oyster beds. Chlorophyll levels declined through the Demonstration Site itself (LP-1.3), with the lowest levels at LP-2, immediately downgradient of the Demonstration Site. The extent of this depletion is not quantifiable from the time-series measurements, as the observed increase in pheophytin *a* in this region partially obscures the loss of chlorophyll *a* (when measured by in situ fluorescence). While the general trend is decreasing concentrations from the head to the mouth of the pond, during bloom conditions chlorophyll concentrations were higher directly upstream of LP-1.3. Spatial trends in chlorophyll concentrations were most pronounced during bloom conditions. It is clear from the limited time-series sites that there were lower chlorophyll *a* levels within the Demonstration Site. Moreover, continuous fluorescence sensors for chlorophyll do not differentiate between chlorophyll *a* and pheophytin *a*, thus the magnitude of the changes may be reduced.

In addition, the removal of particles is expected to result in a change in water clarity. Time-series measures of water clarity were consistent with the time-series fluorescence measures and the water quality grab sampling results, in that the water showed increased clarity within the Demonstration Site (LP-1.3) relative to upgradient and downgradient sites. Independent measurements demonstrate a phenomenon occurring within the oyster deployment area, consistent with oysters removing significant amounts of phytoplankton and particulates from the water column. This is expected as it is a direct result of feeding, which is further evidenced by the localized spike in pheophytin *a*.

Nutrient Data:

The removal of phytoplankton/particles by the oysters could also be seen in the total nitrogen (TN) results from the 2013 post-oyster deployment versus 2012 pre-oyster deployment. In 2013 TN showed a decline on the ebbing tide through the deployment area. A peak in chlorophyll *a* is seen at LP-1.2, and rapidly declines at LP-1.3 with a minimum concentration seen at LP-2. In 2012, the concentration of chlorophyll *a* showed relatively small change from station to station (i.e. flat gradient; Figures 8 and 9). The “oyster effect” was not as large in the TN data as in the other parameters noted above (Figures 4 thru 7), but is still clearly present and shows a similar pattern as chlorophyll *a*, peaking at LP-1.2, upgradient of the Demonstration Site and declining at LP-1.3, within the oyster deployment area. TN is comprised of a large dissolved organic nitrogen fraction which is relatively constant throughout the pond waters, presenting a large relatively inactive background nitrogen pool. This background obscures the effects of the oysters because their impact is primarily on particulate and inorganic nitrogen. In order to discern the oysters’ potential impact on TN constituents, the TN pool was fractionated into particulate nitrogen and inorganic nitrogen.

Inorganic nitrogen can be generated in several ways. It can be directly excreted by the oysters from the digestion of particulate organic nitrogen (phytoplankton) to the surrounding water, or it can be formed from the decomposition of particulate matter some of which is released and some of which is oxidized to nitrate prior to entering the water column. Examining the data for ammonium and nitrate+nitrite (NO_x), there is no clear increase in either nitrogen species within the deployment area. The only evidence of a potential effect of the oysters stems from

comparing the 2013 and 2012 (pre-deployment) data (Figures 10 and 11). In 2012 the NO_x and ammonium showed smooth gradients, with levels declining from the headwaters to the tidal inlet. In contrast, in 2013 the gradients in ammonium tended to show a break from above to below the oyster deployment area. It is possible that the relatively low levels of inorganic nitrogen and the rapid uptake by phytoplankton (once released to the water column) obscure any clear pattern associated with the oysters. At this point these data are supportive but not compelling. In contrast, the PON results showed a clear pattern of removal by the oysters, consistent with the observations of chlorophyll *a* and particulate carbon discussed above. It appears that removal of particulate nitrogen by oysters is the predominant cause of the reduction in TN. However, at this time the fate of this particulate nitrogen is not yet quantified.

Particulate nitrogen once removed by oysters can be consumed and digested with incorporation into tissue or excreted as waste, this represents a small fraction of what the oysters collect with the result that a substantial amount of pseudo-feces are generated. These pseudo-feces once released can be transported in tidal waters as additional particulates (TSS) or reach the pond sediments where the nitrogen is remineralized and either released to the water column as inorganic nitrogen and consumed in part or fully by phytoplankton and bacteria or be denitrified (coupled nitrification-denitrification). This latter process is routinely measured at SMAST and our quantification of this removal resulted in MassDEP granting in the Town's wastewater discharge permit a 40% removal of nitrogen entering Mashapaquit Creek in West Falmouth.

One concern related to potential negative effects of the oysters on the pond system stems from the above mentioned potential increase in deposition of particles to the sediments. This would result from a strong localized change in organic matter deposition and one result might be low oxygen. While in 2013 Little Pond experienced hypoxia, this phenomenon occurred both prior to, and after the deployment of the oysters. Further, hypoxia was not focused within the deployment area. It is possible that oxygen conditions improved in both surface and bottom waters on the ebbing tide as the water passed through the oyster deployment site. Improved oxygen condition in the Demonstration Site paralleled the decline in particulate organic matter. While there are a myriad of potential causes for this pattern in oxygen level, it is clear that the oysters were not resulting in a depletion of oxygen in the surface or bottom waters. This is further supported by the historical oxygen measurements by the MEP and PondWatch which indicate the existence of periodic summertime hypoxia in Little Pond for over two decades.

Conclusions (2013):

The water quality monitoring results clearly document that the deployment of oysters in Little Pond did produce modest water quality improvements near-field to the deployment area. The primary mechanism of this water quality improvement appears to be the uptake of phytoplankton by the oysters.

Lines of evidence from nutrient data (TN, PON, POC), chlorophyll *a*, fluorescence and turbidity analyses (detailed below in Section IV) indicate that the oysters are removing particles from the surface layer of Little Pond, with their effect clearly discernible in the near-field region (LP-1.2, 1.3, 2). It is likely that tidal action, dilution and other biologic processes tend to predominate in other areas, muting the oyster effects at these monitoring stations.

Several independent measurements support this conclusion:

- Nutrient data show a decrease in water column total nitrogen (TN) at LP-1.3, within the oyster deployment area compared to upgradient sites on the ebbing tide.
- Nutrient data shows lower POC and PON at LP-1.3 than in stations above the Demonstration Site.
- Lab analysis of water samples for chlorophyll *a* shows reduced phytoplankton at LP-1.3 on the ebbing tide.
- Lab analysis of water samples for pheophytin *a* show an increase within the deployment area, which is the result of the degradation of phytoplankton chlorophyll *a* to pheophytin as oysters feed.
- Time-series measurements from moored instruments at 4 sites show that chlorophyll *a* increased above, and declined across the Demonstration Site.
- Time-series measurements from moored instruments at 4 sites (Section IV) show an improvement in water clarity (i.e. decreased turbidity).
- The moderate stratification of the water column focused the “oyster effect” in the surface layer where they were deployed. Comparisons between 2013 (oyster deployment) and 2012 (no oyster deployment) demonstrate that it was the oysters, and not natural gradients that were producing the observed effects in the region nearfield to the deployment area.

While there were initial theoretical questions regarding the potential for oyster aquaculture to negatively impact oxygen dynamics, data from 2012, as well as the 2006 Little Pond MEP Report and earlier data documents that hypoxia is a condition in Little Pond preceding the oyster deployment by decades. Moreover, the oysters were effectively separated from the bottom water by the moderate stratification. The pattern of bottom water oxygen suggested that the oysters may have had a positive effect (if any) on oxygen conditions. Based on the water quality monitoring, the oyster deployment was not found to have any negative ecological impacts on the estuarine habitats within the Little Pond System.

The 2013 oyster deployment consisted of ~1.25 million oysters. In 2014, the deployment of an additional 0.25 million oysters, for a total of 1.5 million oysters, was used to enhance the effect in the associated monitoring data. With this additional oyster activity, it was hoped that a better quantification of nitrogen removal would be possible.

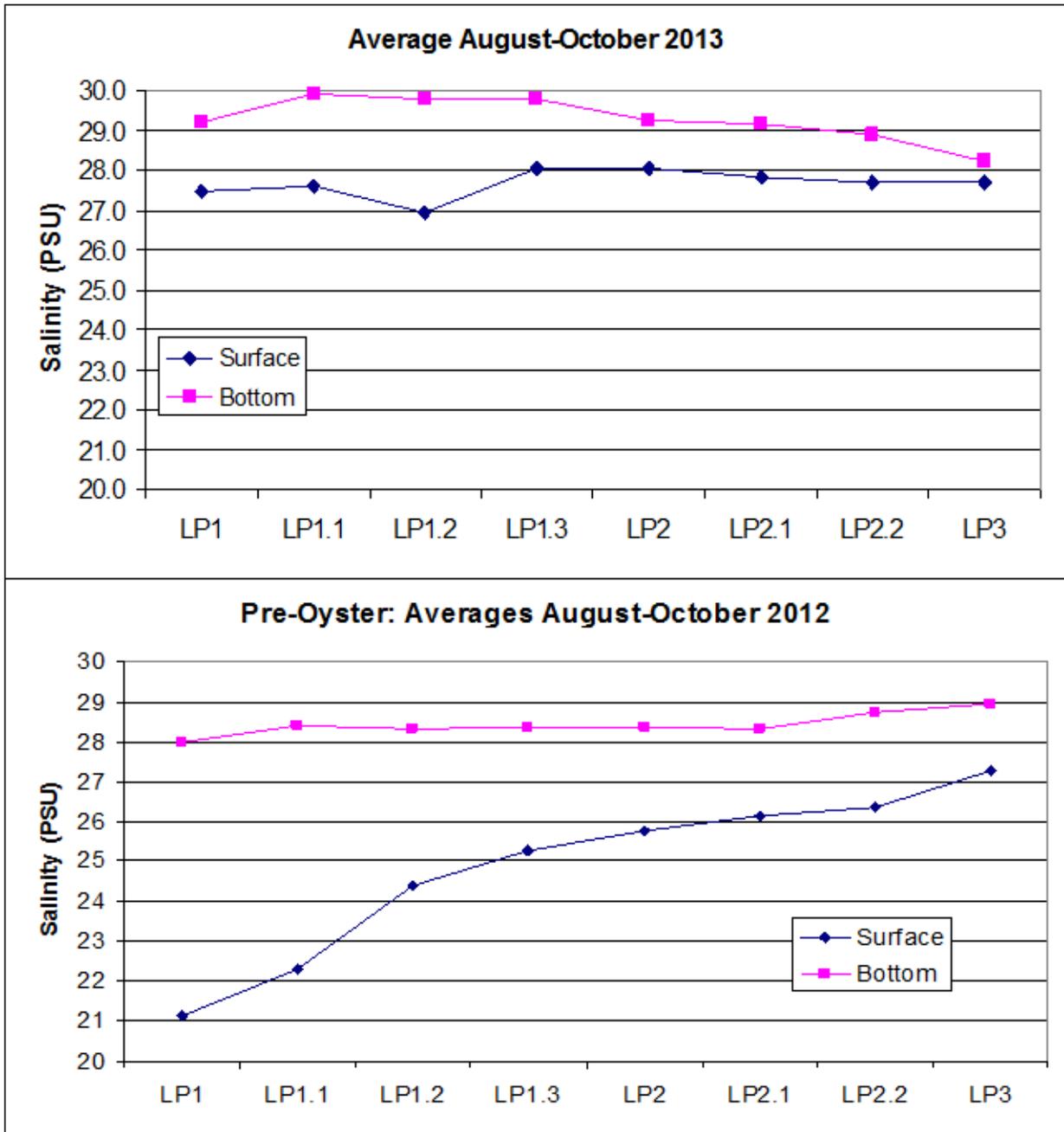


Figure 3. Water column salinity averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA. Water was collected near surface (0.15 m depth) and near bottom (0.3 m above) in, Top 2013 (oysters) and Btm, 2012 (no-oysters), The water column was moderately stratified in both years..

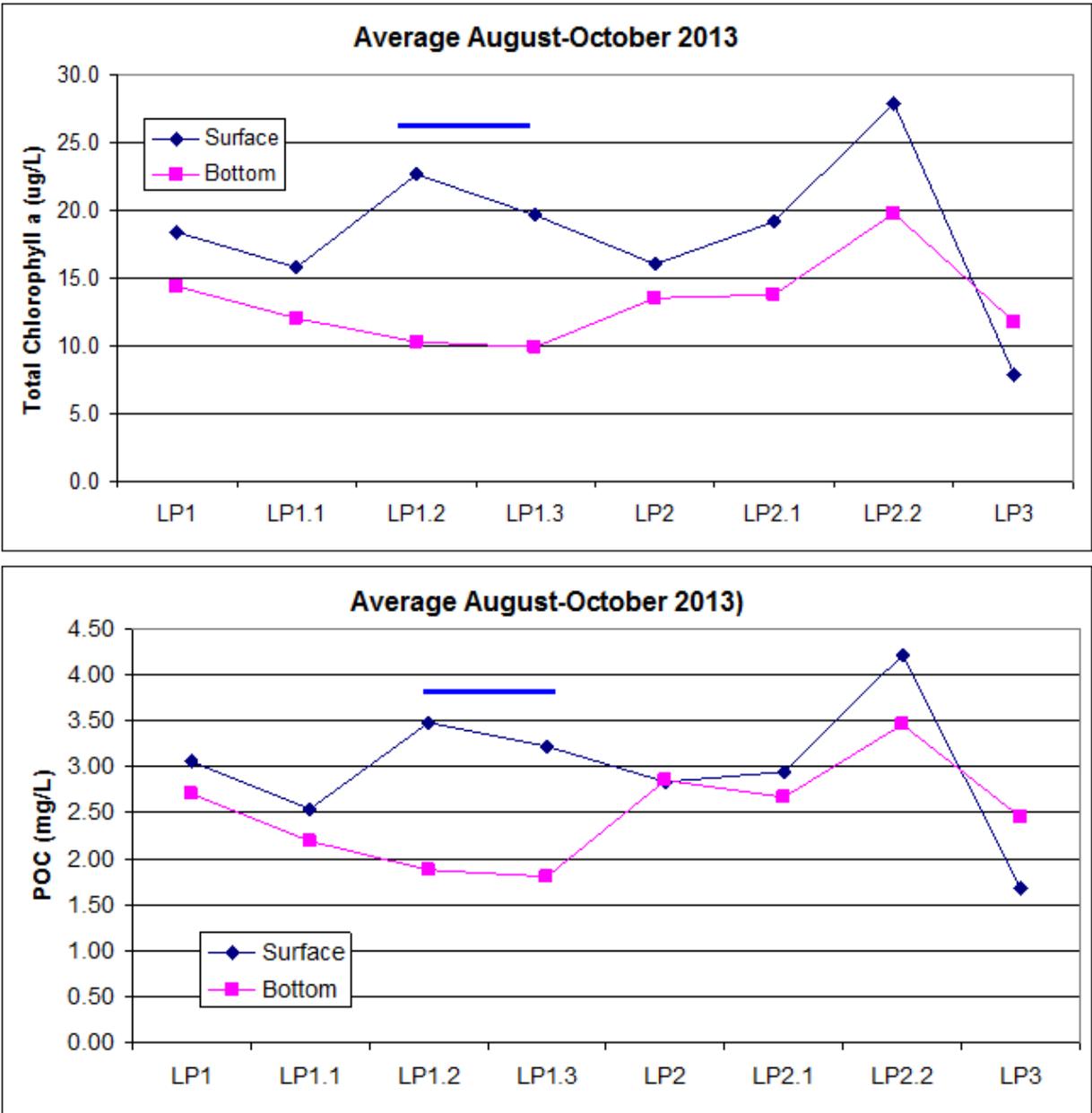


Figure 4. Water column phytoplankton biomass metric averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2013. (Top) Total Chlorophyll a and (Btm) Particulate Organic Carbon. Both parameters relate to both filtration and fecal production by oysters. Bar shows most likely area of "oyster effect".

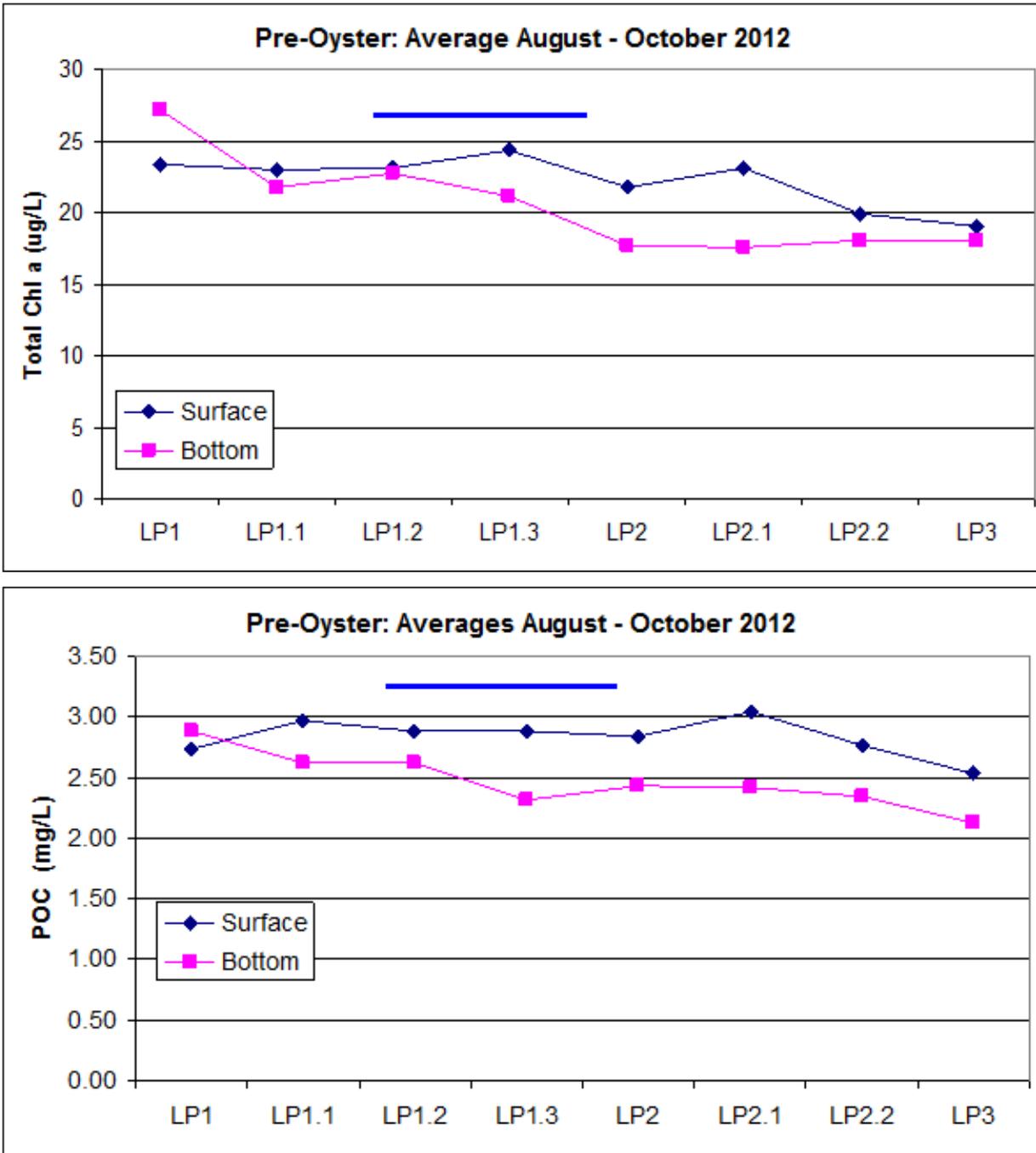


Figure 5. Water column phytoplankton biomass metric averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2012. (Top) Total Chlorophyll a and (Btm) Particulate Organic Carbon. Both parameters relate to both filtration and fecal production by oysters in 2013, but 2012 served as a no-oyster control summer for comparison to 2013 (Figure 3). Horizontal bar shows

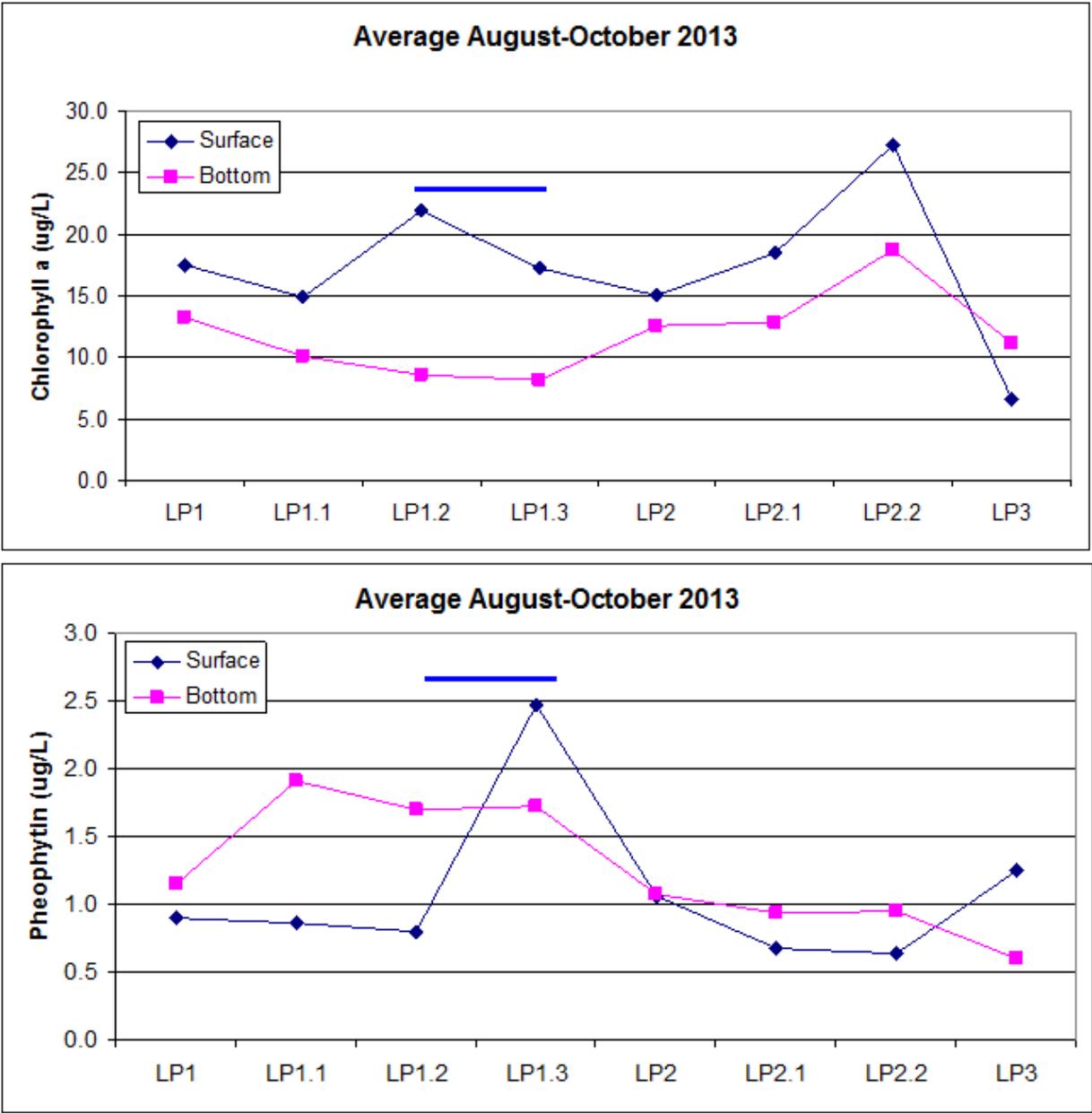


Figure 6. Water column phytoplankton pigment averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2013. (Top) active Chlorophyll a and (Btm) initial degradation product of Chlorophyll a, generally associated with phytoplankton senescence or invertebrate grazing/feeding. Shifts from Chlorophyll a to Pheophytin a can be used as an indicator of oyster feeding.

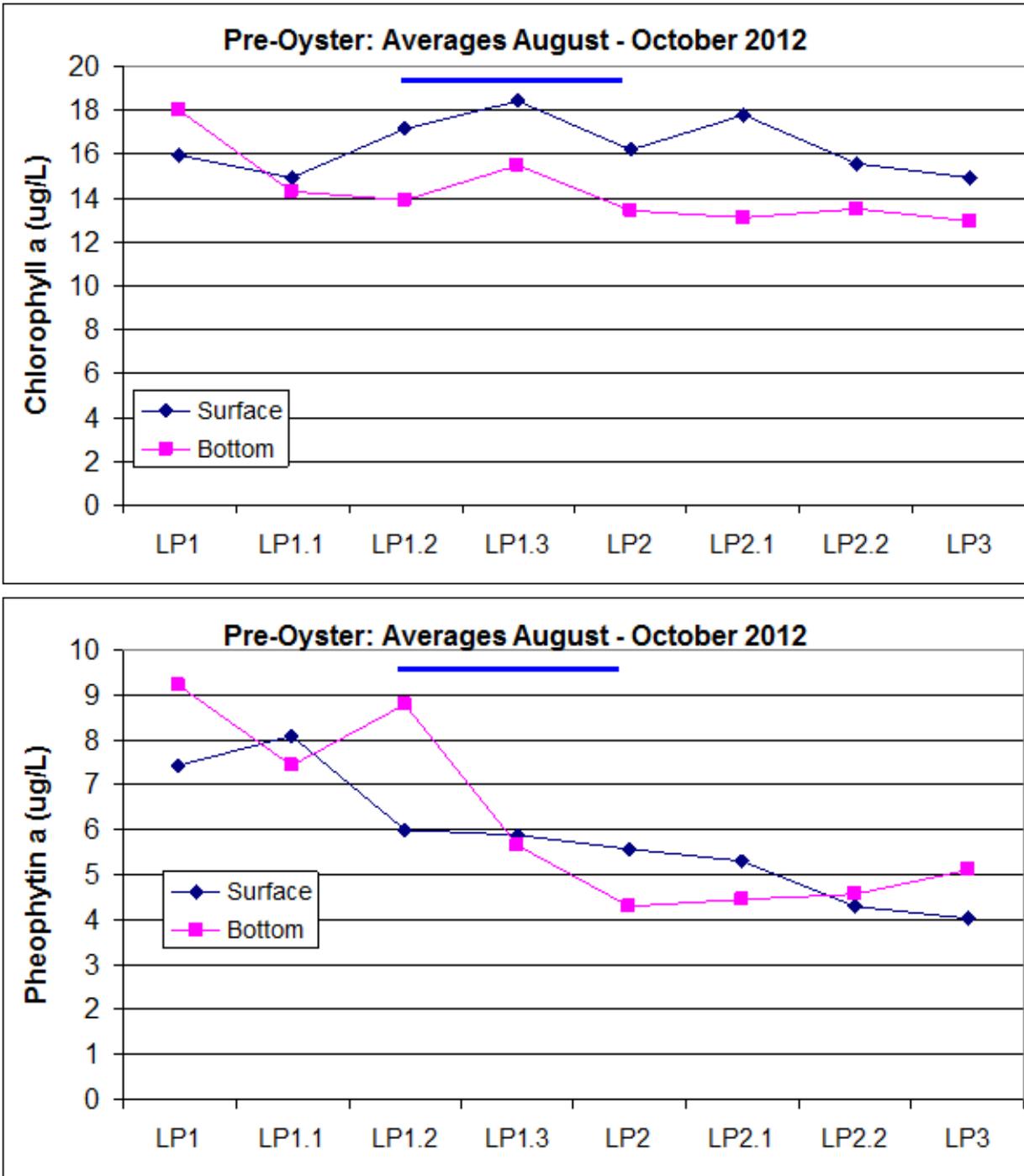


Figure 7. Water column phytoplankton pigment averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2012. (Top) active Chlorophyll a and (Btm) initial degradation product of Chlorophyll a, generally associated with phytoplankton senescence or invertebrate grazing/feeding. As there were no oysters deployed, shifts from Chlorophyll a to Pheophytin a were judged to be associated primarily with phytoplankton senescence.

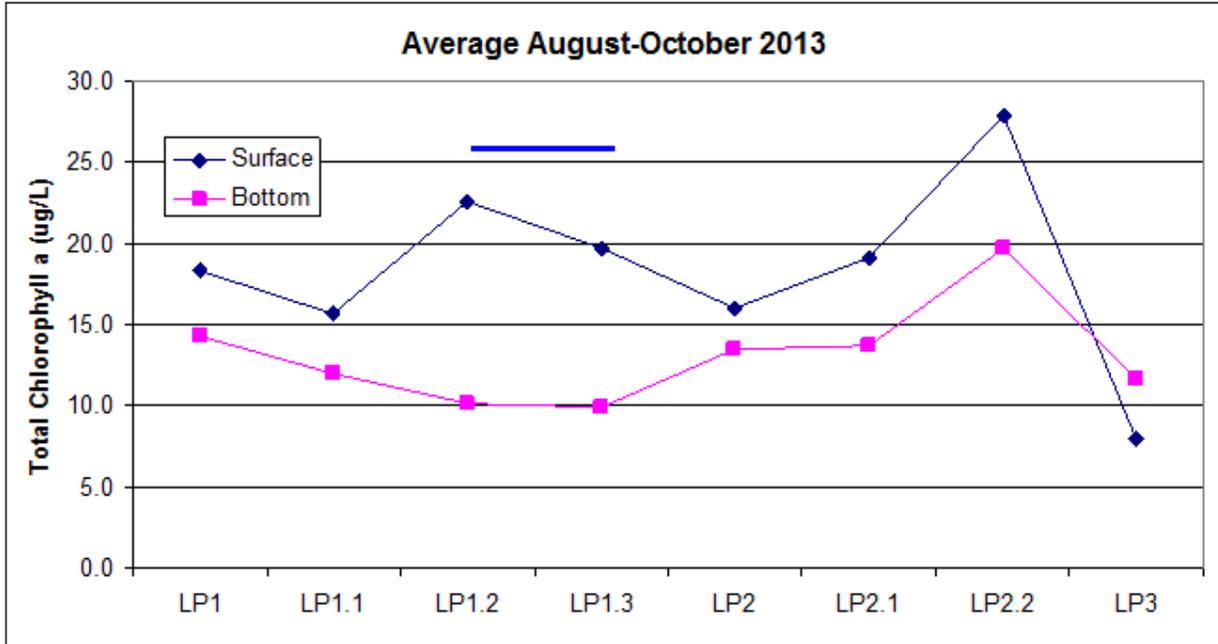
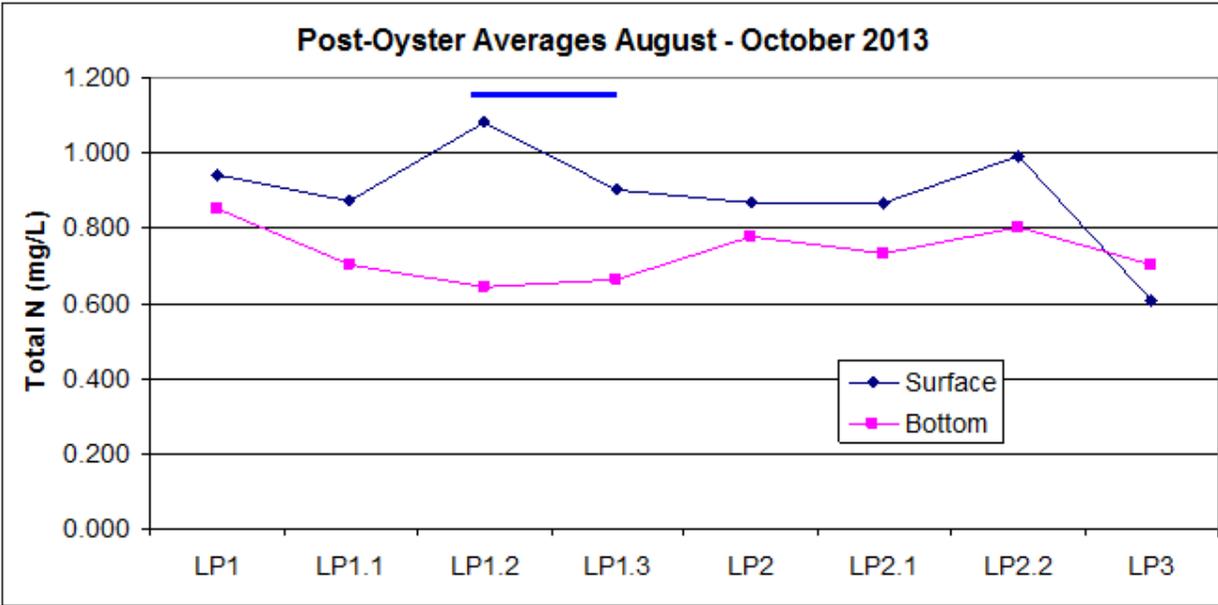


Figure 8. (Top Panel) water column total nitrogen and (Bottom Panel) phytoplankton biomass (total chlorophyll a pigment) averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2013.

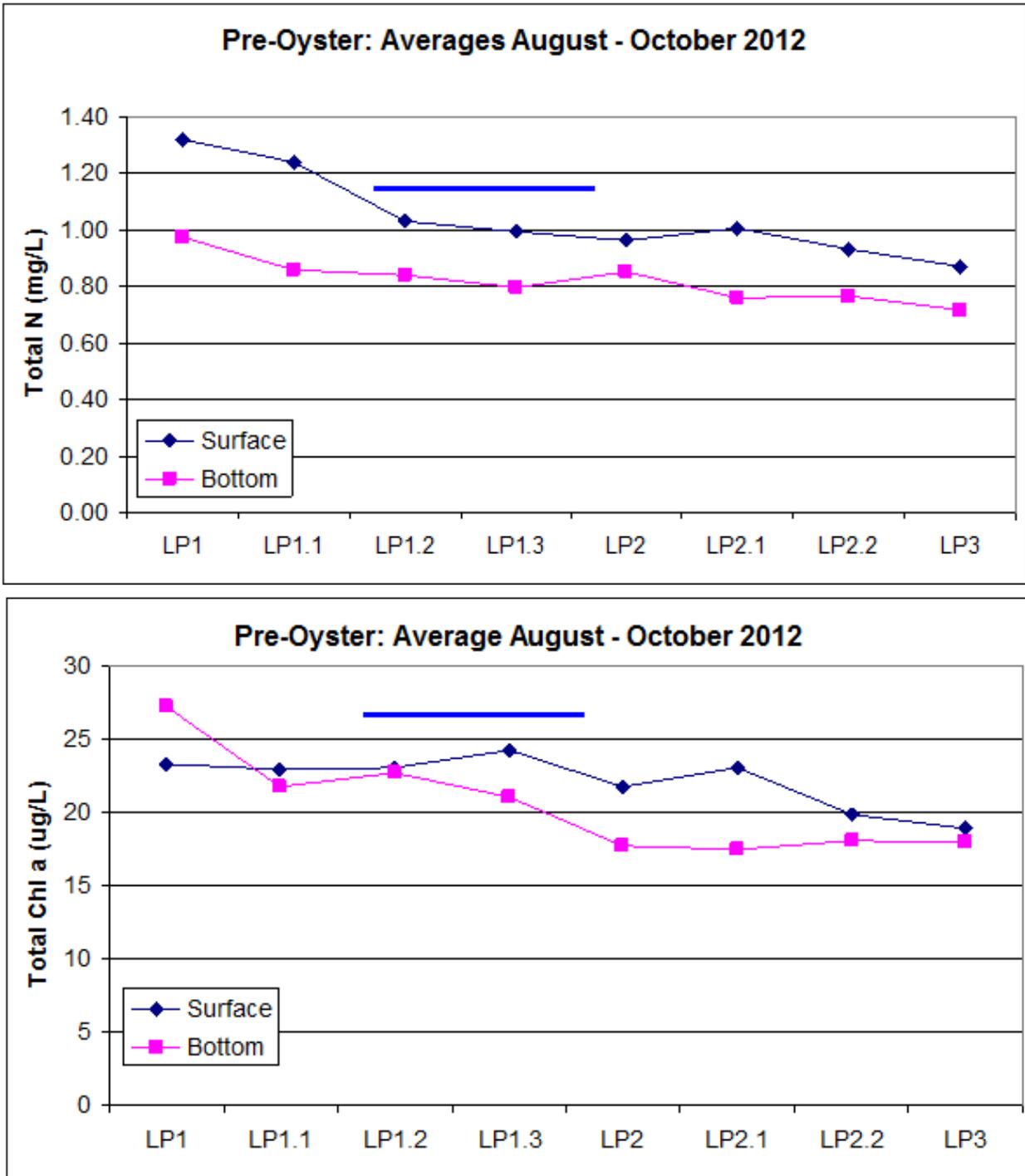


Figure 9. (Top Panel) water column total nitrogen and (Bottom Panel) phytoplankton biomass (total chlorophyll a pigment) averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2012.

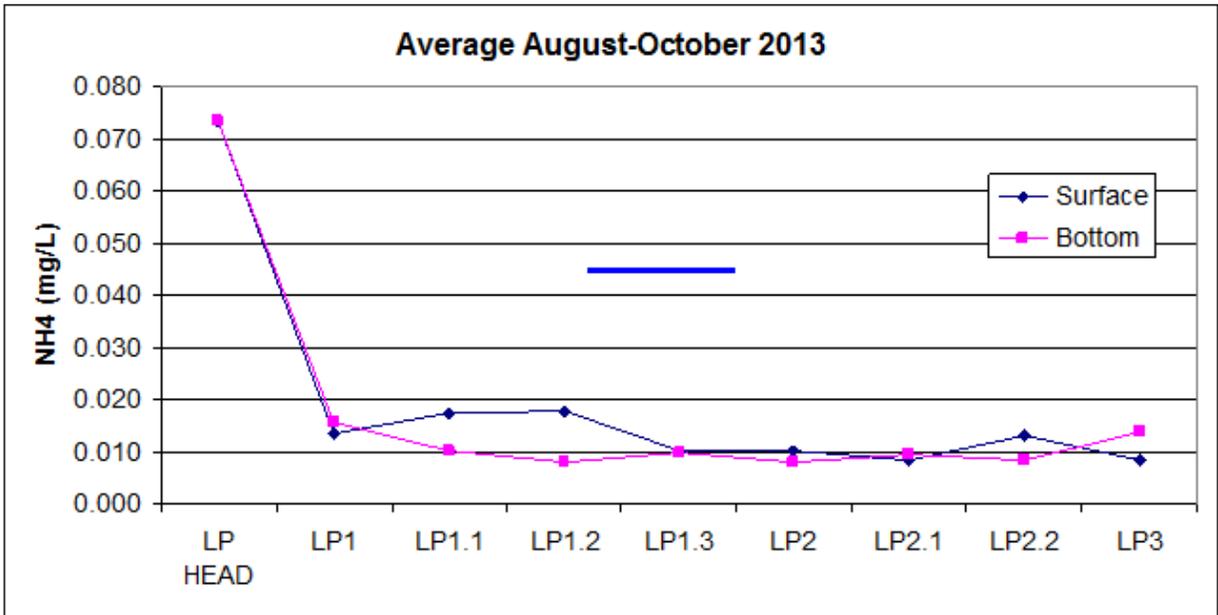
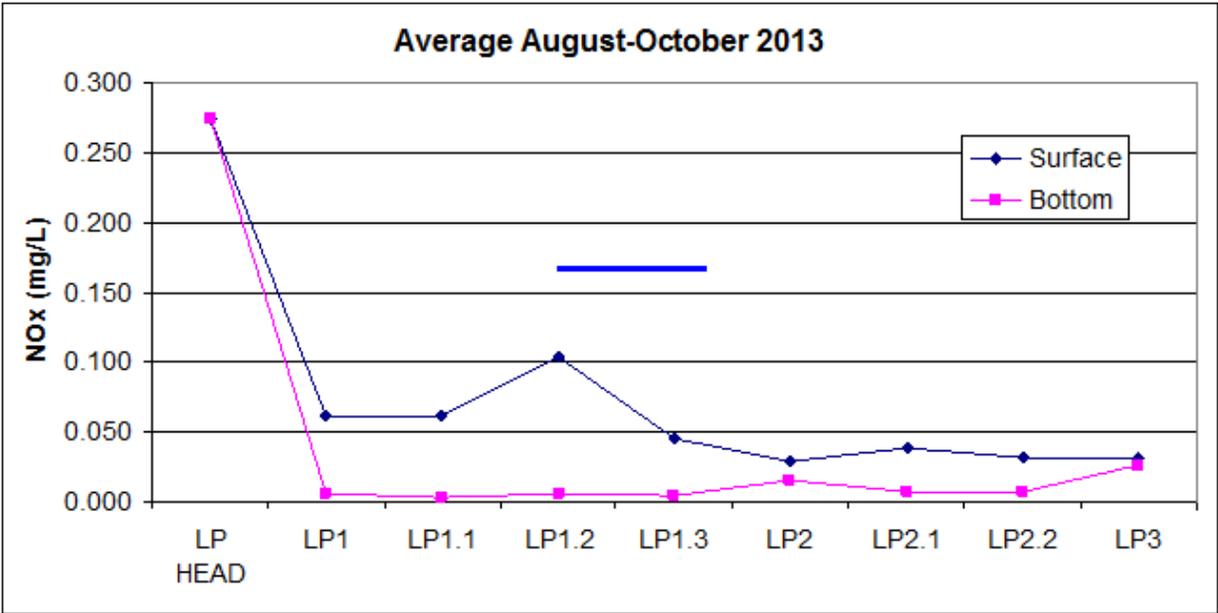


Figure 10. Water column inorganic nitrogen averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2013. (Top Panel) water column nitrate+nitrite and (Bottom Panel) ammonium. Bar represents region of maximum change.

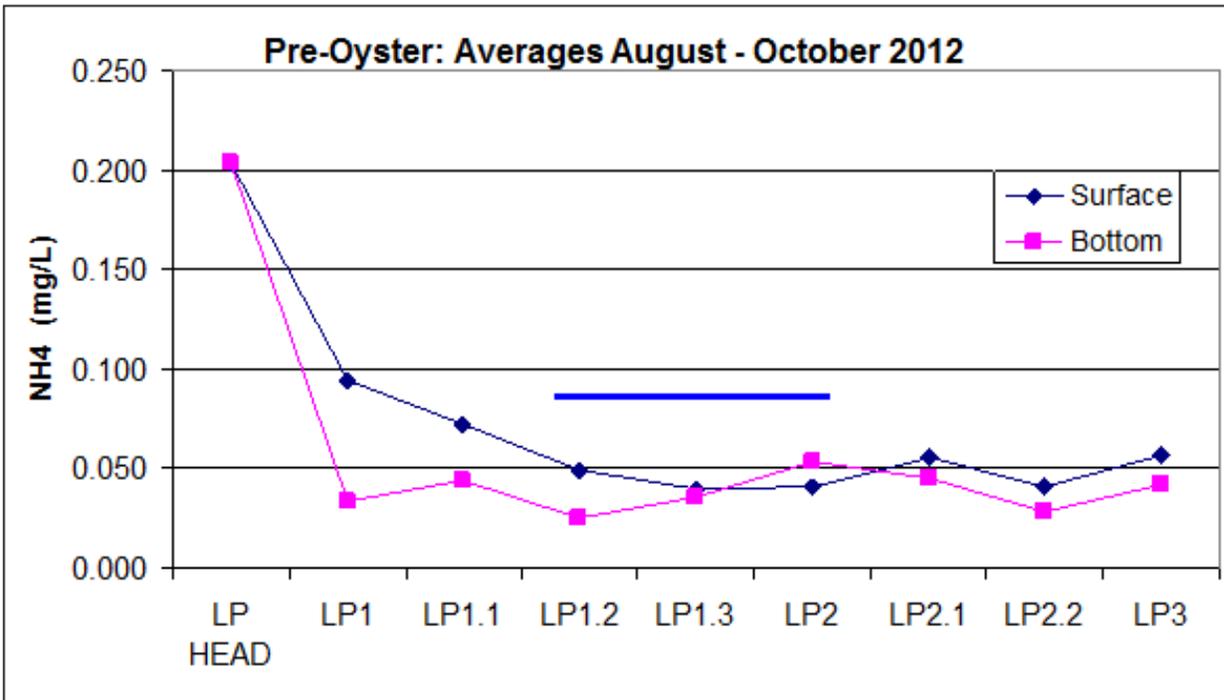
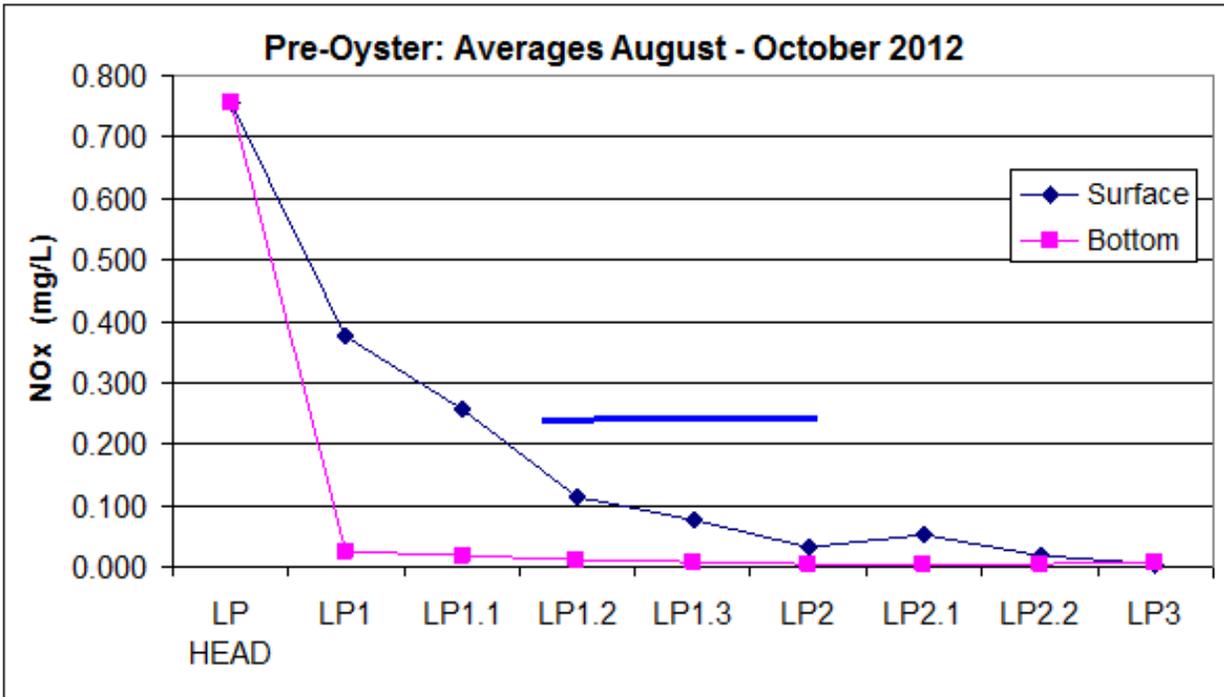


Figure 11. Water column inorganic nitrogen averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2012. (Top Panel) water column nitrate+nitrite and (Bottom Panel) ammonium. Bar represents region of projected maximum change when oysters are deployed.

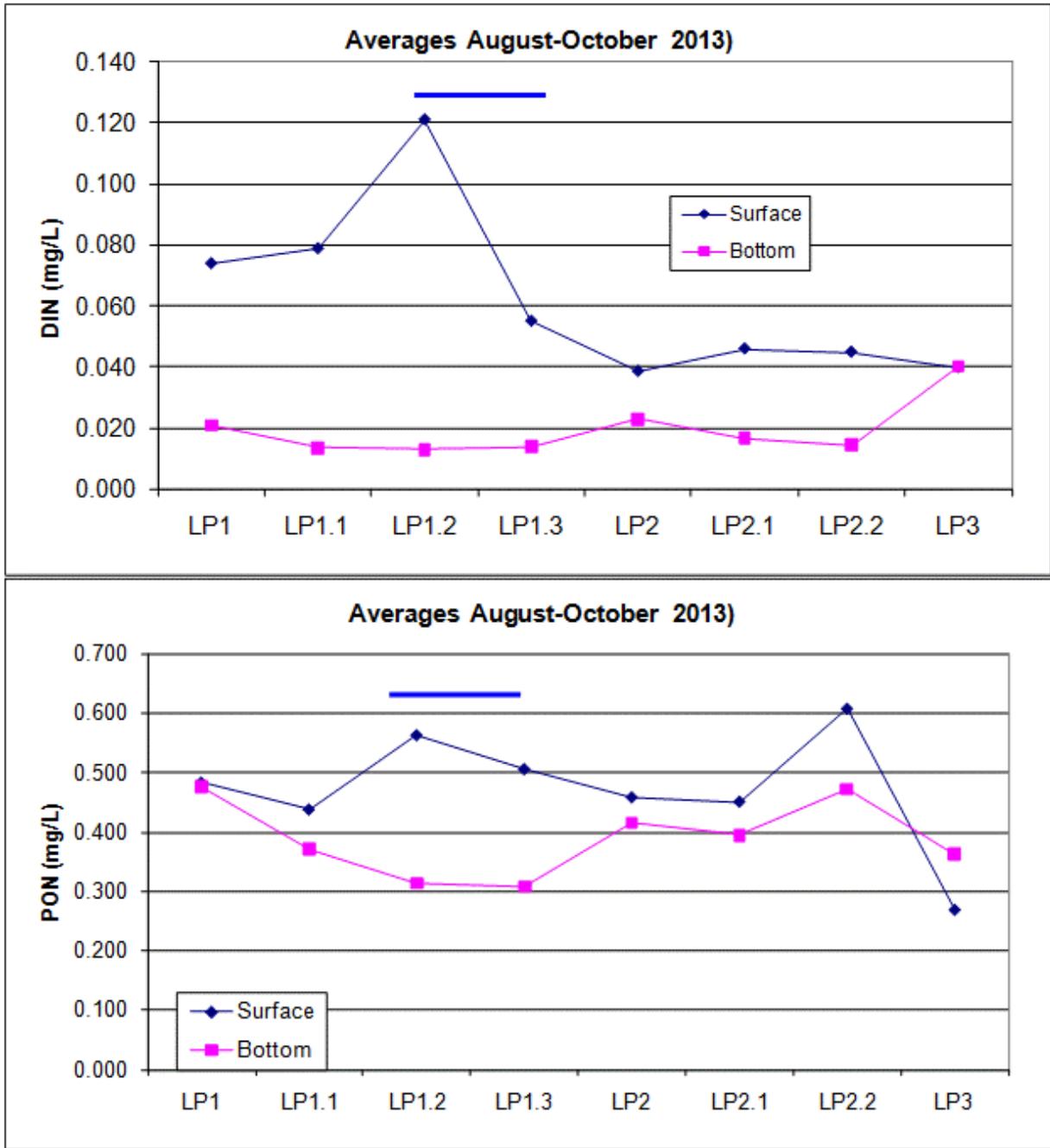


Figure 12. Water column bioactive nitrogen averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2013. (Top Panel) water column dissolved inorganic nitrogen (ammonium+nitrate +nitrite) and (Bottom Panel) particulate organic nitrogen primarily associated with phytoplankton cells living and dead. Bar represents region of maximum change.

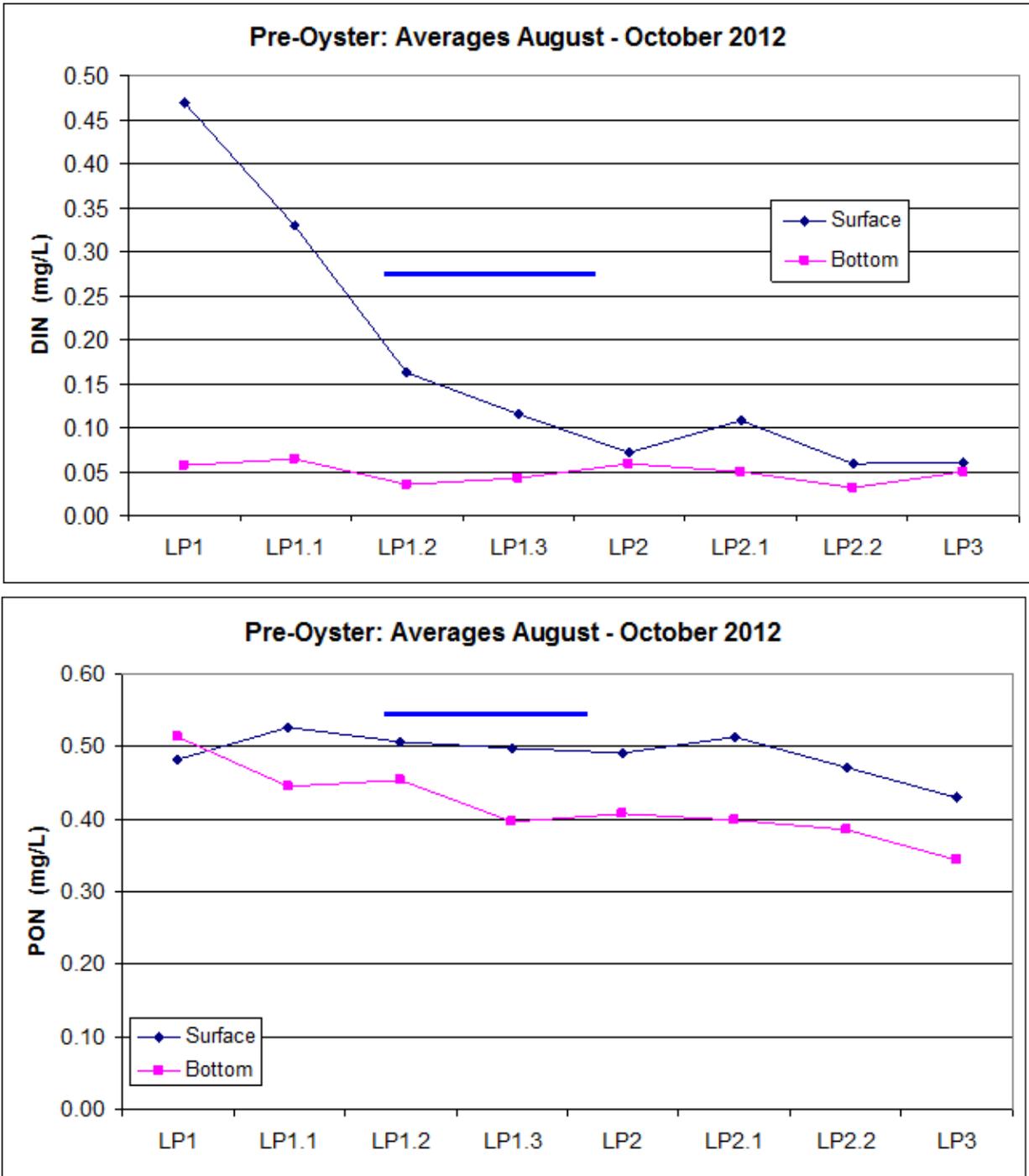


Figure 13. Water column bioactive nitrogen averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2012. (Top Panel) water column dissolved inorganic nitrogen (ammonium+nitrate +nitrite) and (Bottom Panel) particulate organic nitrogen primarily associated with phytoplankton cells living and dead. Bar represents region of maximum change.

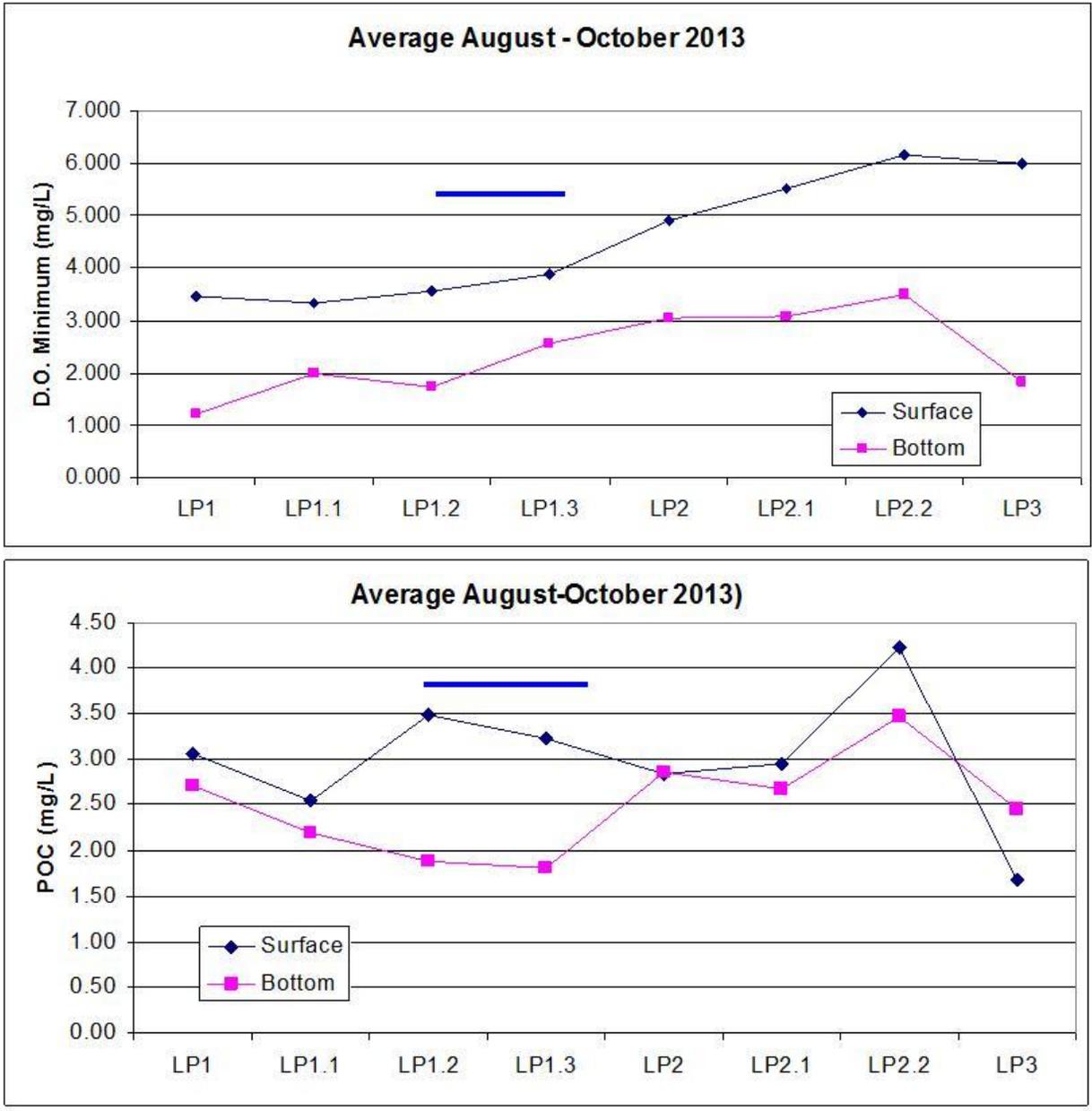


Figure 14. (Top Panel) Bottom water oxygen minimum measured during the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2013. (Bottom Panel) particulate organic carbon concentration presented as an indicator of potential oxygen uptake (as substrate or as phytoplankton. Bar indicates region of maximum change.

Results from Year 2 (2014) Sampling: As in 2013, the major question to be addressed by the sampling program continued to be the degree to which the oysters deployed in Little Pond would make a discernible change in the water column nitrogen related constituents. Similar to 2013, since oysters were introduced to the surface waters of the pond in July 2014 and removed in late October, that was the primary period for evaluation. The analytical approach involved comparing the gradients in water quality parameters both during the oyster deployment (2014) and during the same period in 2013 to determine if the oyster deployments had a consistent effect on water quality during both summer seasons. Since the oysters were deployed in floating bags, initially as small spat, their effect over the first month in the pond was expected to be negligible. Therefore, the period for gauging the effect of the Year 2 deployment of ~1.5 million oysters deployed was August through the end of October, while the oysters were larger and actively feeding. Although the oysters were “larger” by August, they were only 1”-1.5” by their transfer date in October/November, they should reach 3.5” by the end of their second growing season. This size difference from year 1 to year 2 is critical in their filtering and nitrogen sequestration rates, with approximate increases of about 10 fold from the end of year 1 to the end of year 2. 2014 focused on the effects of first year grow-out oysters (approx. spat to 3”). In the coming year, 2015, it was projected that the program would include some follow-up on oysters year class 2013 and analysis of the larger second year of grow-out of oysters in Quissett and West Falmouth Harbors that were relayed from Little Pond in the fall of 2014. This is important as the nitrogen removal and bio-deposition by year 2 oysters appears to be multi-fold higher than during year 1. Analysis using the earlier portion of the year 1 oyster growth dataset (May-July 2013, 2014) was also performed to characterize conditions prior to the oysters having any substantive effect on water quality due to their very small size.

Water-column Stratification of Little Pond:

In both 2013 and 2014, the Little Pond water column showed moderate water column stratification³, due to salinity (Figure 15). However, stratification in 2014 was greater than in 2013 and more similar to conditions in 2012. Stratification of an estuarine water column is most commonly the result of salinity differences from the surface to the bottom waters, as opposed to temperature. This salinity difference results from fresh waters entering from the watershed and not mixing vertically throughout the water column, rather they differentially freshen the surface water, and marine waters entering from the tidal inlet differentially increasing the salinity of bottom waters. A secondary factor in the density difference is the occurrence of colder bottom waters overlain by warmer surface waters. The salinity difference is clear in all years (2012-2014), although the salinity gradient was much larger in 2012 and 2014 (~6 PSU) than 2013 (~1-2 PSU) (Figure III.2-2). The salinity differences show stratification at all stations, but diminishing from the headwaters towards the tidal inlet, due to wind and tidal mixing. Although it is difficult to quantify, it appears that stratification focused the effects of the oysters on the surface layer in 2014 even more strongly than in 2013, since the oysters were deployed in floating bags at the pond surface. From the water quality sampling it is clear that the surface and bottom layers of the pond water column are not tightly coupled through the warmest months of the study when the oysters were having their greatest effect (see below).

The stratification of surface and bottom waters can be seen in the key oyster food indicators of total chlorophyll-a pigment and particulate organic carbon (Figure 16). It appears from the surveys that during 2013 the moderate stratification held phytoplankton in the surface layer due to periodic vertical mixing of the watercolumn, while in 2014 once particles settled into the

³ Well mixed conditions show similar salinity and temperature at surface and bottom, while moderate stratification shows higher salinity (1-2 PSU) at bottom than surface.

bottom layer they appear to have remained and were typically slightly higher in concentration in the bottom layer than the top layer.

In 2014 down-gradient of the oyster rafts starting in the region of stations LP-2 and LP-2.1, the surface versus bottom water difference between total chlorophyll and POC is significantly reduced and the concentrations are essentially the same. The large difference seen in 2013 is likely due to the higher phytoplankton production in the surface layer, most likely due to light availability, as seen in the higher chlorophyll-a pigments and POC concentrations in surface waters. Overall, it appears that differences in vertical mixing (2013>2014) due to the much stronger salinity stratification present in 2014 and its effect on vertical transport of particles and up-mixing of nutrients is consistent with the POC and chlorophyll-a distribution.

Chlorophyll, Particulate Organic Carbon (POC) and Fluorescence Analysis:

Particulate Organic Carbon and Total Pigment Data

Data for both total chlorophyll-a and POC⁴ shows higher phytoplankton concentrations in the stations up-gradient (LP-1.2) of the deployment area (LP-1.3). Concentrations on the ebbing tide decrease measurably at LP-1.3, with a continued decline or leveling at LP-2, down-gradient of the demonstration site in both years in surface waters but is most clearly seen in the later season in 2014. The effect is seen both in POC and Total Chlorophyll. The stronger effect in the later season is consistent with the larger oysters on site at that time of the summer..

Station	Sample Depth	2013	POC (mg/L)	Total Chla (ug/L)	Station	Sample Depth	2014	POC (mg/L)	Total Chla (ug/L)
LP1.2	S	may-july	2.61	19.04	LP1.2	S	May-July	0.889	3.7
LP1.3	S	may-july	2.28	16.99	LP1.3	S	May-July	0.821	3.7
LP1.2	B	may-july	1.55	10.00	LP1.2	B	May-July	0.995	4.6
LP1.3	B	may-july	1.41	8.68	LP1.3	B	May-July	1.011	4.3
LP1.2	S	Aug-Oct	3.48	22.66	LP1.2	S	Aug-Oct	1.333	6.2
LP1.3	S	Aug-Oct	3.23	19.69	LP1.3	S	Aug-Oct	1.217	5.6
LP1.2	B	Aug-Oct	1.88	10.20	LP1.2	B	Aug-Oct	1.534	8.8
LP1.3	B	Aug-Oct	1.81	9.90	LP1.3	B	Aug-Oct	1.343	7.7

This effect was seen in the surface and bottom waters where the decline from upper (LP-1.2) to lower (LP-1.3) station was 0.116 and 0.191 mg C/L for POC respectively and 0.6 and 1.0 ug/L for Total Chlorophyll-a respectively. This decline was seen across the surface and bottom waters across these sites, further supporting the conclusion that the decline is due to the removal of particles by the oysters in the surface layer, with deposition likely down-gradient as the particles settle.

⁴ There is a linear relationship between total chlorophyll a and POC in Little Pond water as in many other estuaries on Cape Cod. This was presented in the 2012 Pre-Oyster Deployment Monitoring Report [B.L. Howes, S.J. Sampieri and R.I. Samimy. 2013. Nutrient Related Water Quality Monitoring Baseline for Gauging Nitrogen Removal by Town of Falmouth Oyster Pilot Project in Little Pond Summer 2012, Technical Memorandum from the Coastal Systems Program-SMAST to the Town of Falmouth.].

Analysis of the 2012 water quality results from these same 3 sites, when there were no oysters deployed, shows no significant decline in POC or Total Chlorophyll-*a*. This is consistent with the conclusion that the pattern in 2013 and 2014 resulted from the addition of oysters and not from a natural gradient within the estuary (Figures 16).

Chlorophyll-*a* and Pheophytin-*a* Data

When oysters filter phytoplankton and process the particles, the chlorophyll-*a* in the phytoplankton chloroplasts is typically degraded to pheophytin-*a*. This can also occur when zooplankton graze on phytoplankton cells and is a well-documented effect of grazing.

Examining the chlorophyll-*a* and pheophytin-*a* gradients in the 2013 and 2014 monitoring indicates that there is moderate "grazing" of phytoplankton in both surface and bottom water during the 2014 deployment compared to intense "grazing" of phytoplankton in the surface layer in 2013, but not in 2012, and not in the bottom waters (Figure 17). In 2014 there is a decline in chlorophyll-*a* concentration through the near-field, with concentrations up-gradient > oyster site > down-gradient station on the outgoing tide but it did not appear as large as in the 2013 data. Both the surface and bottom layer showed this pattern. Additionally, the 2014 data showed significantly higher pheophytin-*a* concentrations in the bottom water as might be expected from activity occurring in the surface water containing the oyster rafts, which were generating fecal casts from their filtration activities. The 2012 data showed the opposite, with chlorophyll-*a* increasing to a peak at the site of the next year's oyster deployment and the pheophytin-*a* showing a continuing decline through the area. Of particular note in 2013, the pheophytin-*a* "spiked" within the oyster deployment area, compared to up-gradient and down-gradient sites. This was not apparent in the 2014 data where bottom water pheophytin-*a* gradually declines from LP-1.2 to LP-1.3 to LP-2. This was also the case in the surface water with the exception of a slight increase in pheophytin-*a* concentration from LP-1.3 within the oyster raft and LP-2 down-gradient of the rafts on the ebbing tide.

Fluorescence Data

Although the time-series data varies considerably throughout the three month deployment, there were generally trends seen from the head of the pond down to the mouth. Highest chlorophyll fluorescence was generally recorded up-gradient of the oyster beds. Chlorophyll levels declined through the Demonstration Site itself (LP-1.3), with the lowest levels immediately down-gradient of the Demonstration Site during the flood and ebb tides. The extent of this depletion is not quantifiable from the time-series measurements, as the observed increase in pheophytin-*a* in this region partially obscures the loss of chlorophyll-*a* (when measured by in situ fluorescence). While the general trend is decreasing concentrations from the head to the mouth of the pond, during bloom conditions chlorophyll concentrations were higher directly upstream of the oyster culture site. Spatial trends in chlorophyll concentrations were most pronounced during bloom conditions. Even with the variation in chlorophyll-*a* fluorescence, the results clearly showed that within the oyster culture area the phytoplankton were being removed from the water column resulting in a localized depression in chlorophyll-*a* levels. The magnitude of the plankton removal is technically limited as fluorescence sensors for chlorophyll do not differentiate between chlorophyll-*a* and pheophytin-*a*, thus the magnitude of the depression is likely underestimated.

In addition, the removal of particles is expected to result in a change in water clarity. Examination of the time-series measures of water clarity made in parallel with the fluorescence measurements showed the associated increase in water clarity with the decrease in chlorophyll-*a* (phytoplankton biomass). Similarly, particulate data from the water quality grab sampling were consistent with the increased clarity within the Demonstration Site (LP-1.3) relative to up-

gradient and down-gradient sites. Independent measurements demonstrate a phenomenon occurring within the oyster deployment area, consistent with oysters removing significant amounts of phytoplankton and particulates from the water column. This is expected as it is a direct result of feeding, which is further evidenced by the localized spike in pheophytin-a. Particle removal within the oyster deployment site was confirmed by the direct measurements of particle deposition by these oysters in the field.

Nutrient Data:

The removal of phytoplankton/particles by the oysters could also be seen in the total nitrogen (TN) results from the 2014 water sampling. TN concentrations showed a clear decrease through the oysters beds (Figure 18) whereby average TN concentration at LP-1.2 (up-gradient on the ebb tide) was greater than LP-1.3 situated in the oyster bed and this was generally mirrored by total chlorophyll-a concentrations. In both 2013 and 2014 there is clearly a lower TN level at LP-1.3 than at 1.2 at both surface and bottom. Sometimes this decline continued to LP-2 or was seen at LP-1.1 but it was clearly associated with the oyster deployment site. In some cases in 2014 concentrations even increased at LP-2 over LP-1.3 on ebb tides. In 2013 TN showed a decline on the ebbing tide through the deployment area. In 2013 a peak in chlorophyll-a was seen at LP-1.2, and rapidly declines at LP-1.3 with a minimum concentration seen at LP-2. In 2014 the decline from LP-1.2 to LP-1.3 was also found, particularly in TN. Only in 2012 was the concentration of chlorophyll-a relatively constant from station to station. In the 2014 data the “oyster effect” was clearer in the TN data than in the other parameters noted above (Total Chlorophyll and POC), however, the patterns of each parameter (TN, Chla, Pheophytin) are consistent in the sense that the patterns are the similar, with each showing a decrease at LP-1.3 that is situated within the rafts. It is important to note that stratification in 2012 and 2014 was very similar and yet the TN gradient around the oyster bed area only showed an “oyster effect” in 2014, when the oysters were deployed.

TN is comprised of a large dissolved organic nitrogen fraction which is relatively constant throughout the pond waters, presenting a large relatively inactive background nitrogen pool. This background can obscure the effects of the oysters because their impact is primarily on particulate (PON) and inorganic nitrogen (NO_x and NH_4). In order to discern the oysters' potential impact on TN constituents, the TN pool was fractionated into particulate nitrogen and dissolved inorganic nitrogen ($\text{DIN} = \text{NO}_x + \text{NH}_4$).

Inorganic nitrogen can be generated in several ways. It can be directly excreted by the oysters (NH_4) from the digestion of particulate organic nitrogen (phytoplankton) to the surrounding water, or it can be formed from the decomposition of particulate matter some of which is released and some of which is oxidized to nitrate prior to entering the water column. As in 2013, examination of the 2014 data for ammonium and nitrate+nitrite (NO_x) shows that there is no clear increase in either inorganic nitrogen species from up-gradient to within the oyster deployment area in the bottom water, however, both ammonium and NO_x are elevated in the surface water compared to 2013. Moreover, in both 2013 and 2014 the NO_x and NH_4 concentrations trend downwards in the surface water through the oyster rafts with $\text{LP-1.2} > \text{LP-1.3} > \text{LP-1.2}$ (Figure 19 and Figure 20). However, the key finding is that the both inorganic nitrogen species are higher in the surface water in 2014 than 2013. It appears that this may be related to the greater inorganic nitrogen uptake in 2013 from the higher phytoplankton biomass at these sites compared to 2014. This is consistent with nitrogen being the nutrient to manage to control plant growth. It is possible that the greater biomass in 2013 resulted from better mixing of waters and more light penetration in 2013. Unfortunately, it appears that the relatively

low levels of inorganic nitrogen in 2013 and in bottom waters in 2014 and the rapid uptake by phytoplankton (once released to the water column) obscure any clear pattern associated with the oysters. It should be noted that the noticeable difference between 2013 and 2014 is that DIN in the surfacewater is higher and PON is higher in the bottom water in 2014 compared to the surfacewater. However, in both years PON levels decline from up-gradient (LP-1.2) to the oyster area (LP-1.3) in the surfacewater almost certainly due to removal by the oysters (Figure 20), consistent with the observations of chlorophyll-*a* and particulate carbon discussed above, both of which were lower in the surfacewater compared to the bottom water.

Particulate nitrogen once removed by oysters can be consumed and digested with incorporation into tissue or excreted as waste, this represents a small fraction of what the oysters collect with the result that a substantial amount of pseudo-feces are generated. These pseudo-feces once released can be transported in tidal waters as additional particulates (TSS) or reach the pond sediments where the nitrogen is remineralized and either released to the water column as inorganic nitrogen and consumed in part or fully by phytoplankton and bacteria or be denitrified (coupled nitrification-denitrification). The quantification of the nutrient fluxes from the sediments and how they are affected by the oyster rafts was undertaken in the 2014 year 2 monitoring and is discussed in detail below in Section VI. The process of coupled nitrification-denitrification is routinely measured by the Coastal Systems Program at SMAST and is the predominant denitrification pathway in shallow estuarine sediments, like those in Little Pond.

One concern related to potential negative effects of the oysters on the pond system stems from the above mentioned potential increase in deposition of particles to the sediments. This would result from a strong localized change in organic matter deposition and one result might be low oxygen. While in 2013 Little Pond experienced hypoxia, this phenomenon occurred both prior to, and after the deployment of the oysters. Further, hypoxia was not focused within the deployment area. It is possible that oxygen conditions improved in both surface and bottom waters on the ebbing tide as the water passed through the oyster deployment site. Improved oxygen condition in the Demonstration Site paralleled the decline in particulate organic matter. While there are a myriad of potential causes for this pattern in oxygen level, it is clear that in 2013 during the year 1 oyster deployment, the oysters were not resulting in a depletion of oxygen in the surface or bottom waters. This was further supported by the historical oxygen measurements by the MEP and PondWatch which indicated the existence of periodic summertime hypoxia in Little Pond for over two decades.

To confirm that the larger 2014 oyster deployment (1.5 million vs. 1.25 million in 2013) did not have a negative effect on oxygen dynamics in the immediate vicinity of the rafts, additional dissolved oxygen mooring deployments were undertaken to confirm the results of the 2013 oxygen monitoring as described in detail in Section IV.2. Additionally, dissolved oxygen measurements were taken during the ebb tide water quality sample collection. These DO measurements indicate only periodic hypoxia (2 mg/L), but oxygen depletion appears to be part of the pond-wide oxygen gradient and not driven by the oysters (LP-1.2, LP-1.3, LP-2) as depicted in Figures 21 and 22. The pond-wide oxygen depression appears to result from eutrophication of pondwaters, and is not localized in the oyster deployment area nor is there a low oxygen zone associated with the deployment area. Equally important, oxygen depletion was greater in the up-gradient sites, not associated with the oysters, which is consistent with other studies.

Conclusions (2014):

As in 2013, the 2014 water quality monitoring results clearly document that the deployment of oysters in Little Pond did produce modest water quality improvements near-field to the deployment area, without concomitant negative impacts on dissolved oxygen. The primary mechanism of this water quality improvement appears to be the uptake of phytoplankton by the oysters.

Lines of evidence from nutrient data (TN, PON, POC), chlorophyll-a, fluorescence and turbidity analyses (detailed below in Section IV below) indicate that the oysters are removing particles from the surface layer of Little Pond, with the effect clearly discernible in the near-field region (LP-1.2, LP-1.3, LP-2, LP-2.1A). It is likely that tidal action, dilution and other biologic processes tend to predominate in other areas. DIN (ammonia and NOx) was significantly higher in 2014 compared to 2013 in the surface water, however, the concentrations of each nitrogen species (DIN, NOX, NH4) trended downwards across the oyster deployment area.

While there were initial theoretical questions regarding the potential for oyster aquaculture to negatively impact oxygen dynamics, data from 2014, 2013 and 2012, as well as the 2006 Little Pond MEP Report and earlier data, documents that hypoxia is a condition in Little Pond preceding the oyster deployment by decades. Moreover, the oysters were effectively separated from the bottom water by the moderate stratification in 2013 and more significant stratification in 2014. The pattern of bottom water oxygen suggested that the oysters may have had a positive effect (if any) on oxygen conditions and this is particularly clear in the 2014 DO record (Figure III.2-8). Based on the 2014 water quality monitoring, the oyster deployment was not found to have any negative ecological impacts on the estuarine habitats within the Little Pond System.

The 2013 oyster deployment consisted of 1.25 million oysters. In 2014, the deployment of an additional 0.25 million oysters, for a total of 1.5 million oysters, appears to have resulted in stronger trends being observed in the associated monitoring data, particularly with respects to total nitrogen and dissolved inorganic nitrogen.

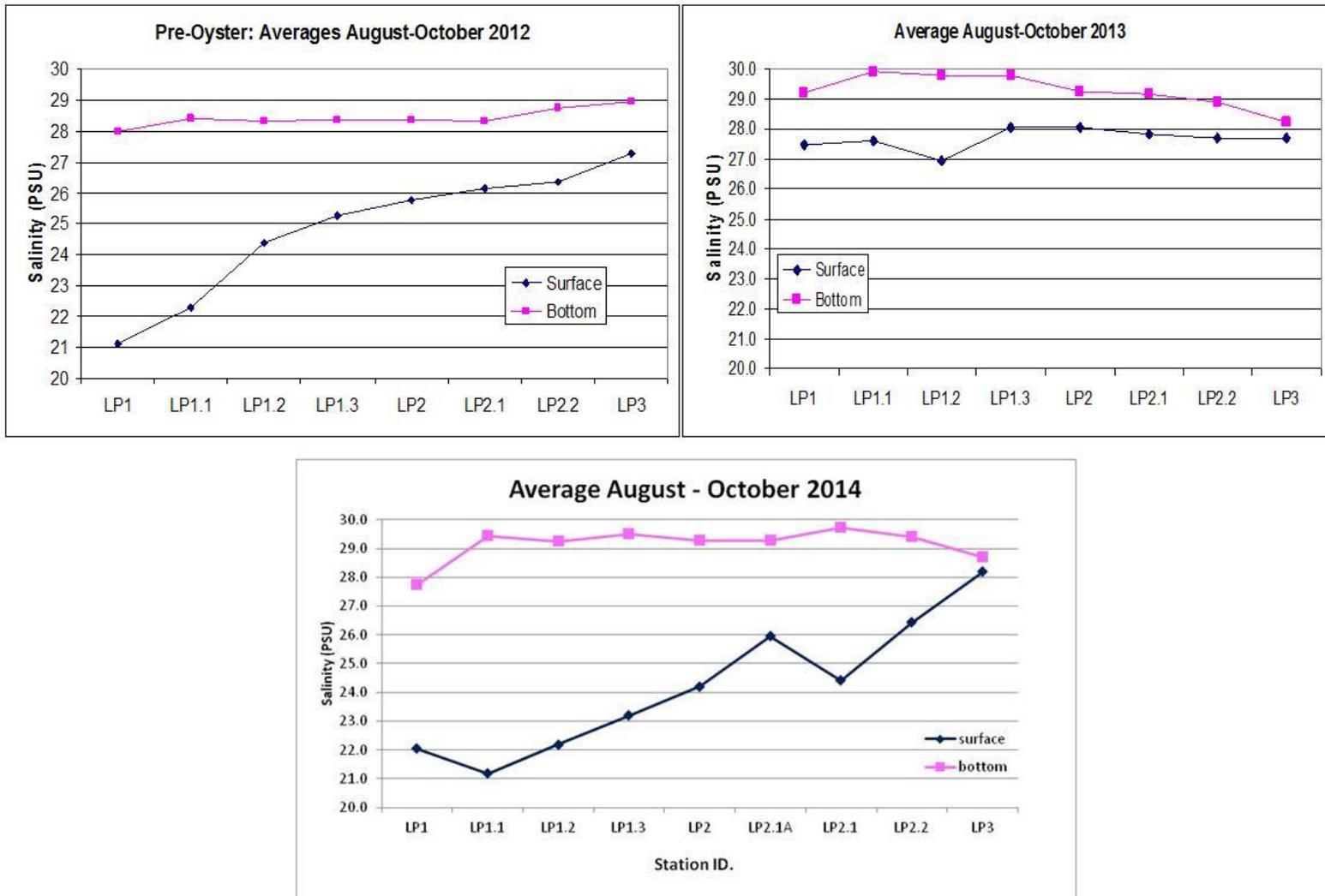


Figure 15 Water column salinity averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA. Water was collected near surface (0.15 m depth) and near bottom (0.3 m above). Top left 2012 (no oysters), Top right 2013 (oysters) and Btm, 2014 (oysters). The water column was moderately stratified in all years.

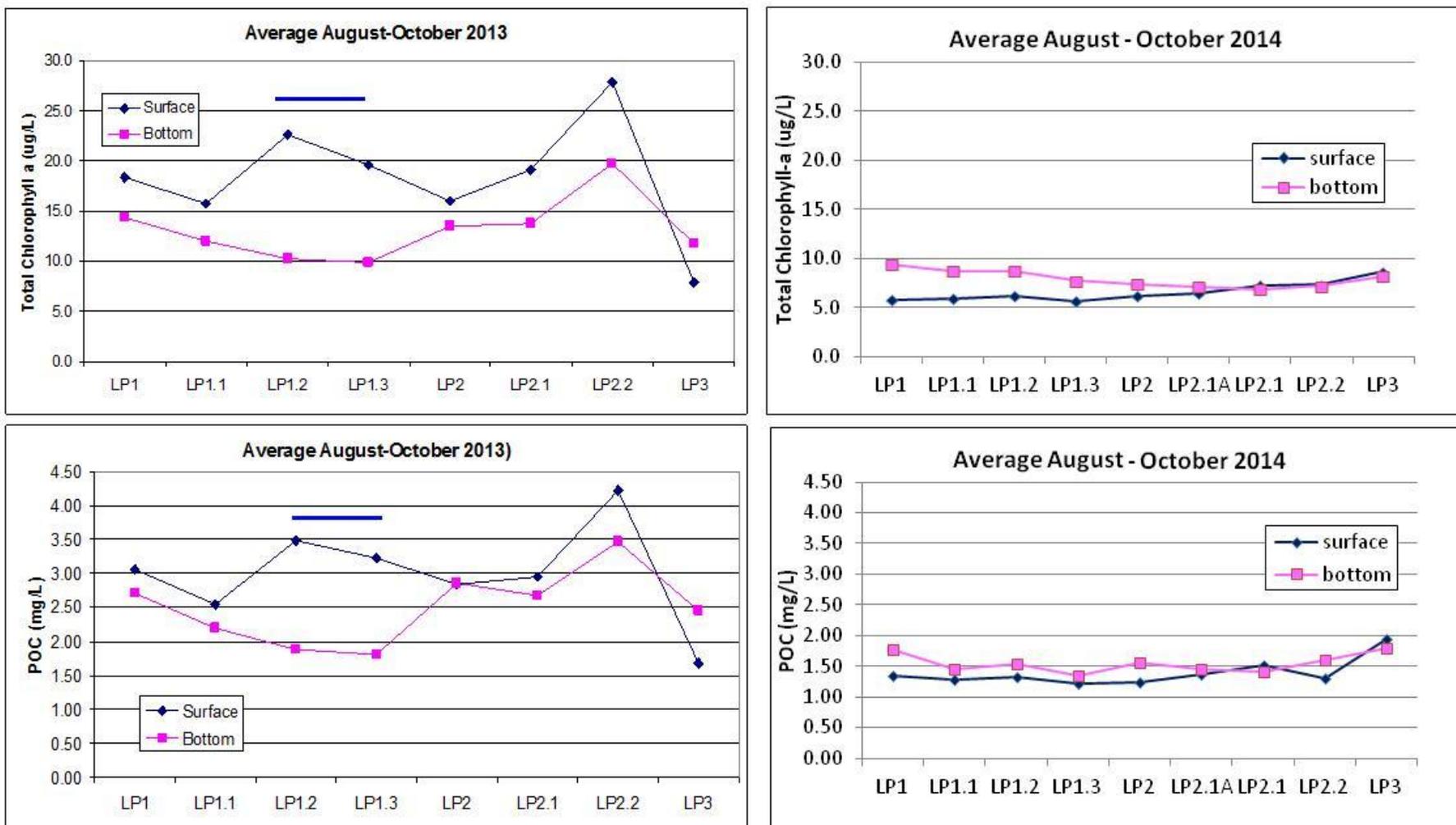


Figure 16 Water column phytoplankton biomass metric averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2013 (left panels) and August through mid October, 2014 (right panels). (Top) Total Chlorophyll-a and (Btm) Particulate Organic Carbon. Both parameters relate to both filtration and fecal production by oysters. Bar shows most likely area of “oyster effect”.

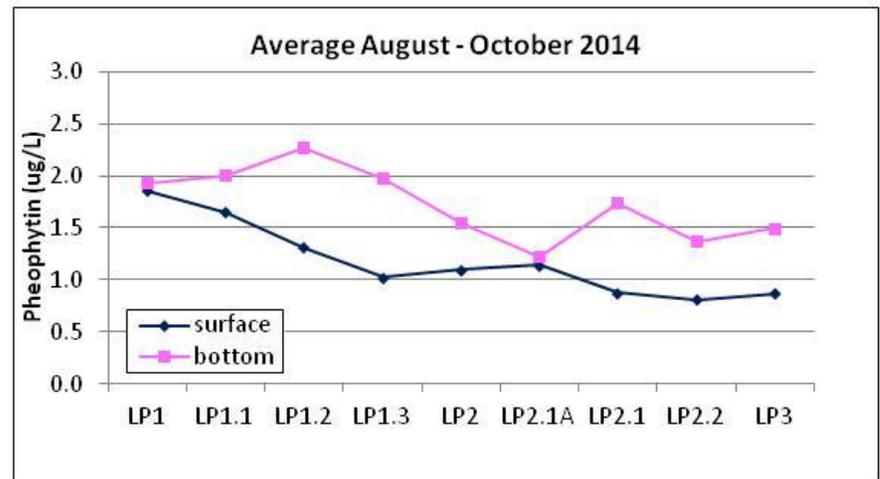
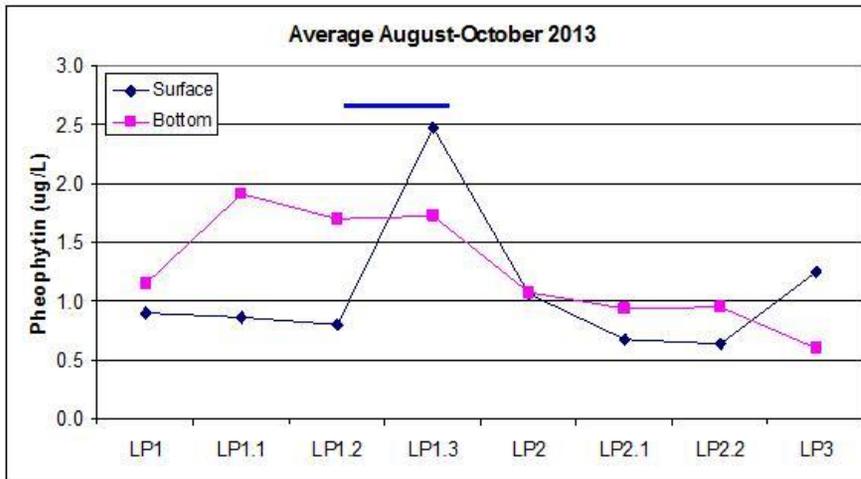
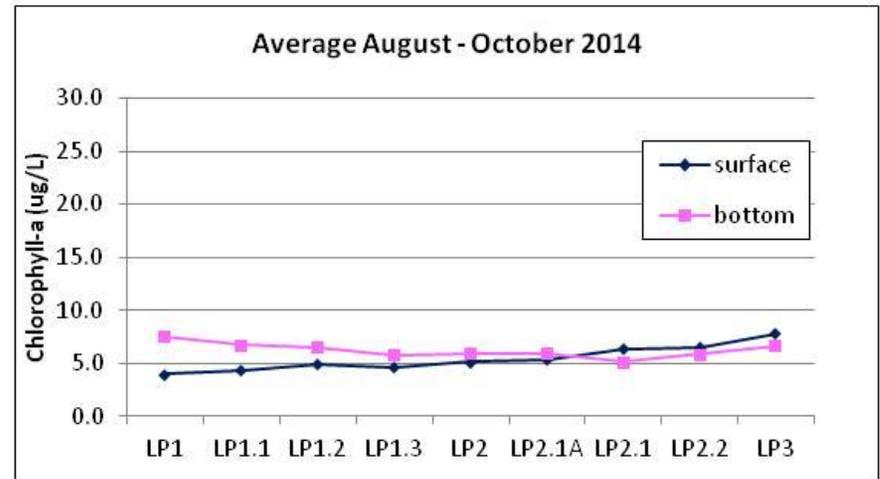
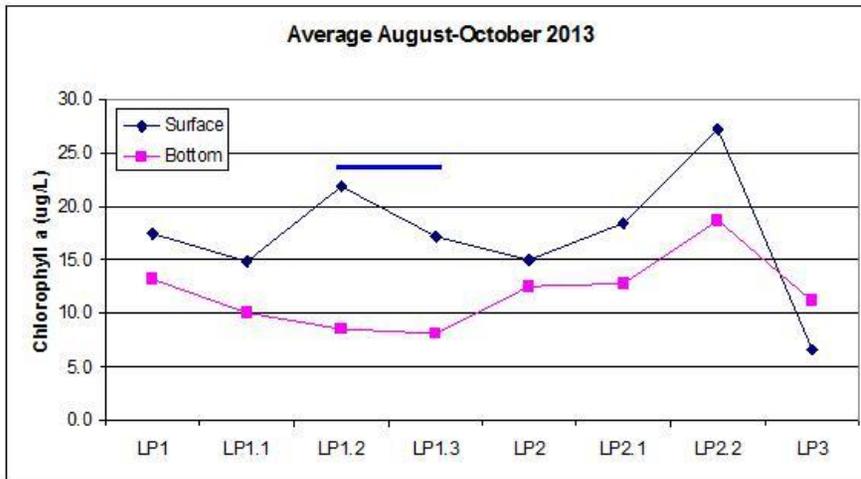


Figure 17 Water column phytoplankton pigment averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2013 (left panels) and August through mid October, 2014 (right panels). (Top) active Chlorophyll-a and (Btm) initial degradation product of Chlorophyll-a, generally associated with phytoplankton senescence or invertebrate grazing/feeding. Shifts from Chlorophyll-a to Pheophytin-a can be used as an indicator of oyster feeding.

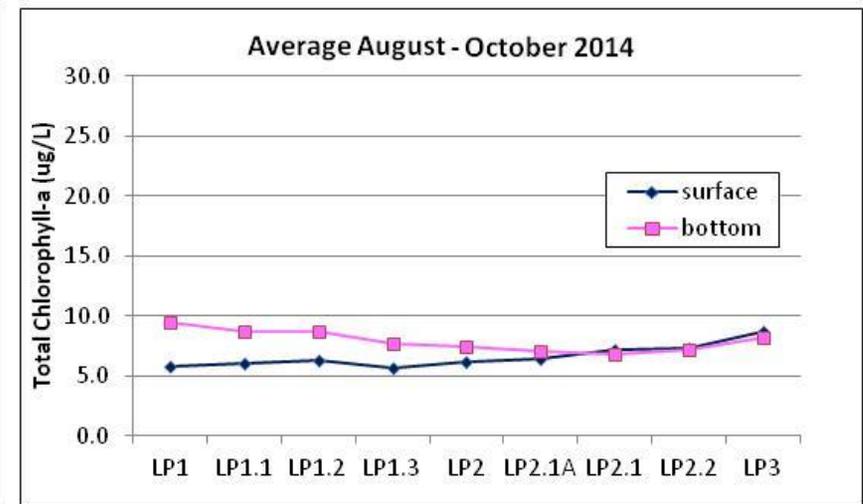
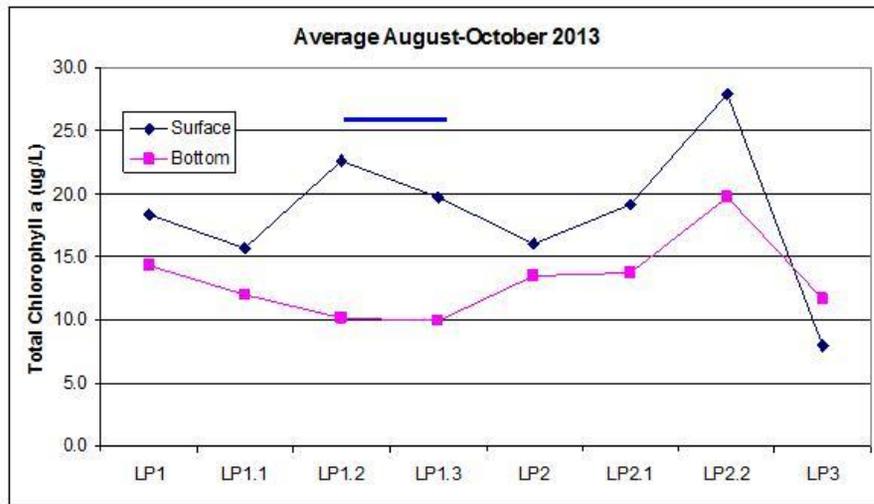
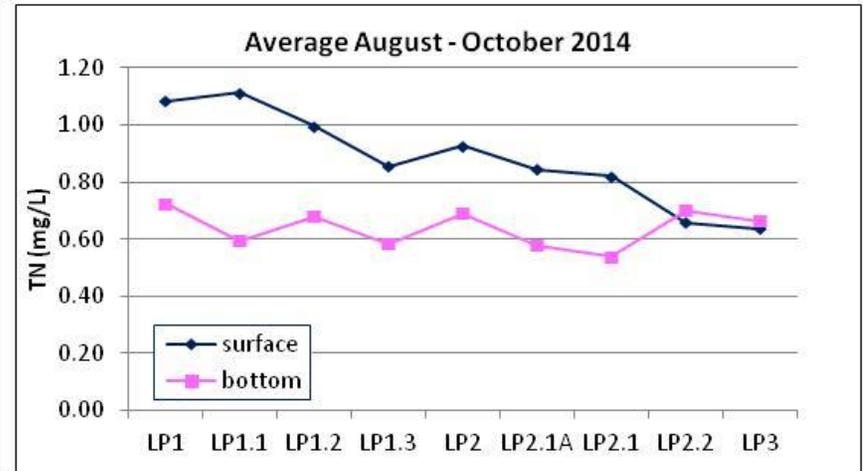
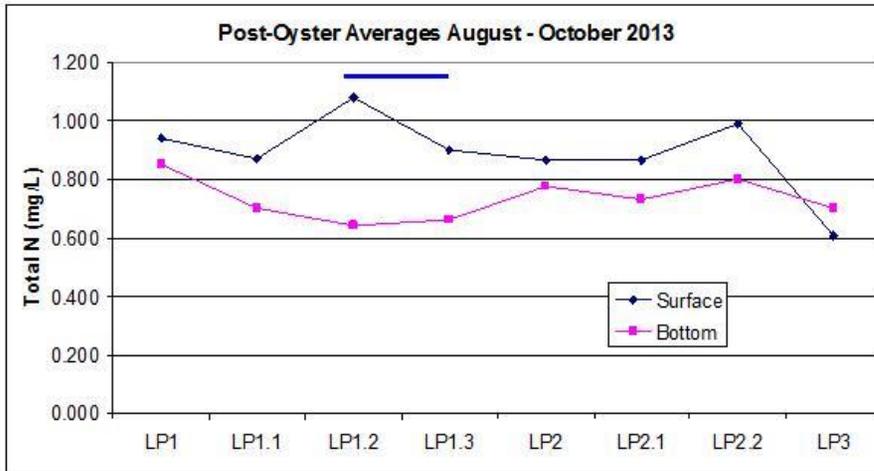


Figure 18 (Top) water column total nitrogen and (Bottom) phytoplankton biomass (total chlorophyll-a pigment) averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2013 (Left panels) and August through mid October, 2014 (Right panels).

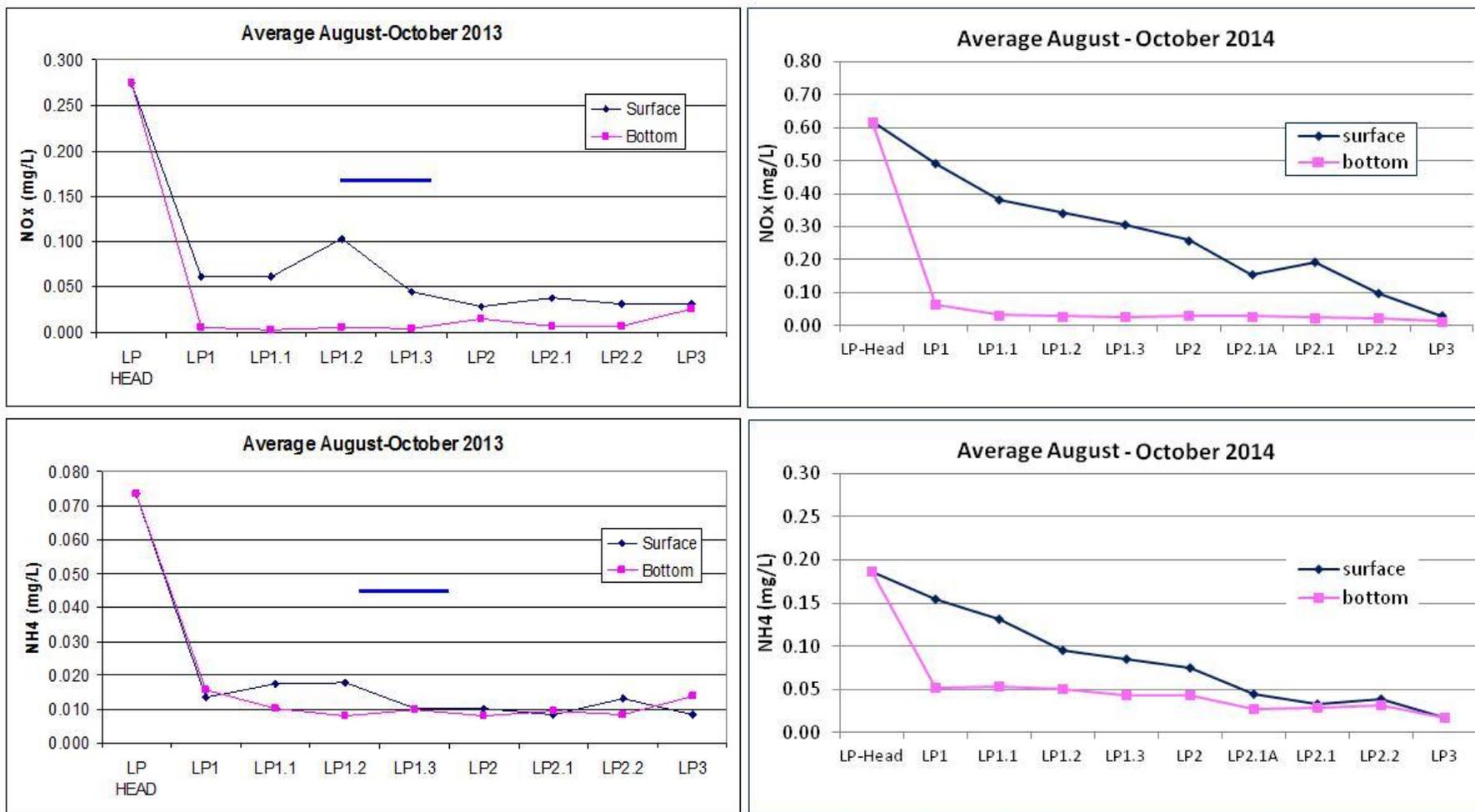


Figure 19 Water column inorganic nitrogen averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through mid October, 2013 (Left panels) and August through late October, 2014 (Right panels). (Top) water column nitrate+nitrite and (Bottom) ammonium. Bar represents region of maximum change.

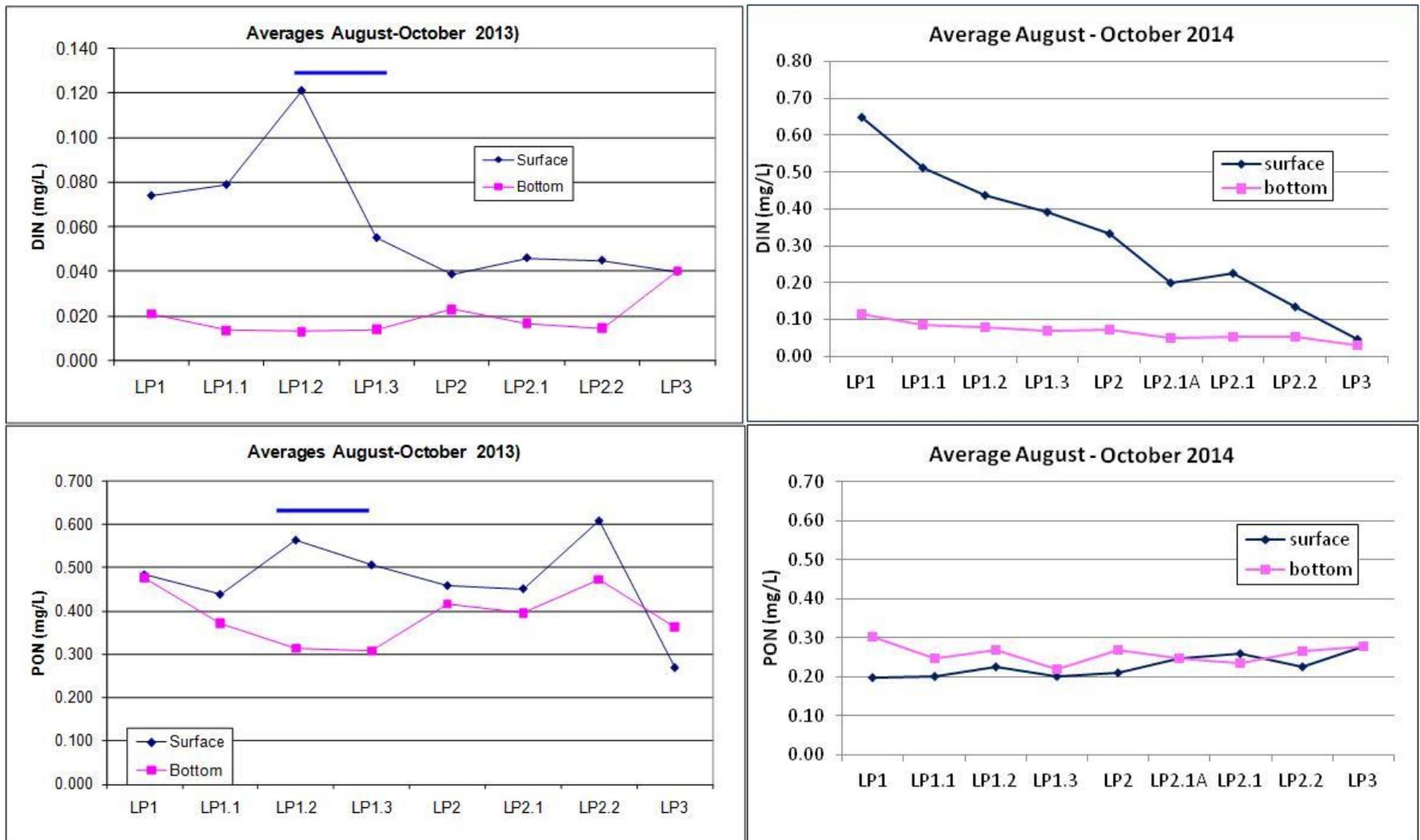


Figure 20 Water column bioactive nitrogen averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2013 (Left panels) and August through mid October 2014 (Right panels). (Top) water column dissolved inorganic nitrogen (ammonium+nitrate +nitrite) and (Bottom) particulate organic nitrogen primarily associated with phytoplankton cells living and dead. Bar represents region of maximum change.

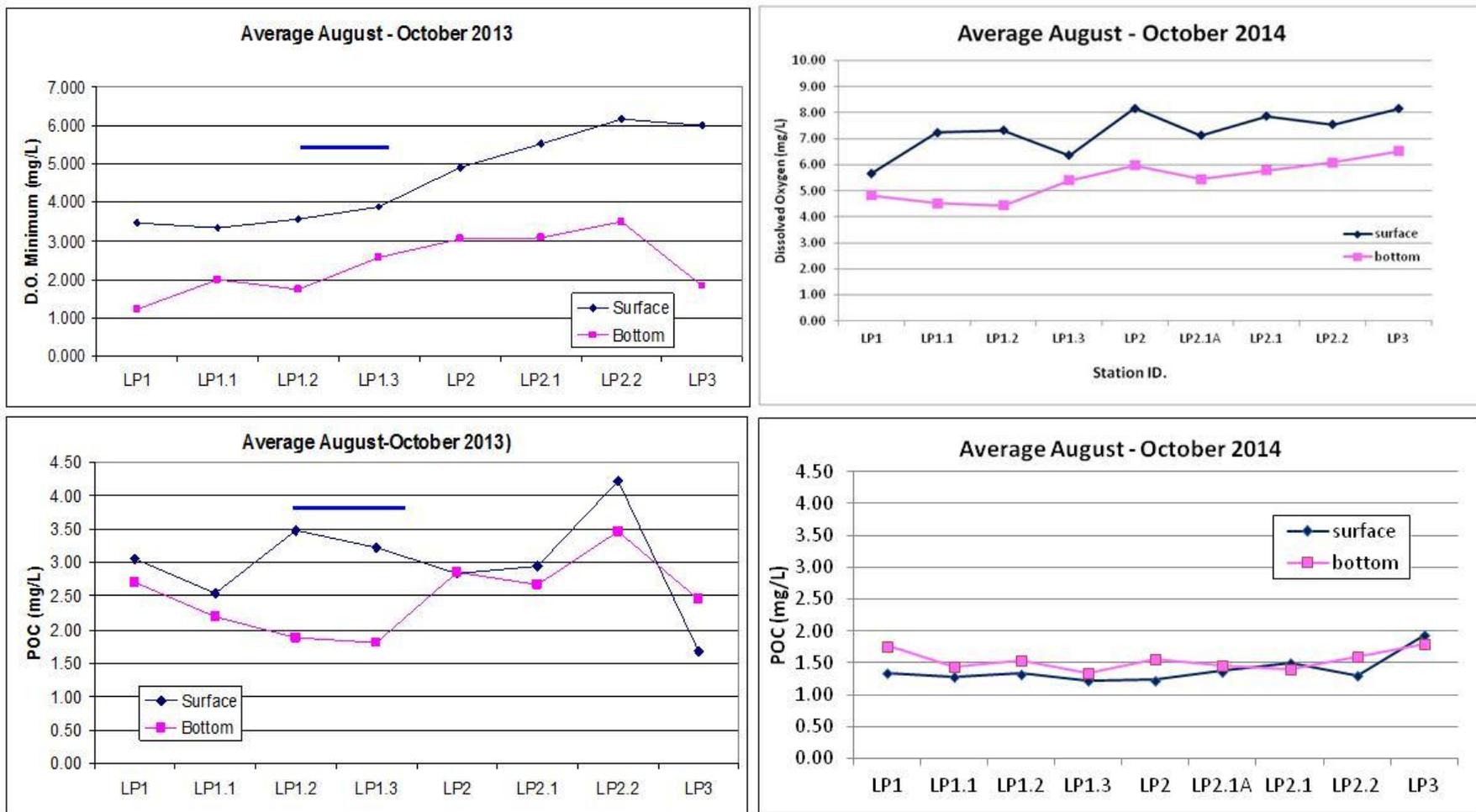


Figure 21 (Top) Bottom water oxygen minimum measured during the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from July 31 (nominally August) through late October, 2013 (Left panels) and August through mid October 2014 (Right panels). (Bottom) particulate organic carbon concentration presented as an indicator of potential oxygen uptake (as substrate or as phytoplankton. Bar indicates region of maximum change.

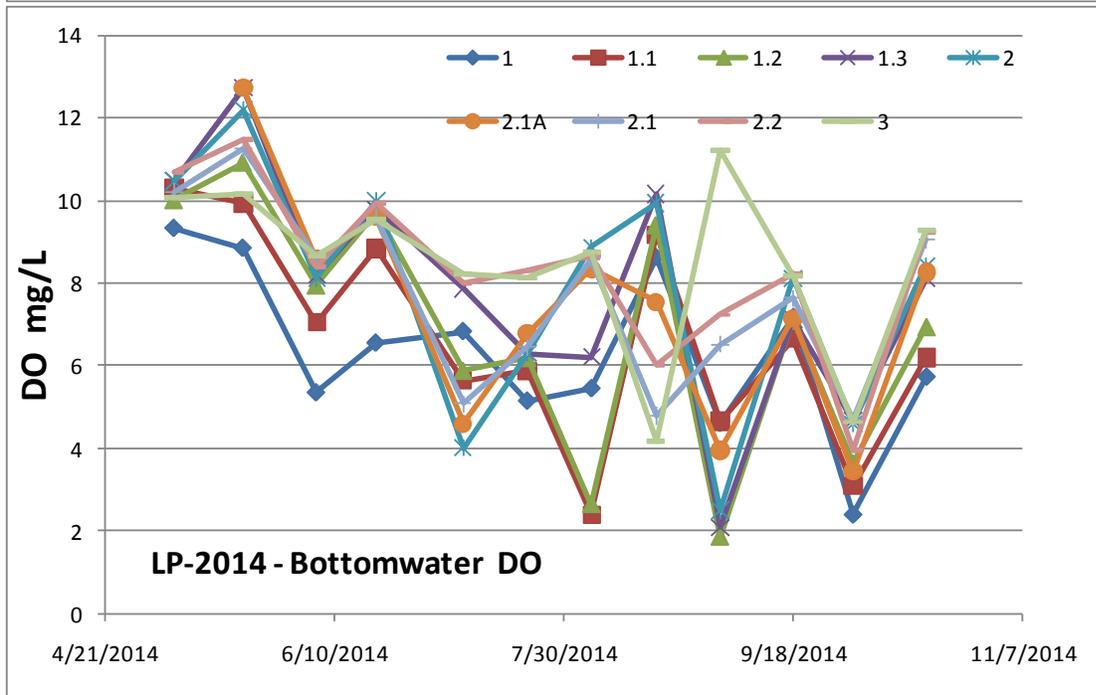
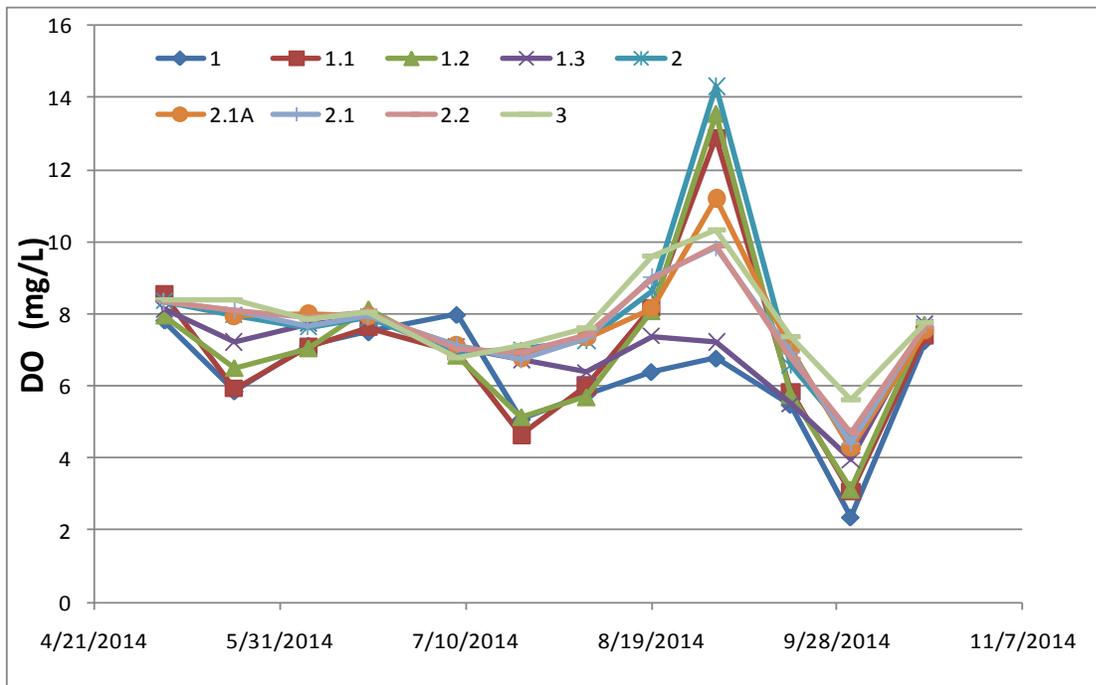


Figure 22. Surface and bottom water dissolved oxygen during mid-ebb tide from May thru October 2014. It appears that low oxygen events are initiated in the upper pond (LP-1, LP-1.1, LP-1.2) above the oyster culture area, consistent with pond-wide eutrophication rather than spatially dependent on system and oyster oxygen uptake. Both the surface and bottomwater oxygen levels show a similar pattern to long-term monitoring by PondWatch.

Results from Year 3 (2015) Sampling: As in 2013 and 2014, the major question to be addressed by the sampling program continued to be the degree to which the oysters deployed in Little Pond would make a discernible change in the water column nitrogen related constituents. Similar to 2014, since oysters were introduced to the surface waters of the pond in July and intended removal in late October, that was the primary period for evaluation. However, an additional level of analysis was conducted and is included in Appendix A where the nutrient data over the summer period was divided into two different time periods based upon the removal of the oysters at the end of August (8/25/15) due to a significant low oxygen event. Water quality data was averaged for the period late July to late August when the oysters were present in Little Pond as well as for the period September through October when the oysters were no longer present in Little Pond. For consistency, the initial analytical approach involves comparing the gradients in water quality parameters both during the 2015 oyster deployment and during the same period in 2014 to determine if the oyster deployment had a consistent effect on water quality during both summer seasons.

Water-column Stratification of Little Pond:

In 2013, 2014 and 2015, the Little Pond water column ranged from weak to moderate water column stratification⁵, due to salinity (Figure 23). However, stratification in 2015 was more similar to conditions in 2013 making the 2014 stratification the more severe of the four years (2012, 2013, 2014, 2015). Stratification of an estuarine water column is most commonly the result of salinity differences from the surface to the bottom waters, as opposed to temperature. This salinity difference results from fresh waters entering from the watershed and not mixing vertically throughout the water column, rather they differentially freshen the surface water, and marine waters entering from the tidal inlet differentially increasing the salinity of bottom waters. A secondary factor in the density difference is the occurrence of colder bottom waters overlain by warmer surface waters. The salinity difference is clear in all years (2012-2015), although the salinity gradient was much larger in 2012 and 2014 (~6 PSU) than 2013 (~1-2 PSU) and 2015 (~2-5 PSU) (Figure 23). As in previous summers, the salinity differences show stratification at all stations, but diminishing from the headwaters towards the tidal inlet, due to wind and tidal mixing. Although it is difficult to quantify, it appears that stratification focused the effects of the oysters on the surface layer relative to the extent of each years salinity difference, since the oysters were deployed in floating bags at the pond surface. From the water quality sampling it is clear that the surface and bottom layers of the pond water column are not tightly coupled through the warmest months of the study when the oysters were having their greatest effect (see below).

Chlorophyll, Particulate Organic Carbon (POC) and Fluorescence Data Analysis:

Particulate Organic Carbon and Total Pigment Data

The 2015 field season had a watercolumn only weakly stratified such that the focusing of the effect in the surface layer was not as pronounced as in 2013 or 2014. During the May-July period, prior to the oyster deployment or when the spat were very small, there was no discernible effect on water column particulate concentrations, particularly POC and Total Pigment. Concentrations were constant in and around the deployment area. During the later season there was a more heterogeneous concentration field, with a tendency for increased plankton biomass downgradient of the oyster area (Figure 24, Total Chlorophyll a pigment) likely due to the input of inorganic nitrogen from grazing. The bulk concentrations did not show the typical depression in particulate levels within the oyster area possibly due to the greater vertical

⁵ Well mixed conditions show similar salinity and temperature at surface and bottom, while weak stratification shows higher salinity (1-2 PSU) and moderate (2-4 PSU) at bottom than surface.

mixing in 2015 which diluted the signal compared to prior years. However, there still was a slight decline in POC from LP 1.2 to 1.3 to 2 particularly in the bottom water (Figure 24). This may also have resulted from the slightly different distribution of the oysters in 2015 compared to previous years. It is also likely that the “oyster” signal was obscured due to how the data was averaged to be consistent with the 2014 analysis, i.e. averaging used the same time window, even though the oysters were active only until the end of August. The effect was that the “oyster effect” was diluted by the data from the latter end of the summer (September – October). The alternate averaging analysis is presented in Appendix A and the third table below presents the POC and Total Pigment (CHLA+Pheophytin) data based on sample averages for when the oysters were in the pond (late July to late August) and after they had been moved out of Little Pond (September-October).

Even with the concentration on the July-August period the small size of these early season oysters obscured determination of a strong oyster effect (see tables below, Appendix A). It appears that larger oysters later in the season are the major driver of the 2013 and 2014 oyster effect. This size dependence effect is due to the much greater filtration rates in the larger oysters, as has been discussed previously. The management result of this size effect is that use of oysters for water quality improvements must ensure a population of large oysters for the July-September time period, which can be best achieved by maintaining a mixed age class population and harvesting in the fall (October-November). This need to maintain a large capacity filtering community adds an additional layer to managing oyster operations for water quality.

Station	Sample Depth	2014	POC (mg/L)	Total Pig. (ug/L)	Station	Sample Depth	2015	POC (mg/L)	Total Pig. (ug/L)
LP1.2	S	May-July	0.889	3.7	LP1.2	S	May-July	1.136	5.4
LP1.3	S	May-July	0.821	3.7	LP1.3	S	May-July	1.034	5.7
LP1.2	B	May-July	0.995	4.6	LP1.2	B	May-July	1.054	5.8
LP1.3	B	May-July	1.011	4.3	LP1.3	B	May-July	1.078	7.1
LP1.2	S	Aug-Oct	1.333	6.2	LP1.2	S	Aug-Oct	1.335	9.5
LP1.3	S	Aug-Oct	1.217	5.6	LP1.3	S	Aug-Oct	1.383	11.0
LP1.2	B	Aug-Oct	1.534	8.8	LP1.2	B	Aug-Oct	1.186	7.2
LP1.3	B	Aug-Oct	1.343	7.7	LP1.3	B	Aug-Oct	1.148	6.3

Station	Sample Depth	2015	POC (mg/L)	Total Chla (ug/L)
LP1.2	S	July-Aug	1.542	12.2
LP1.3	S	July-Aug	1.499	12.3
LP1.2	B	July-Aug	1.140	6.4
LP1.3	B	July-Aug	1.220	6.3
LP1.2	S	Sept-Oct	1.140	7.8
LP1.3	S	Sept-Oct	1.254	9.5
LP1.2	B	Sept-Oct	1.083	7.4
LP1.3	B	Sept-Oct	0.933	6.3

Chlorophyll-a and Pheophytin-a Data

As noted above total pigment showed a peak just down gradient of the oyster area, possibly due to nutrient release from oyster feeding activities. The peak was in the surface layer when there was sufficient light penetration to support phytoplankton growth. The same effect was not seen in the bottom layer or in the 2014 results under stronger stratification. However, the pheophytin a gradient in both 2014 and 2015 was similar showing a decline through the oyster area, except that under stronger stratification (2014) the effect was confined to the surface layer and under the weak stratification in 2015 the effect was seen in both surface and bottom waters. This decline in pheophytin a through the oyster deployment area appears to result from the packaging and deposition of filtered phytoplankton by the oysters, effectively removing the grazed phytoplankton from the watercolumn. The increase in chlorophyll a would then result from phytoplankton growth in this region of the Pond. This is consistent with the Total Pigment and POC results as well.

Dissolved Oxygen Data

As seen in previous years oxygen depression is not evident associated with the oyster deployment. This was a potential concern due to the deposition of organic rich materials as a result of oyster filtering and excretion. In contrast, it appears generally that there is a small increase each year in the oxygen field within and down gradient of the oyster rafts. This is seen in both the upper and lower layer in both 2014 and 2015 (Figure 29). The mechanism is currently being investigated, but may result from turbulence in the oyster deployment area causing surface aeration, the removal of oxygen consuming organic matter from the water column or the stimulation of phytoplankton growth and oxygen production. Whatever the cause the key finding is that the oyster deployment is not causing a localized oxygen depletion, which is consistent with the infaunal habitat findings, below.

Nutrient Data:

There was generally a declining gradient in TN and its constituents (DIN, PON) moving from above to below the oyster deployment area in the surface waters. The bottom waters also showed a slight decline apparently related to oyster activities in bottom waters, but it was small. It should be noted that the smaller signal is potentially the result of how the data was averaged. Data was re-evaluated based on samples for the period when there were oysters present in Little Pond as well as for the period when oysters were no longer present in Little Pond. Based on the modified averaging approach (refer to Appendix A), the effect of the oysters is more apparent. The general decline is part of the overall decrease in nutrient levels moving from the Little Pond headwaters toward the tidal inlet. Most significantly was the slight drop in PON associated with the oyster area and down gradient, in both the surface and bottom waters. Although there is certainly some enhancement of inorganic nitrogen release in the region of the oyster deployment due to both direct (excretion) and indirect (increased sediment regeneration) oyster effects, there is little evidence of an increase in the DIN pool in this region. It appears that the increased DIN input is either rapidly diluted or is rapidly taken up by phytoplankton and therefore transformed to organic forms. Evidence for the latter mechanism can be seen in the increase in chlorophyll a in this region of enhanced DIN input due to the oysters.

Conclusions (2015):

Overall, the 2015 water column monitoring results were consistent with the prior 2 years except that the effect of the oysters on filtering particulates was not as pronounced (more likely due to how the data was averaged in the more generalized analysis). However, there was still clear evidence of PON removal from both surface and bottom waters, but a apparent stimulation of phytoplankton down gradient of the oyster racks possibly due to enhanced DIN release. Equally important, there was again no clear indication of any negative effect on the oxygen field associated with the oyster deployments, in fact a slight increase in oxygen levels is suggested in the immediate area and down gradient. The infaunal survey results (below) were consistent with the oxygen results and also did not show a negative response to the oyster growing operation. However, TN levels remain high in Little Pond and the small size oysters in the 2015 deployment (and prior deployments), while showing positive effects on key water quality metrics, is insufficient to result in a dramatic and large scale improvement. Use of oysters for water quality restoration will require many more oysters and a standing stock of sufficient size (filtration capacity). However, it does appear that suspended bags is a viable deployment approach for this purpose. Unfortunately, it appears that the level of TN enrichment in Little Pond will required multiple approaches to restore this estuary (tidal flushing, source reduction) in addition to oyster culture for estuarine restoration.

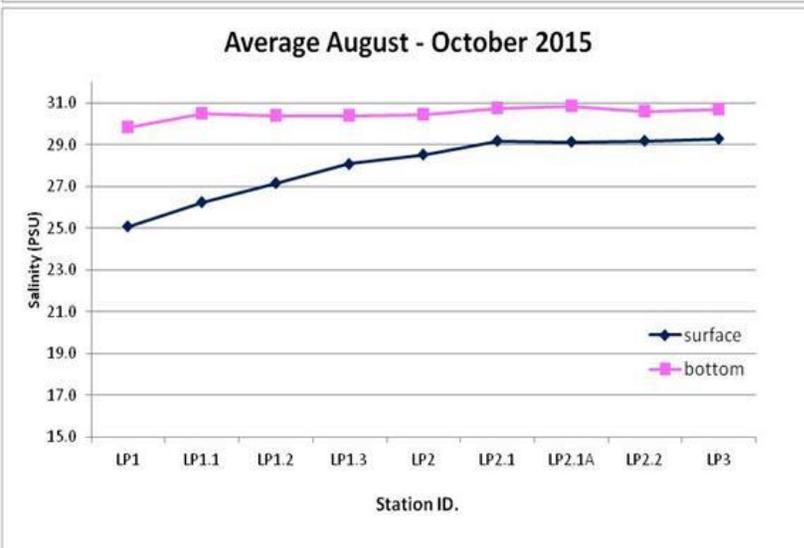
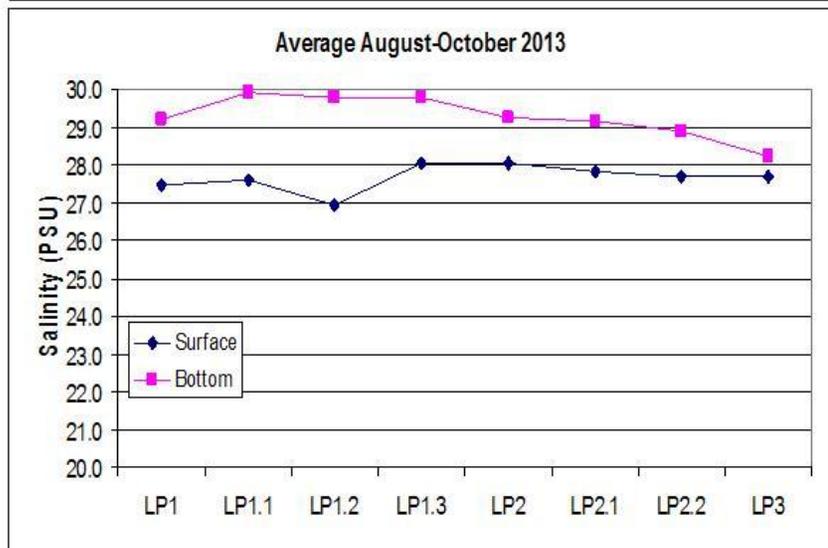
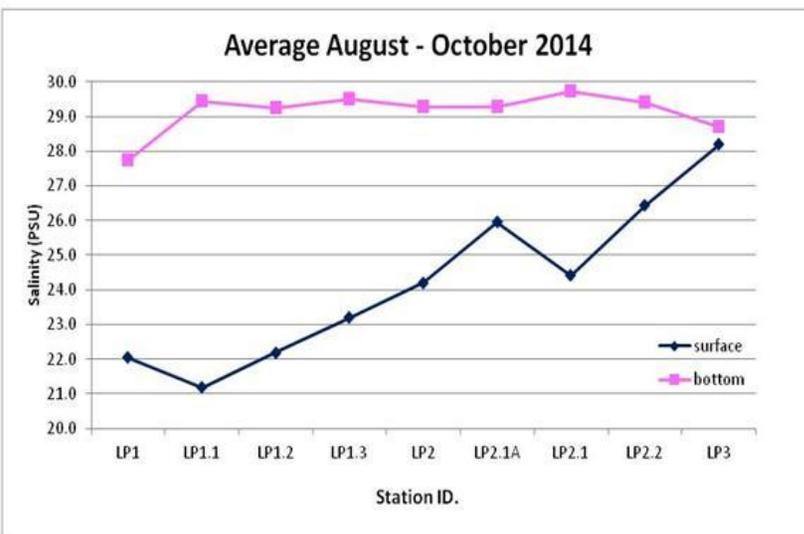
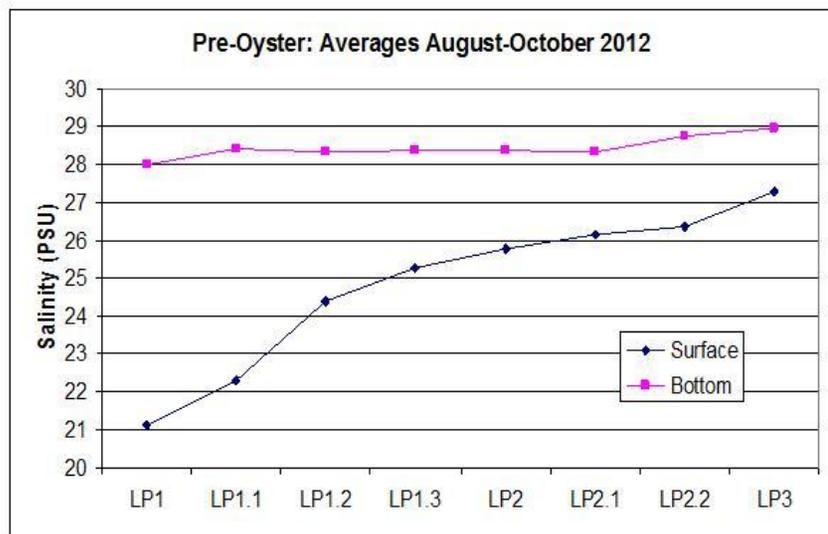


Figure 23 Water column salinity averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA. Water was collected near surface (0.15 m depth) and near bottom (0.3 m above). Top left 2012 (no oysters), Bottom left 2013 (oysters), Top right 2014 (oysters) and Bottom right, 2015 (oysters). The water column was moderately stratified in all years.

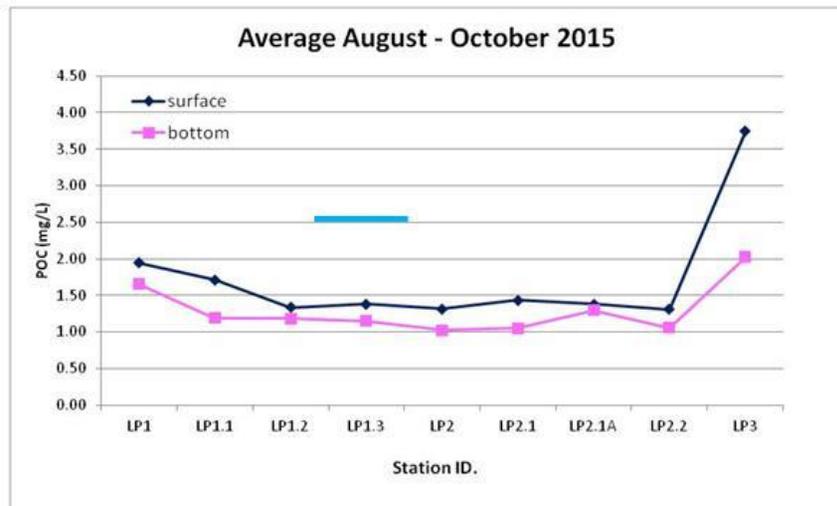
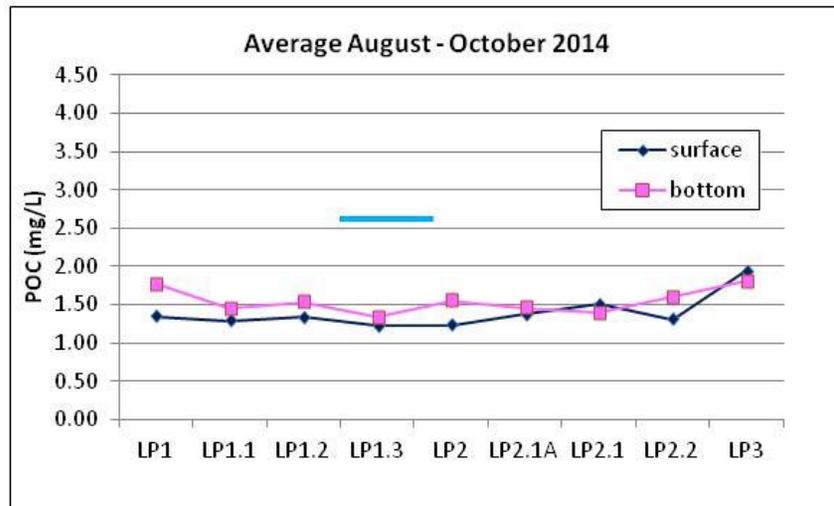
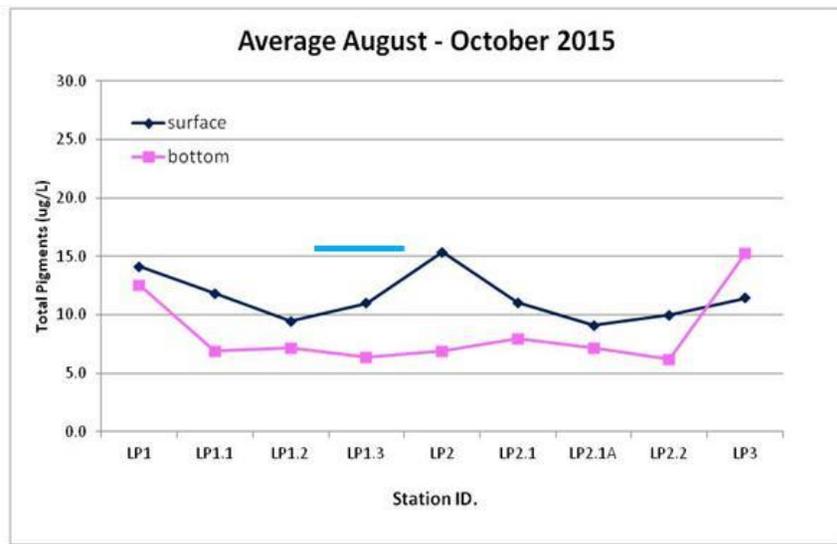
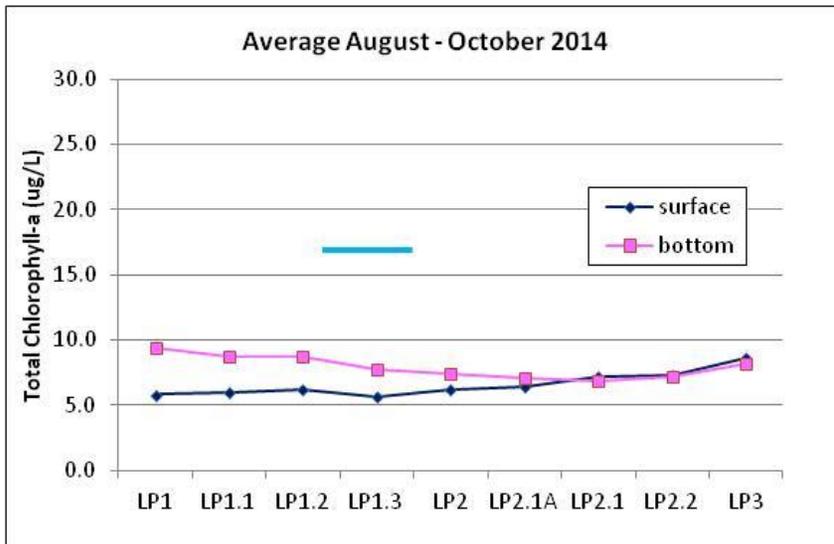


Figure 24 Water column phytoplankton biomass metric averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from August through mid October, 2014 (left panels) and August 7 through late October (10/28), 2015 (right panels). (top panels) Total Chlorophyll-a and (bottom panels) Particulate Organic Carbon. Both parameters relate to both filtration and fecal production by oysters. Blue bar shows most likely area of “oyster effect”.

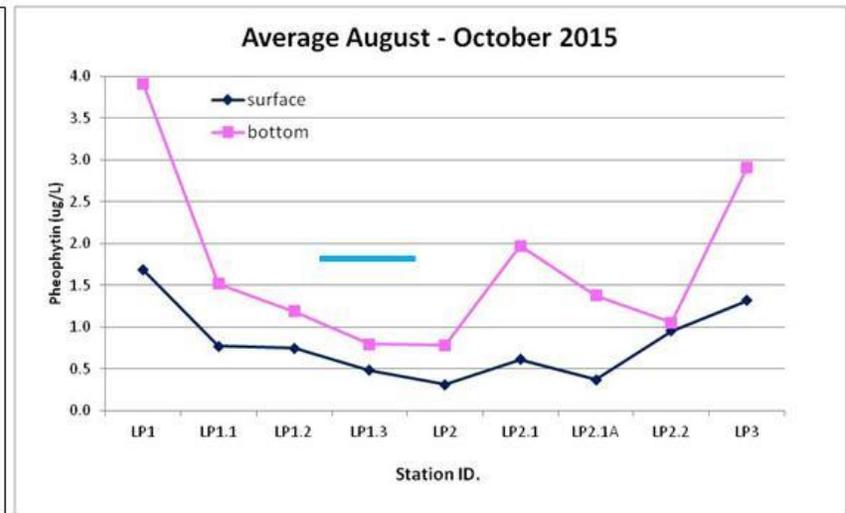
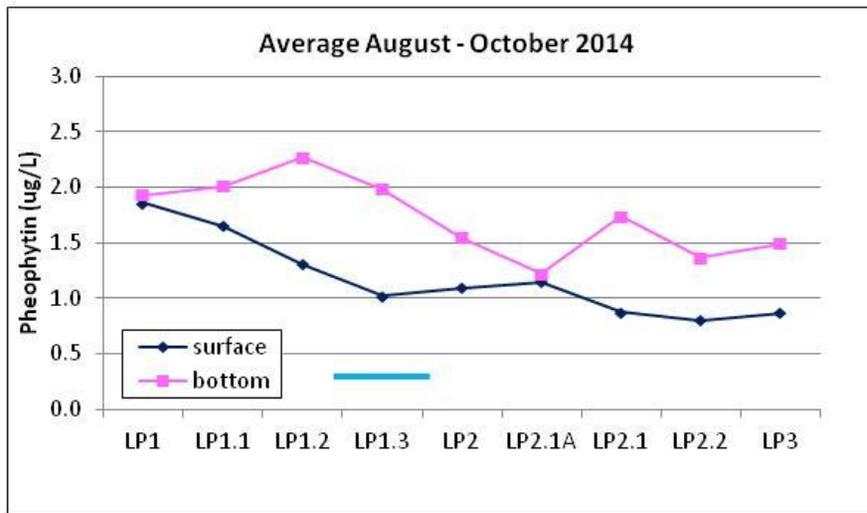
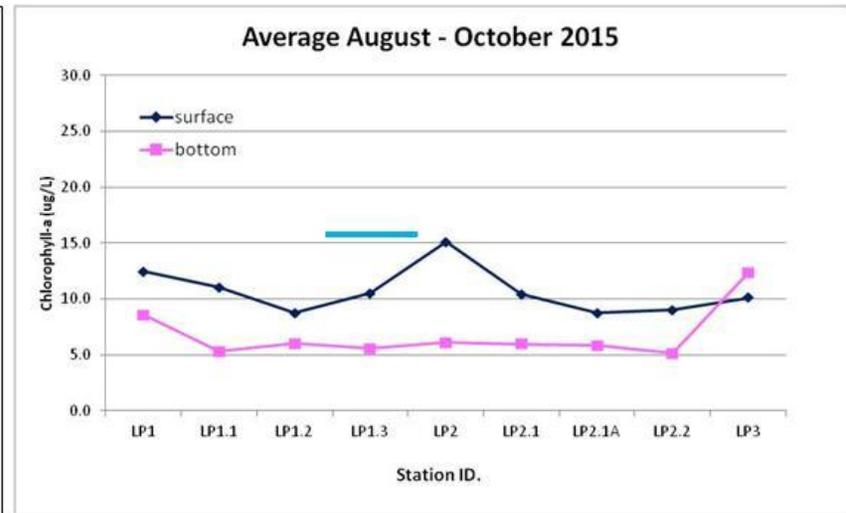
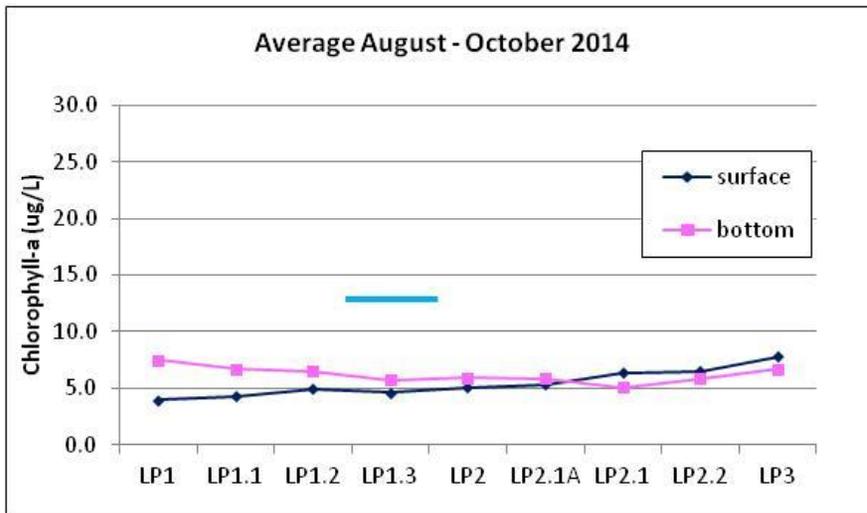


Figure 25 Water column phytoplankton pigment averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from August through mid October, 2014 (left panels) and August through late October, 2015 (right panels). (Top) active Chlorophyll-a and (Btm) initial degradation product of Chlorophyll-a, generally associated with phytoplankton senescence or invertebrate grazing/feeding. Shifts from Chlorophyll-a to Pheophytin-a can be used as an indicator of oyster feeding.

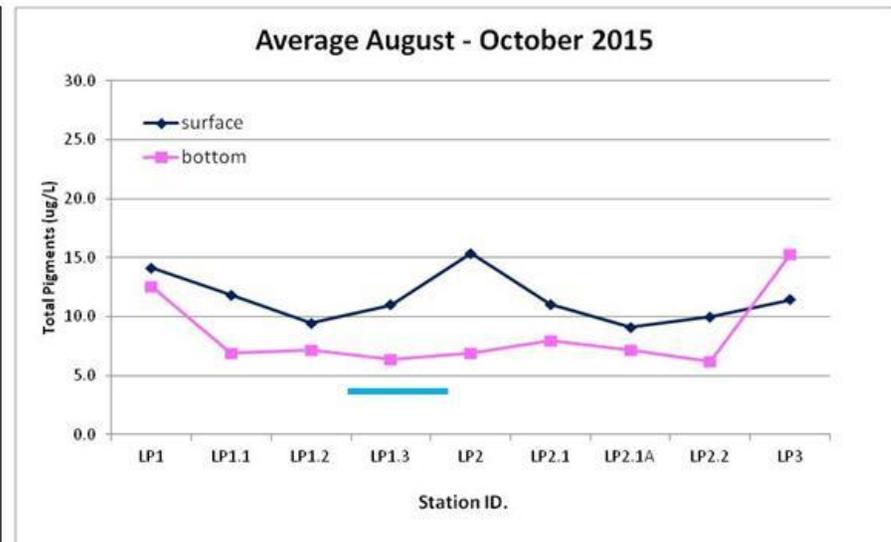
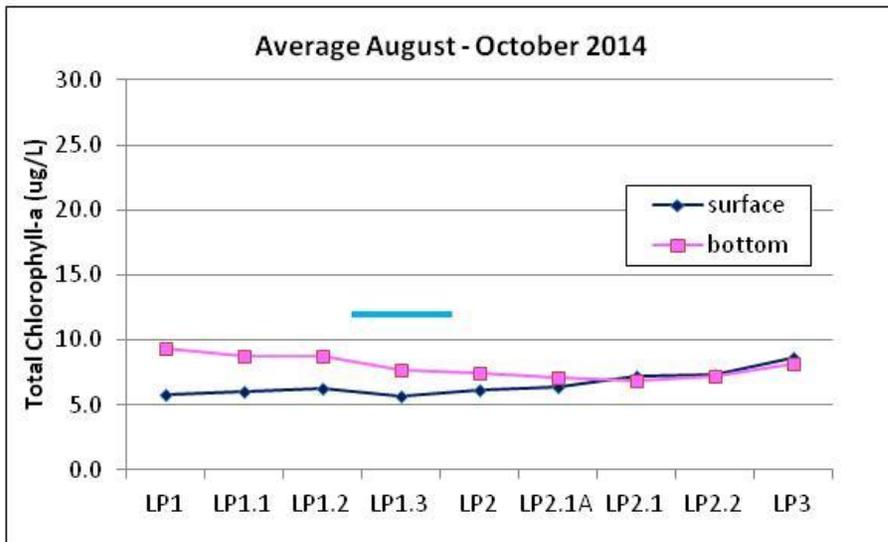
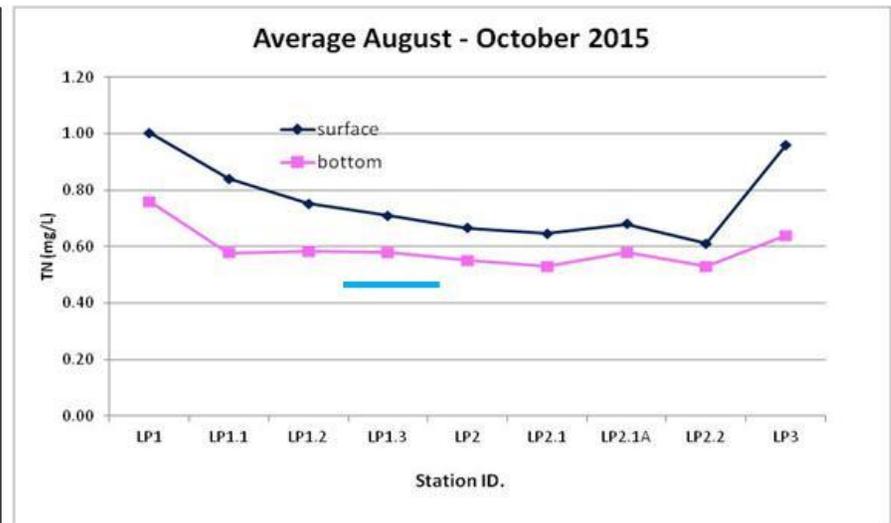
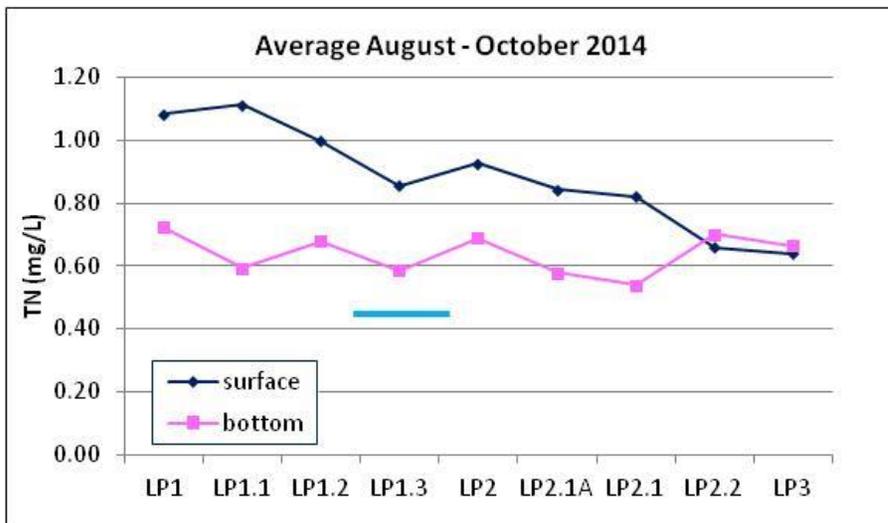


Figure 26 (Top) water column total nitrogen and (Bottom) phytoplankton biomass (total pigment, Chla+pheophytin) averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from August through mid October, 2014 (Left panels) and August through late October, 2015 (Right panels).

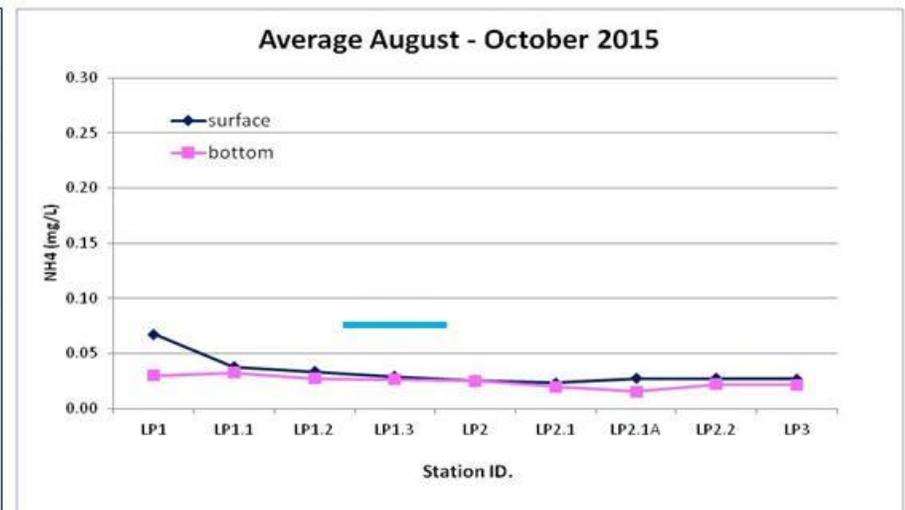
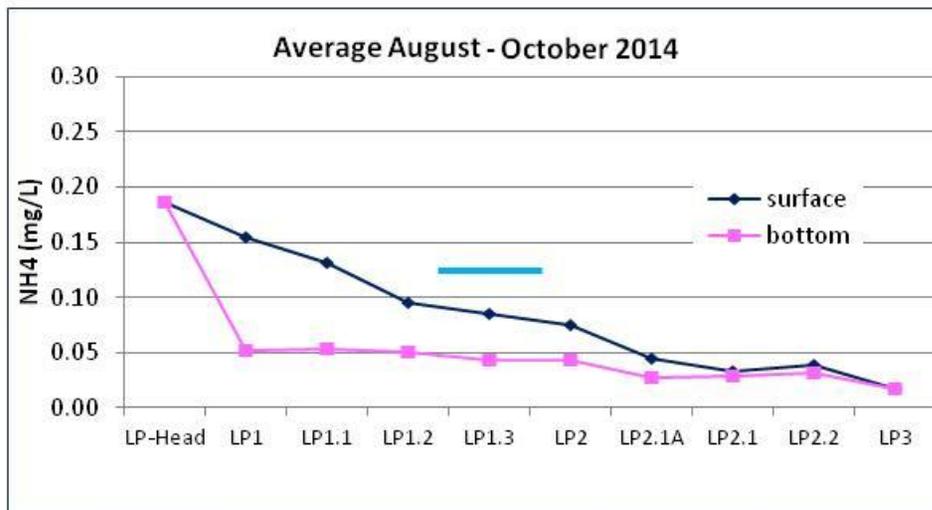
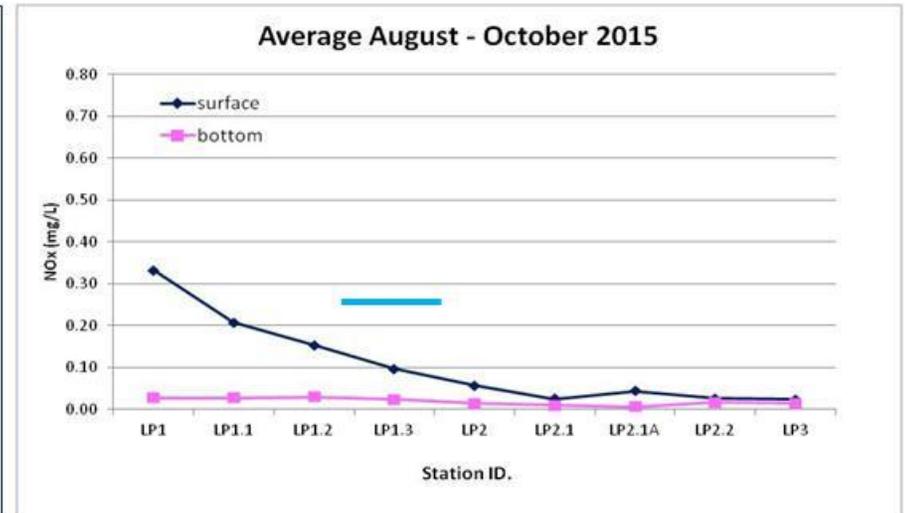
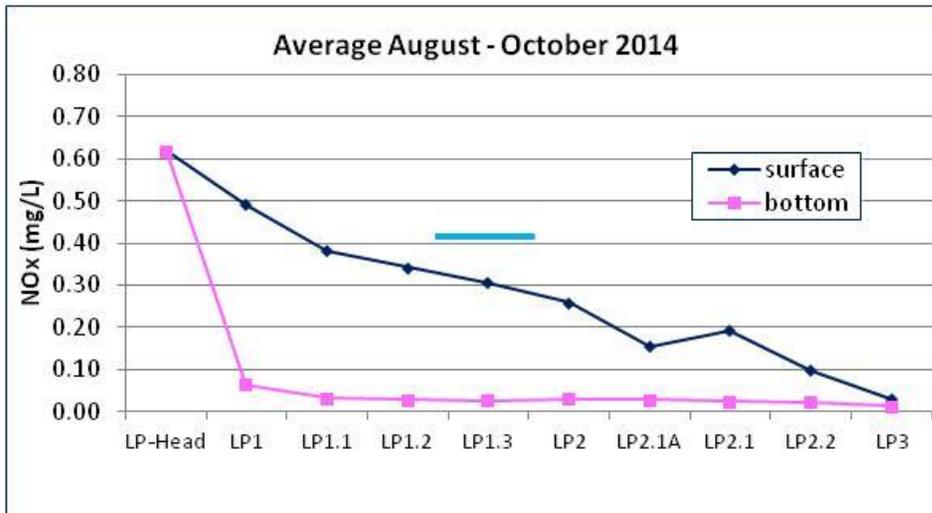


Figure 27 Water column inorganic nitrogen averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from August through mid October, 2014 (Left panels) and August through late October, 2015 (Right panels). (Top) water column nitrate+nitrite and (Bottom) ammonium. Bar represents region of potential change due to oysters.

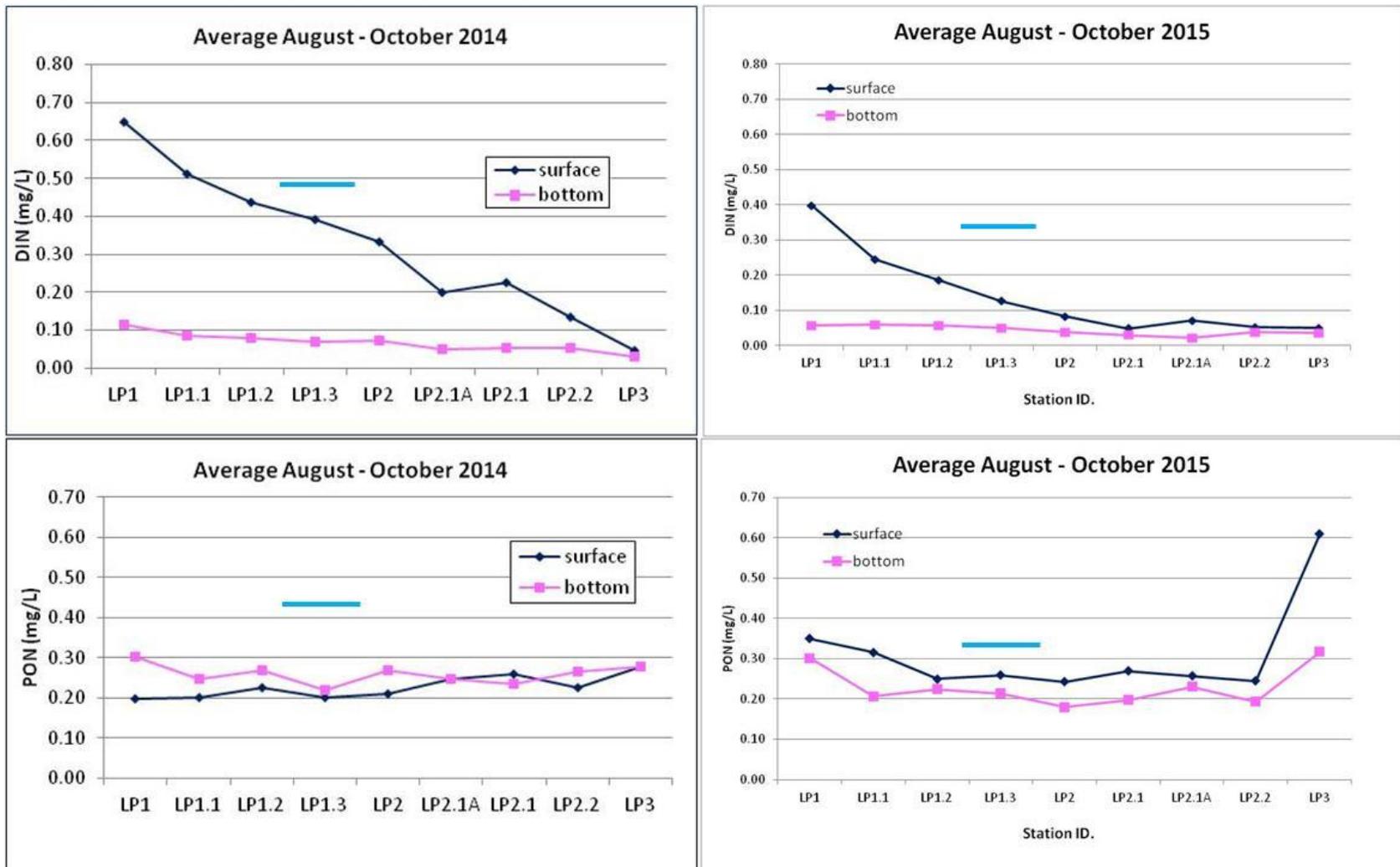


Figure 28 Water column bioactive nitrogen averages from the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from August) through mid October, 2014 (Left panels) and August through late October 2014 (Right panels). (Top) water column dissolved inorganic nitrogen (ammonium+nitrate +nitrite) and (Bottom) particulate organic nitrogen primarily associated with phytoplankton cells living and dead. Bar represents region of maximum potential change from oysters.

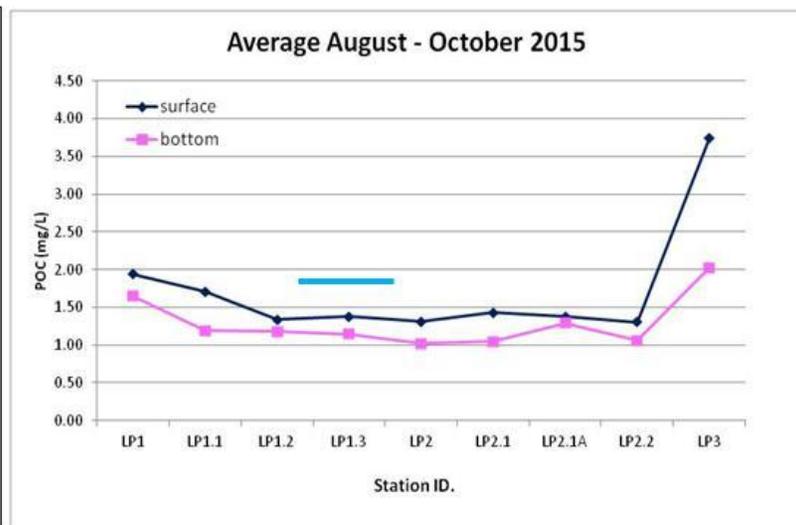
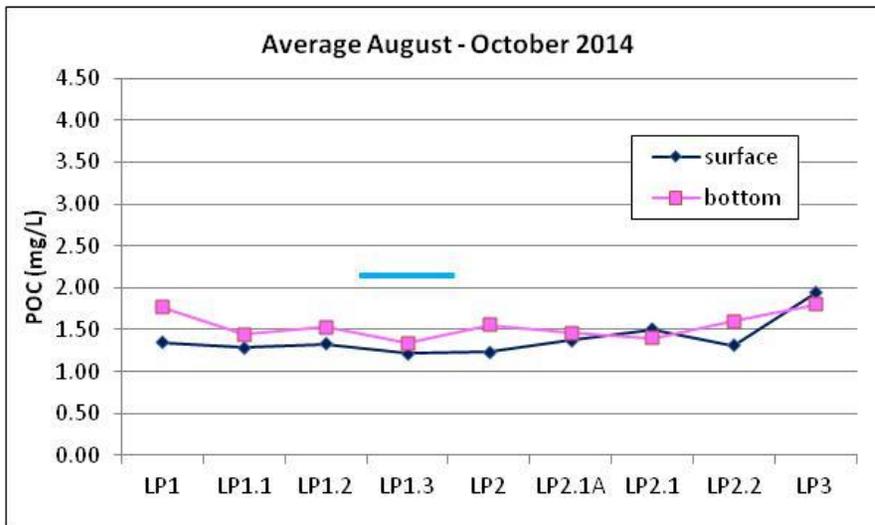
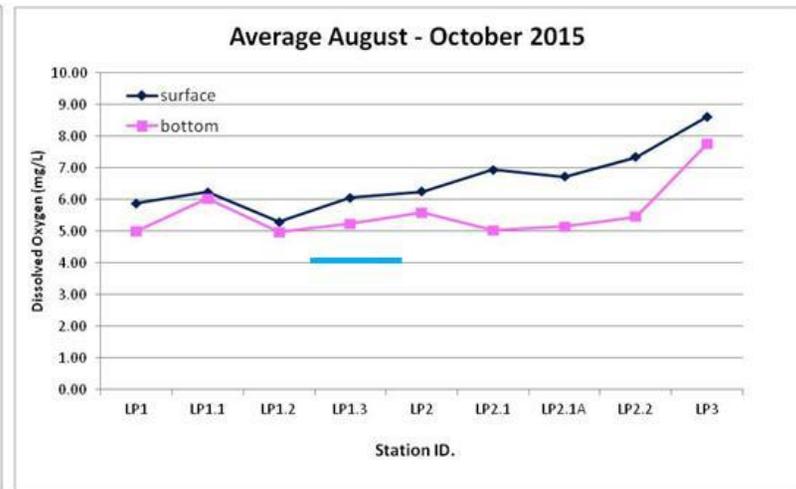
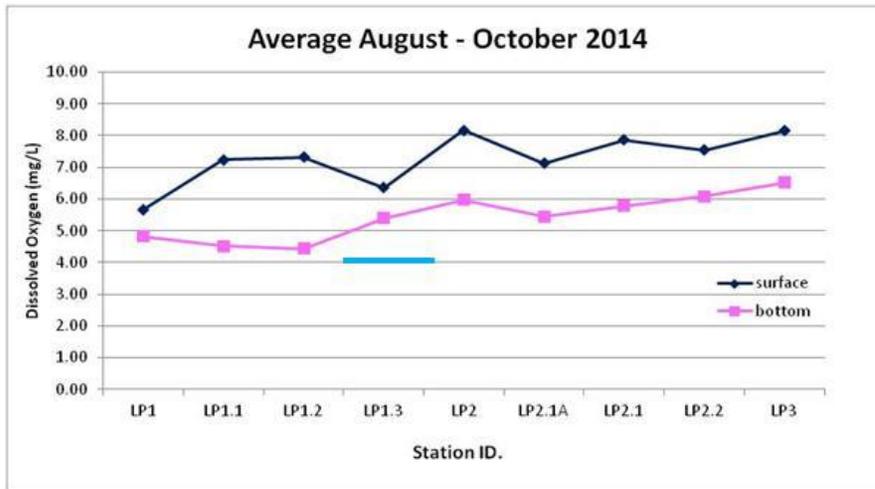


Figure 29 (Top) Bottom water oxygen minimum measured during the high frequency grab sampling surveys conducted in Little Pond, Falmouth MA from August through mid October, 2014 (Left panels) and August through late October 2015 (Right panels). (Bottom) particulate organic carbon concentration presented as an indicator of potential oxygen uptake (as substrate or as phytoplankton). Blue bar indicates region of maximum potential change due to oysters.

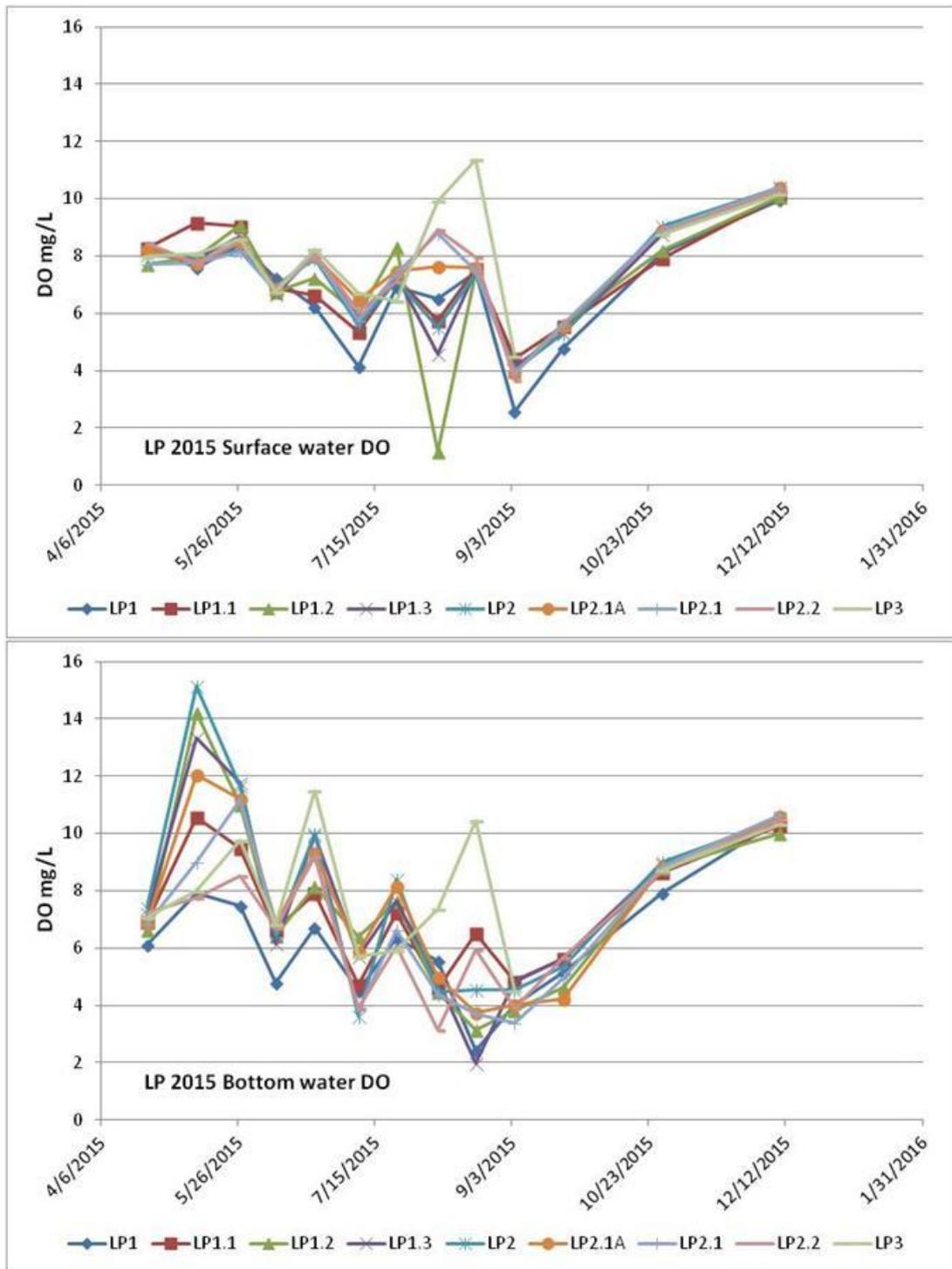


Figure 30. Surface and bottom water dissolved oxygen during mid-ebb tide from May thru October 2015. As in 2014, it appears that low oxygen events are initiated in the upper pond (LP-1, LP-1.1, LP-1.2) above the oyster culture area, gradually worsen through the summer months and are consistent with pond-wide eutrophication rather than spatially dependent on system and oyster oxygen uptake. Both the surface and bottomwater oxygen levels show a similar pattern to long-term monitoring by PondWatch.

Dissolved Oxygen and Chlorophyll-a Monitoring in Little Pond

Results from Year 1 (2013) Mooring Deployment: Bottom moored sondes capable of high frequency measurements of both dissolved oxygen and chlorophyll-a were deployed July 1, 2013 at locations noted in Figure 31. Moorings were deployed 30 cm from the sediment surface. On July 9 and 10, 2013 physical samples were collected at each site and the DO Upper B mooring was moved to the location labeled DO Upper A BOTTOM to reflect amendments made in the original 2013 scope of work.

Figure IV-1 shows the deployment locations and nomenclature used throughout the study as follows:

- LP Upper B **BOTTOM**
- LP Upper A **BOTTOM**
- LP Oyster Raft **SURFACE**
- LP Lower A **BOTTOM**
- LP Lower B **BOTTOM**

At one week intervals calibration samples were collected at the specific depth and location of each sonde. Sondes were then inspected, cleaned and the data was downloaded. Sondes were returned to the moorings and secured. Calibration sampling included triplicate Winkler samples for dissolved oxygen determination as well as whole water for chlorophyll extraction. Calibration samples were used to correct time series data for slight calibration drift during the deployment.

In Year 1 (2013) dissolved oxygen levels were generally low after the first few days of deployment and remained anoxic or hypoxic for a majority of the time, with the exception of the LP Oyster Raft SURFACE sonde which experienced little influence from sediment oxygen demand. Low bottom water dissolved oxygen appears to be the result of water column salinity and temperature stratification (Figure 32 and IV 33). The Oyster Raft sonde, located at the surface, had consistently lower salinity and higher temperatures than all other sondes which were moored near the sediment surface, thus confirming a potential barrier to oxygen exchange with the bottom water. The remaining four sondes all had similar temperatures and salinities.

The physical parameters of salinity, temperature and depth create an environment that is sensitive to changes in primary production and respiration. Fresh water from head waters and surface runoff both enhances stratification and stimulates primary production through nutrient inputs. Thus, large salinity drops at the surface moored Oyster Raft sonde are followed by increases in phytoplankton chlorophyll (Figure 34). Since this sonde was located at the surface, above the stratified layer, the oxygen produced by the additional phytoplankton during the day result in late afternoon spikes in oxygen concentration well above air saturation. During the dark hours, when that same additional phytoplankton respire, water column oxygen drops below saturation. The result was large diurnal swings in dissolved oxygen. Unlike the bottom moorings (Figures 35 through 38) however, the dissolved oxygen concentrations rarely reach anoxia because exchange of oxygen with the atmosphere was not impeded by stratification.

Bottom moorings (Figures 35 through 38) received only a fraction of the light received at the surface thereby decreasing primary production by phytoplankton and concomitantly decreasing oxygen production during daylight hours. In addition, these instruments were close to the

sediment surface which continuously respired water column oxygen. Thus, compared to the surface, bottom water oxygen concentrations were depressed, often to the point of anoxia, while diurnal excursions in oxygen concentration were of a similar magnitude throughout much of the deployment. Low levels of sulfide were detected in the bottom water during the July 9 sampling and were episodic throughout most of the deployment period. Particulate sulfur was observed in the bottom water on July 10 and July 19 indicating persistent anoxic conditions.

Large blooms of phytoplankton were associated with rain events bring nutrients into the pond, most notably at the beginning of the mooring record, which coincided with a storm which dropped several inches of rain in a single day. Salinity gradients produced by the fresh water stream at the head of Little Pond suggest that much of the nutrient inputs come from this source. The decreasing concentration of chlorophyll during bloom conditions observed with increasing distance from the head waters was consistent with this process. (See Figures 35 through 37, ~7/29/13). It should be noted that the large diurnal oscillations in chlorophyll concentrations are mainly an artifact of using the proxy measurement of fluorescence (standard method) to measure chlorophyll concentrations. The strength of the fluorescent response to sunlight (and the pulse of light produced by the sonde prior to measurement) by individual phytoplankton tends to be lower during daylight hours when the chlorophyll is more likely to be saturated with light than at night when ambient light is absent. Thus, the large concentration changes seen in the data reflect diurnal changes in the phytoplankton status and not actual concentration changes over a day/night cycle. While this is generally not accounted for by many users of YSI moorings, it is a phenomenon noted by many researchers.

Chlorophyll concentrations decreased somewhat during the latter part of the deployment. Cooler water, which can hold more oxygen, had the effect of generally increasing dissolved oxygen concentrations in the bottom water as well. Most interesting, with respect to the oyster transplants, was that once all the oysters were placed in the pond there appeared to be a decrease in the amplitude of phytoplankton blooms downstream of the rafts. Although we cannot ascribe causation at this time the observation is consistent with the hypothesis that oyster culture would tend to remove phytoplankton from the water. There was, however, no clear relationship between decreased phytoplankton and elevated bottom water dissolved oxygen. Little Pond represents a shallow, eutrophic estuary in which sediment respiration makes a large contribution to the overall water column oxygen budget, so if the observed decrease in phytoplankton density downstream from the oyster rafts turns out to be causally related it may take several years before the decreased organic load to the sediment is reflected in the water column oxygen concentrations.

It is clear that the oxygen conditions were showing depletion at both the surface and bottom, but the observed depletions did not appear to be related to the oysters that have been placed in the pond. Conditions were poor before oyster introduction and either remained poor or improved throughout the summer. Oxygen conditions were no worse within the oyster culture area (Upper A (Bottom)) than anywhere else, in fact better than some suggesting that accelerated deposition of fecal pellets below the rafts was either not an important factor or that the observed poor water quality left little margin for detecting deleterious effects.

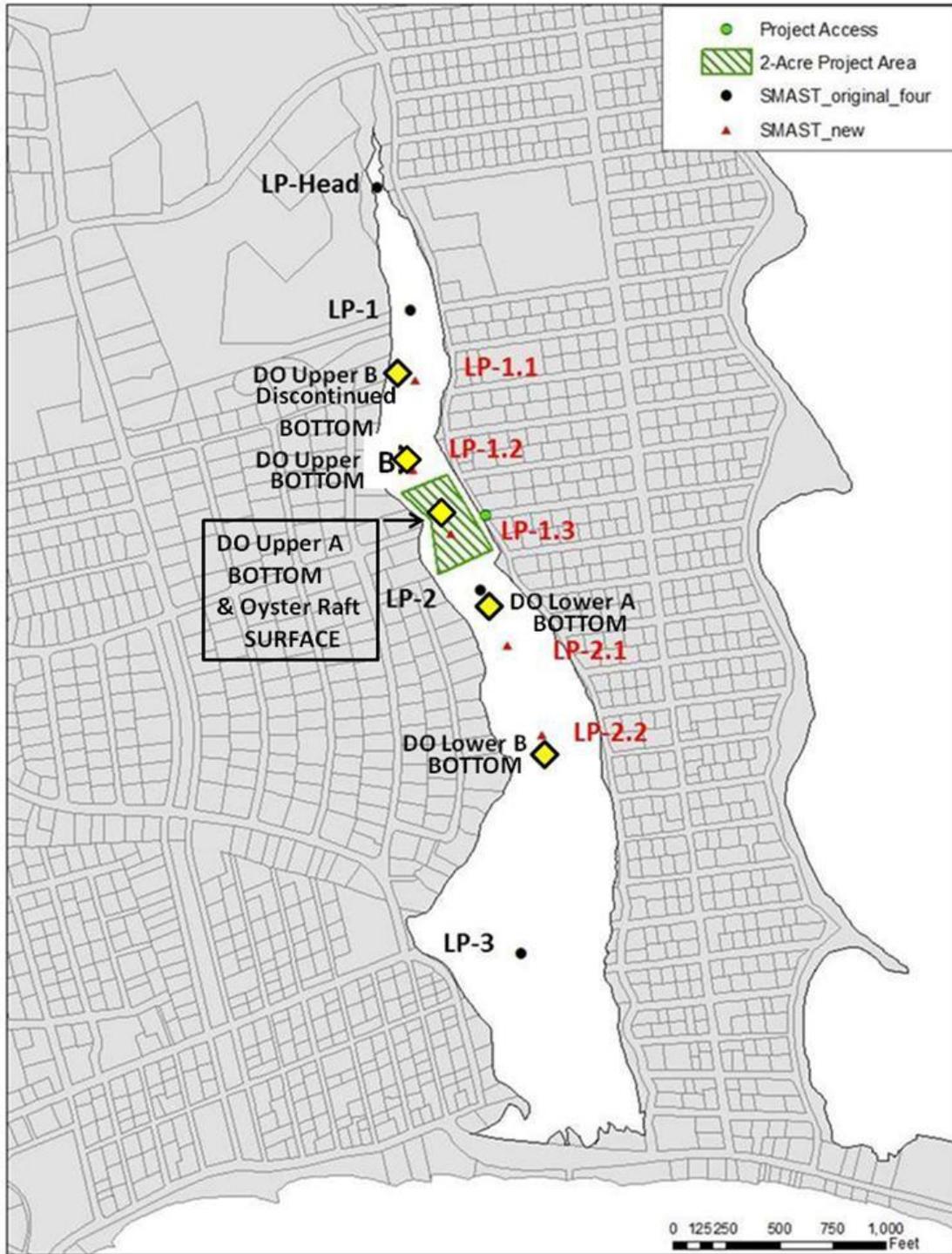


Figure 31. Final Year 1 (2013) mooring locations.

Mooring Temperatures

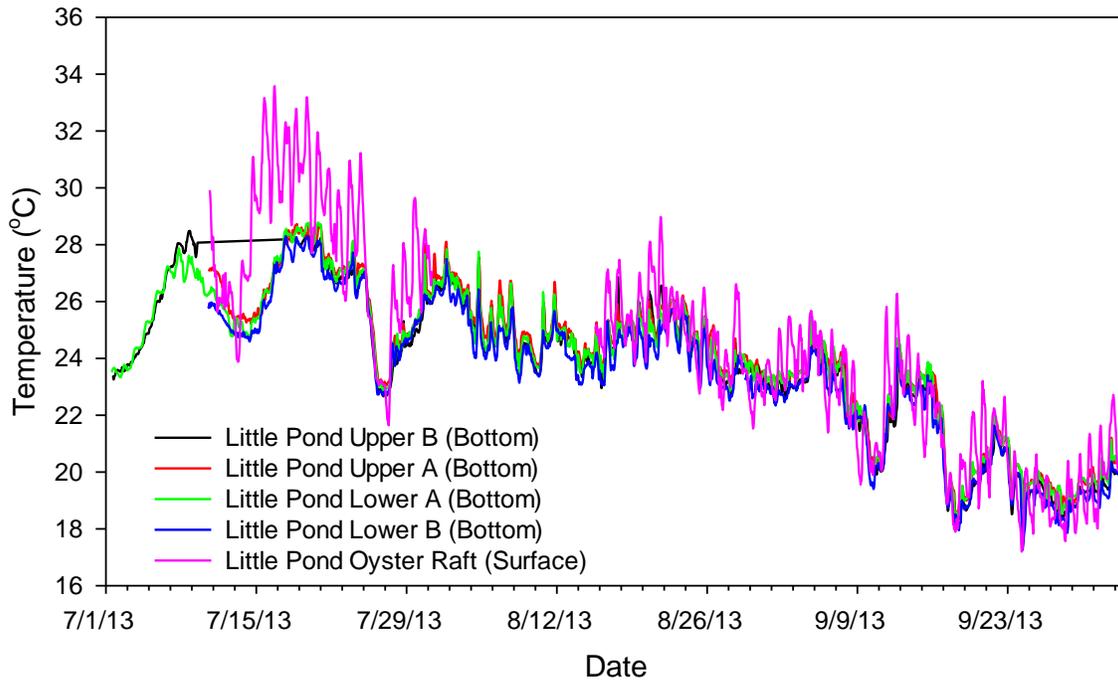


Figure 32. Time series record of temperature for all 2013 moorings.

Mooring Salinities

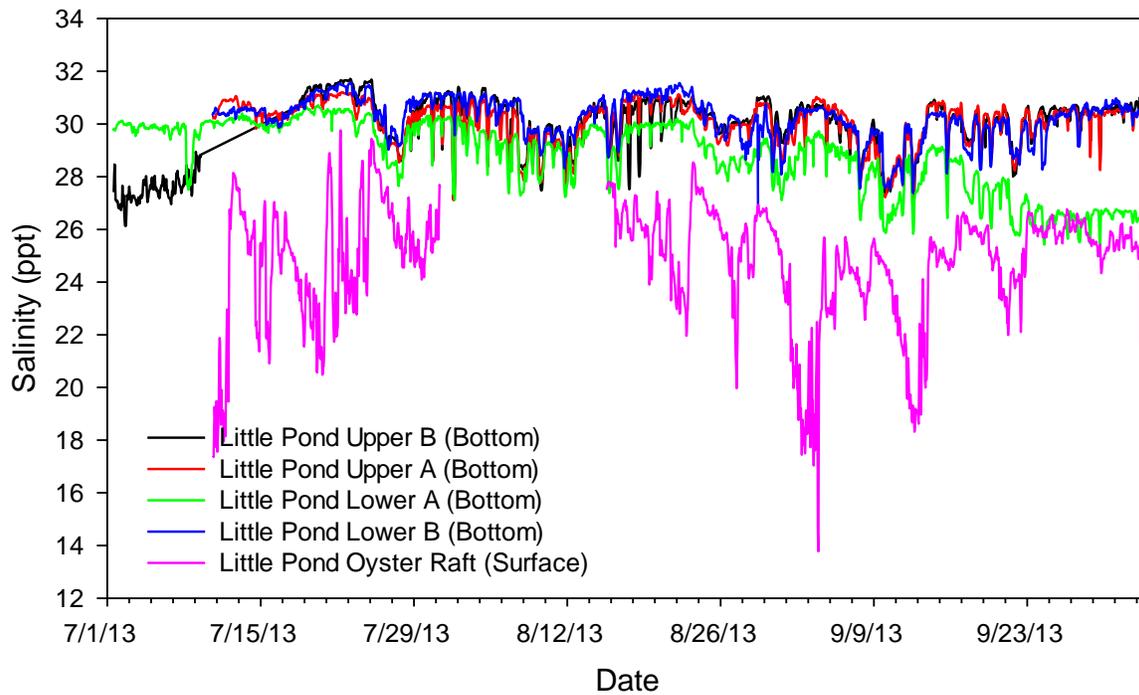


Figure 33. Time series record of salinity for all 2013 moorings.

Oyster Raft (Surface)

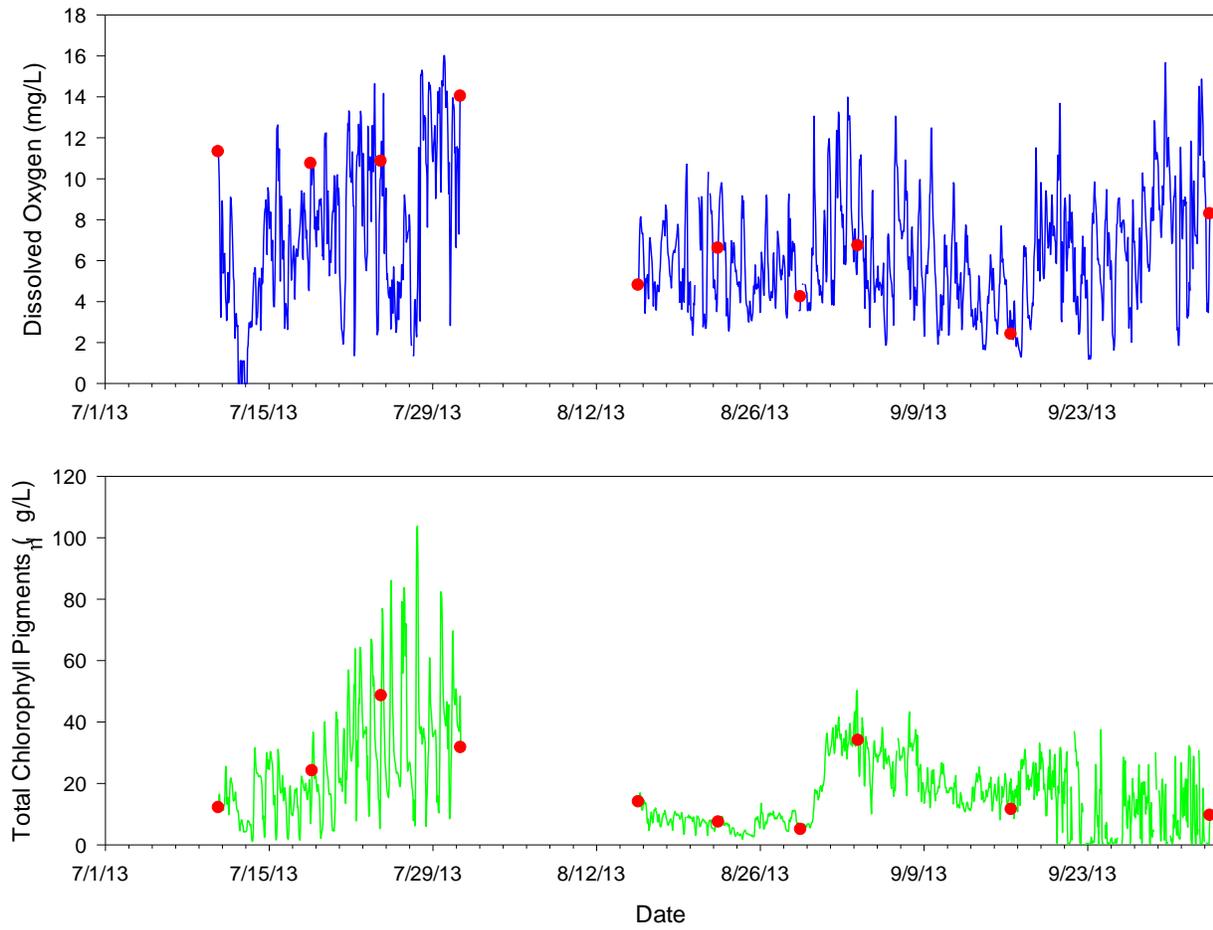


Figure 34. Dissolved oxygen and chlorophyll time series data plots for surface deployed Oyster Raft sonde in 2013. Red dots denote calibration samples.

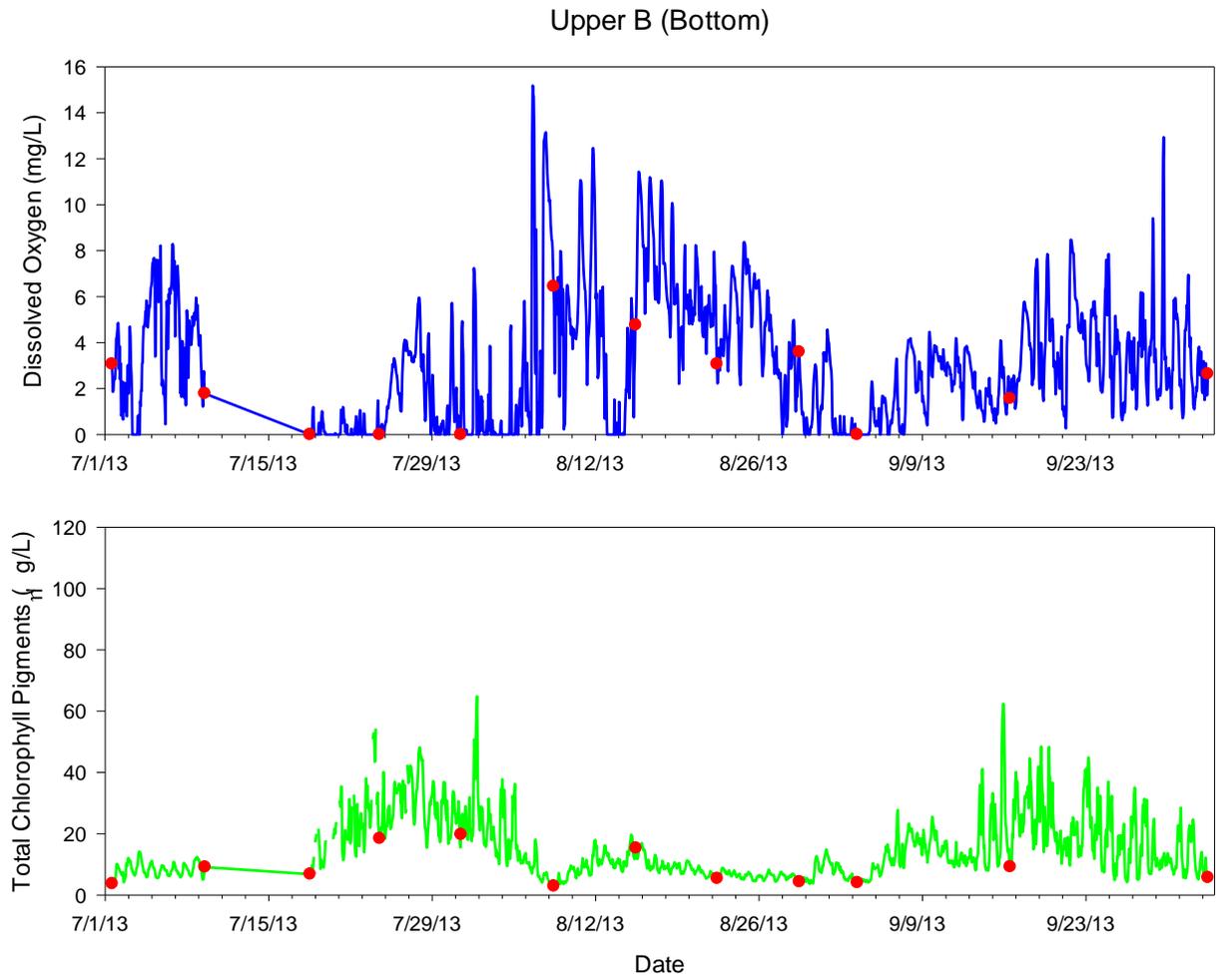


Figure 35. Dissolved oxygen and chlorophyll time series data plots for surface deployed Upper B (Bottom) sonde in 2013. Red dots denote calibration samples.

Upper A (Bottom)

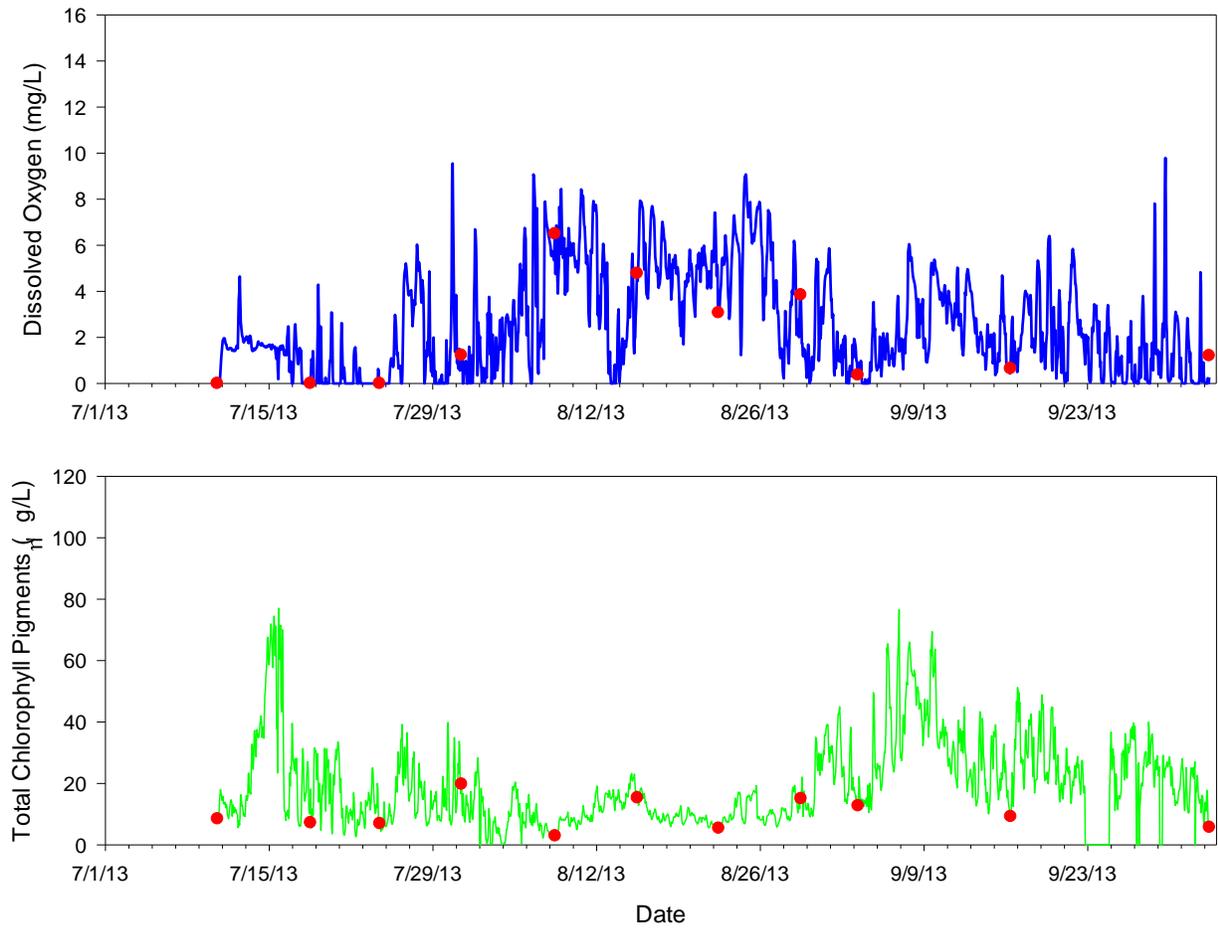


Figure 36. Dissolved oxygen and chlorophyll time series data plots for surface deployed Upper A (Bottom) sonde. Red dots denote calibration samples.

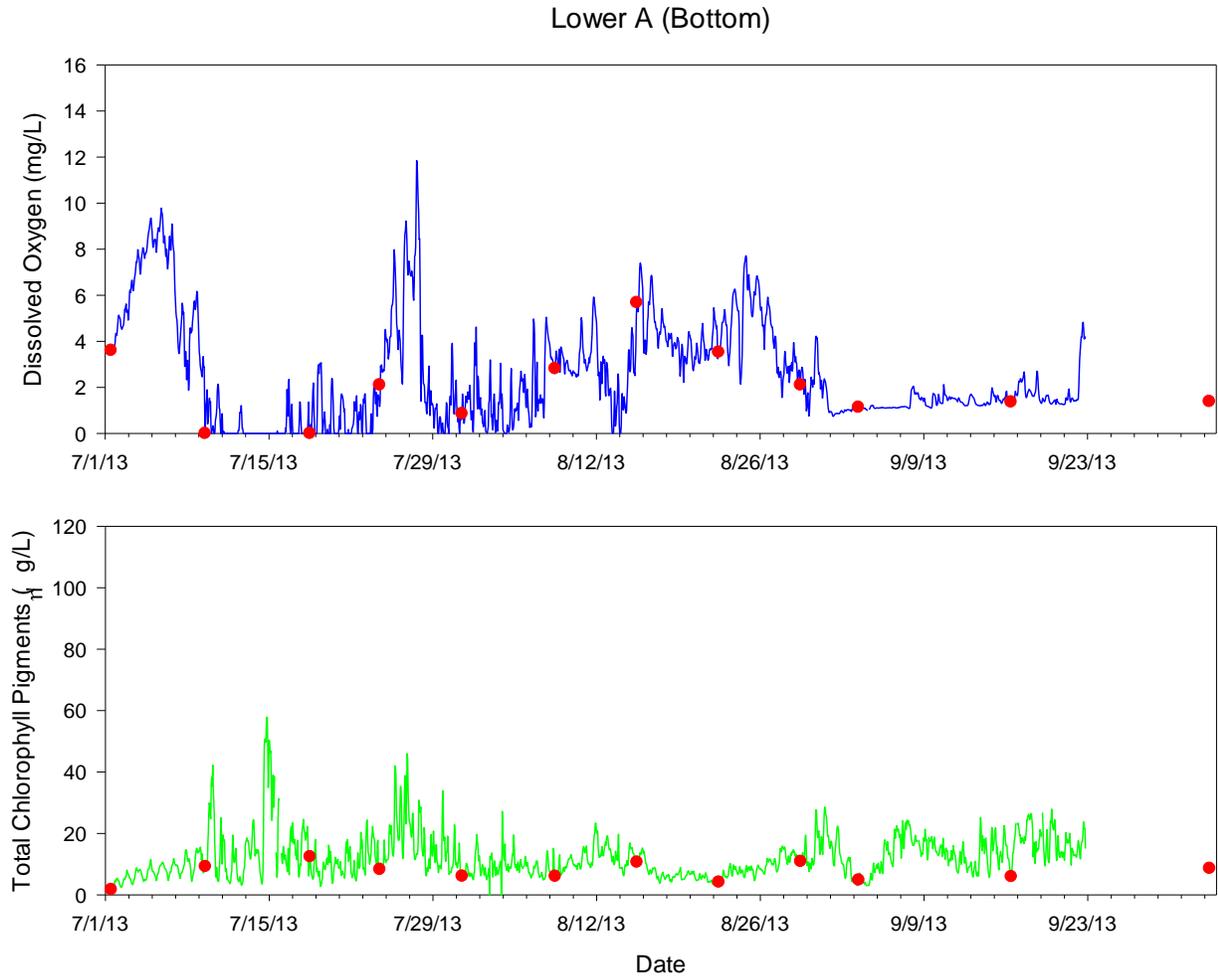


Figure 37. Dissolved oxygen and chlorophyll time series data plots for surface deployed Lower A (Bottom) sonde in 2013. Red dots denote calibration samples.

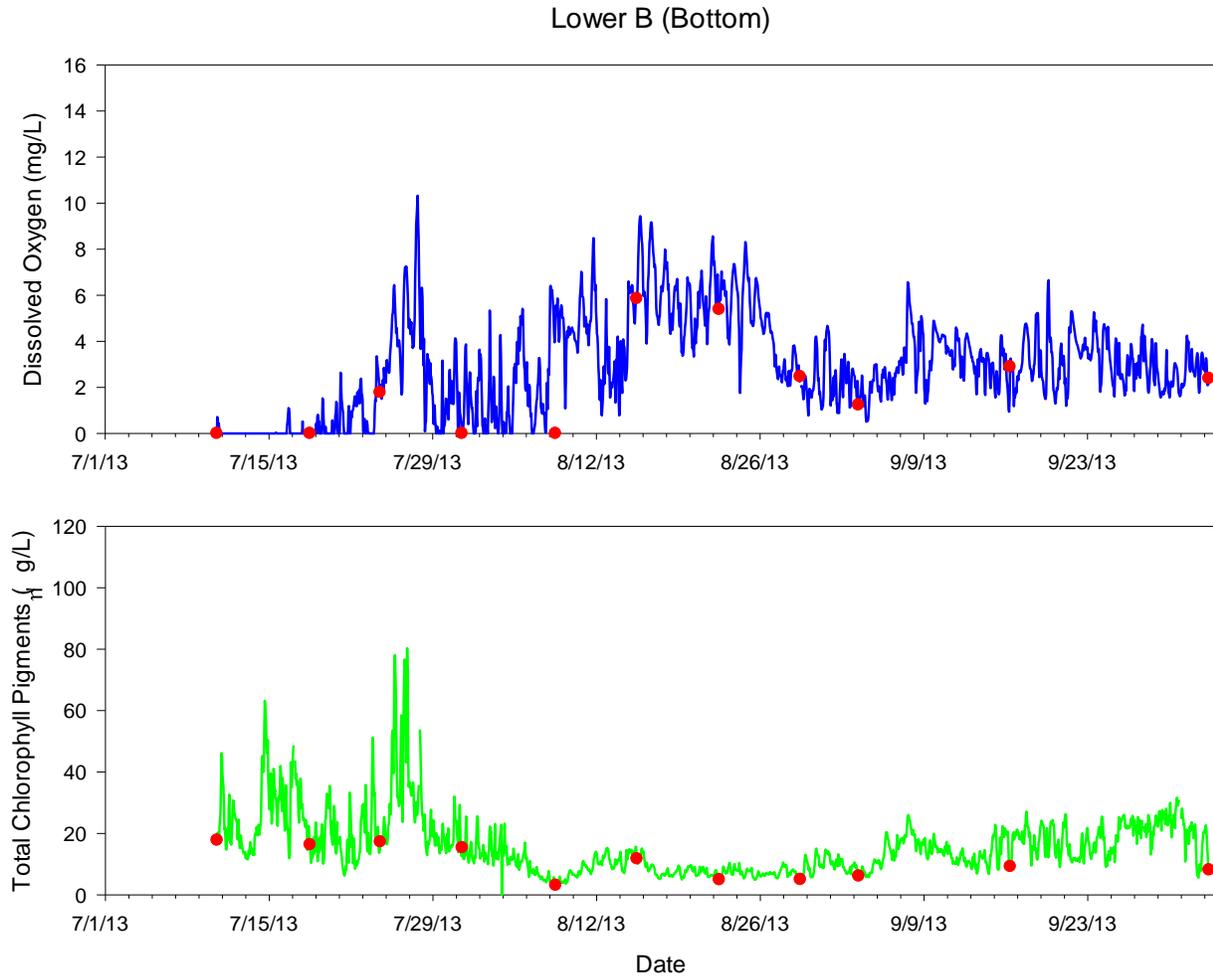


Figure 38. Dissolved oxygen and chlorophyll time series data plots for surface deployed Lower B (Bottom) sonde in 2013. Red dots denote calibration samples.

Conclusions of Year 1 (2013) DO / CHLA Mooring Deployment: The mooring study indicated that surface oxygen conditions were conducive to oyster survival and chlorophyll levels were generally high >10-15 ug/L providing ample food supply. Temperature and salinity are important factors to consider, particularly during transplant operations. Temperatures as high as 34°C and surface salinities as low as 14 ppt could severely stress immature oysters that are acclimated to conditions similar to offshore waters.

The data showed generally poor oxygen conditions and moderate to high chlorophyll levels throughout the transplant area. These conditions were present before the introduction of oysters to the pond and did not appear to change as a result of the oyster addition. In fact, during the last half of the deployment there appeared to be a decrease in phytoplankton abundance south of the oyster rafts suggesting that as the oysters grew larger and filtered more water that they may reduce the water column burden of phytoplankton in a noticeable way. One specific concern was that accelerated deposition of organic matter under the oyster rafts might adversely affect the benthos. No indication of this phenomenon was apparent in the sonde records, though the poor water quality observed leaves little margin for detecting deleterious effects. Based upon the data collected the instrument placement was appropriate to detect any

possible influence on water quality resulting from the oyster culture. It is likely that the benefits of oyster culture on water column clearance of phytoplankton suggested by the data would be enhanced by the introduction of more oysters or oysters of a larger size class. Any deleterious effect this may have on the benthic environment is still uncertain, so continued monitoring would be recommended. Intensive monitoring would also serve to validate the beneficial effects suggested by this pilot project.

Results from Year 2 (2014) Mooring Deployment: In 2014 there were two changes to the 2013 mooring program. First, the oyster raft surface sensor was free floating at about 5 cm from the surface; in 2013 the mooring was approximately 15cm below the surface and attached to one of the oyster bag mooring lines. In addition, a sixth mooring (LP Lower C) was deployed on the bottom between LP Lower A Bottom and LP Lower B Bottom in order to better define any near field effects and gradients produced by the oyster culture program. All other locations and monitoring parameters remained the same, with one exception. Possibly due to expansion of the number of oysters placed in the pond in 2014, the LP OYS 2 Bottom mooring, which was located beside the LP Oyster Raft Surface mooring within the oyster deployment area, was often below the oyster bags (Figure 39). In 2013 the mooring was never found beneath the oyster bags. This circumstance may help to elucidate the immediate spatial effects of the oysters by capturing the signal from detritus raining down from the bags.

There were clear inter-annual differences in the mooring results in Year 2 (2014) versus the previous Year 1 (2013) record as reflected in plots of the DO and Chlorophyll a results (Figures 40 to 63). In both Year 1 and 2 the time-series mooring data was comparable to the grab sample monitoring data, although the moorings yield more information on diurnal and tidal variations in key parameters. In 2014 oxygen concentrations were consistently higher with less oxygen depletion and shorter periods of hypoxia and fewer instances of anoxia in the bottom water. Chlorophyll concentrations were lower at all of the mooring locations compared to 2013, as well. The higher dissolved oxygen levels were surprising given the much stronger stratification in 2014 compared to 2013, as seen by comparing the Oyster Raft Surface and LP OYS2 Bottom mooring salinity data and the full season salinity profiles from the water quality program. Although the observed difference in the degree of stratification may have been the result of the Oyster Raft Surface mooring being placed slightly closer to the water surface (centimeters), only the LP OYS2 Bottom mooring displayed depressed oxygen concentrations that were coincident with stratification.

As observed during a major stratification event in the early portion of the 2013 deployment the oxygen deficit was brief, lasting approximately 36 hours. Phytoplankton blooms in response to rain events on 7/15/14, 7/30/14, 8/19/14 and 9/4/14 were much smaller in magnitude than those observed following rain events in 2013 reaching 20-25 ug/L only at the LP OYS 2 Bottom mooring and LP Oyster Raft Surface mooring. Persistence of the bloom at the surface mooring was very brief suggesting that particle filtering by the oysters may have had an impact on the bloom intensity. While the bloom was apparent within the oyster area no significant increase in chlorophyll was seen at bottom mooring locations either above or below the oyster culture area. It is somewhat counter intuitive; however, this could be suggestive of the oysters having a positive impact of the pond's water quality. In 2013 most of the phytoplankton blooms were coincident at all the mooring locations. The distances between the moorings being small, despite the slow tidal currents in Little Pond one would expect the high concentrations of chlorophyll-a to spread through advection, and yet the blooms were not obvious outside the culture area. Although a short period of anoxia was observed, the oxygen conditions were comparable to the other mooring locations with regards to the frequency and duration of low oxygen events. It should be noted that the large spike in chlorophyll seen at the end of the

record from LP Lower B Bottom is an apparent artifact resulting from macroalgae becoming entangled with the instrument. Upon recovering the mooring large sheets of Ulva were found draping the sonde. Likewise, the large dip in oxygen seen at the LP Oyster Raft Surface mooring near 7/30/2014 we believe was related to bio-fouling. The cage protecting the sensors was replaced during routine maintenance on 8/5/2014.

Key findings:

Overall, there was a decline in chlorophyll-a moving through the moorings from inland to the inlet, except for the elevated levels recorded by the sensor directly within the oyster culture area.

- It appears that the higher chlorophyll-a associated with the oysters is most likely the result of their feeding and deposition to bottom waters. The higher chlorophyll-a therefore is associated with deposition and not a bloom. This is supported by the water quality results and the higher phaeophytin-a below the oysters, an initial breakdown product of chlorophyll-a which is also part of the fluorescence measurements by the sensors.
- The elevated chlorophyll levels do not extend to the down gradient sensors, consistent with fecal deposition rather than a bloom which should expand and not be isolated in a tiny area. The spatial pattern also follows the measured dispersal of the feces/pseudofeces, projected to be within 20m of the source (see ADCP below), so not reaching the next mooring.
- It appears that the oysters are clearing particles from the water column and the effects of deposition are localized; that oxygen conditions in both 2013 and 2014 were not negatively impacted by the oysters, i.e. oxygen depletion and hypoxia were not increased; that water clarity is increased; and that the effects of the oysters on Little Pond are not significantly altered by the intensity of stratification.

Table 6. DO /CHLA Mooring locations for the 2014 Year 2 sampling period.

2014 DO MOORING LOCATIONS		
Markers	Coordinates:	
LP UPPER B	N 041° 33' 17"	W 070° 35' 28"
LP OYS RACK	N 041° 33' 13"	W 070° 35' 27"
LP OYS 2	N 041° 33' 14"	W 070° 35' 28"
LP LOWER A	N 041° 33' 11"	W 070° 35' 24"
LP LOWER B	N 041° 33' 6"	W 070° 35' 20"
LP LOWER C	N 041° 33' 6"	W 070° 35' 23"

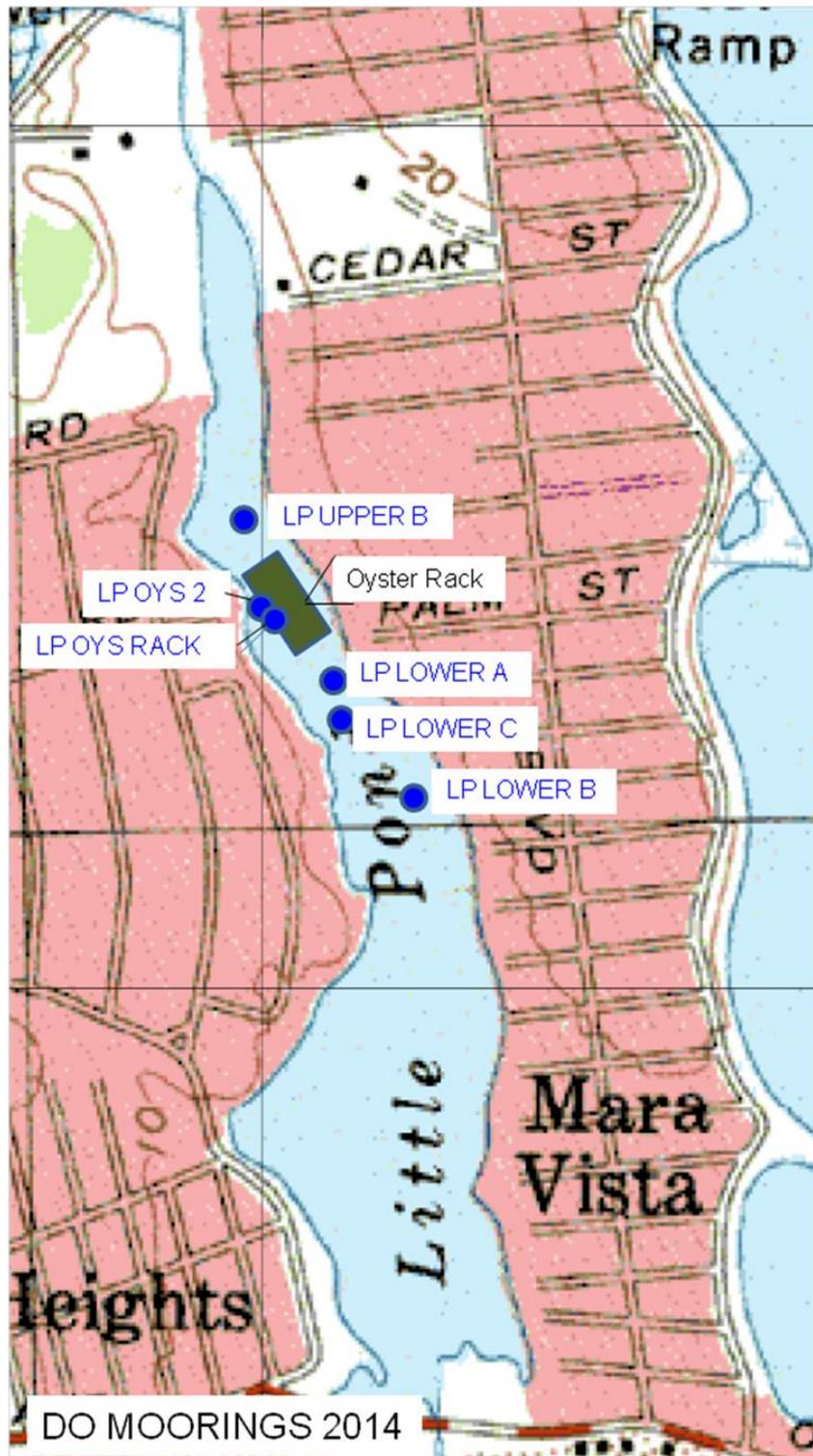


Figure 39. Final mooring locations reflecting modified deployment pattern. LP Upper A (2013) which measured bottom water DO was shifted into the rafts and re-labeled LP OYS2 for 2014 (also measuring bottom water DO).

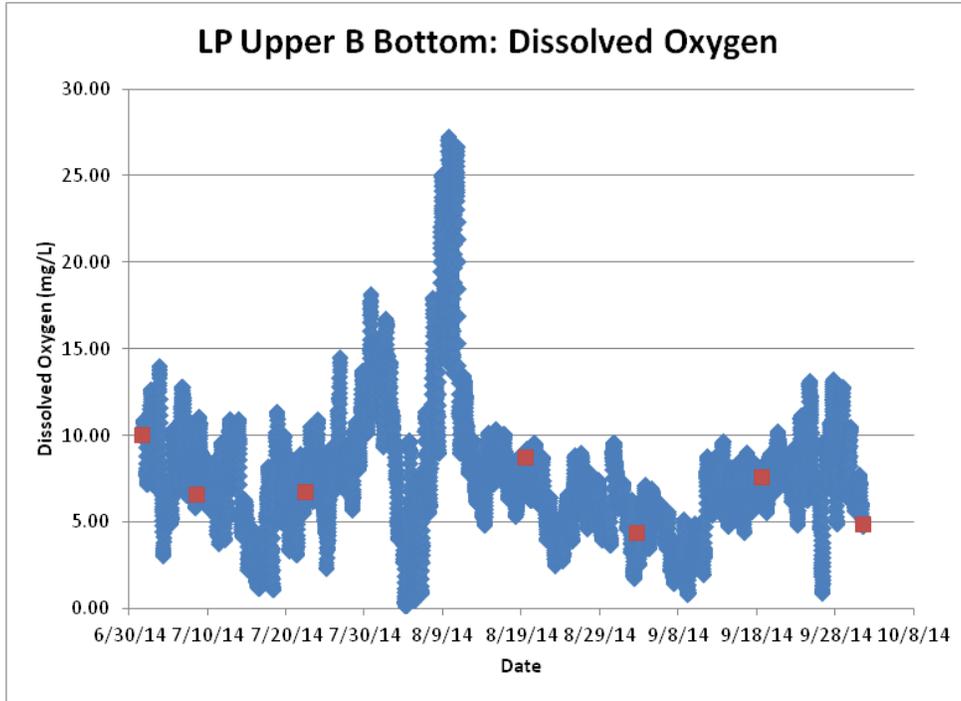


Figure 40. Dissolved oxygen time series data plots for surface deployed LP Upper B sonde. Red dots denote calibration samples.

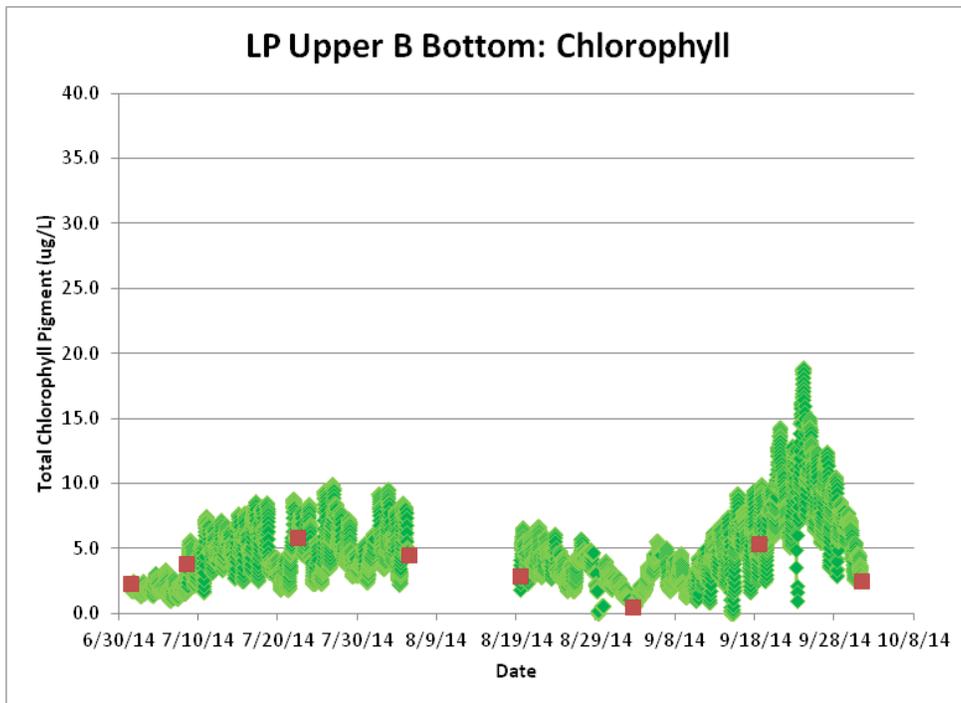


Figure 41. Chlorophyll-a (CHLA) time series data plots for surface deployed LP Upper B sonde. Red dots denote calibration samples.

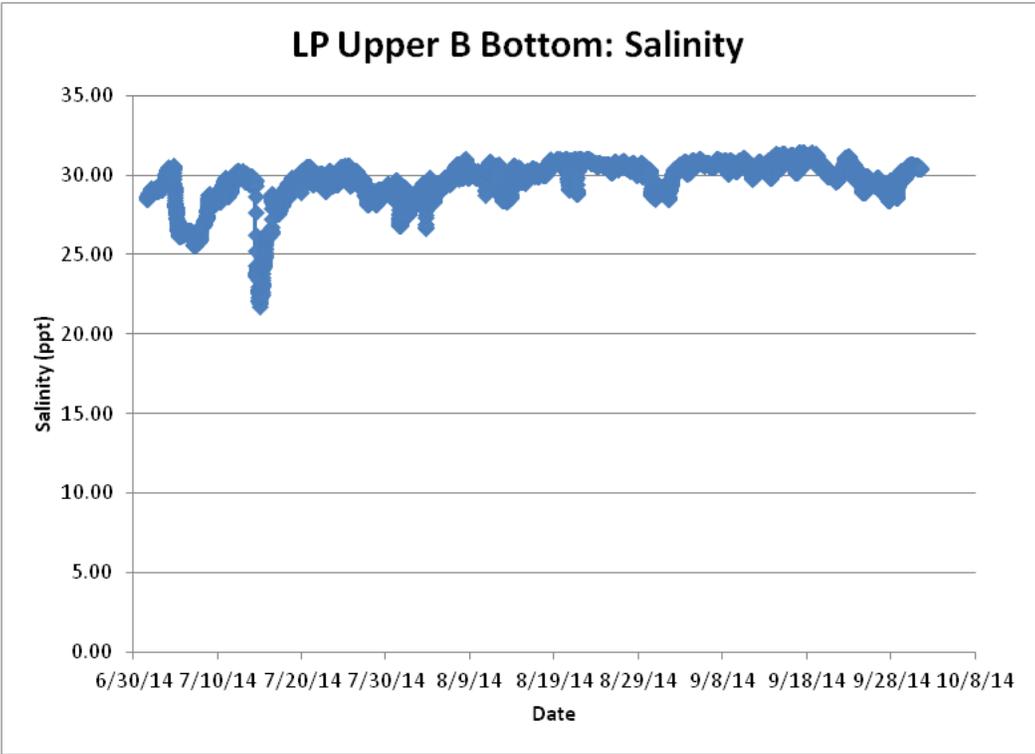


Figure 42. Time series record of salinity for LP Upper B mooring.

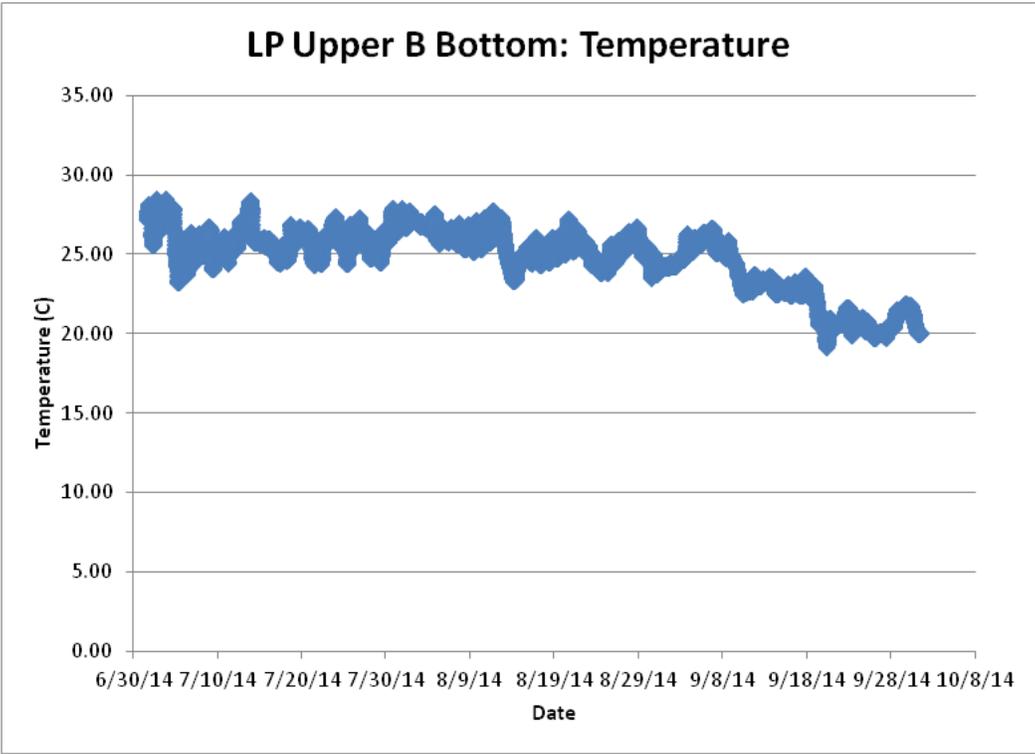


Figure 43. Time series record of temperature for LP Upper B mooring.

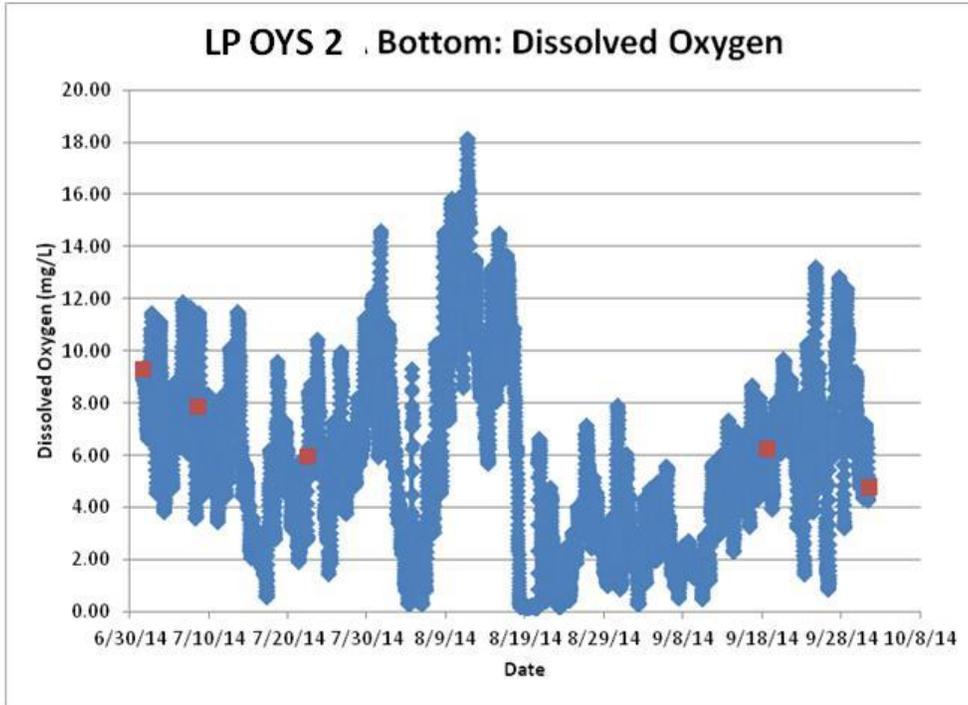


Figure 44. Dissolved oxygen time series data plots for surface deployed LP OYS 2 sonde. Red dots denote calibration samples.

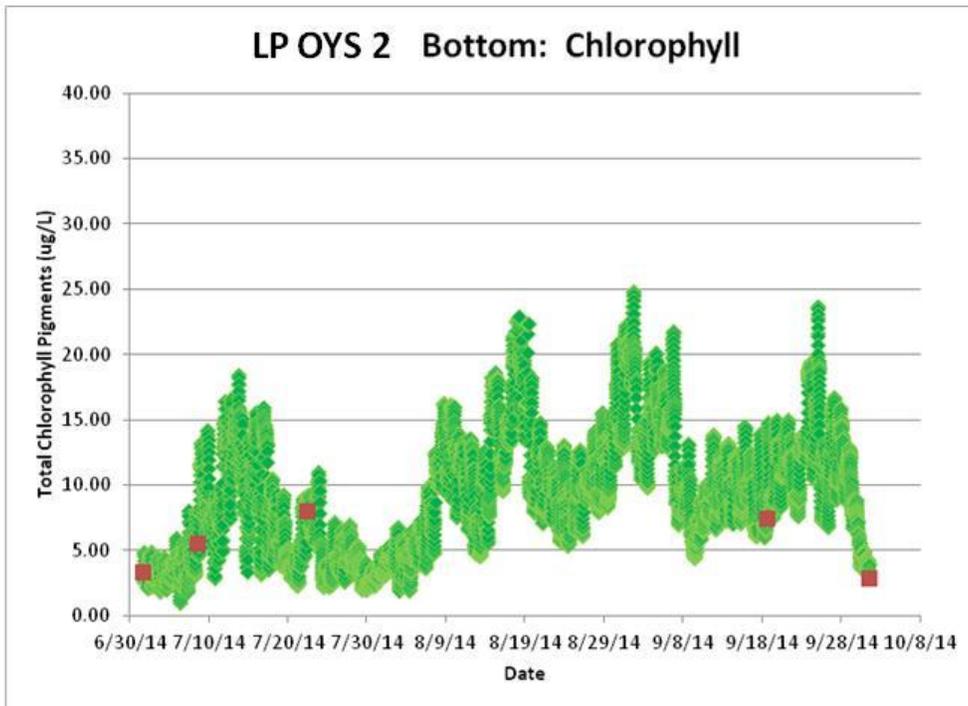


Figure 45. Chlorophyll-a (CHLA) time series data plots for surface deployed LP OYS 2 sonde. Red dots denote calibration samples.

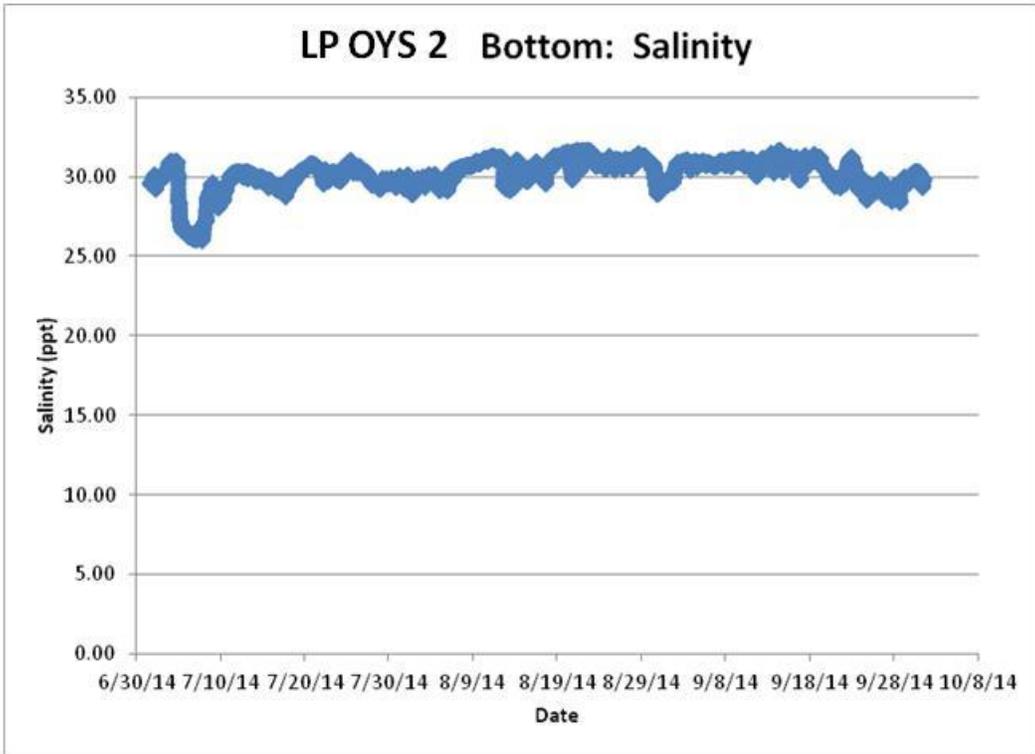


Figure 46. Time series record of salinity for LP OYS 2 Bottom mooring.

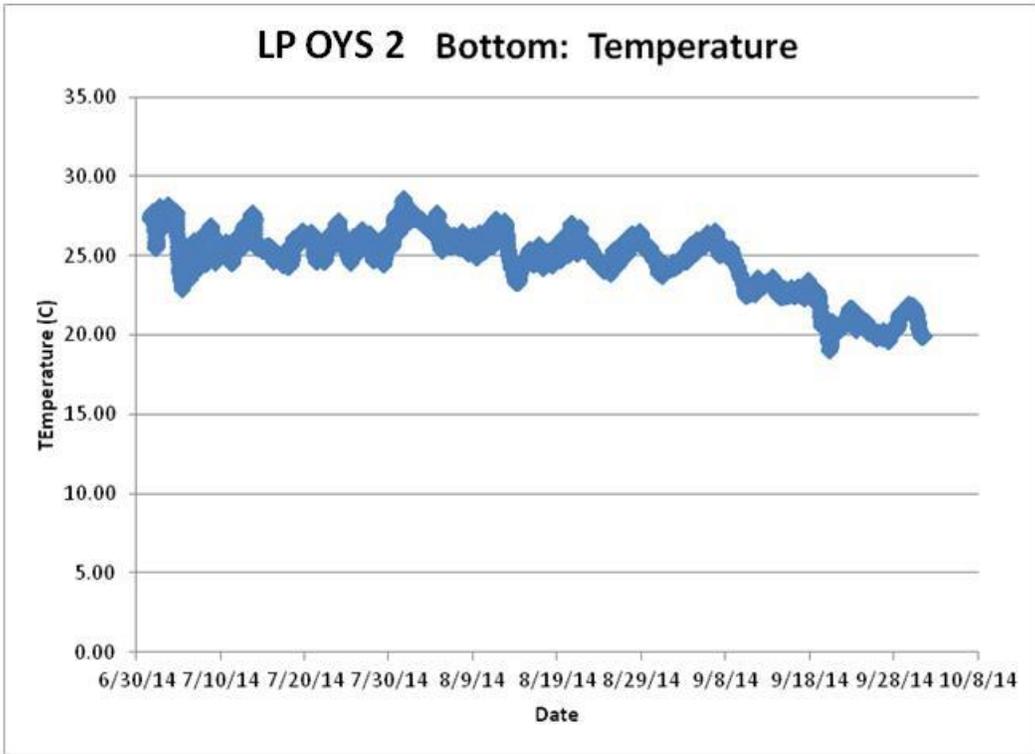


Figure 47. Time series record of temperature for LP OYS 2 Bottom mooring.

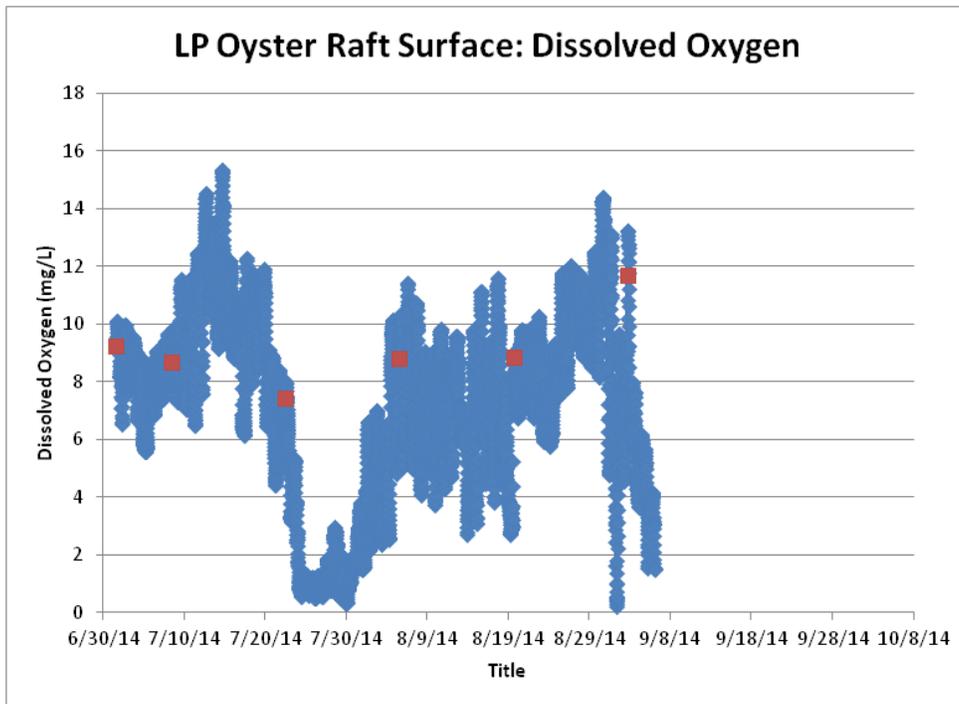


Figure 48. Dissolved oxygen time series data plots for surface deployed LP Oyster Raft Surface sonde. Red dots denote calibration samples.

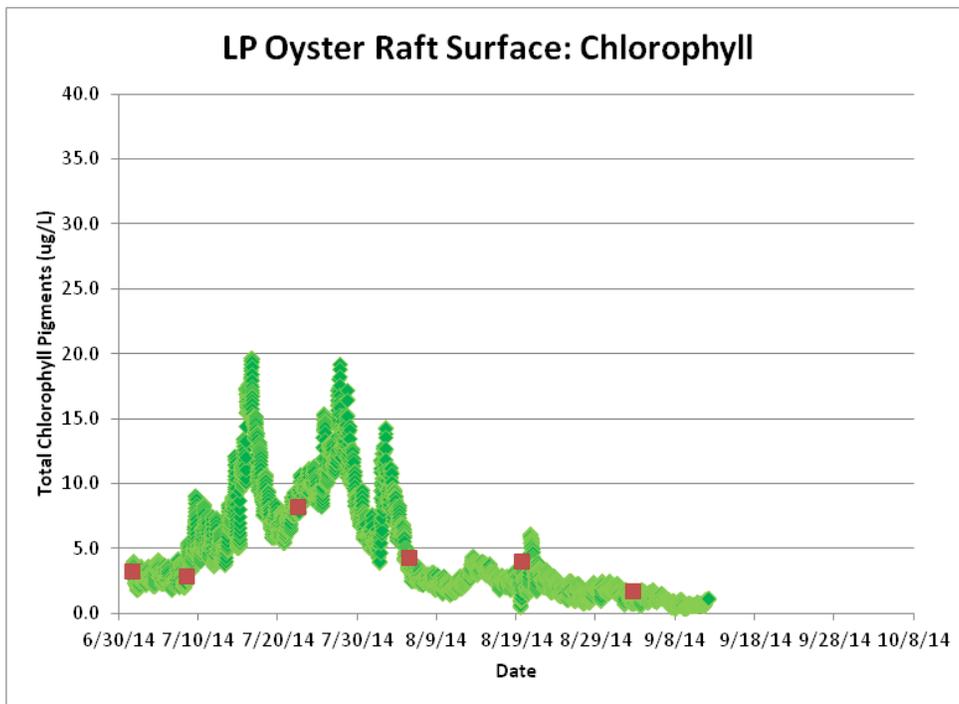


Figure 49. Chlorophyll-a (CHLA) time series data plots for surface deployed LP Oyster Raft Surface sonde. Red dots denote calibration samples.

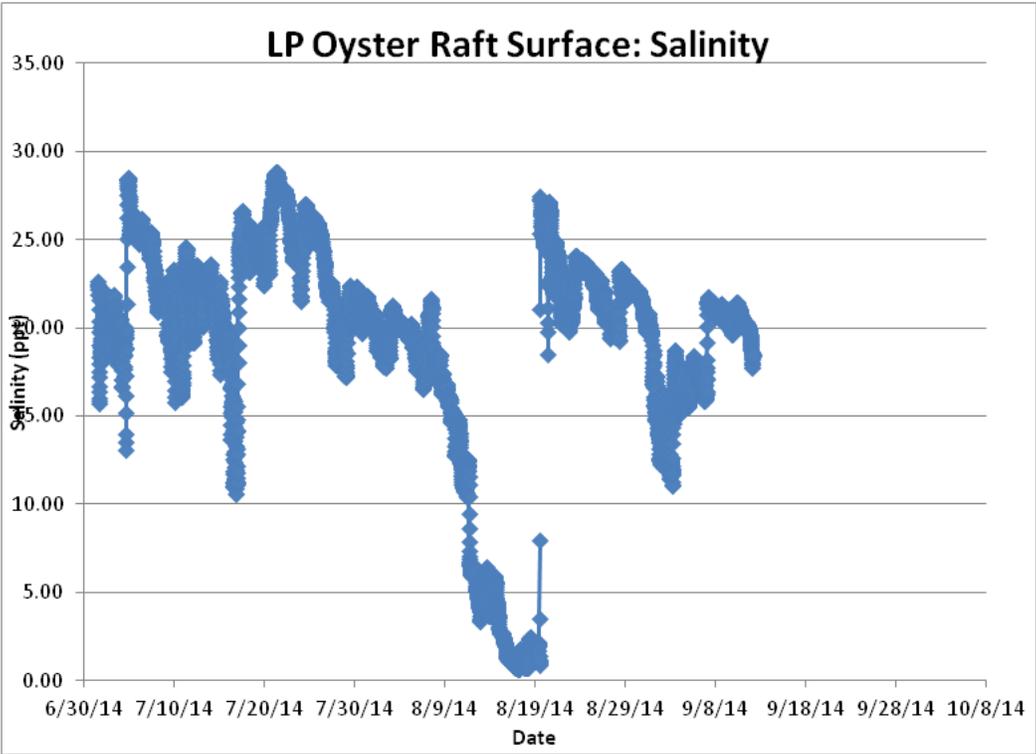


Figure 50. Time series record of salinity for LP Oyster Raft Surface mooring.

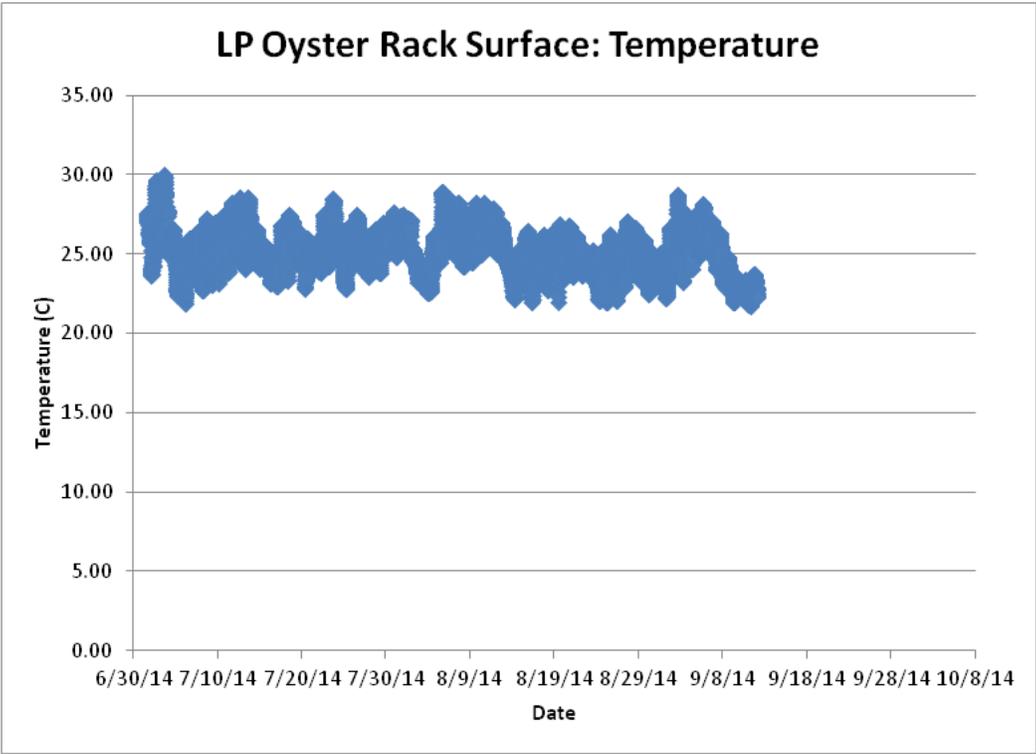


Figure 51. Time series record of temperature for LP Oyster Raft Surface mooring.

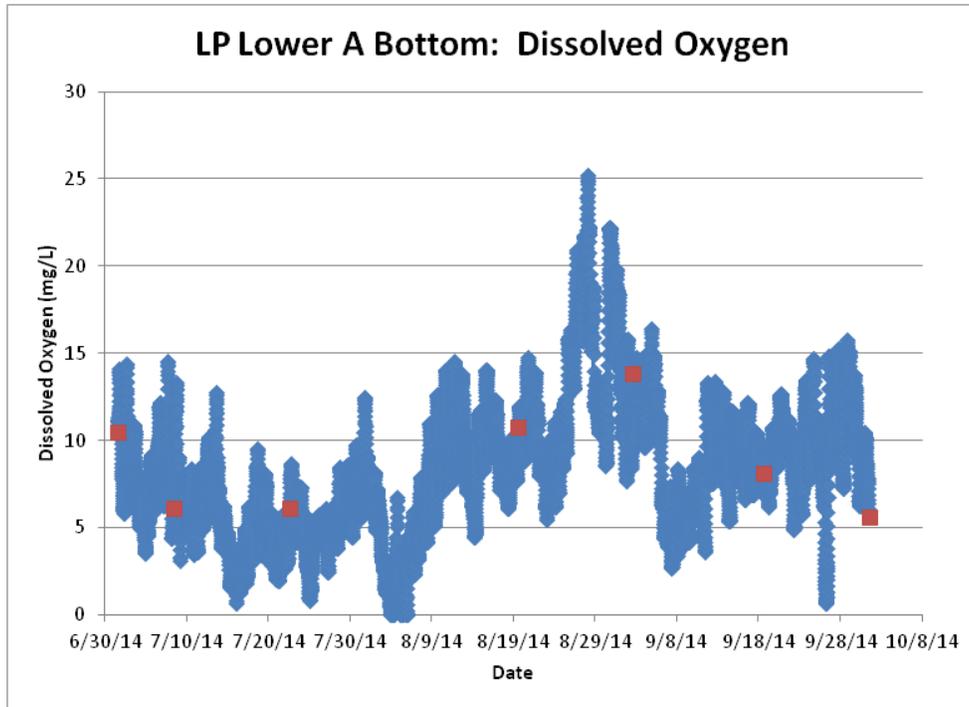


Figure 52. Dissolved oxygen time series data plots for surface deployed LP Lower A sonde. Red dots denote calibration samples.

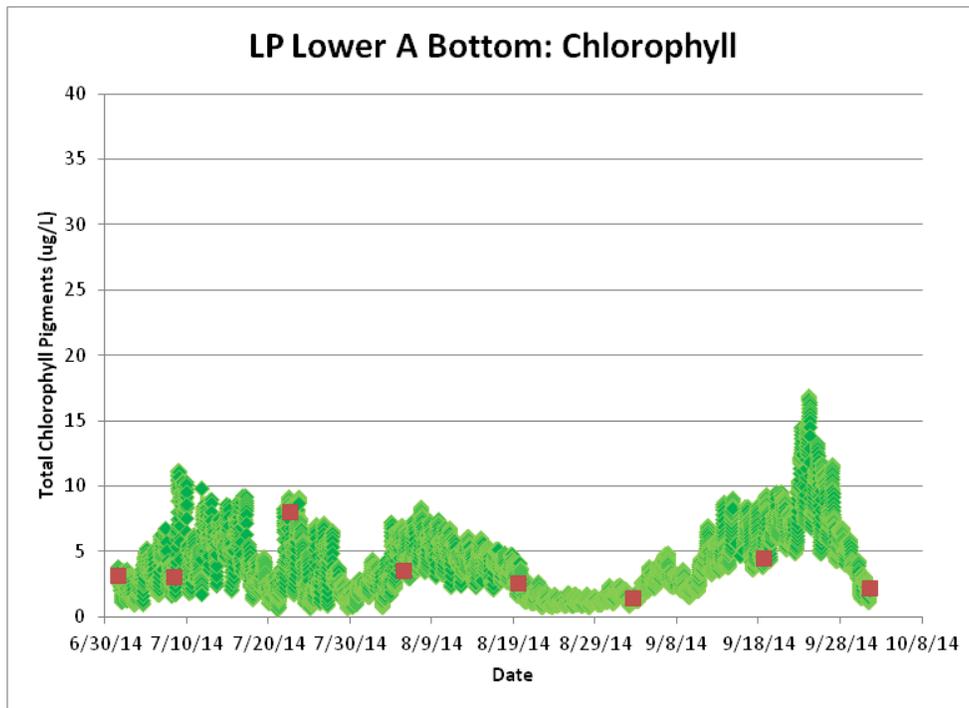


Figure 53. Chlorophyll-a (CHLA) time series data plots for surface deployed LP Lower A sonde. Red dots denote calibration samples.

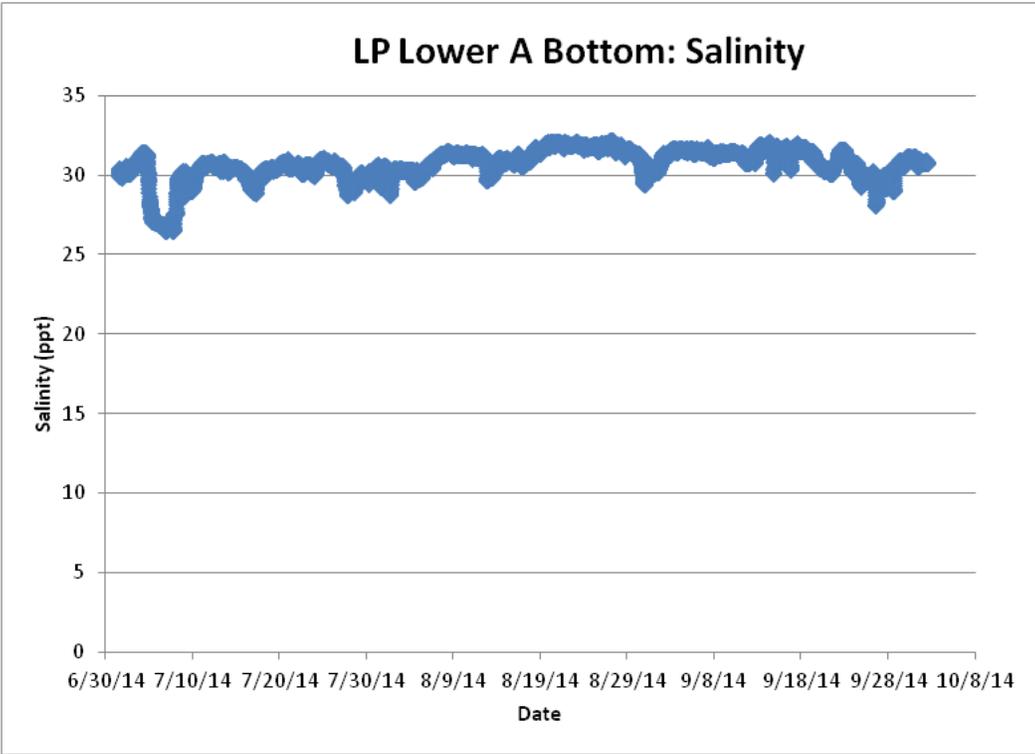


Figure 54. Time series record of salinity for LP Lower A mooring.

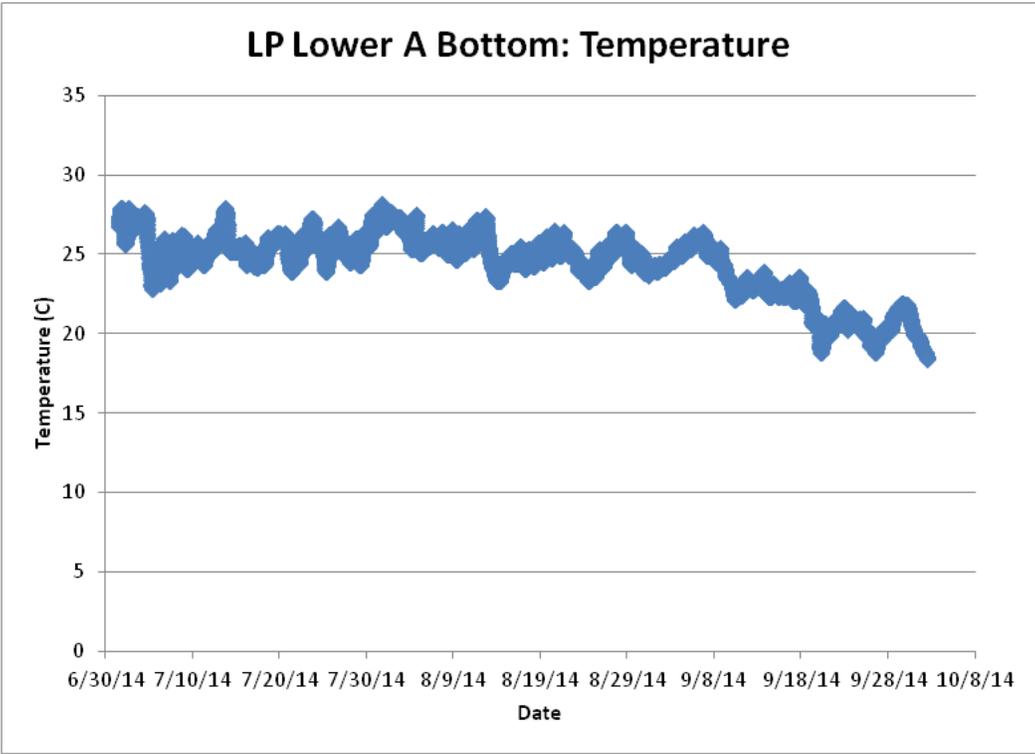


Figure 55. Time series record of temperature for LP Lower A mooring.

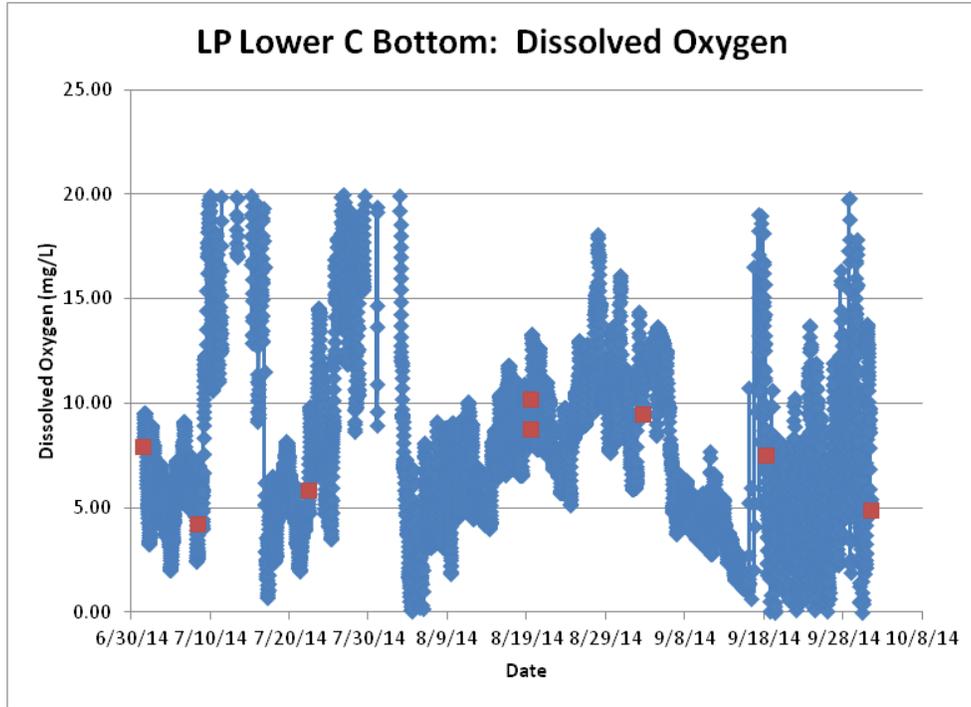


Figure 56. Dissolved oxygen time series data plots for surface deployed LP Lower C sonde. Red dots denote calibration samples.

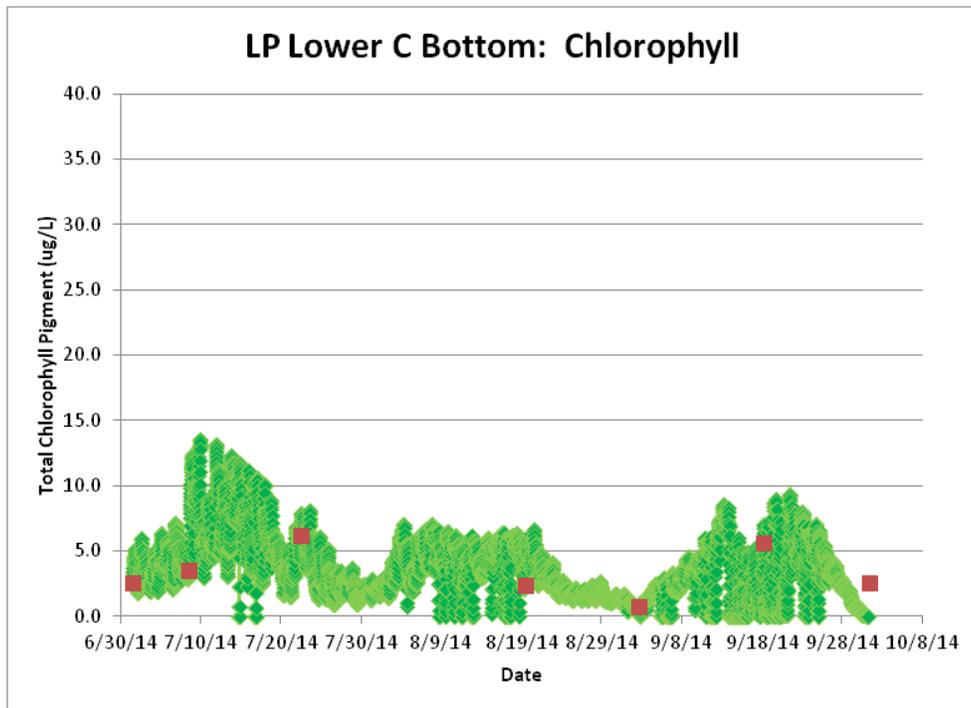


Figure 57. Chlorophyll-a (CHLA) time series data plots for surface deployed LP Lower C sonde. Red dots denote calibration samples.

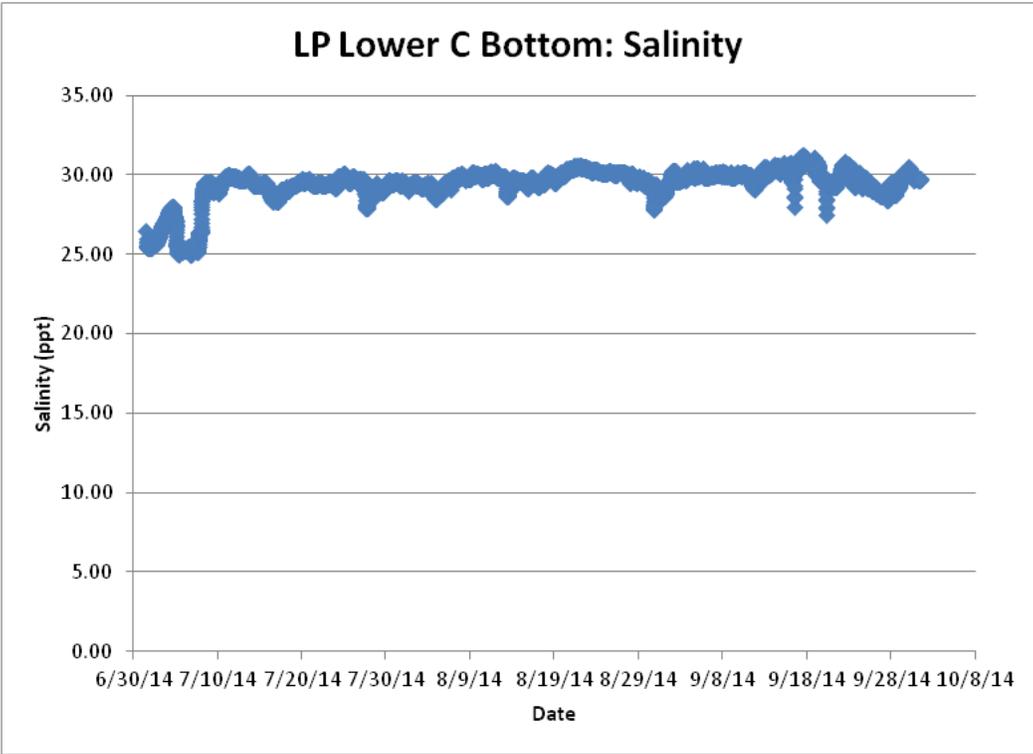


Figure 58. Time series record of salinity for LP Lower C mooring.

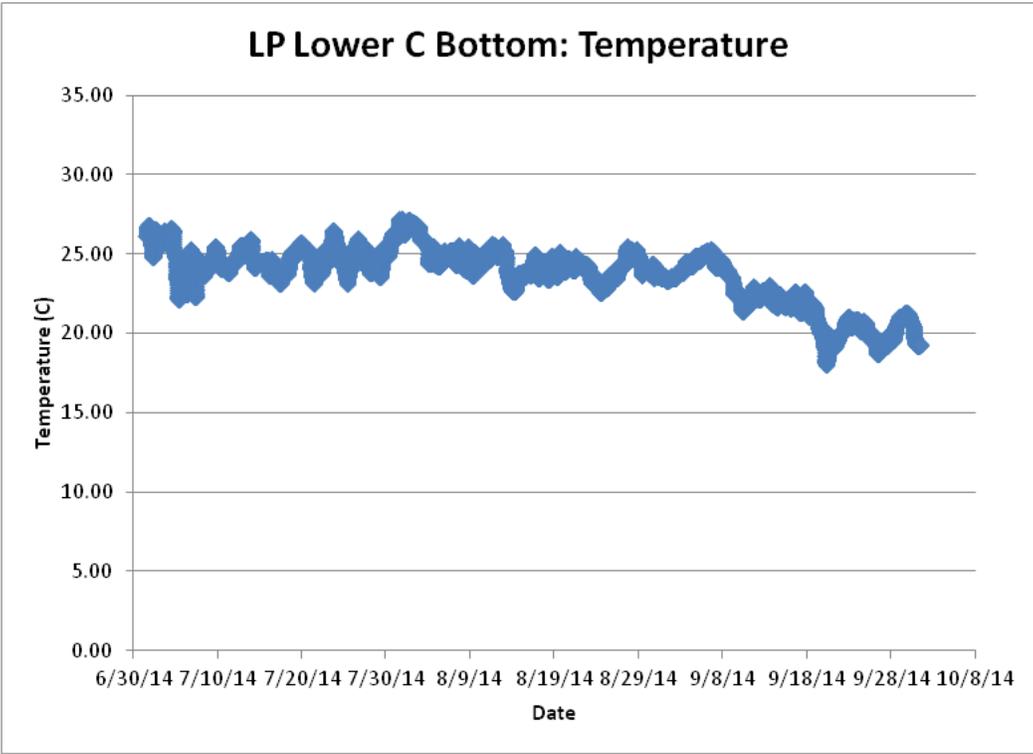


Figure 59. Time series record of temperature for LP Lower C mooring.

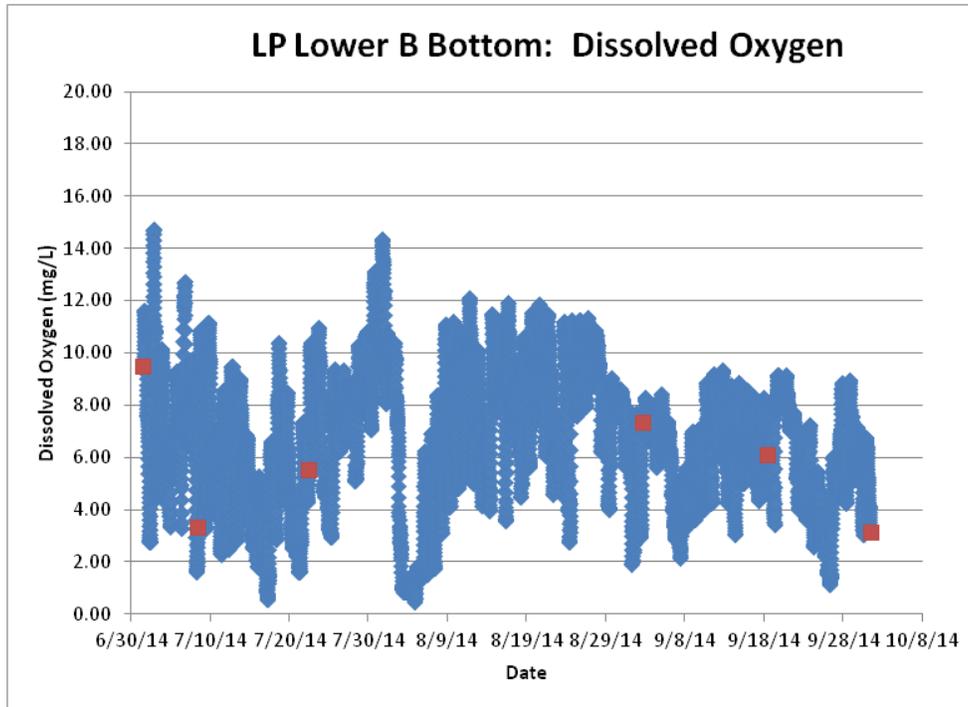


Figure 60. Dissolved oxygen time series data plots for surface deployed LP Lower B sonde. Red dots denote calibration samples.

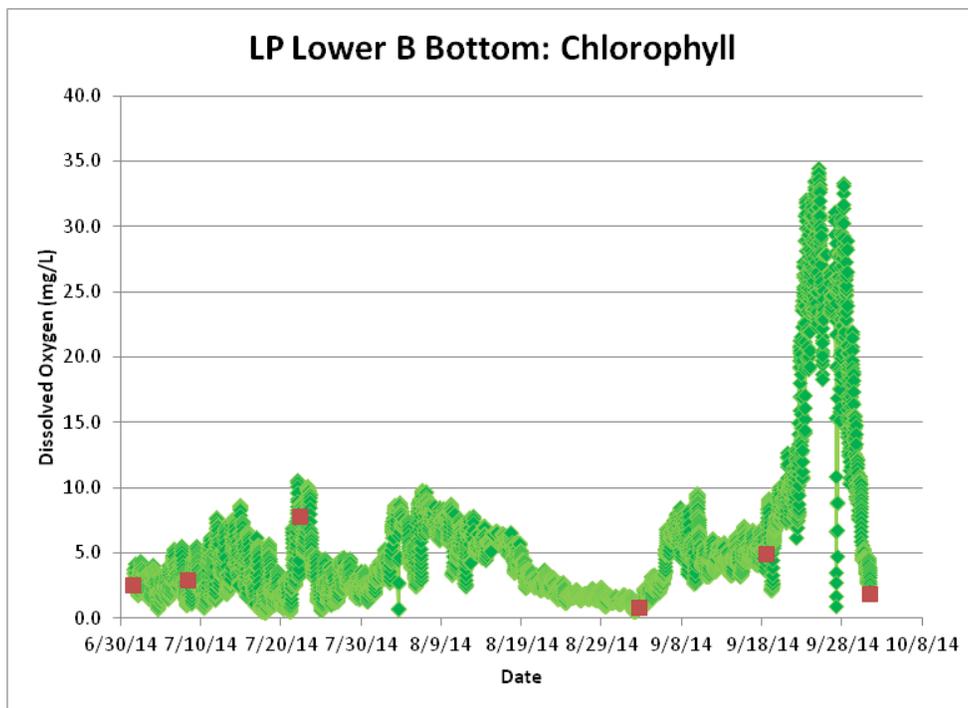


Figure 61. Chlorophyll-a (CHLA) time series data plots for surface deployed LP Lower B sonde. Red dots denote calibration samples.

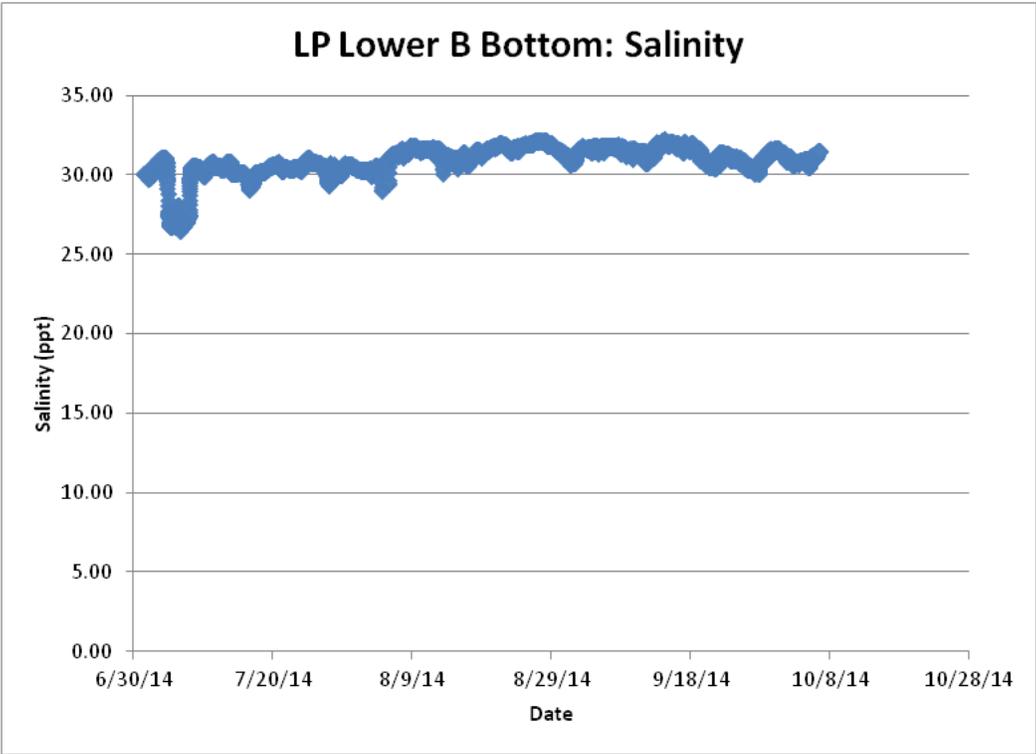


Figure 62. Time series record of salinity for LP Lower B mooring.

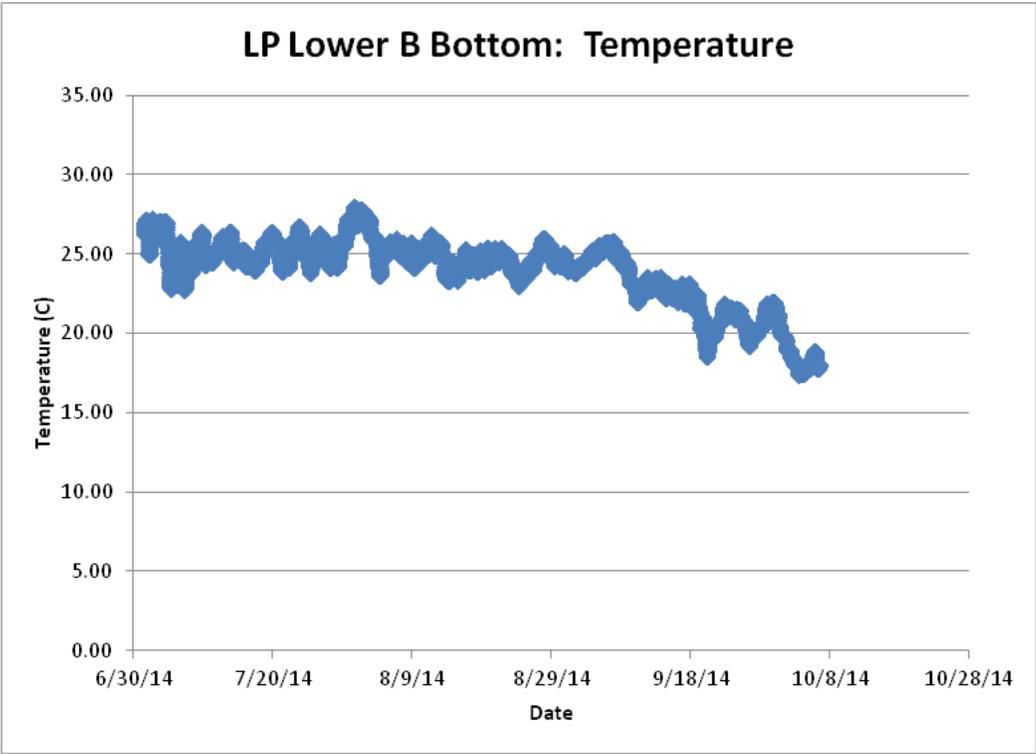


Figure 63. Time series record of temperature for LP Lower B mooring.

Results from Year 3 (2015) Mooring Deployment: In 2015 there were no changes to the mooring deployment program from the approach and protocols used in the 2014 program. Results from the 2014 deployment program indicated that sondes were placed appropriately relative to the oyster racks as well as the up and downgradient locations. As in 2014, the oyster raft surface sensor was free floating at about 5 cm from the surface (LP OYS RACK). Additionally, LP OYS 2 (bottom mooring) was deployed adjacent to the oyster rack but far enough away that it was not directly under the racks during any slight shifts in location of the racks due to wind or tidal effects. All other locations and monitoring parameters remained the same as in 2014.

Table 7 DO /CHLA Mooring locations for the 2015 Year 3 sampling period.

2015 DO MOORING LOCATIONS		
Markers	Coordinates:	
LP UPPER B	N 041° 33.283'	W 070° 35.476'
LP OYS RACK	N 041° 33.223'	W 070° 35.461'
LP LOWER A	N 041° 33.185'	W 070° 35.408'
LP LOWER C	N 041° 33.146'	W 070° 35.373'
LP LOWER B	N 041° 33.110'	W 070° 35.343'

The time-series moorings show a similar, but more refined, picture of the gradient in chlorophyll a and dissolved oxygen through the oyster deployment area. In general the patterns follow those from the grab sampling program, but with more detail. First, it appears that the oxygen depletion in Little Pond is more severe than found from the water column sampling, due to the higher frequency of sampling and the proximity to the bottom of the bottom sensors.

The water column in the region of the moorings was vertically stratified during the recording period with the effect that oxygen levels in the surface layer were consistently higher than those at each of the bottom sensors. The level of oxygen depletion and the vertical gradient is consistent with the high nitrogen enrichment (TN = 0.8 – 0.6 mg/L) and chlorophyll a levels (10-25 ug/L).

In general, the oxygen field showed a slight improvement in the direct vicinity of the oyster deployment but the enhancement was small and variable. However, this oxygen “bump” disappeared by mooring Lower B, being evident mainly near the rack and moorings Lower B and C. Similarly, chlorophyll a levels were generally high (10-25 ug/L) and diminished slightly down gradient to a low at mooring Lower C and rising again by Lower B. There was a single pronounced bloom which was clearest within the deployment area, possibly resulting from the DIN release associated with the oyster activities. But overall, conditions within the oyster area appeared to be as good or slightly better than in the adjacent areas, so that there was no evidence of a negative impact of the oysters.

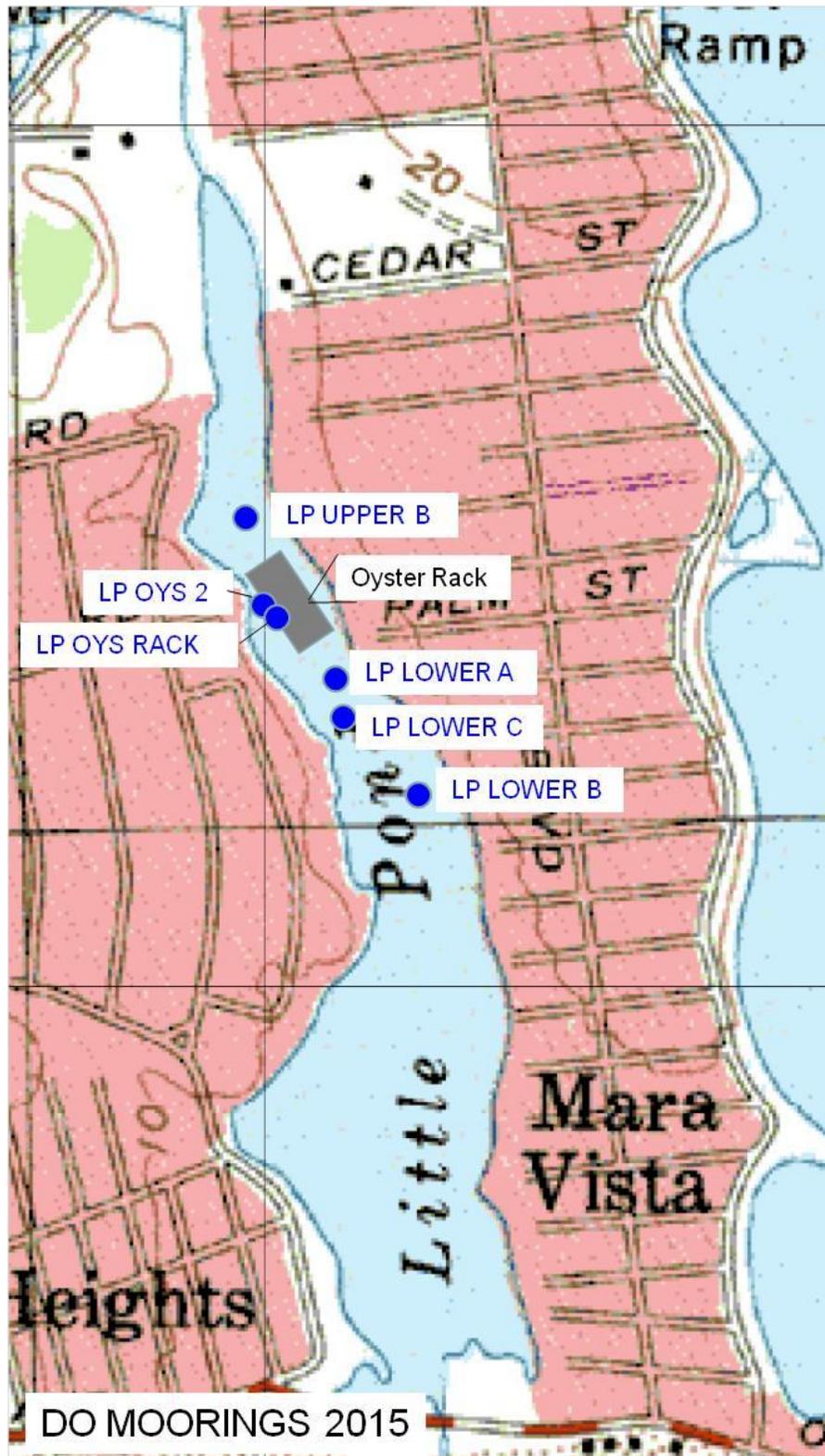


Figure 64. Final mooring locations reflecting deployment pattern in 2015 consistent with deployments in 2014 for cross comparability.

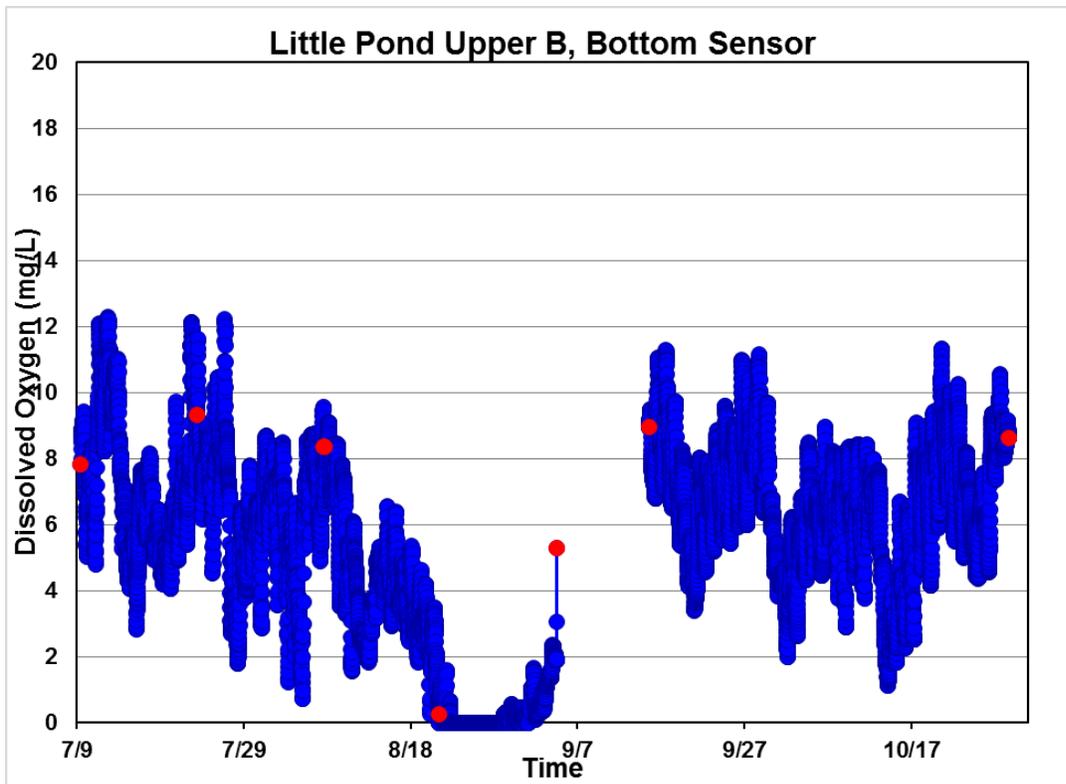


Figure 65. Oxygen time-series Little pond Upper B station, Bottom Sensor, 2015.

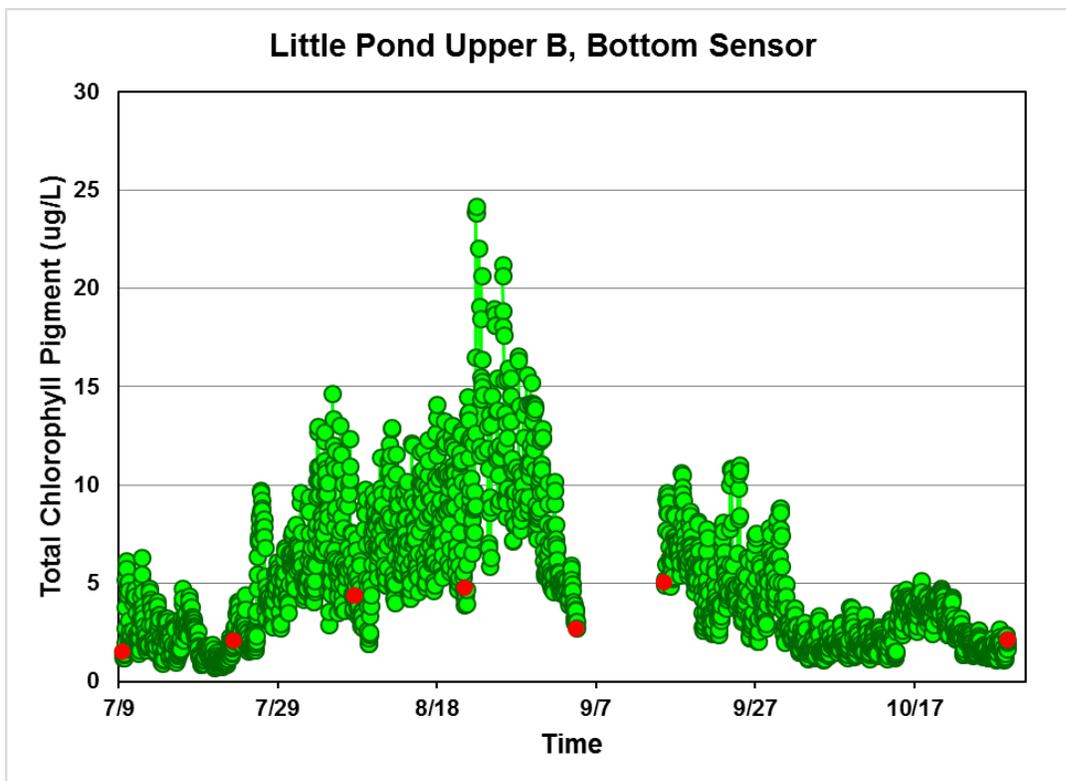


Figure 66. Chlorophyll a fluorescences time-series Little pond Upper B station, Bottom Sensor, 2015.

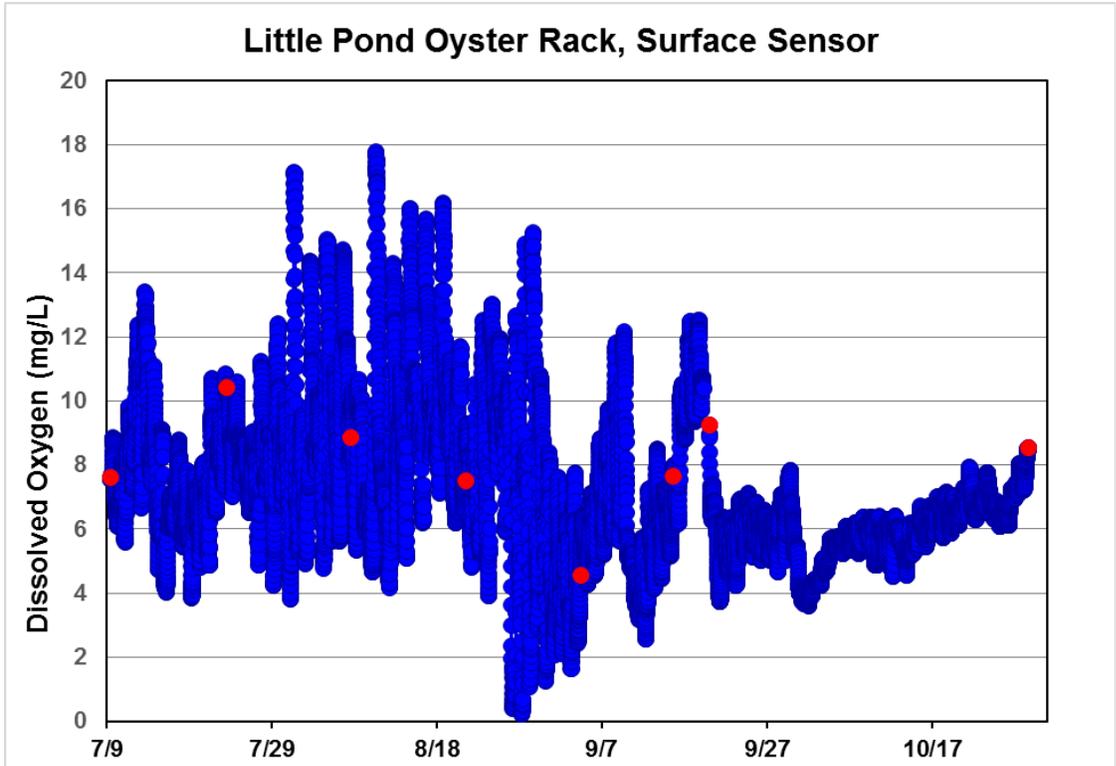


Figure 67 Oxygen time-series Little Pond Oyster Rack, Surface Sensor, 2015.

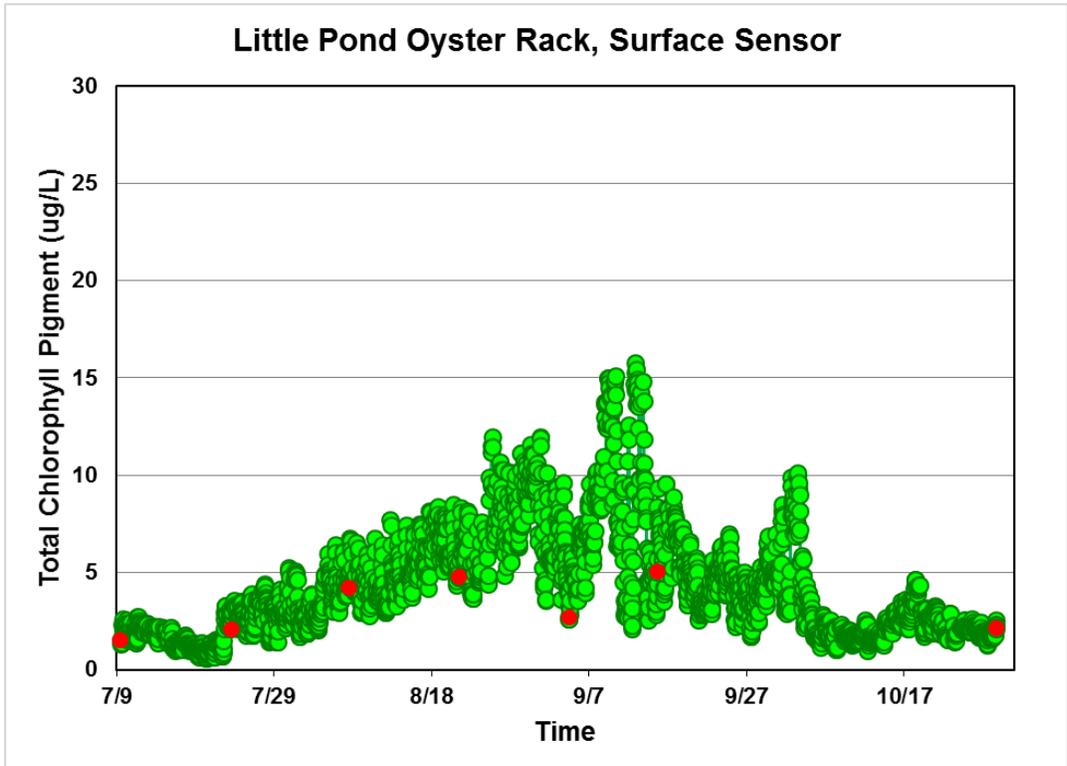


Figure 68. Chlorophyll a fluorescences time-series Little pond Oyster Rack Surface Sensor, 2015.

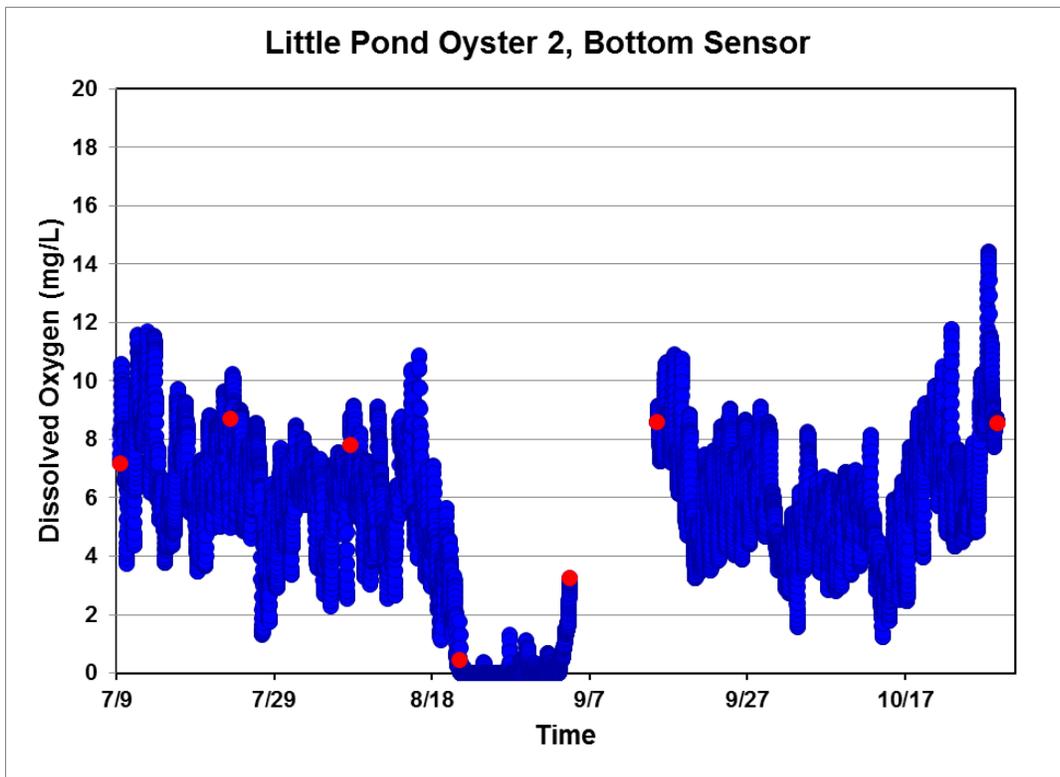


Figure 69. Oxygen time-series Little Pond Oyster 2, Bottom Sensor, 2015.

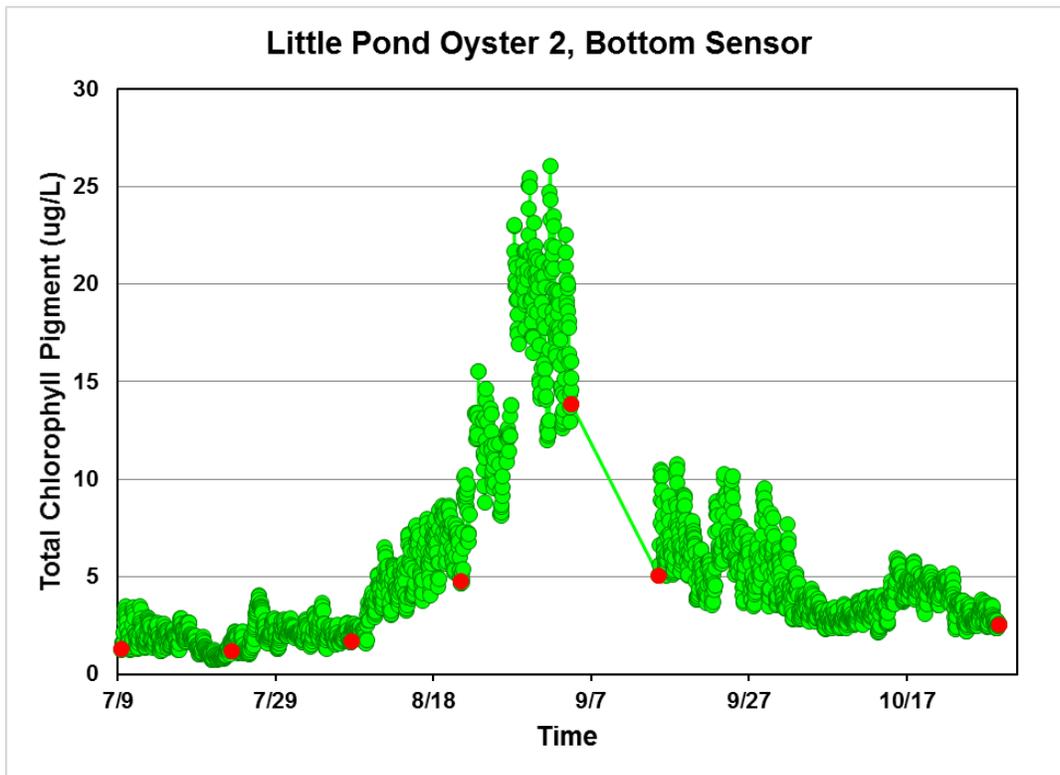


Figure 70. Chlorophyll a fluorescence time-series Little Pond Oyster 2, Bottom Sensor, 2015.

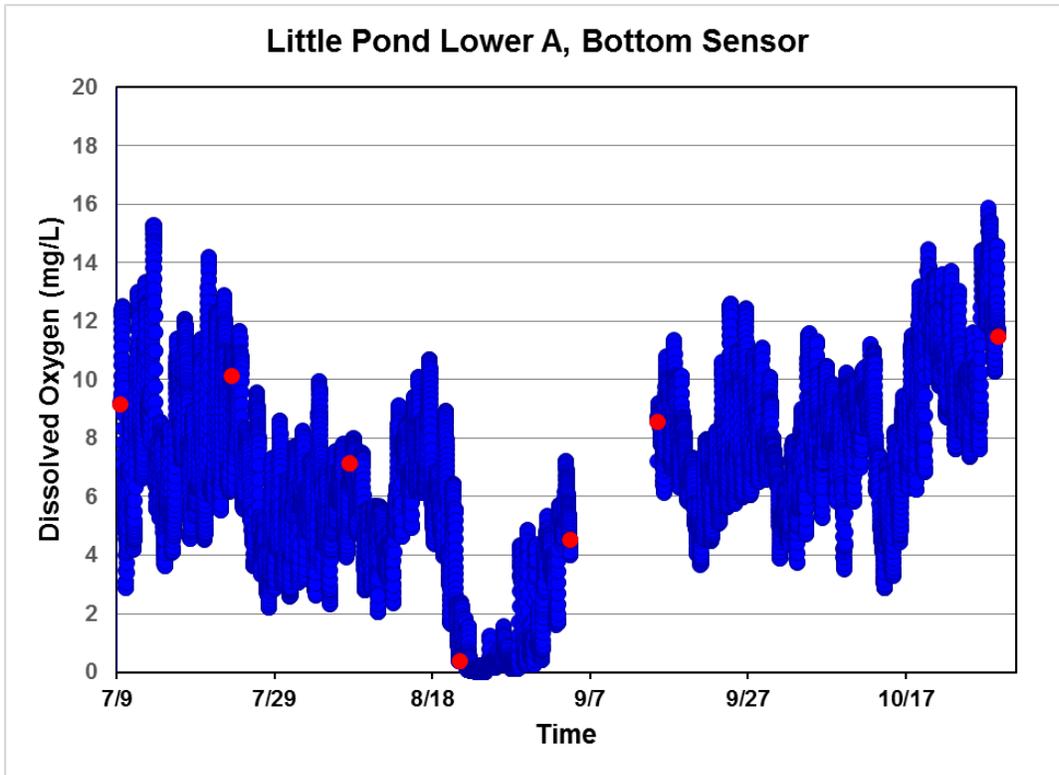


Figure 71. Oxygen time-series Little Pond Lower A, Bottom Sensor, 2015.

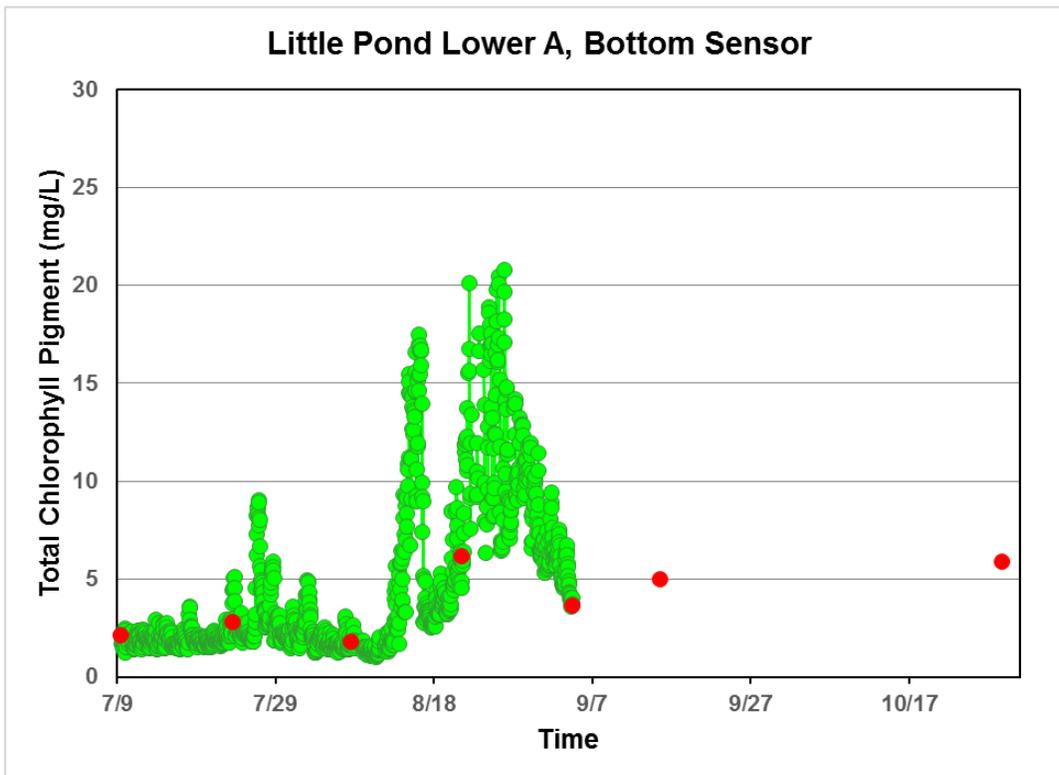


Figure 72. Chlorophyll a fluorescence time-series Little Pond Lower A, Bottom Sensor, 2015.

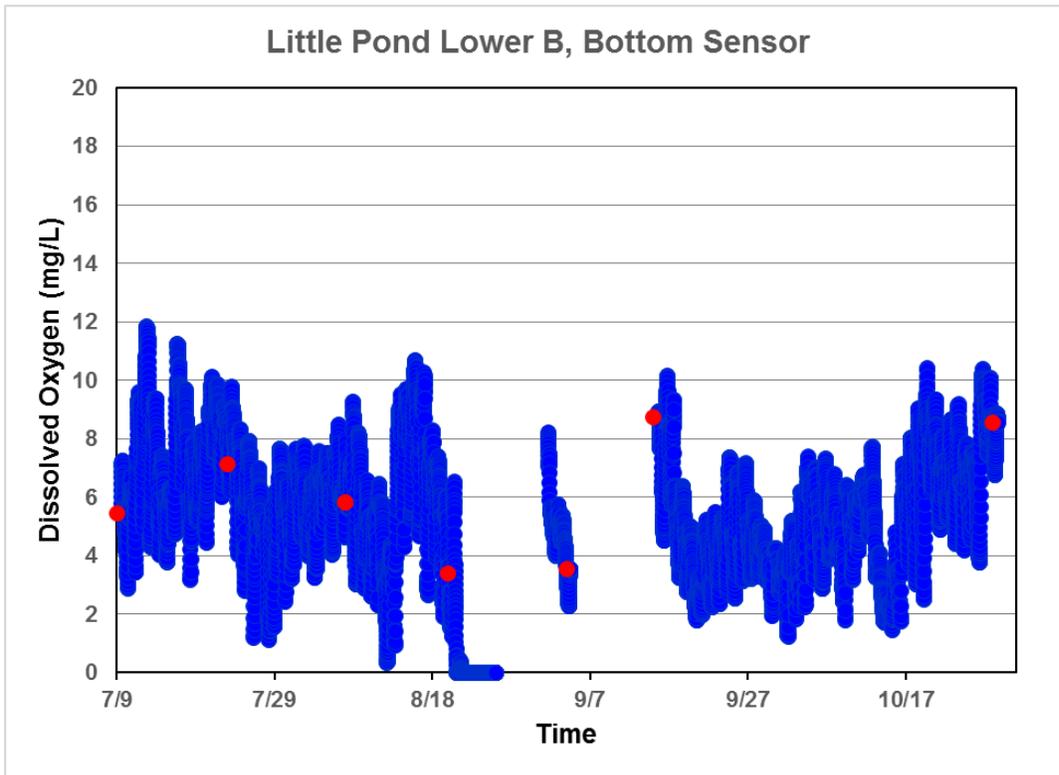


Figure 73. Oxygen time-series Little Pond Lower B, Bottom Sensor, 2015.

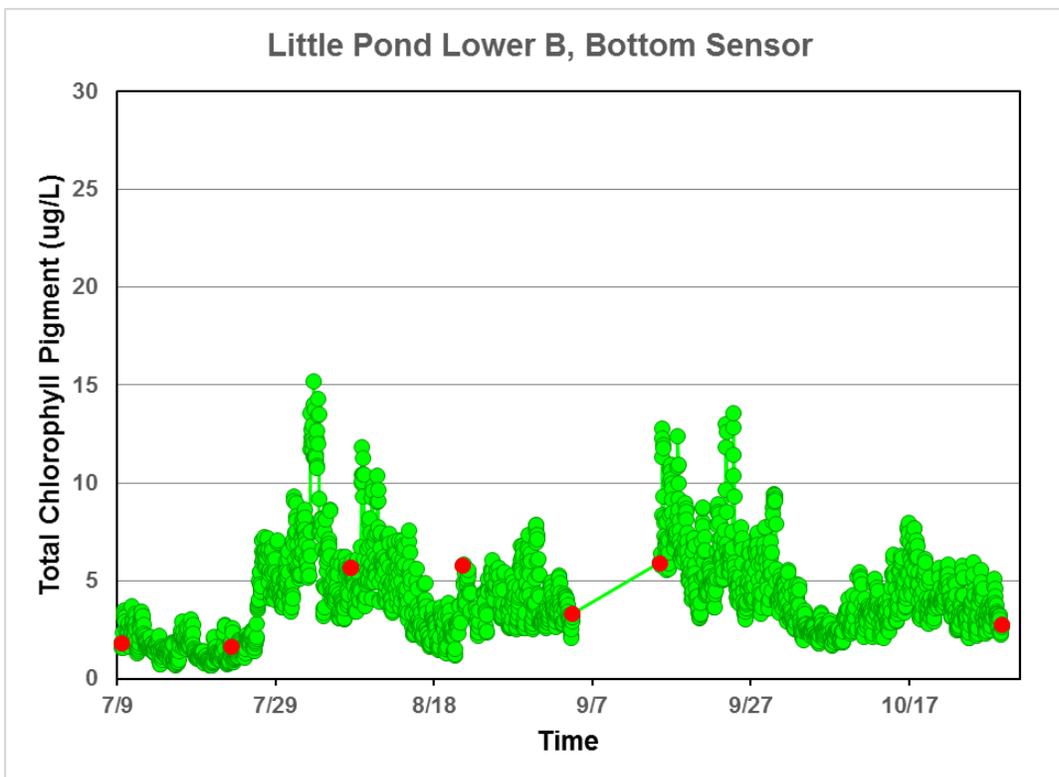


Figure 74. Chlorophyll a fluorescence time-series Little Pond Lower B, Bottom Sensor, 2015.

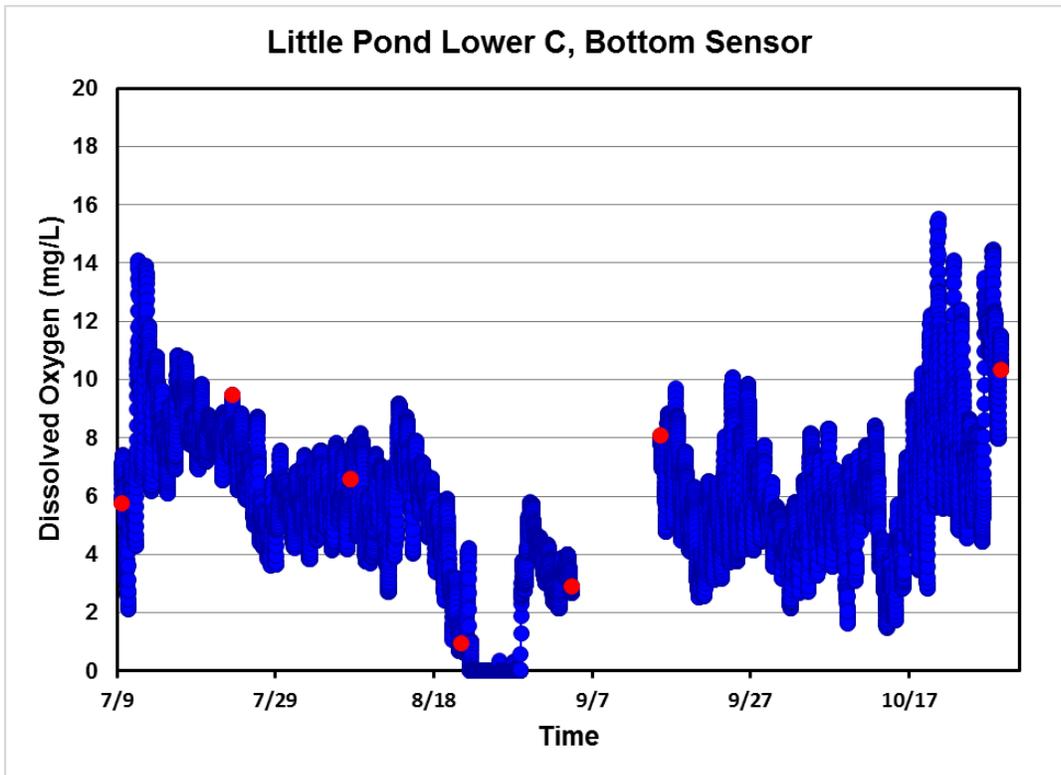


Figure 75. Oxygen time-series Little Pond Lower C, Bottom Sensor, 2015.

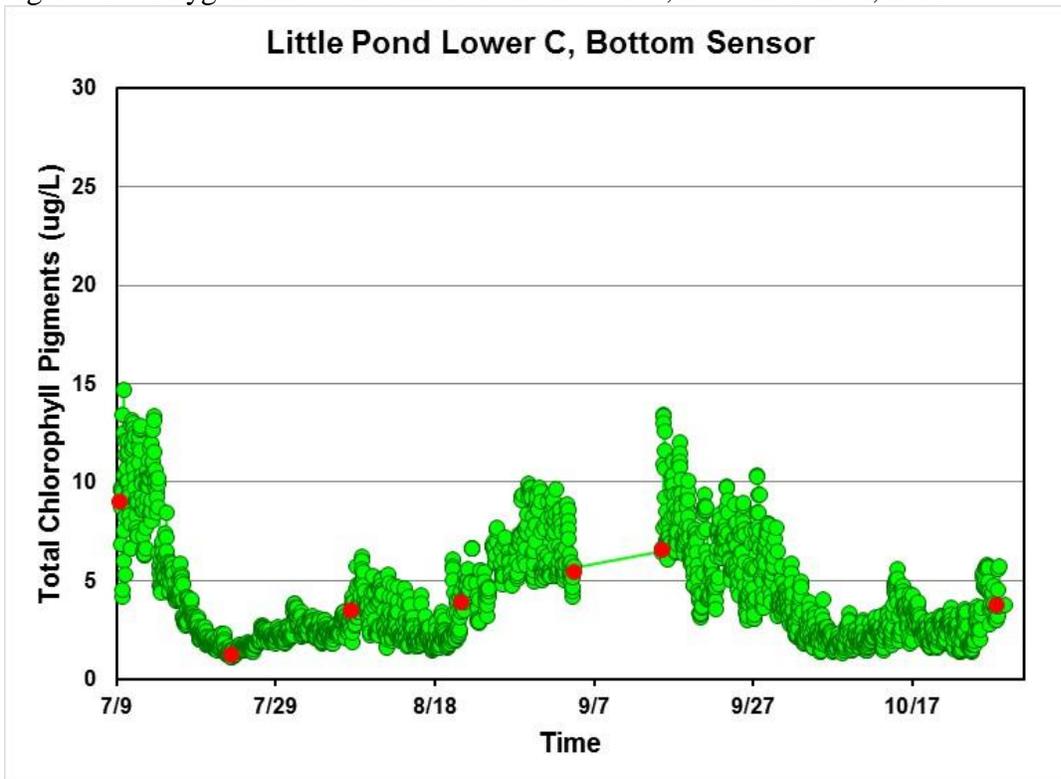


Figure 76. Chlorophyll a fluorescence time-series Little Pond Lower C, Bottom Sensor, 2015.

Analysis of Turbidity in Little Pond

Analysis of Turbidity in Little Pond for 2013 and 2014 Oyster Deployments: Turbidity is a measure of the water clarity and was determined at each of the 4 final mooring locations (Figure 77) using HOBO® Temperature/Light Pendant Data Loggers (UA-002-64). These light pendants were permanently positioned just below the waters surface (0.2m) and close to the bottom at a depth of 1m at each station. Data was compiled from July 2-October 2, 2013 for all sites except LP OYS2, which was added on July 9. There was a gap in data collection from August 8-15 due to technical difficulties and the compiled data reflects these time frames.

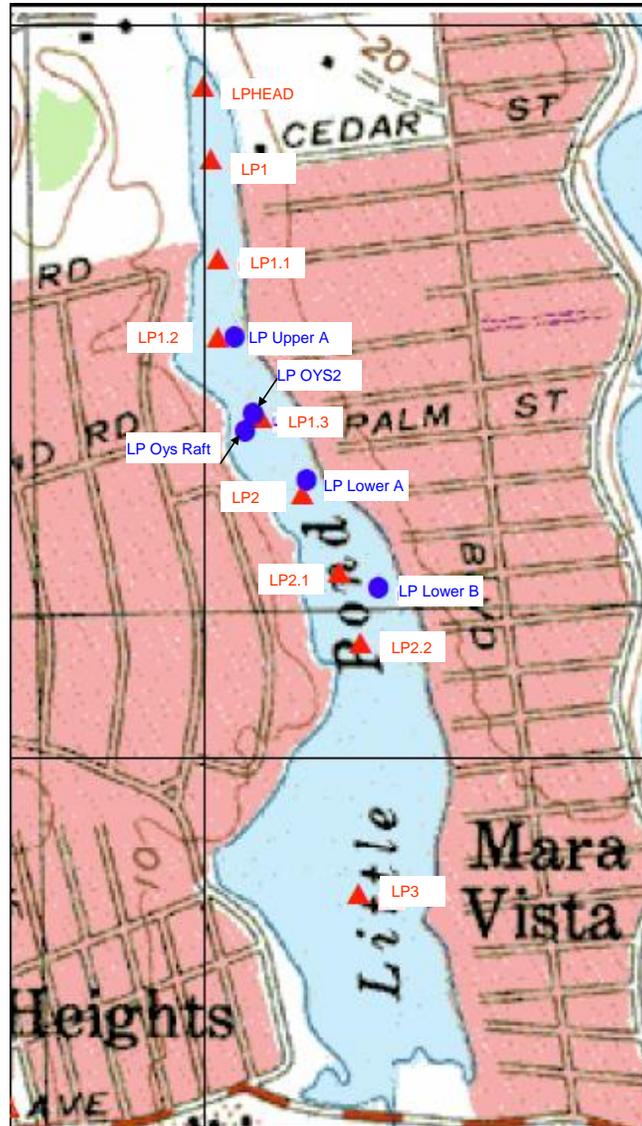


Figure 77: Site locations of the water quality monitoring (in red) and dissolved oxygen/chlorophyll moorings (in blue) for Little Pond.

The light pendants measured light intensity in units of $\mu\text{E}/\text{m}^2/\text{s}$ every 5 minutes and profiles were used to calculate the percent surface irradiance and the light extinction coefficient (k) within the water column. The light extinction coefficient, k was calculated using the Beer-

Lambert Law which describes the logarithmic decay of light through a medium; the larger the light extinction coefficient, the more rapid the loss of light through the water column. In contrast, small light extinction coefficients reflect greater light transmission through the water column. The mean daily light intensity was also calculated using only the active photoperiod. In addition to the discrete light profile measurements, a water sample was collected 30cm from the bottom and filtered for total suspended solids, TSS and chlorophyll-a. The site located within the oyster raft only included a YSI DO/chla sonde at the surface.

The light characteristics using the light profiles and water quality samples taken at the moorings pertaining to Little Pond during the oyster pilot project are shown below (Table 8). The highest light penetration was located at the site closest to the oyster raft, LP OYS2 (Figure 77) and the light extinction coefficient was markedly lower at the same site closest to the oysters, indicating the oysters influenced the turbidity of the water (Figure 78). There was a distinctive linear trend of decreasing light extinction coefficients from the head to the mouth of Little Pond when excluding the site closest to the oyster raft ($r^2=0.99$) giving a positive indication for the oysters improving the water clarity. The total suspended solids and total chlorophyll pigments do not however show a relationship with the light extinction coefficients or light penetration.

Table 8. Results from the continuous light profiles measurements from Little Pond during year 1 (2013) showing the mean light intensity, penetration, and the light extinction coefficients along with the total suspended solids and total chlorophyll pigments at each station.

Station	Approximate distance from head (ft)	Depth	Light Intensity (mE/m ² /s)	Mean Penetration	Beer-Lambert Light extinction coefficient (k)	Total Suspended Solids (mg/L)	Total Chlorophyll-a Pigments (mg/L)
LP Upper A	1500	Surface	231.66				
		Bottom	63.69	27.69%	1.92	26.79	11.93
LP OYS2	1700	Surface	174.59				
		Bottom	55.22	32.83%	1.74	32.00	11.68
LP Oyster Rack	1850	Surface	ND	ND	ND	20.68	20.78
LP Lower A	2050	Surface	217.73				
		Bottom	60.11	27.49%	1.82	14.17	14.08
LP Lower B	2750	Surface	208.33				
		Bottom	60.34	30.09%	1.64	31.24	9.68

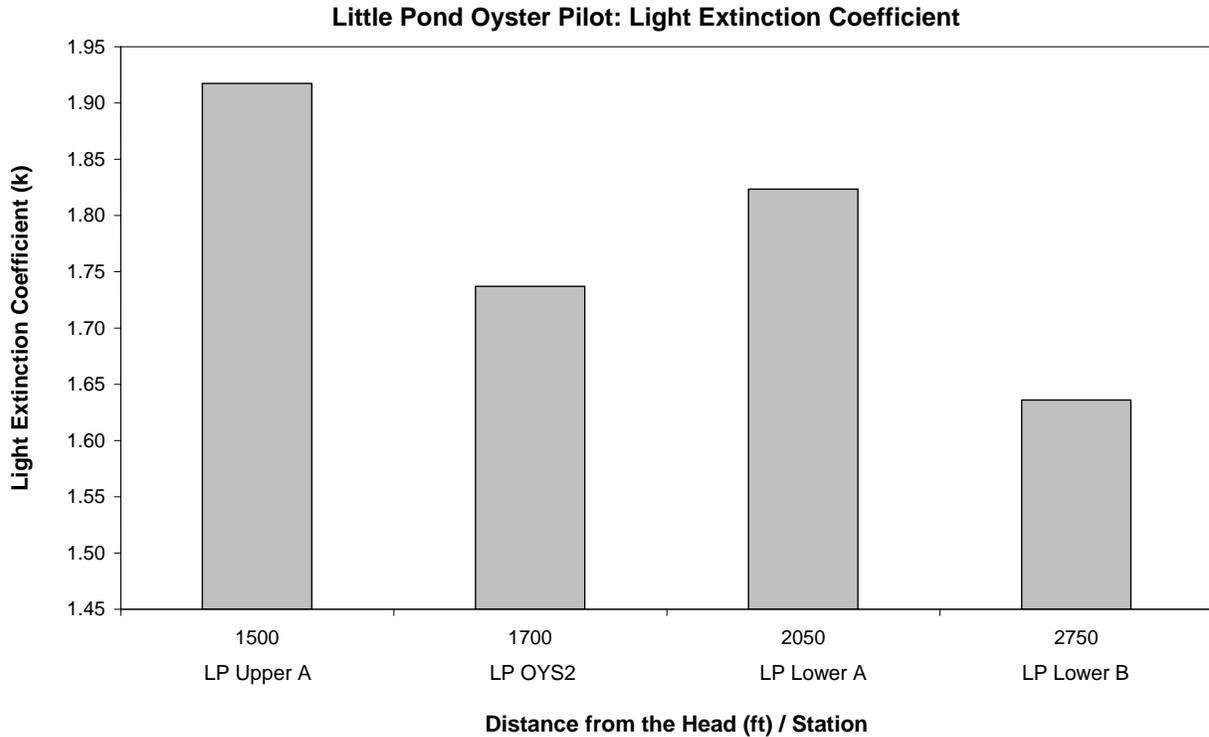


Figure 78: Results showing mean light extinction coefficients calculated using the light profiles at each site in Little Pond in 2013.

Turbidity can be related to the tides, with the highest tides producing the largest water volume and thus more turbid waters, and the opposite concept being true for the lowest tides. The spring tides produce the strongest high and lowest low tides and occur during the full and new moons, with the extreme tides occurring on the new moon. Neap tides have the smallest amplitude high and low tides and occur during the first and third quarter moons. The tidal amplitude in Vineyard Sound in the vicinity of Little Pond is relatively small, around 1.5 feet. By looking at the light intensity of the stations profiles, you can see the surface and bottom are correlated, but a relationship between turbidity and tides over the duration of the monitoring effort is unclear (Figure 79).

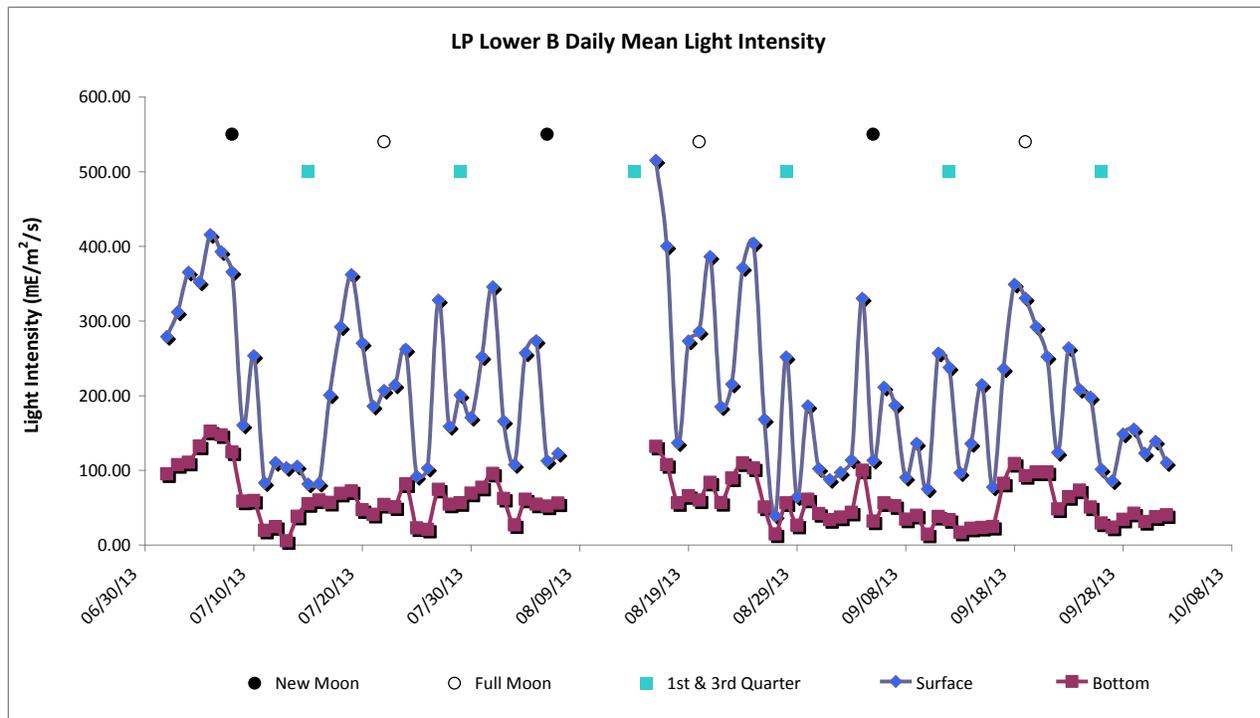


Figure 79: Light intensity time series for the site closest to the mouth of Little Pond, LP Lower B, in conjunction to the moon phase which reflects tidal amplitude.

Displaying a direct correlation of turbidity and tides in the entire data set is not concise enough to show a direct connection, but by using the extreme high tide and low tides during a new moon and a specific light profile can show the influence of tides on turbidity more closely. The new moon tides during this project occurred on July 8, August 6, and September 5, which coincided with extreme low tides between 5-6:00 a.m./p.m. and high tides between 11:30-noon. When plotting each station's light intensity and light penetration for these days it appears the photoperiod plays an over-arching role in light (Figure 80). There is about 25% light penetration to the bottom during the extreme low tides, with the most penetration occurring at 12:25 p.m. It is interesting to note though that with the extreme high tide predicted for 12:05 a.m. for July 8 there was a dramatic drop in light penetration even though the sun is at its zenith. This illustrates that the extreme high water did reduce the watercolumn light intensity and penetration, with increased turbidity for a window of time. It is more difficult to pinpoint a decrease in turbidity with the extreme low tides occurring at 6:44 a.m. and 6:57 p.m. since the sunrise and set were so close to these times (5:43 a.m. & 7:52 p.m. respectively).

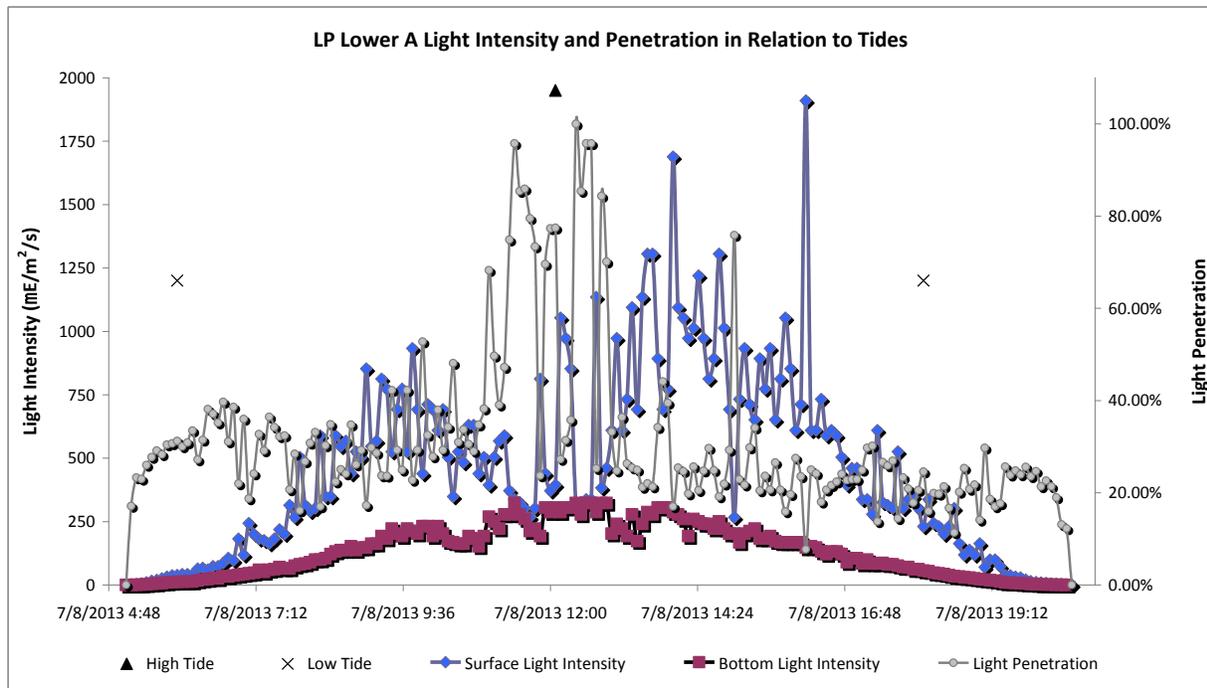


Figure 80: Light intensity and penetration during the extreme high/low spring tide of the new moon on July 8, 2013.

Another potential contributor to turbidity could be precipitation and wind strength and direction. A due south wind would drive boundary water from Vineyard Sound into Little Pond. During the summer, there is predominantly a southwest wind. During the duration of the 2013 Little Pond Oyster project there were several rain events (Table 9), but most occurring in the twilight or overnight hours when light measurements are low or zero. A substantial rain event occurred on July 26 where the effects of rain on turbidity could be explored, yet there was no direct and immediate relationship that shows an increase in turbidity (higher light extinction coefficient or decreased light penetration) with precipitation (Figure 81). The same trends were seen in all four stations and this could be due to lower photosynthetically active radiation (PAR) reaching the pond surface, typical of cloudy, rain events. By looking at the days preceding and following the storm event and the corresponding average PAR measurements, it can be seen that the average PAR makes a significant difference in the amount of light penetration possible (Figure 81). There was no rain recorded on July 25, but the average PAR was similar to July 26 (274 & 273 $\mu\text{mol}/\text{m}^2/\text{sec}$ respectively) when there was a rain event. In addition, both days had very similar light penetration (Figure 81), suggesting changes in turbidity here are more dependent on incoming light than rain and storm run-off. The average PAR measurements were measured at the NERRS meteorological station in Waquoit Bay.

Table 9 Date and time of rain events and corresponding precipitation and wind characteristics from a meteorological station in Waquoit Bay supplied by the NOAA NERR Centralized Data Management Office <http://cdmo.baruch.sc.edu/get/export.cfm> from July-October 2013.

Date	Time	Duration	Cumulative Precipitation (mm)	Wind Speed (m/s)	Max Wind (m/s)	Average Wind Direction (degrees)	Average Wind (cardinal direction)
7/1/2013	14:45	0:15	13.7	1.6	4.7	222	SW
7/10-7/11/13	23:45-0:15	1:30	2.5	1.3	4.7	249	WSW
7/21/2013	4:45-6:00	1:15	14.2	1.1	2.6	230	SW
7/25-7/26/13	22:30-17:45	19:15	15.7	2.4	5.9	187	S
7/28/2013	2:30-4:30	2:00	5.3	0.8	2.1	112	ESE
8/13/2013	11:30-14:30	9:15	2.8	0.7	2.1	166	SSE
8/18/2013	17:45-20:45	3:00	1.1	0.3	0.9	118	ESE
8/27/2013	5:00-10:00	5:00	16.5	0.5	1.5	185	S
9/1/2013	1:15-2:15	2:00	14.7	1.9	6.3	238	SW
9/3/2013	15:45-19:30	3:45	29.5	0.8	2.4	177	S
9/13/2013	4:30-9:30	5:00	8.9	0.9	2.7	251	WSW

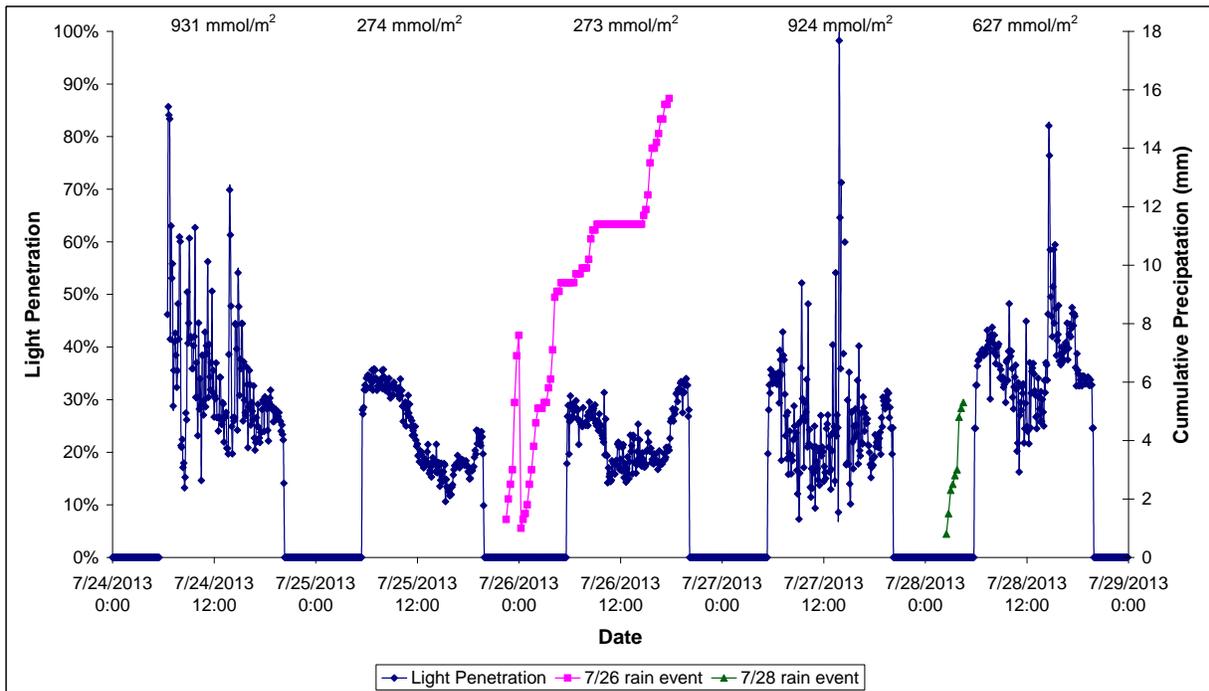


Figure 81. Light extinction coefficient relative to the cumulative precipitation during the July 26 and 28, 2013 rain events at the Little Pond station LP Lower B ($\mu\text{mol}/\text{m}^2/\text{sec}$).

Water Temperature: Temperature was measured every 5 minutes using the HOBO temperature and light pendants and averaged from July 2-October 2, 2013 for all sites except for LP OYS2, which was added on July 9, 2013. There was a gap in the data collection from August 8-15, 2013. The temperature was averaged for each station and depth reflecting the above time frames (Table 10 below). Light sensors were not deployed at the surface Oyster Raft station.

Table 10. 2013 Temperature profiles for the light meters sites in Little Pond in 2013.

Station	Depth	Temperature (°C)
LP Upper A	Surface	25.01
	Bottom	24.57
LP OYS2	Surface	24.83
	Bottom	24.46
Lp Lower A	Surface	25.02
	Bottom	25.54
LP Lower B	Surface	24.69
	Bottom	24.42

Analysis of Turbidity in Little Pond 2014: Light profiles were measured in the 4 same mooring locations in 2014 as 2013 (Figure 77) using HOBO® Temperature/Light Pendant Data Loggers (UA-002-64). An additional dissolved oxygen mooring was deployed in 2014, LP Lower C. Data was compiled from July 1-October 6, 2014 for all sites except LP Lower A, which collected data until August 19 due to damage to the meter (Table 11).

Table 11. 2014 Results from the continuous light profiles measurements from Little Pond showing the mean light intensity, penetration, and the light extinction coefficients along with the total suspended solids and total chlorophyll pigments at each station.

Station	Approximate distance from head (ft)	Depth	Light Intensity (mE/m ² /s)	Mean Penetration	Beer-Lambert Light extinction coefficient (k)	Total Suspended Solids (mg/L)	Total Chlorophyll-a Pigments (mg/L)
LP Upper A	1500	Surface	208.46				
		Bottom	67.56	36.11%	1.47	31.70	3.64
LP OYS2	1700	Surface	136.57				
		Bottom	65.52	47.01%	1.05	37.27	5.63
LP Oyster Rack	1850	Surface	ND	ND	ND	33.85	4.60
LP Lower A	2050	Surface	255.63				
		Bottom	111.94	45.35%	1.08	31.71	3.34
LP Lower C	2250	Bottom	ND	ND	ND	35.54	4.02
LP Lower B	2750	Surface	178.45				
		Bottom	95.16	55.43%	0.87	34.15	3.72

Little Pond Oyster Pilot: Light Extinction Coefficient

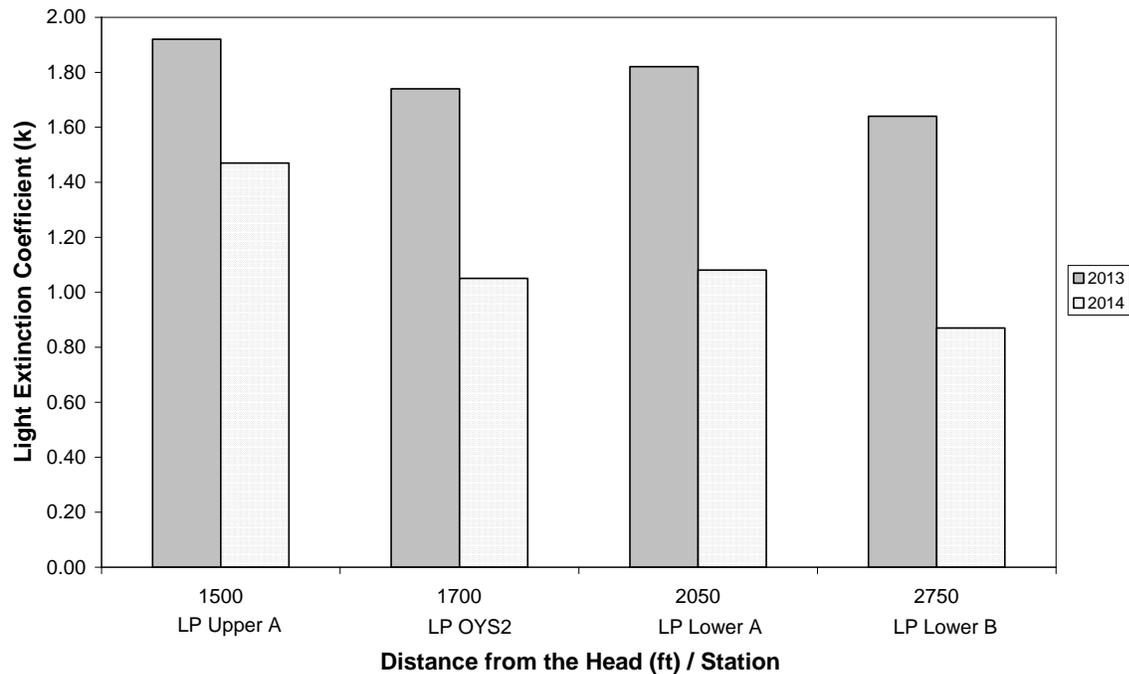


Figure 82. Comparison of mean light extinction coefficients calculated using light profiles in Little Pond in 2013 (solid bars) and 2014 (lightly shaded bars).

As stated above, the 2014 data showed the same trend as 2013 of decreasing light extinction coefficients from the head to the mouth of Little Pond when excluding the site closest to the oyster raft (LP OYS2, $r^2=0.97$), which was lower than expected in relation to location, giving a positive indication for the oysters improving the water clarity (Figure 82). It should be noted that light extinction coefficients at all sites in Little Pond during 2014 were lower than in 2013, yet the positive impact of the oysters on water clarity was similar.

The overall reduction in turbidity from 2013 was associated with distinctly lower total chlorophyll pigment concentrations. This significant decrease in total pigments in the water column is reflected in the higher mean light penetration and lower light extinction measurements revealed in 2014 results (Table 11).

The National Estuarine Research Reserve System monitors rain and wind at its Waquoit station. When comparing the 2013 and 2014 sampling seasons, the frequency of rain events does not differ significantly, but there were 2 major rain events in July 2014 that produced close to 16 and 12 mm of rain respectively (Figure 83). Also, the average and maximum wind speeds were greater in 2014 compared to 2013 during the same time period (2014 average wind speed 1.24 m/s, max. 6.1 m/s; 2013 average wind speed 1.18 m/s, max. 3.9 m/s).

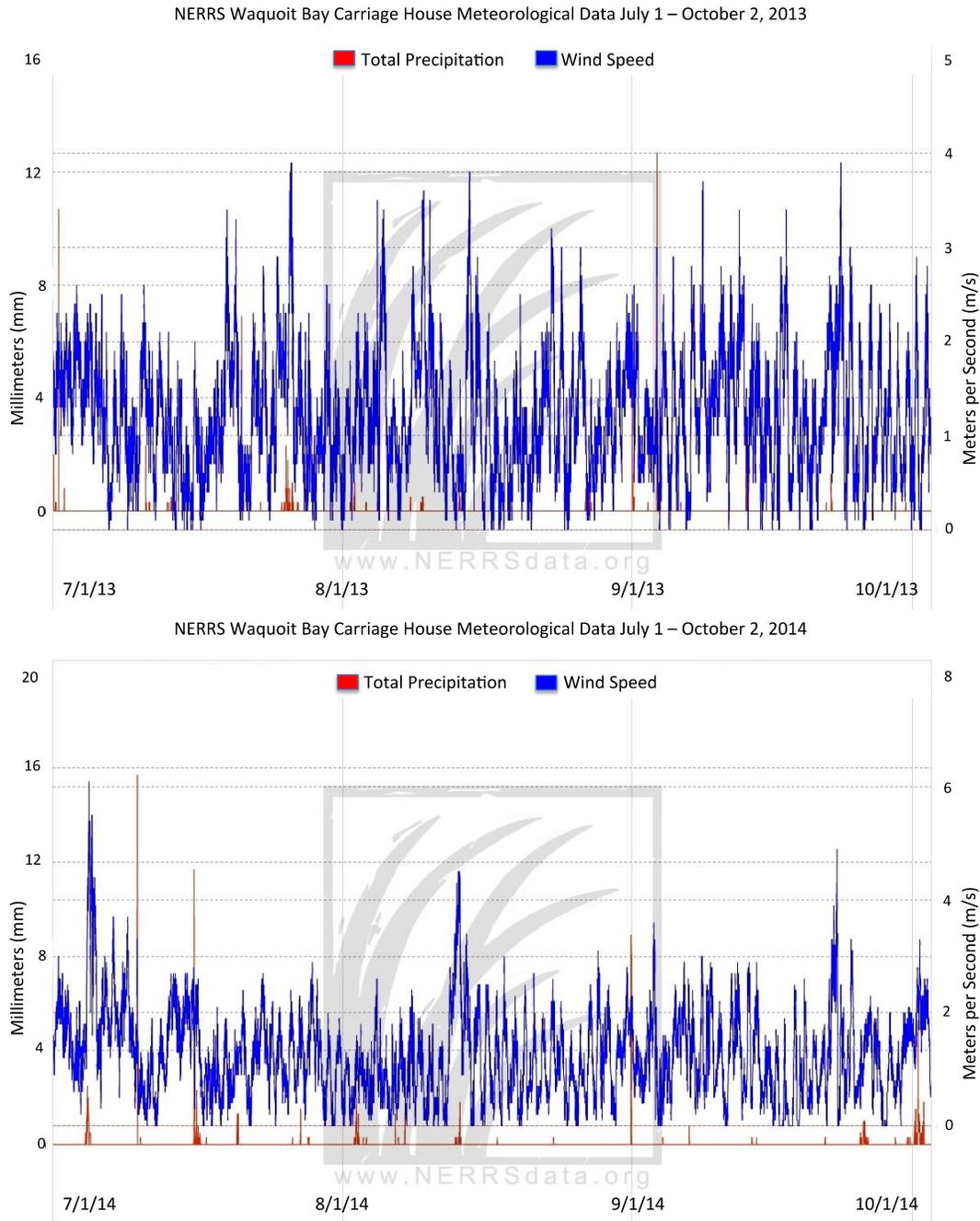


Figure 83. Precipitation and wind speed in Waquoit Bay, MA in 2013 and 2014.

The specific effects of rain on turbidity could be investigated on August 2, when the rain occurred during the photoperiod. The previous two storms mentioned occurred at night. During the August 2 rain event, it rained steady from around 9 am to ~1:30 pm (Figure 84). During noon when the sun is at its zenith, one would assume light penetration would be greatest, but it was during this time the rain was occurring and penetration was around 55% (Figure 84). There was an increase in light penetration once the initial pulse of rain subsided around 1:30 pm.

Clouds can significantly reduce the light intensity and are a factor to consider when trying to determine relative turbidity. Increased turbidity is not a factor of cloudiness, but due to suspended material in the water scattering light. It is important to determine that turbidity is not erroneously being attributed to changing cloud cover during a rain event and this was accomplished by comparing the surface PAR (photosynthetically active radiation), during the same time period (Figure 84). Light intensity (PAR) was strongest during the noon and the relatively lower light penetration was due to the rain event.

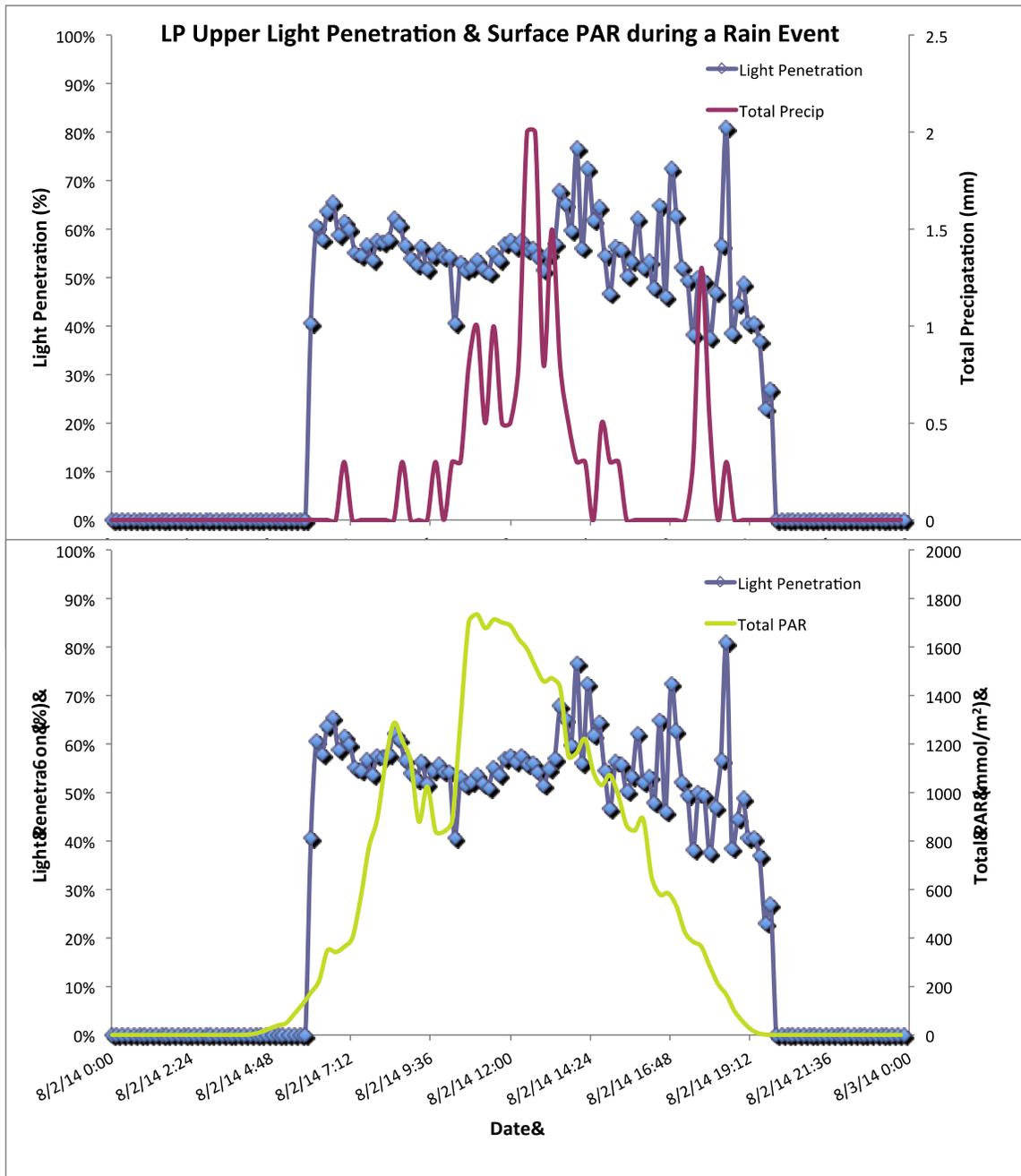


Figure 84. Comparing light penetration and surface PAR during a rain event on August 2, 2014 in Little Pond.

Turbidity may also be affected by tides and the most dramatic changes in tides can be found during a new moon phase, which occur monthly. New moons during the 2014 data collection were on July 26, August 25, and September 24. The extreme low tides were around 5:30 am and extreme high tides around 11:30 am for these dates. When looking at the light characteristics on the new moon date of July 26, you can see the light penetration decreased during the high tide despite the zenith position of the sun (Figure 85). Higher light penetration bracketed the 11:30 am high tide. The incoming tide can carry in with it light attenuating dissolved and particulate particles and even though the tidal amplitude in Little Pond is only around 0.4 m, this increases the distance (depth) light needs to travel to penetrate to the bottom.

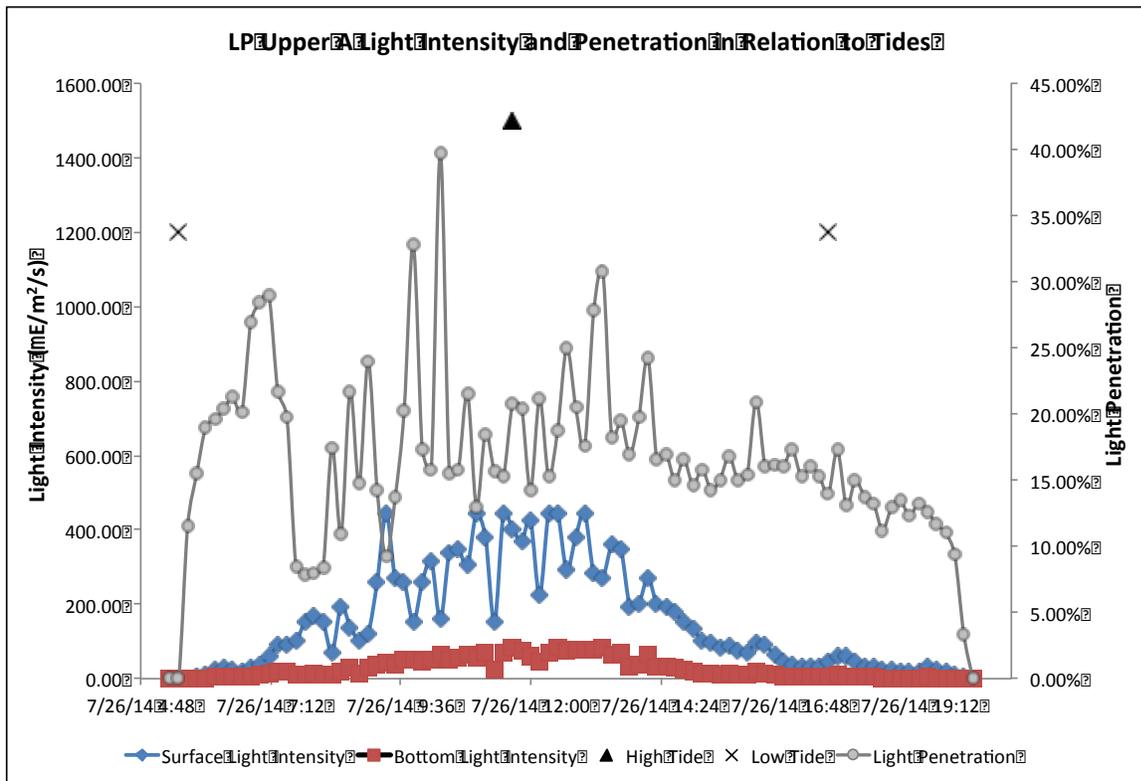


Figure 85. A new moon high tide and the effect on light characteristics in Little Pond.

There was more rain and wind on average and higher maximums of these parameters in 2014 compared to 2013, which may be the cause of the higher TSS values seen in the 2014 samples (Table 8 and 11). TSS does not seem to be the primary driver on turbidity in Little Pond though, since despite the increases in TSS, the other measures of turbidity improved. Higher light penetration and lower light extinction coefficients may be due partly to the significantly reduced total chlorophyll-a pigments. This is not to say that TSS is not a factor, since light penetration through the water column was reduced during the August 2 rain event even during the time of highest PAR signal (Figure 84).

There was a system-wide reduction in total chlorophyll, but it is unclear if this can be attributed to the presence of oysters. A more compelling metric supporting the notion that the oysters are filtering and improving water clarity would be a significant reduction in chlorophyll and TSS within the oyster raft and there are slightly lower concentrations of these parameters compared to the nearest LP OYS2 site (Table 11).

Water Temperature 2014: Temperature was measured every 10 minutes using the HOBO temperature and light pendants and averaged from July 2-October 2, 2014 for all sites except for LP Lower A surface, which only has data until August 19 and then damaged and is thus skewed higher. The temperature was averaged for each station and depth reflecting the same time range as the 2013 data (Table 12). Temperature between years is very similar.

Table 12 Mean water temperature profiles from the light meters in Little Pond during the same time period in 2013 and 2014, July 2-October 2. Highlighted station represents abridged data to August 19.

Station	Depth	Temperature (°C)	
		2013	2014
LP Upper A	Surface	25.01	25.13
	Bottom	24.57	25.06
LP OYS2	Surface	24.83	25.11
	Bottom	24.46	24.91
Lp Lower A	Surface	25.02	26.19
	Bottom	25.54	24.85
LP Lower B	Surface	24.69	24.67
	Bottom	24.42	24.46

Conclusions (oysters and water clarity) Year 1 and Year 2 (2013, 2014)

- In both 2013 and 2014 turbidity measurements, light characteristics and water quality showed comparable results with the highest light penetration and corresponding lowest light extinction coefficient, k , found at the site closest to the mouth of Little Pond, LP Lower B (Figure 82).
- In both 2013 and 2014 light penetration was relatively high and light extinction coefficient was reduced at the site closest to the oysters (LP OYS2), indicating that particle removals by the feeding oysters was increasing water clarity. This is supported by the finding of significantly more turbid waters, based on measured light penetration and k values, only 200 feet upstream of the oyster area and outside the influence of their feeding activities.

It appears that in both years the spatial pattern of key turbidity parameters (light extinction and light penetration) show similar results indicating that oyster culture resulted in increased water clarity in associated Little Pond waters in both 2013 and 2014.

Analysis of Turbidity in Little Pond 2015: Turbidity is a measure of water clarity and was determined at four of the mooring locations: LP Upper A, LP OYS2, LP Lower A, and LP Lower B (Figure 86) using HOBO® Temperature/Light Pendant Data Loggers (UA-002-64). These light pendants are the same as those used previously during the year 2 (2014) monitoring and were deployed similarly for cross comparability to previous years data. The light sensors were permanently positioned just below the waters surface (0.2m) and close to the bottom at a depth of 1m at each station. Data was compiled from July-October 2015 for all sites. These are the same locations used in the 2013 and 2014 Little Pond monitoring projects and all data was averaged over the same time period for consistency.

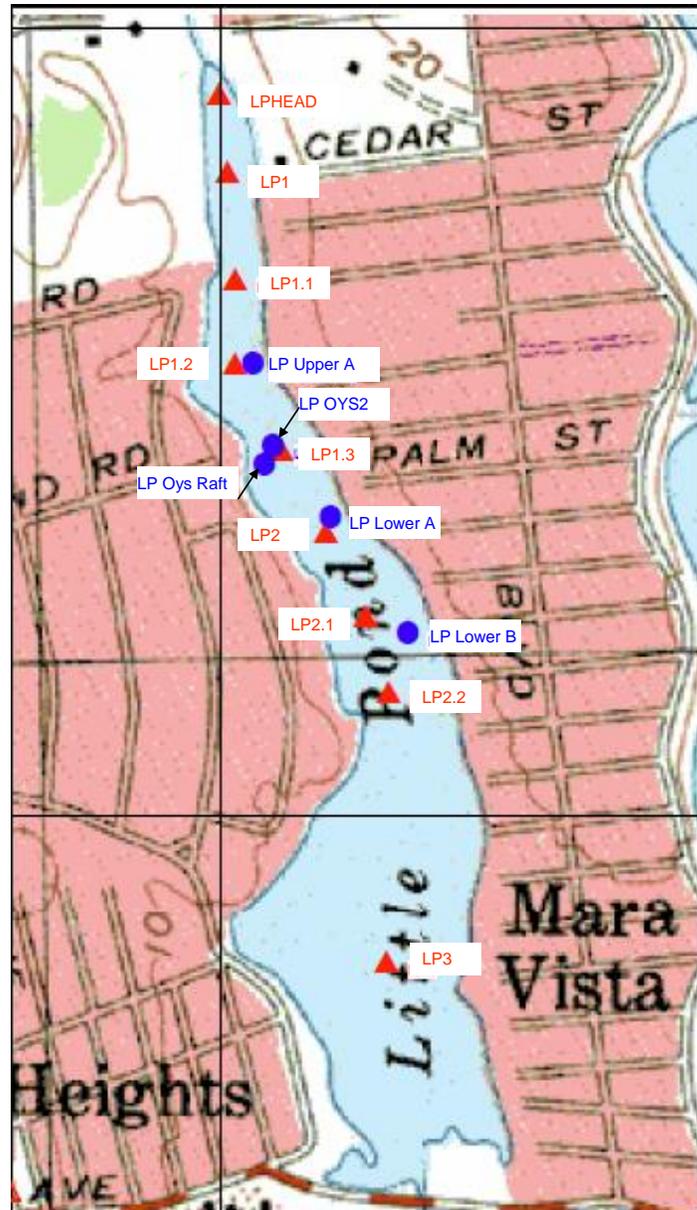


Figure 86. Site locations of the water quality monitoring (in red) and dissolved oxygen/chlorophyll moorings (in blue) for Little Pond.

The light pendants measured light intensity in units of $\mu\text{E}/\text{m}^2/\text{s}$ every 10 minutes and profiles were used to calculate the percent surface irradiance and the light extinction coefficient (k) within the water column. As in previous years, the light extinction coefficient, k was calculated using the Beer-Lambert Law which describes the logarithmic decay of light through a medium; the larger the light extinction coefficient, the more rapid the loss of light through the water column. In contrast, small light extinction coefficients reflect greater light transmission through the water column. The mean daily light intensity was also calculated using only the active photoperiod. In addition to the discrete light profile measurements, a water sample was collected 30cm from the bottom and filtered for total suspended solids, TSS, and chlorophyll-*a*. The site located within the oyster rack only included a YSI DO/chla sonde at the surface.

The light characteristics using the continuous light profiles taken at the moorings during the 2013, 2014, and 2015 Little Pond oyster pilot projects are shown below (Table 13). Each data set was averaged over the same time period of July-October for consistency. The lowest light intensity and penetration during the 2015 season was located at the site closest to the oysters, LP OYS2 (Figure 87) and the light extinction coefficient was markedly higher at the site closest to the oysters (Figure 88), which may indicate the oysters negatively influenced the turbidity of the water, which is an opposition to year 1 and 2 results. Over the 3 years the site of highest light penetration has changed from OYS2 (2013), Lower B (2014), Lower A (2015), while the lowest light extinction coefficient has been located more consistently toward the mouth of the pond (Lower B in 2013-14 and Lower A in 2015). During year 1 and 2, the site closest to the oysters, OYS2, seemed to have a positive influence on water clarity relative to its position near the head of Little Pond, but year 3 results show this site to be the most turbid.

Table 13. Results from the continuous light profiles measurements from Little Pond during years 1 (2013), 2 (2014), and 3 (2015) showing the mean light intensity, penetration, and the light extinction coefficients at each station.

Station	Approximate distance		Light Intensity ($\text{mE}/\text{m}^2/\text{s}$)			Mean Penetration (%)			Light Extinction Coefficient (k)		
	from head (ft)	Depth	2013	2014	2015	2013	2014	2015	2013	2014	2015
LP Upper A	1500	Surface	236.33	184.50	258.41	-	-	-	-	-	-
		Bottom	64.58	60.16	80.40	27.60	38.83	31.63	1.92	1.42	1.73
LP OYS2	1700	Surface	180.65	123.71	228.61	-	-	-	-	-	-
		Bottom	56.58	54.55	37.17	32.36	49.81	21.86	1.75	1.01	2.44
LP Lower A	2050	Surface	212.03	255.63	242.84	-	-	-	-	-	-
		Bottom	56.96	88.27	105.41	27.08	45.35	44.35	1.83	1.08	1.15
LP Lower B	2750	Surface	201.83	165.70	313.67	-	-	-	-	-	-
		Bottom	56.30	88.83	98.48	29.76	60.68	32.09	1.65	0.81	1.61

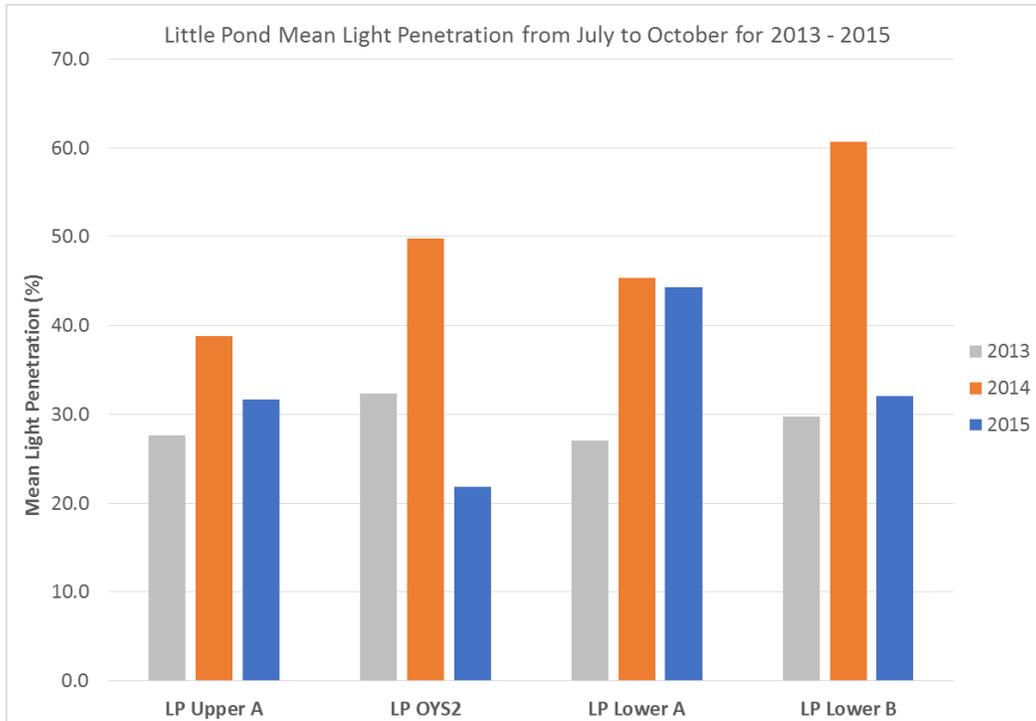


Figure 87: Results showing the mean light penetration at each site during July-October of each monitoring year (2013-2015) in Little Pond. Site LP Lower A is immediately downgradient of the oyster deployment area.

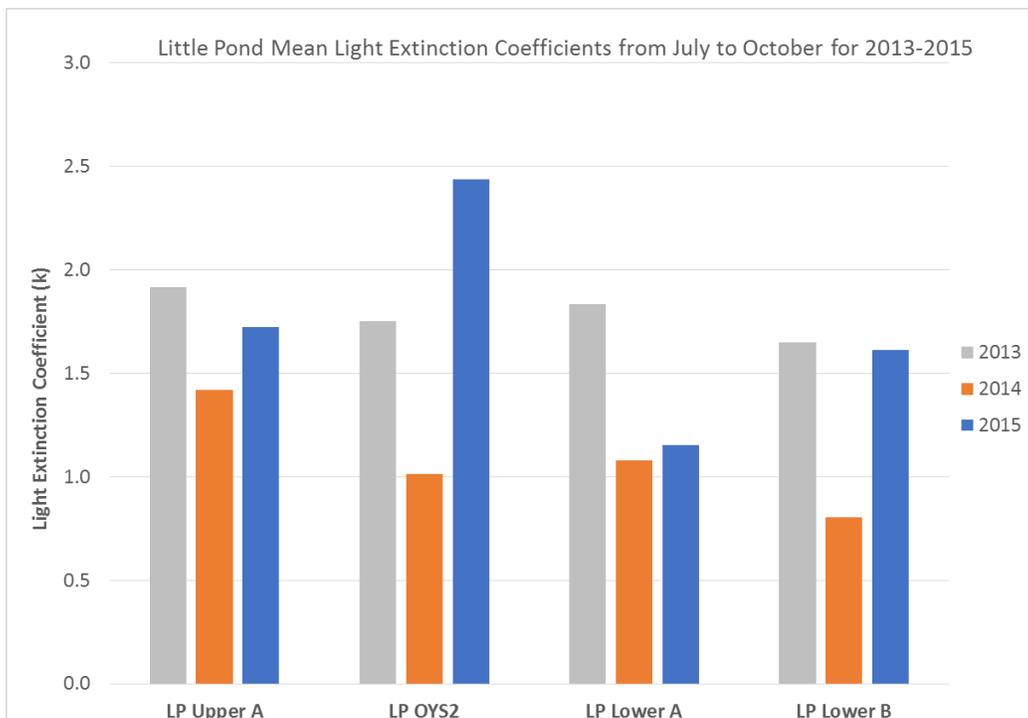


Figure 88: Results showing mean light extinction coefficients calculated using the light profiles at each site during July-October of each monitoring year (2013-2015) in Little Pond.

Turbid water can be a result of an abundance of total suspended solids (TSS), which can originate from inorganic sources like silt and clay or from organic particulates like phytoplankton, zooplankton, bacteria, and detritus. The TSS and chlorophyll pigments collected from site LP OYS2 were the highest in each year except chlorophyll in 2013 (Table 14). TSS and chlorophyll samples were also collected directly in the oyster rack and these results show lower levels of sources of turbidity than that of the OYS2 site in close proximity, but not directly in the oyster culture area. This additional water quality station LP Oyster Rack, which does not have light measurements, leads to the conclusion that the oysters themselves cannot be the major source or turbidity in Little Pond, because if this were the case this site would likely have the highest TSS and chlorophyll concentrations.

Table 14. Results showing the mean total suspended solids and total chlorophyll-a from water samples collected at each mooring location for each monitoring year (2013-2015).

Station	Approximate distance from head (ft)	Total Suspended Solids (mg/L)			Total Chlorophyll-a Pigments (mg/L)		
		2013	2014	2015	2013	2014	2015
LP Upper A	1500	26.79	31.70	23.77	11.93	3.64	3.27
LP OYS2	1700	32.00	37.27	37.97	11.68	5.63	8.47
LP Oyster Rack	1850	20.68	33.85	32.98	20.78	4.60	3.14
LP Lower A	2050	14.17	31.71	23.48	14.08	3.34	6.73
LP Lower B	2750	31.24	34.15	2.24	9.68	3.72	4.20

Turbidity can be affected by precipitation and results of total precipitation from a nearby meteorological station in Waquoit showed the 2015 monitoring season to have highest amount with 255.3 mm of rain, compared to 215.4 mm in 2014, and 150.0 mm in 2013. This increase in rain over the sampling period could explain the overall reduction in light penetration and increase in light extinction coefficients recorded in the 2015 monitoring compared to previous years (Figure 87 and 88).

Relatively high tides can input a larger volume of water and cause more turbid waters, and the opposite concept being true for the lowest tides. The spring tides produce the strongest tidal pulse and occur during full and new moons, with the extreme tides occurring on the new moon. Neap tides have the smallest amplitude and occur during the first and third quarter moons. The tidal amplitude in Vineyard Sound in the vicinity of Little Pond is relatively small, around 1.5 feet. It appears that tides are not the primary driver on the turbidity of the water by looking at the light penetration of the site closest to the oysters in relation to the lunar phase as decrease in light penetration cannot be directly related to the spring tides that occur during the full and new moons (Figure 89). Precipitation on the other hand does seem to show a correlation with turbidity. Significant rain events do coincide with decreases in light penetration evidenced well during rain events on August 4 and 26, and September 10 and 30 (Figure 89).

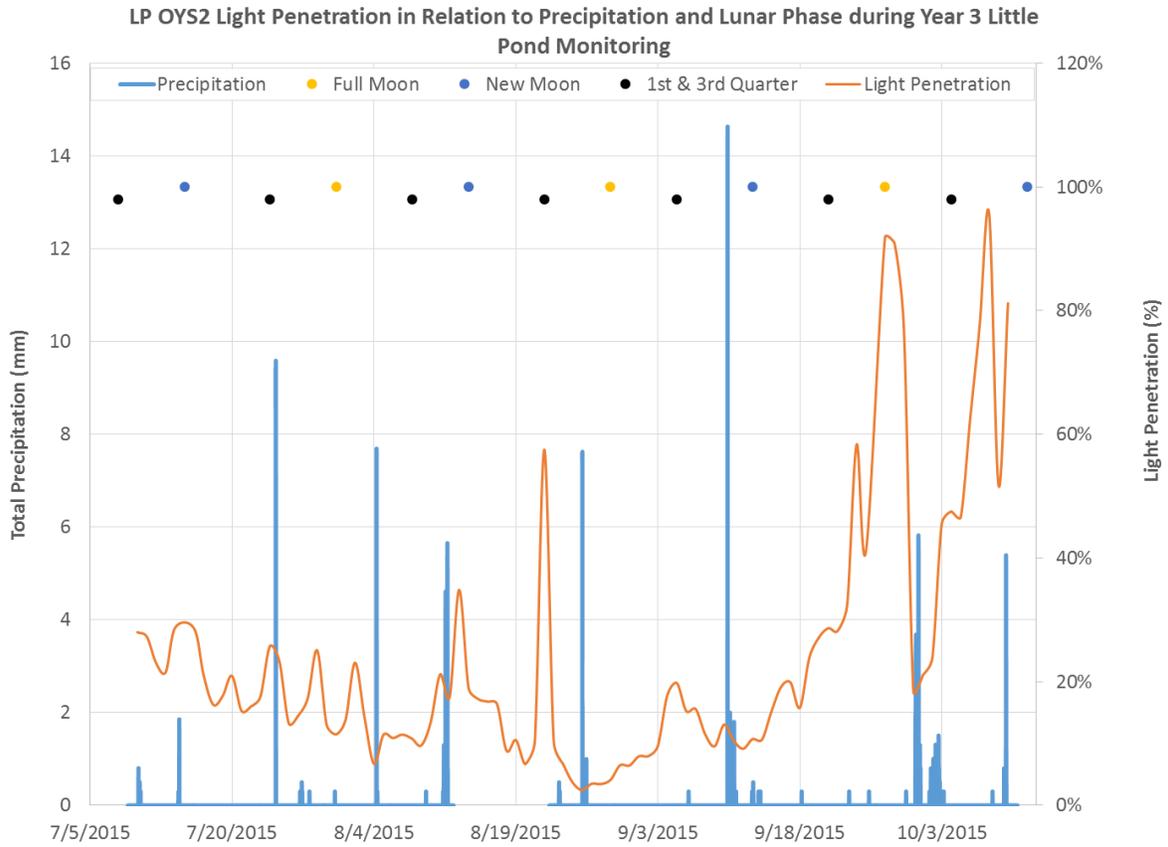


Figure 89. Mean daily light penetration of the site closest to the oysters in Little Pond, LP OYS2, in relation to the moon phase and precipitation.

Water Temperature: Temperature was measured every 10 minutes using the HOBO temperature and light pendants and averaged from July 9 -October 2, for each station and compiled for each year the Little Pond oyster monitoring program has occurred (Table 15 below). Light sensors were not deployed at the surface Oyster Rack station.

Table 15. 2013 Compiled temperature profiles for the mooring stations Little Pond in 2013, 2014 and 2015.

Station	Depth	Temperature (°C)		
		2013	2014	2015
LP Upper A	Surface	25.0	25.0	26.8
	Bottom	24.6	24.9	26.1
LP Oys2	Surface	25.0	25.0	26.6
	Bottom	24.6	24.8	26.2
LP Lower A	Surface	24.9	26.2	26.6
	Bottom	24.5	24.7	26.0
LP Lower B	Surface	24.6	24.6	26.2
	Bottom	24.3	24.3	25.8

The water temperature profiles at each station were at least a degree higher in 2015 in all but one case, the surface waters at LP Lower A during the 2014 season (Figure 90). This significant increase in temperature probably increased the severity in the anoxic event that occurred in the pond during August.

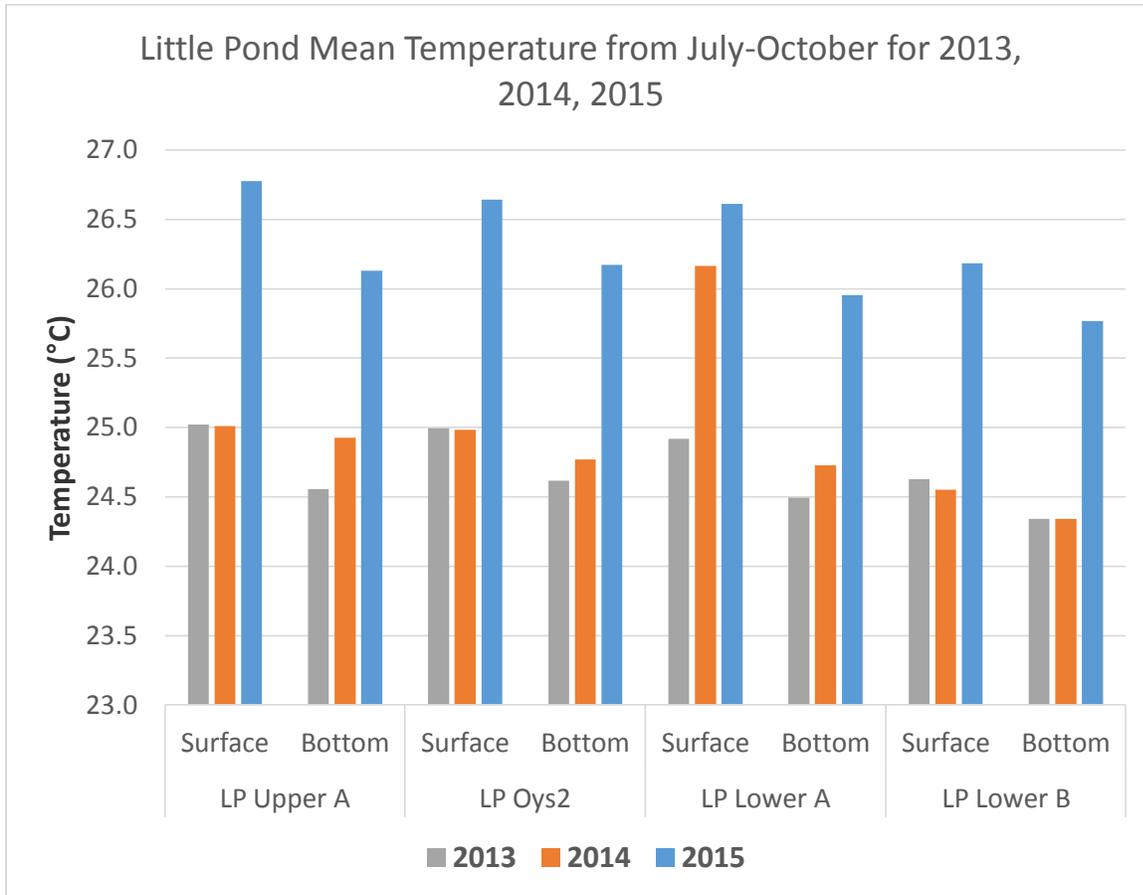


Figure 90. Mean water temperature for each mooring profile in Little Pond compiled for each monitoring year.

Conclusion (oysters and water clarity): The previous results from 2013 and 2014 showed relatively high light penetration and corresponding lower light extinction coefficients at the site closest to the oysters, LP OYS2 indicating the reduced turbidity of the water was associated with particle removals in the oyster culture area. In contrast, the 2015 results show the site closest to the oysters was the most turbid with the lowest light penetration and highest light extinction coefficient. The water quality measurements of TSS and total chlorophyll taken directly in the oyster culture site were however lower than at the LP OYS2 site indicating that the oysters once again were associated with particle removal in Little Pond, despite high turbidity in close proximity.

The cause of the high turbidity at LP OYS2 could be a result of a few different mechanisms. Fresh water inflow from the headwaters, rain run-off and the nearby storm pipe can introduce particles and a strong salinity gradient. Rain water that seeps into the ground can leach organic soil and plant matter as well as inorganic constituents into dissolved and particulate matter. The

mixing of organic matter in fresh water to water with a higher salinity can cause flocculation and thus an increase of particulates in the water column. The increase in particulate and dissolved organic matter would subsequently lead to a decrease in light intensity by scattering, decrease in light penetration, and increase in TSS. The total amount of rain was higher in 2015 with 255.3mm compared to 215.4, and 150.0mm in 2014 and 2013 respectively)

Another explanation for the high turbidity at the LP OYS2 site could be the low dissolved oxygen and specifically the anoxic event that occurred in August altered the water chemistry. The increase of nutrients, higher temperatures, and decrease in salinity from rain or run-off may have made favorable conditions for anoxia to occur. Regardless, anoxia creates an environment where aerobic respiration is no longer an option and denitrification must occur, followed by manganese and iron reduction, then sulfate reduction to derive energy. The resulting ammonium, hydrogen sulfide and reduced metals trigger the formation of metal sulfides, which can increase turbidity.

The movement of oysters could lead to the sloughing off of epiphytic algae from the oyster bags and ropes. As these strings of oyster bags are transported back and forth, the overgrowth of algae becomes reintroduced into the water column leading to an increase in turbidity.

A compounding issue of higher temperatures, which were recording during the 2015 monitoring, decreasing the solubility of dissolved oxygen, and turbidity also increasing water temperature since suspended particles absorb more heat, both lead to a reduction in dissolved oxygen. Overall, the 2015 results continue to show that the oyster culture area has lower concentrations of TSS and chlorophyll relative to the nearby LP OYS2 site, indicating the oysters are effectively filtering and removing particles in the water.

Benthic Infaunal Sampling in Little Pond

Benthic Infaunal Analysis (2013): Changes in the Little Pond ecosystem due to the oyster culture may impact the benthic community, which was a key measure of ecosystem status during the MEP assessment. In order to more holistically measure the impact of the oyster culture demonstration, CSP-SMAST assessed and quantified the impacts of the oyster culture on the benthic community in the oyster aquaculture area.

The benthic animal community throughout Little Pond (including where the oysters were deployed) were characterized and quantified per the scope of work for the oyster monitoring project. The locations were selected during an initial field reconnaissance, and the following spatial pattern was chosen:

- 2 sites above the oyster deployment site,
- 2 sites within the oyster deployment area,
- 2 sites below the oyster deployment area.

This plan placed 2 up-gradient and 2 down-gradient sampling sites near the benthic infaunal sampling sites previously established by the MEP in 2003 (Figure 91). This placement was important since both the up-gradient and down gradient sites showed relatively poor animal habitat in 2003 and any potential assignment of impacts due to the oyster deployment must be made in that light.

Consistent with sampling undertaken by the MEP (for cross comparison purposes) samples collected in 2013 were obtained using a Young modified Van Veen grab at each site. Analysis included both the species and numbers of individuals per species within each sample. Key metrics such as Weiner Diversity and Evenness were also calculated and directly compared to the MEP 2003 benthic infauna analysis completed in Little Pond prior to this oyster cultivation project. Benthic communities were evaluated relative to the total nitrogen – species numbers relationship developed for Cape Cod estuaries by CSP-SMAST, as well as traditional established indicators. All procedures followed the MEP analytical approach and the USEPA/MassDEP approved MEP QAPP developed by CSP-SMAST.

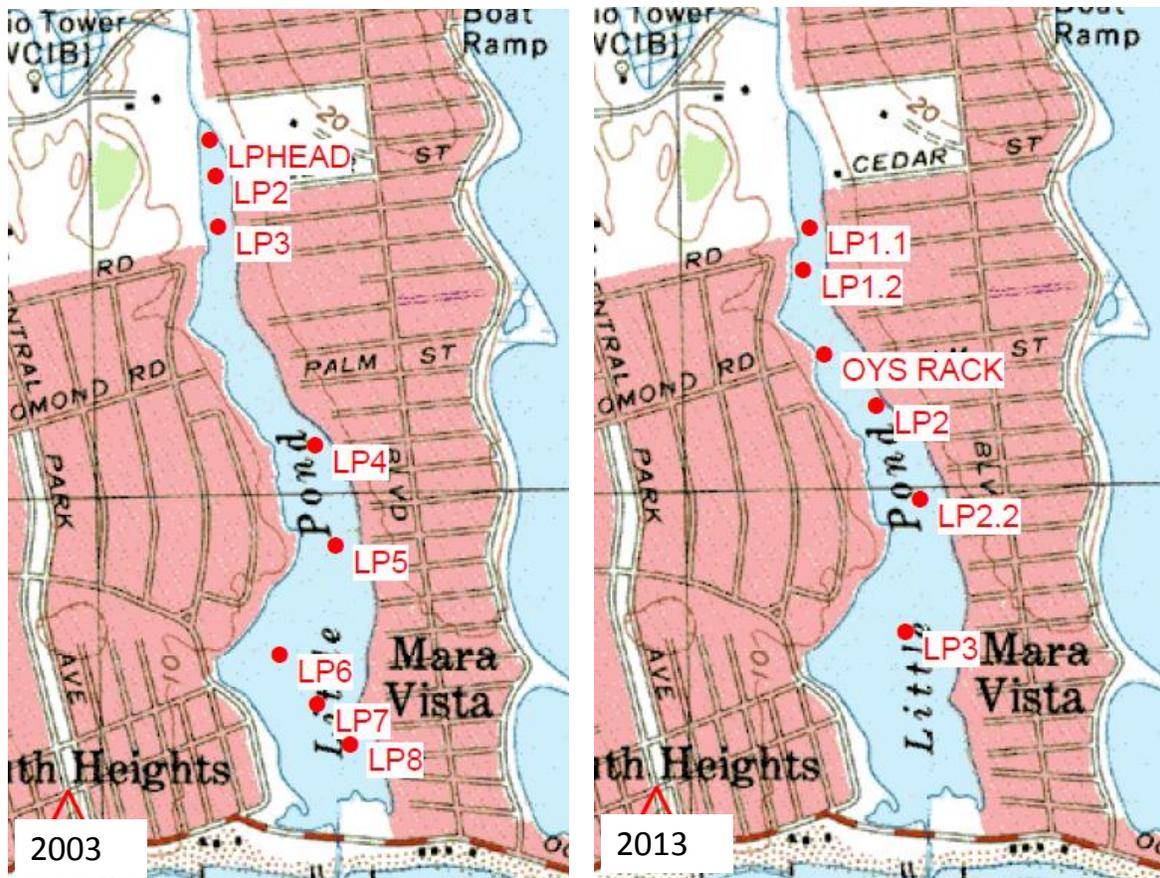


Figure 91. Benthic infauna station maps for pre (MEP 2003) and post (2013) oyster project in Little Pond, Falmouth, MA.

Benthic Animal Community Results:

The 2013 infauna results (Tables 16 and 17) document a nutrient impaired habitat for benthic infauna throughout Little Pond. This is consistent with the 2013 measured hypoxia throughout all pond basins and the high total nitrogen, phytoplankton biomass (chlorophyll a) and particulate organic matter in pond waters. The observed infauna communities are also consistent with the gradient of declining water quality from the tidal inlet to the upper tidal reach of Little Pond. Although the 2013 results show a potential improvement in habitat quality from 2003 to 2013, based on numbers of species and individuals and diversity, conditions remain poor. The increase in species was due to the presence of only a few rare species and the increase in numbers was due to the dominance of opportunistic species as determined from examination of the species present. These opportunistic species dominate the community frequently, accounting for more than 80% of the population. These species are generally small polychaete worms, specifically *Capitella* and *Streblospio* (as in 2003) and are typical of highly organically loaded sediments. Their life histories allow them to persist in a stressful environment. The obverse was also found, i.e. longer-lived larger species were absent. Based on both findings it is clear that Little Pond remains a significantly impaired system.

Nonetheless, the 2013 data were examined for any potential response to the oyster deployment and none could be documented. Upon initial examination, there is a depression in habitat quality in the region associated with the deployment, however, this depression in species numbers and number of individuals was also seen in the 2003 survey conducted by the MEP (see above). As such, a negative oyster effect cannot be concluded based on infauna habitat analysis. The difficulty in determining a negative or positive effect of oysters on benthic animal habitat in Little Pond appears to result from the very poor quality of the habitat at present. As the pond improves or perhaps, in a higher quality environment, it is likely that effects would be more evident.

Table 16. Benthic infaunal data collected for the 2013 oyster demonstration project.

Station Location	Total Actual Species	Total Actual Individuals	Species Calculated @75 Indiv.	Weiner Diversity (H')	Evenness (E)
Little Pond Embayment System					
LP1.1	11	975	5	1.380	0.399
LP1.2	7	573	4	1.009	0.359
LP Oys Rack	7	333	5	1.482	0.528
LP2	9	203	8	2.116	0.668
LP2.2	9	1176	5	0.982	0.310
LP3	14	913	9	2.471	0.649

Table 17. Comparison of benthic infaunal data collected in 2003 for the MEP and 2013 data collected for the oyster demonstration project.

Location ID 2003	Location ID 2013	Total Actual Species 2003	Total Actual Species 2013	Total Actual Individuals 2003	Total Actual Individuals 2013	Weiner Diversity (H') 2003	Weiner Diversity (H') 2013	Evenness (E) 2003	Evenness (E) 2013
Little Pond Estuary									
LP3	LP1.1	4	11	216	975	1.59	1.38	0.79	0.399
LP4	LP2	3	9	328	203	0.81	2.12	0.51	0.668
LP5	LP2.2	3	9	696	1176	0.37	0.98	0.24	0.310
LP6	LP3	7	14	668	913	1.30	2.47	0.46	0.649

Benthic Infaunal Analysis (2014): In order to more holistically measure the impact of the oyster culture demonstration, CSP-SMAST extended the Year 1 (2013) benthic infaunal community characterization into the Year 2 (2014) monitoring period in order to further assess and quantify the impacts of the larger scale oyster culture (~1.5 million oysters) on the benthic community in the oyster aquaculture area. The spatial pattern established for the 2014 benthic infaunal survey mirrored the 2013 sampling pattern. As in 2013, sediment samples were collected from a total of six sites, 2 sites above the oyster deployment site, 2 sites within the oyster deployment area, and 2 sites below the oyster deployment area (Figure 92, Table 18).

Sampling in 2014 used duplicate Young modified Van Veen grab samples at each site (the same grab approved for use in the MEP and what was used in 2013 for in Little Pond). Analysis currently underway but not yet complete will include both the species and numbers of individuals per species within each sample, key metrics such as Weiner Diversity and Evenness will be calculated and will be directly comparable to the 2013 benthic survey as well as the MEP benthic infauna analysis completed in Little Pond prior to this oyster cultivation project. As in 2013, the 2014 benthic communities are being evaluated relative to the total nitrogen – species numbers relationship developed for Cape Cod estuaries by CSP-SMAST, as well as traditional established indicators. All procedures are following the MEP analytical approach and the USEPA/MassDEP approved MEP QAPP developed by CSP-SMAST.

As for 2013, the 2014 infauna community analysis does not indicate a pattern reflective of a negative impact of the oyster deployment. However, the community indicators point to a lower quality of habitat than even seen in the 2013 sampling. Most importantly the numbers of individuals and species were generally lower in 2014 compared to 2013. The numbers of species are approaching the very poor metrics of 2003 and the numbers of individuals in the mid and upper sites were extremely low (58-92/grab). Only the lower stations (LP2.2, LP3) showed moderate habitat quality, likely due to the generally improving conditions approaching the lower basin, as seen in prior years. Of note though, is that all samples collected in 2014 exhibited the same sediment characteristics as in 2013 (All stations had sulfides and black mud). In addition, Station LP-3 showed the presence of eelgrass whereas that was not the case in 2013.

The significant reduction in habitat quality in 2014 was found at most of the stations and if anything, there was a very minor improvement in the direct vicinity of the oyster racks. The 2014 habitat metrics are consistent with the very strong stratification in 2014 and large oxygen depletions which are a major stress to benthic communities and at slightly greater depletions can result in a loss of the entire community, requiring new larval resettlement to become re-established.

While the poor benthic habitat results from general Little Pond eutrophication exacerbated by the strong 2014 stratification, there is no evidence of a negative effect of deploying the oysters either due to the oyster activities or the management of the gear.

Table 18. GPS locations (LAT, LON) for 2014 benthic infaunal sampling in Little Pond.

2014 BENTHIC INFAUNA LOCATIONS		
Markers	Coordinates:	
LP1.1	N 041° 33' 21.4"	W 070° 35' 29.0"
LP1.2	N 041° 33' 18.20"	W 070° 35' 29.30"
OYS RACK	N 041° 33' 13.6"	W 070° 35' 27.20"
LP2	N 041° 33' 10.70"	W 070° 35' 24.4"
LP2.2	N 041° 33' 04.2"	W 070° 35' 20.70"
LP3	N 041° 32' 57.40"	W 070° 35' 21.50"



Figure 92 Sampling locations for 2014 and 2015 benthic infaunal survey in Little Pond. A total of 12 samples were collected from 6 stations. Each station had duplicate samples collected for QA/QC.

Table 19. Benthic infaunal data collected for the 2014 oyster demonstration project.

Location	Total Actual Species	Total Actual Individuals	Species Calculated @75 Individ.	Weiner Diversity (H')	Evenness (E)
Little Pond Embayment System					
LP Oys Rack	6	92	5	1.32	0.51
LP1.1	8	69	N/A	1.71	0.57
LP1.2	5	58	N/A	2.05	0.88
LP2	9	132	8	2.33	0.73
LP2.2	12	376	8	2.17	0.60
LP3	13	592	7	1.42	0.38

Benthic Infaunal Analysis (2015): The spatial pattern established for the 2015 benthic infaunal survey followed that for 2013 and 2014 to provide a comparable multi-year dataset. As in 2014, sediment samples were collected from a total of six sites, 2 sites above the oyster deployment site, 2 sites within the oyster deployment area, and 2 sites below the oyster deployment area (Figure 92).

Sampling in 2015 used duplicate Young modified Van Veen grab samples at each site (the same grab approved for use in the MEP and what was used in 2013 and 2014 for in Little Pond). Analysis of the 2015 samples includes both the species and numbers of individuals per species within each sample, key metrics such as Weiner Diversity and Evenness were calculated and were directly compared to the 2013 and 2014 benthic surveys as well as the MEP benthic infauna analysis (2003) completed in Little Pond prior to this oyster cultivation project. As in 2013 and 2014, the 2015 benthic communities were evaluated relative to the seasonal total nitrogen and oxygen conditions – species numbers relationship developed for Cape Cod estuaries by CSP-SMAST, as well as traditional established indicators. All procedures are following the MEP analytical approach and the USEPA/MassDEP approved MEP QAPP developed by CSP-SMAST. Of note is that all samples collected in 2015 exhibited the same sediment characteristics as in 2013 and 2014 (All stations had sulfides and black mud).

The results from 2015 (Table 20) were consistent with the high TN levels, weak water column stratification and oxygen depletion of bottom waters. Similar patterns were observed in the 2013 and 2014 samplings and all samples associated with the oyster project showed a general improvement in conditions compared to the 2003 MEP survey. Of the 3 surveys to investigate an “oyster effect”, 2015 showed the least impairment, although 2015 still showed reduced numbers of individuals and species compared to high quality environments. In addition, all years showed stress indicator species (Capitellids) as dominant portions of the community. None-the-less there is no evidence from any of the 3 annual surveys that the oyster deployments are causing measurable habitat impairment. In fact, analyzing all 3 years results together suggests a slight improvement in benthic habitat in the direct region of the oyster deployment. While small, the improvement can be seen in all surveys. Prior annual reports indicated that any improvement was too small to document, but with all 3 years showing a similar results the contention of a positive effect on benthic community cannot be dismissed. If real, the mechanism may result from the delivery of fresh material to the sediment surface or the dispersal of materials over a larger area than normal. The effect of having a diverse assemblage of benthic organisms suspended with the oysters in the bags may also be adding to the benthic community over time. This is seen in oyster reef areas, but with suspended bags the effect will need to be documented.

Table 20. Benthic infaunal data collected for the 2015 oyster demonstration project.

Sub-Embayment	Total Actual Species	Total Actual Individuals	Species Calculated @75 Individ.	Weiner Diversity (H')	Evenness (E)
Little Pond Embayment 2015					
LP 1.1	9	344	5.97	1.50	0.47
LP1.2	8	316	6.17	1.88	0.65
LP Oys Rack	9	348	7.06	2.29	0.72
LP2	9	373	6.83	2.11	0.69
LP2.2	11	368	6.74	1.92	0.56
LP3	12	275	7.28	2.17	0.61

APPENDIX A

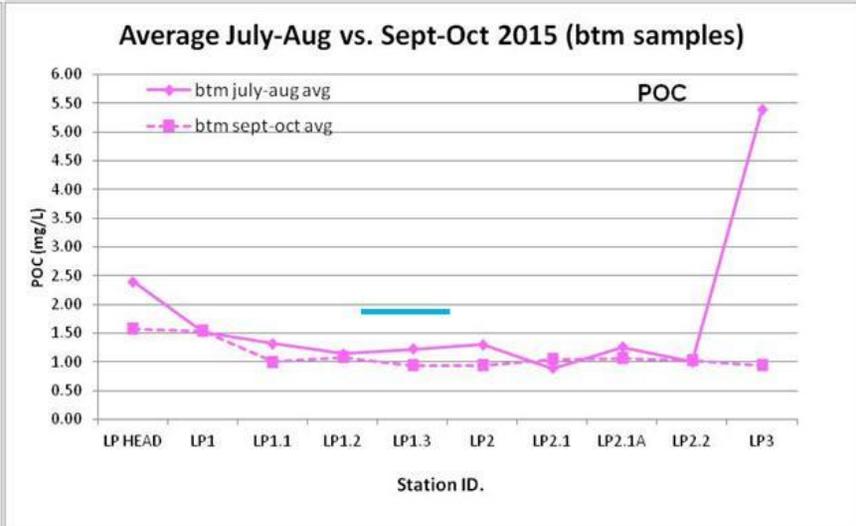
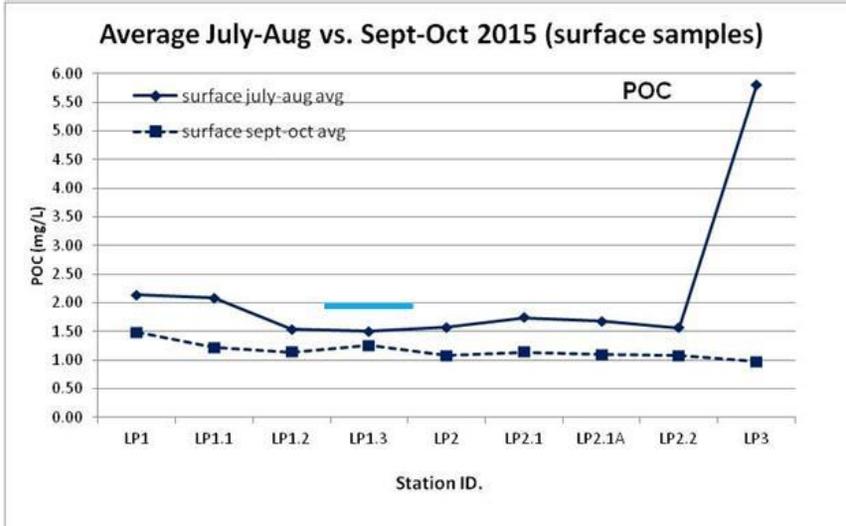
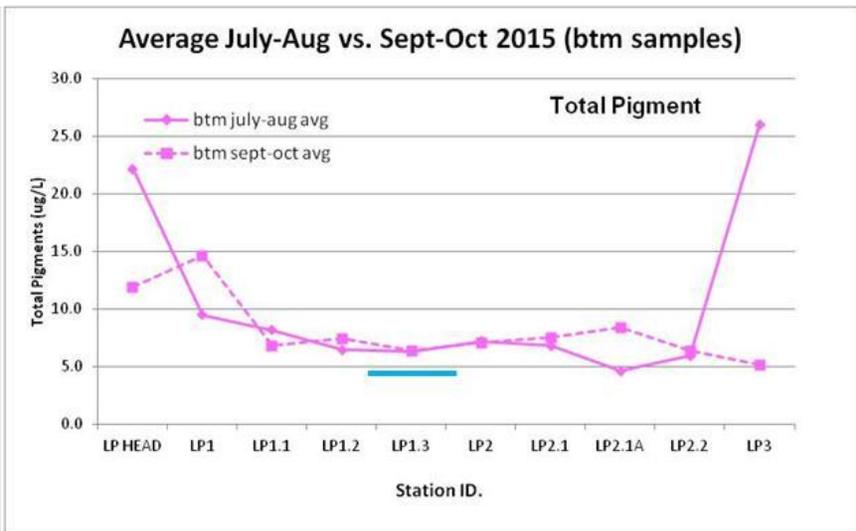
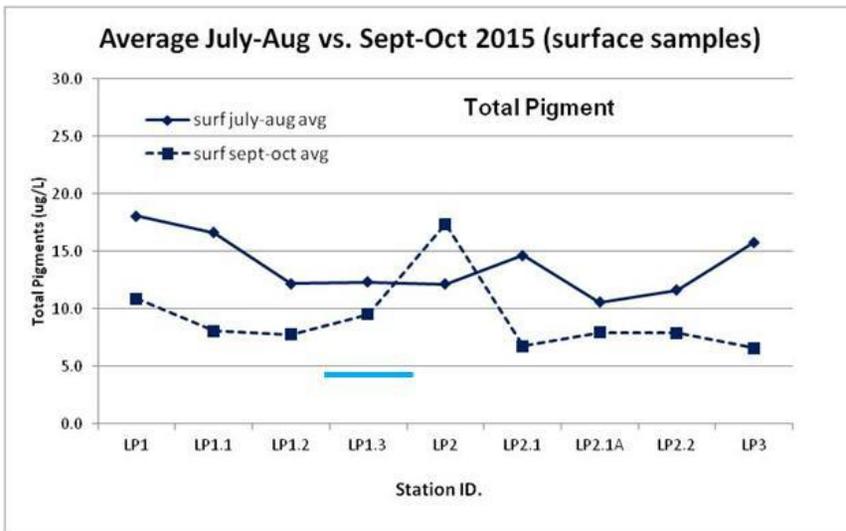
Table and Plots of Nitrogen Concentrations

With Oysters (July-August)

Without Oysters (September-October)

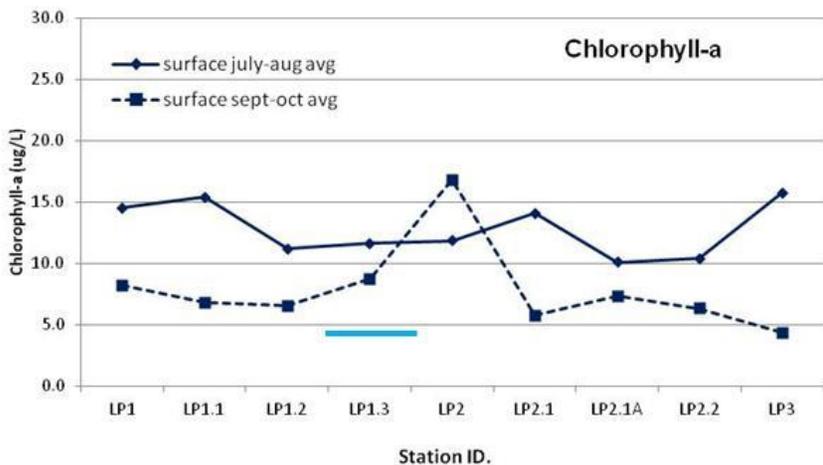
ID	DEPTH	QA/QC	Sal (ppt)	Avg. PO4 (mg/L)	Avg. NH4 (mg/L)	Avg. Nox (mg/L)	Avg. DIN (mg/L)	Avg. DON (mg/L)	Avg. TDN (mg/L)	Avg. POC (mg/L)	Avg. PON (mg/L)	Avg. TON (mg/L)	Avg. TN (mg/L)	CHI-a (ug/L)	Phaeo (ug/L)	Total Pigments (ug/L)	D.O. Meter Salinity Corrected DO (mg/L)
LP HEAD		late july-late aug	20.9	0.006	0.066	0.518	0.584	0.258	0.842	2.393	0.428	0.687	1.271	19.159	3.012	22.171	6.878
LP1	B	late july-late aug	29.9	0.004	0.020	0.036	0.056	0.409	0.465	1.516	0.262	0.671	0.709	8.318	1.179	9.497	4.770
LP1.1	B	late july-late aug	30.9	0.009	0.026	0.007	0.033	0.397	0.430	1.314	0.232	0.629	0.662	5.659	2.518	8.176	6.117
LP1.2	B	late july-late aug	31.0	0.006	0.019	0.004	0.023	0.315	0.338	1.140	0.211	0.526	0.549	5.488	0.955	6.442	5.080
LP1.3	B	late july-late aug	30.6	0.005	0.015	0.006	0.021	0.376	0.396	1.220	0.229	0.605	0.626	5.537	0.807	6.344	4.827
LP2	B	late july-late aug	31.0	0.009	0.018	0.002	0.020	0.406	0.426	1.298	0.209	0.614	0.634	6.118	1.107	7.225	5.799
LP2.1	B	late july-late aug	31.1	0.007	0.007	0.002	0.008	0.338	0.346	0.881	0.160	0.498	0.506	5.686	1.134	6.820	4.906
LP2.1A	B	late july-late aug	31.1	0.006	0.016	0.005	0.021	0.435	0.456	1.257	0.217	0.652	0.673	3.959	0.685	4.644	5.622
LP2.2	B	late july-late aug	31.0	0.011	0.008	0.002	0.010	0.340	0.350	0.999	0.178	0.518	0.529	5.501	0.426	5.926	5.039
LP3	B	late july-late aug	31.4	0.008	0.009	0.003	0.011	0.307	0.319	5.392	0.763	1.070	1.081	20.962	5.072	26.034	7.909
LP1	S	late july-late aug	21.9	0.003	0.054	0.407	0.462	0.294	0.755	2.138	0.380	0.674	1.136	14.517	3.529	18.046	6.946
LP1.1	S	late july-late aug	23.3	0.004	0.017	0.315	0.332	0.343	0.675	2.092	0.392	0.735	1.067	15.421	1.199	16.621	6.840
LP1.2	S	late july-late aug	24.9	0.002	0.016	0.210	0.226	0.323	0.550	1.542	0.278	0.601	0.827	11.238	0.936	12.174	5.643
LP1.3	S	late july-late aug	26.6	0.002	0.012	0.118	0.129	0.339	0.468	1.499	0.268	0.607	0.737	11.624	0.689	12.313	6.459
LP2	S	late july-late aug	27.5	0.002	0.007	0.058	0.065	0.366	0.431	1.577	0.276	0.642	0.707	11.861	0.265	12.126	6.691
LP2.1	S	late july-late aug	28.8	0.002	0.007	0.009	0.016	0.400	0.416	1.741	0.319	0.719	0.735	14.101	0.529	14.629	7.892
LP2.1A	S	late july-late aug	28.6	0.003	0.012	0.014	0.026	0.374	0.400	1.686	0.305	0.679	0.705	10.113	0.451	10.564	7.585
LP2.2	S	late july-late aug	28.7	0.003	0.010	0.008	0.018	0.362	0.380	1.566	0.283	0.645	0.663	10.406	0.258	11.601	7.995
LP3	S	late july-late aug	29.1	0.014	0.018	0.012	0.030	0.348	0.378	5.809	0.939	1.287	1.317	15.743	0.025	15.768	9.236
LP HEAD		sept-oct	27.2	0.010	0.088	0.214	0.302	0.284	0.586	1.569	0.288	0.572	0.874	8.314	3.597	11.911	4.975
LP1	B	sept-oct	29.8	0.009	0.037	0.022	0.059	0.357	0.416	1.533	0.292	0.649	0.708	8.466	6.190	14.656	5.691
LP1.1	B	sept-oct	30.1	0.006	0.033	0.039	0.073	0.254	0.326	0.996	0.169	0.423	0.496	5.495	1.297	6.792	6.357
LP1.2	B	sept-oct	29.8	0.006	0.029	0.046	0.075	0.293	0.367	1.083	0.207	0.499	0.574	6.266	1.176	7.442	5.753
LP1.3	B	sept-oct	30.2	0.006	0.031	0.035	0.065	0.261	0.326	0.933	0.171	0.432	0.498	5.239	1.110	6.349	6.468
LP2	B	sept-oct	29.8	0.006	0.028	0.021	0.049	0.271	0.320	0.940	0.164	0.435	0.484	6.432	0.634	7.065	6.306
LP2.1	B	sept-oct	30.4	0.006	0.028	0.015	0.043	0.258	0.301	1.035	0.196	0.454	0.497	5.336	2.155	7.491	5.715
LP2.1A	B	sept-oct	30.6	0.007	0.015	0.009	0.023	0.240	0.263	1.061	0.196	0.436	0.459	6.615	1.773	8.388	5.700
LP2.2	B	sept-oct	30.2	0.004	0.029	0.026	0.055	0.256	0.312	1.022	0.191	0.447	0.502	5.062	1.332	6.394	6.087
LP3	B	sept-oct	30.0	0.003	0.029	0.023	0.052	0.274	0.326	0.935	0.169	0.443	0.495	4.174	0.976	5.149	6.610
LP1	S	sept-oct	28.3	0.007	0.059	0.145	0.204	0.252	0.456	1.484	0.267	0.518	0.722	8.256	2.623	10.879	5.153
LP1.1	S	sept-oct	29.1	0.005	0.047	0.038	0.085	0.232	0.317	1.225	0.218	0.451	0.536	6.808	1.266	8.074	5.962
LP1.2	S	sept-oct	29.4	0.003	0.042	0.050	0.092	0.308	0.400	1.140	0.218	0.526	0.618	6.530	1.230	7.760	5.944
LP1.3	S	sept-oct	29.6	0.004	0.039	0.049	0.088	0.297	0.385	1.254	0.240	0.537	0.625	8.749	0.780	9.529	6.076
LP2	S	sept-oct	29.5	0.005	0.036	0.047	0.083	0.301	0.384	1.083	0.210	0.511	0.594	16.839	0.504	17.342	6.118
LP2.1	S	sept-oct	29.5	0.003	0.034	0.037	0.070	0.270	0.340	1.142	0.222	0.492	0.562	5.738	0.998	6.736	6.152
LP2.1A	S	sept-oct	29.6	0.004	0.034	0.061	0.096	0.307	0.402	1.096	0.210	0.517	0.612	7.354	0.596	7.949	6.125
LP2.2	S	sept-oct	29.6	0.004	0.036	0.039	0.075	0.258	0.333	1.085	0.208	0.466	0.541	6.343	1.568	7.911	6.254
LP3	S	sept-oct	29.5	0.002	0.040	0.035	0.076	0.294	0.370	0.970	0.177	0.471	0.547	4.395	2.176	6.570	6.617

Average nutrient concentrations during period when oysters were present in Little Pond (late July to late August) compared to average nutrient concentrations during period when oysters were NOT present in Little Pond (September and October). Averages for when oysters present are comprised three sampling dates: 7/23/15, 8/7/15, 8/21/15. Oysters removed from Little Pond on August 28, 2015. Averages for when oysters not present in Little Pond are also comprised of three sampling dates: 9/4/14, 9/22/15, 10/28/15.

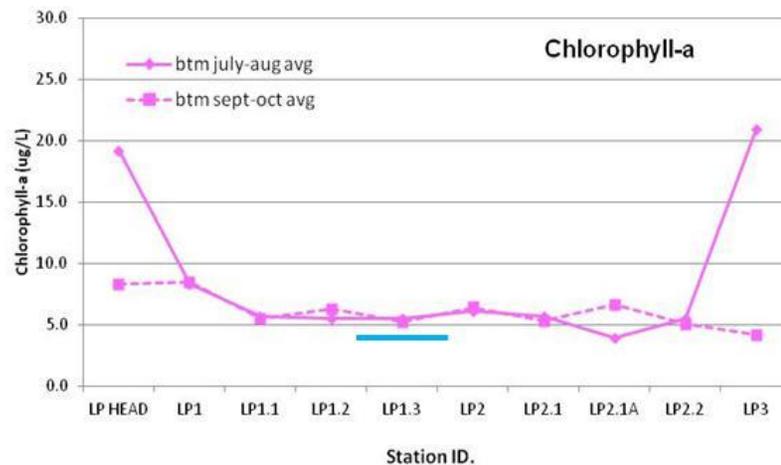


Location of oyster deployments represented by blue line in all plots. Oyster deployment (blue line) situated between stations LP-1.2 and LP-2 with LP-1.3 positioned amongst the strings of oyster bags. LP1.2 is up-gradient of the oyster deployment on an ebbing tide.

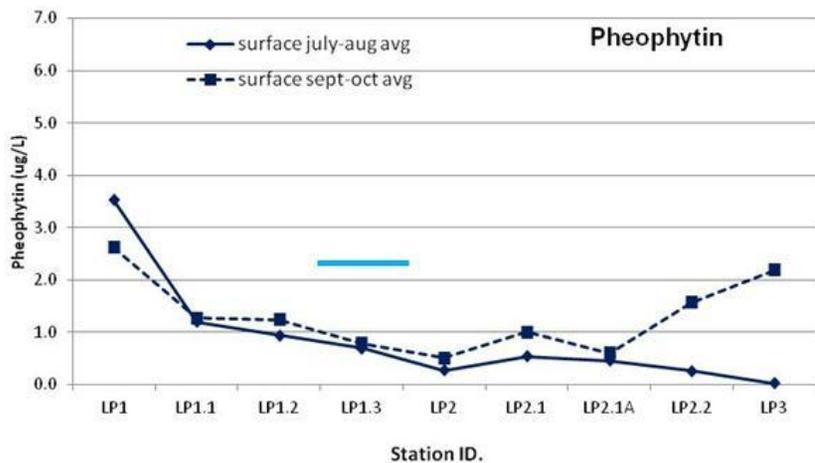
Average July-Aug vs. Sept-Oct 2015 (surface samples)



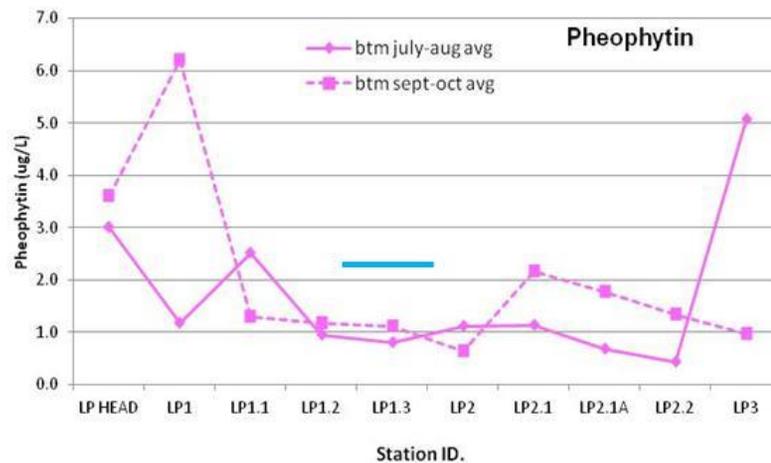
Average July-Aug vs. Sept-Oct 2015 (btm samples)



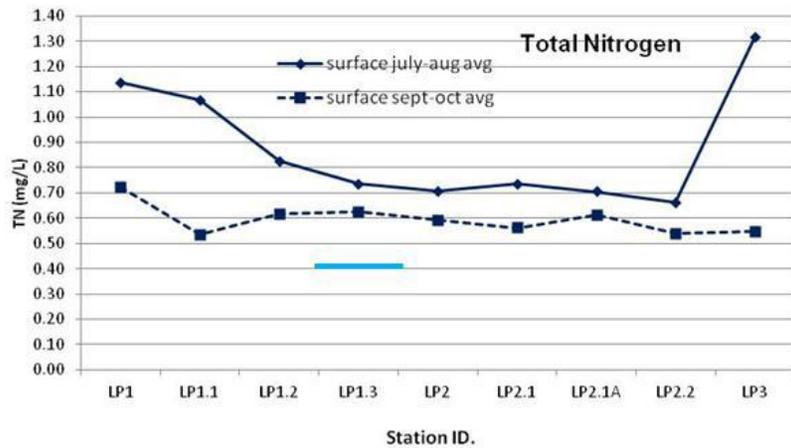
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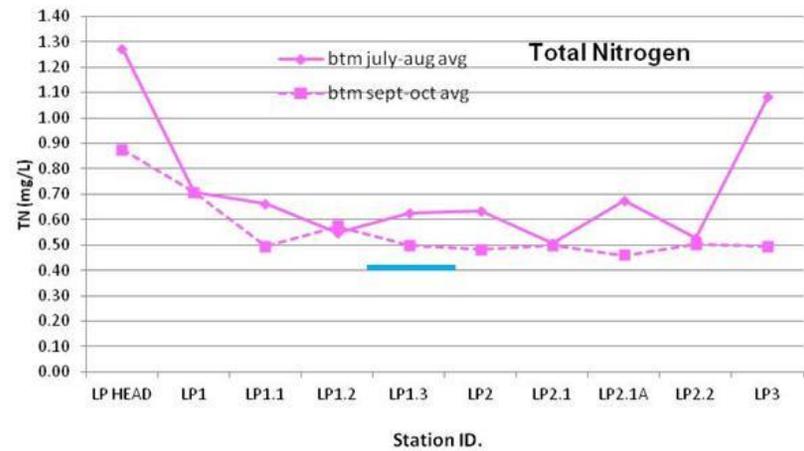
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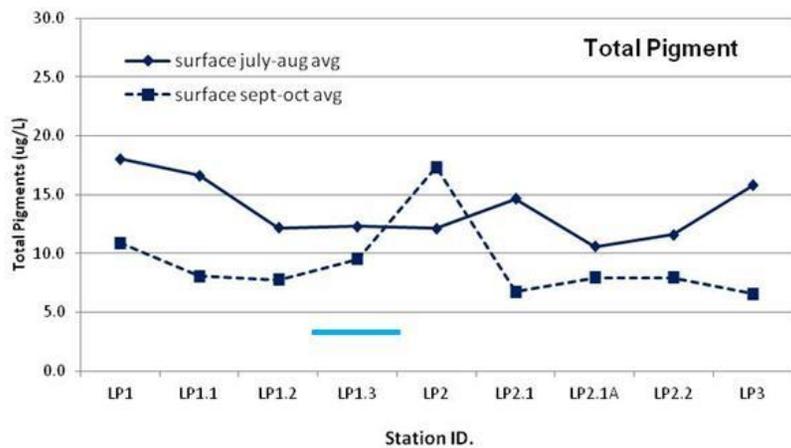
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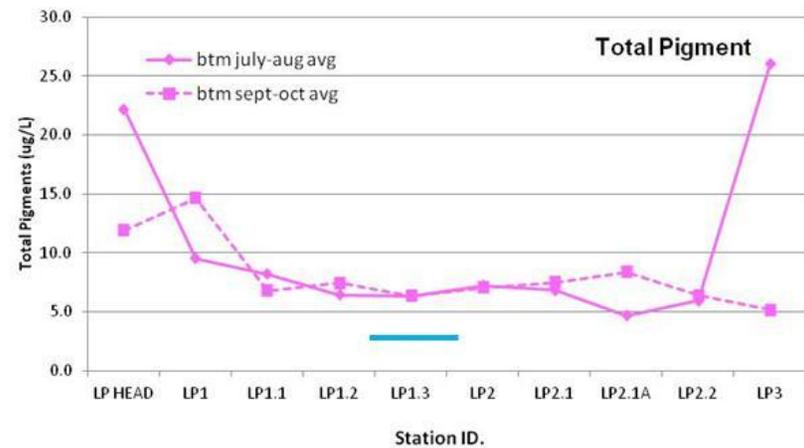
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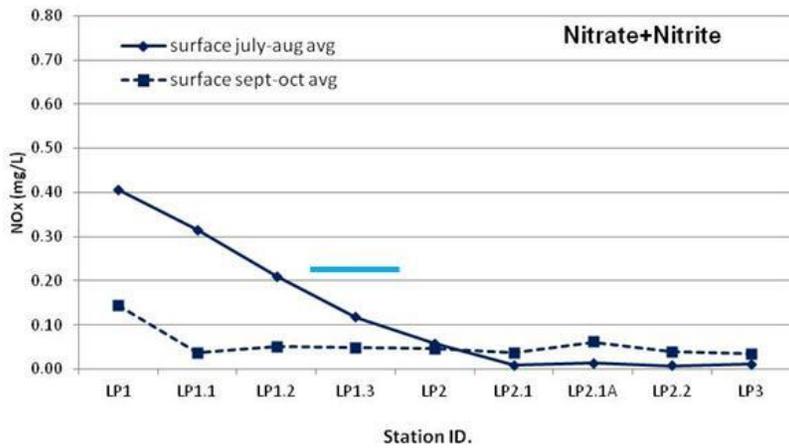
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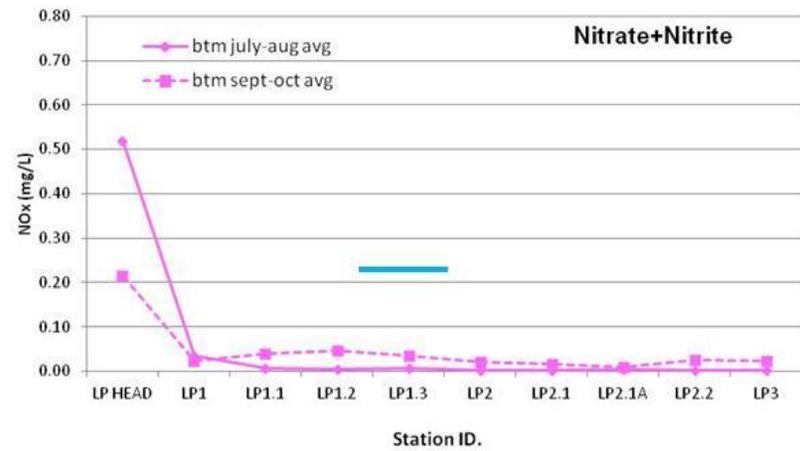
Average July-Aug vs. Sept-Oct 2015 (btm samples)



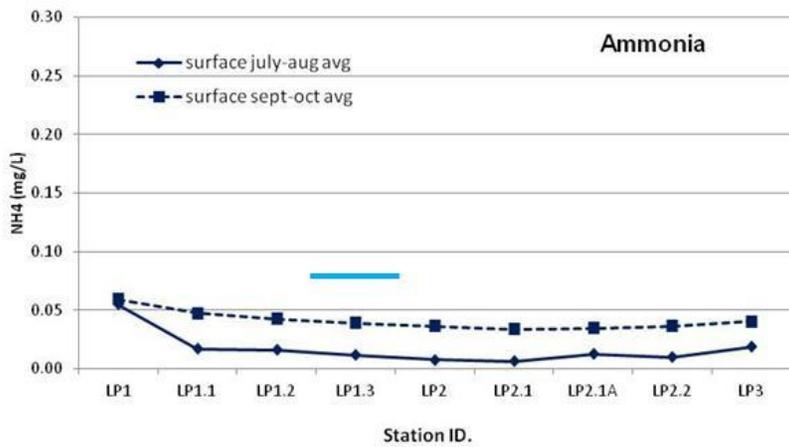
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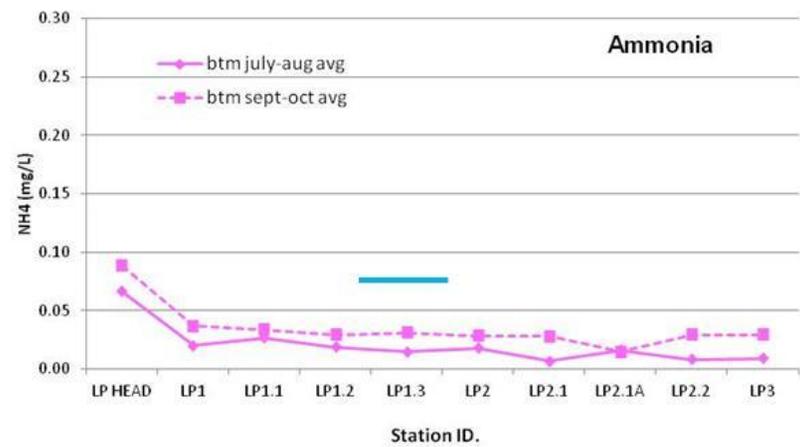
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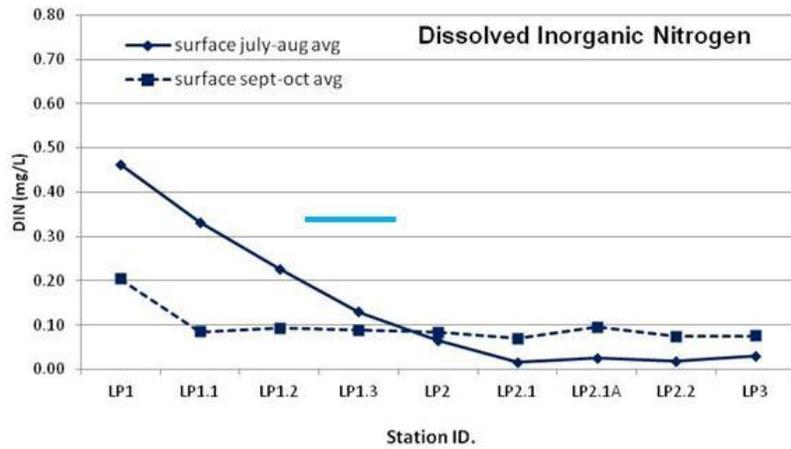
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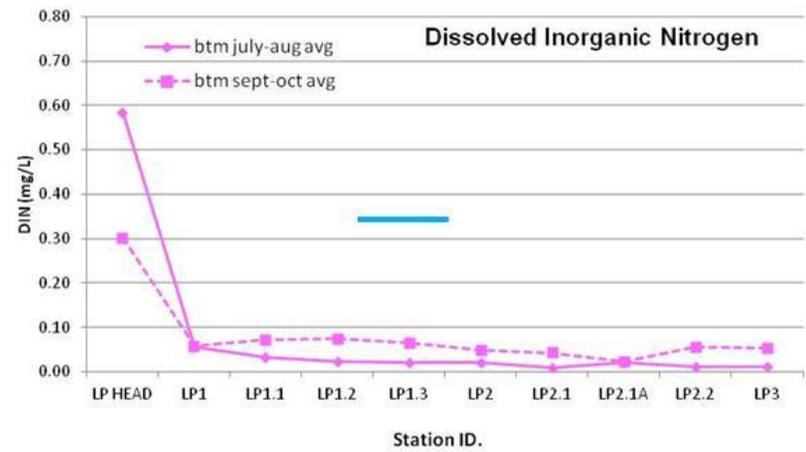
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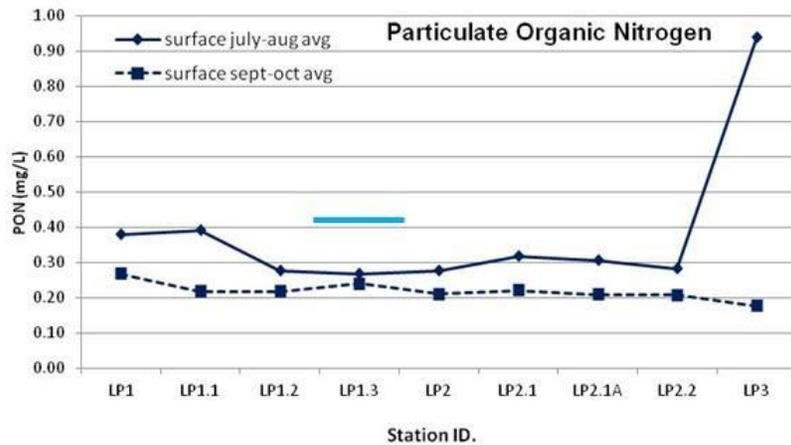
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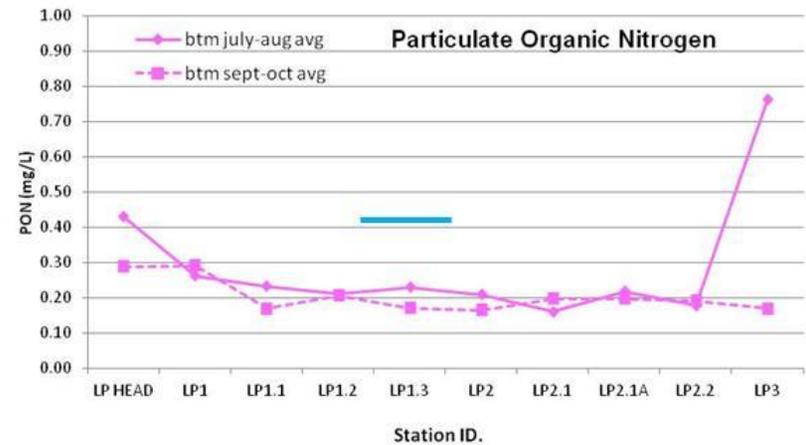
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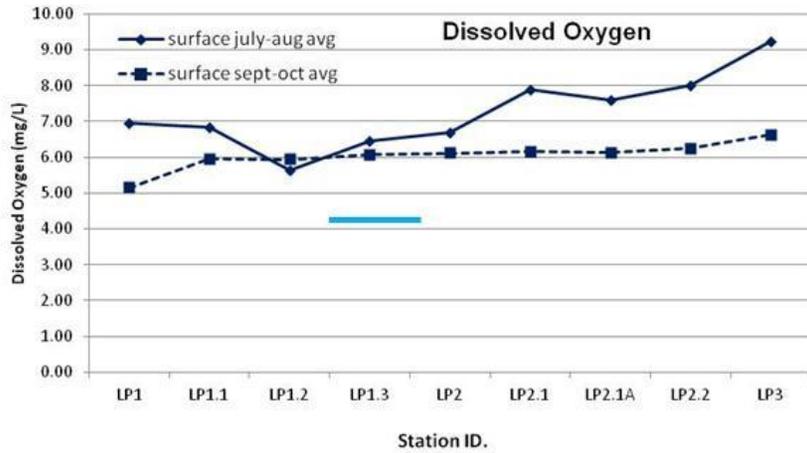
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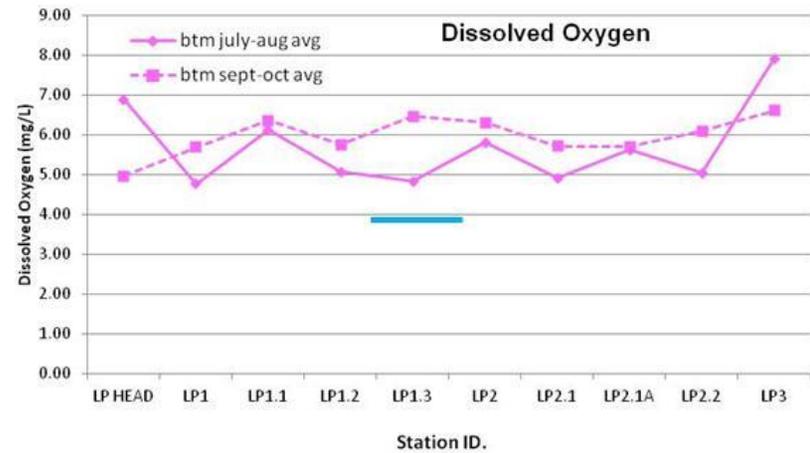
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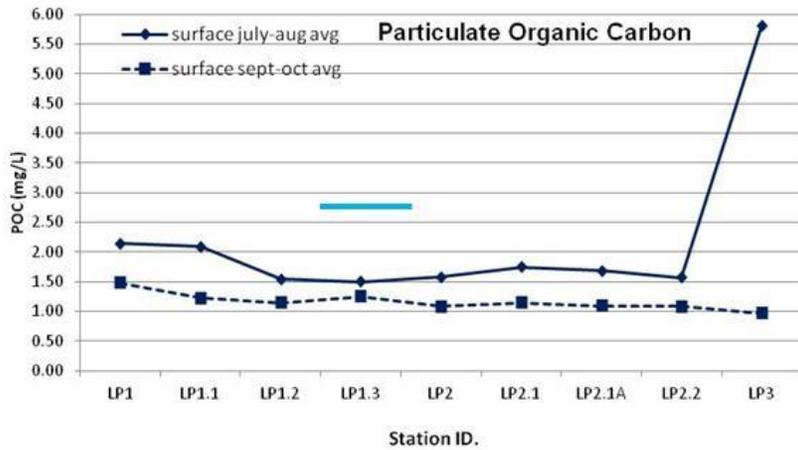
Average July-Aug vs. Sept-Oct 2015 (surface samples)



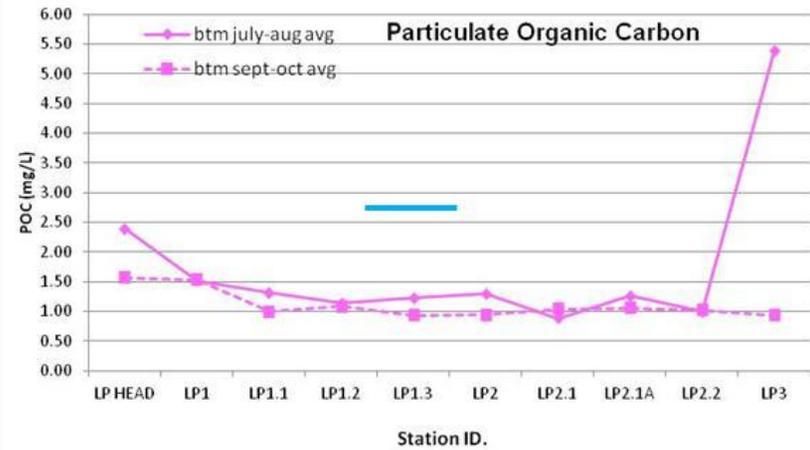
Average July-Aug vs. Sept-Oct 2015 (btm samples)



Average July-Aug vs. Sept-Oct 2015 (surface samples)



Average July-Aug vs. Sept-Oct 2015 (btm samples)



Appendix 3.2: Shellfish Aquaculture

- West Falmouth Harbor Oyster Bed Project Final Report



FINAL REPORT

West Falmouth Harbor Oyster Bed (Reef) Development Project

April 24, 2017

Prepared by:

Anastasia Karplus, Science Wares, Inc.

This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement CE-96198501 to the Massachusetts Executive Office of Energy and Environmental Affairs Buzzards Bay National Estuary Program. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does the EPA endorse trade names or recommend the use of commercial products mentioned in this document.

1. Background

Project Overview and Goals

Over a three-year period beginning in 2014, The Town of Falmouth planned and installed an oyster bed at the location where Mashapaquit Creek enters Snug Harbor. This area in West Falmouth Harbor is shown in Figures 1 and 2. The purpose of this project was to evaluate the growth and nitrogen-removal potential of an oyster bed in this estuary. The Town began this effort in 2014 with a viability study, and continued in 2015 with a pilot-scale effort where 500 bags of oyster remote set were grown for one season and then planted on the sandy bottom in this area. Remote set is shell (typically hard clam) on which oyster seed has been made to attach in a controlled environment. The 2016 implementation phase was funded by a grant from the U.S. Environmental Protection Agency (EPA) through the Southeast New England Program (SNEP) Water Quality Management Grants, administered by the Buzzards Bay National Estuary Program. This phase involved growing 1500 bags of remote set and monitoring the water quality and ecosystem service benefits in collaboration with Woods Hole Oceanographic Institution.

The main goals of the 2016 implementation phase were to:

- Achieve material reductions in the amount of nitrogen in West Falmouth Harbor
- Evaluate whether this oyster bed could be self-sustaining
- Provide a blueprint for developing oyster beds using oyster remote set

West Falmouth Harbor fails to meet water quality standards due to nitrogen pollution. It is listed as a Category 4a water on the Final Massachusetts Year 2012 Integrated List of Waters. Originally listed as a Category 5 nitrogen impaired waterbody in 2002, a Total Maximum Daily Load, (TMDL) was approved by EPA in 2008 establishing a nitrogen concentration limit of .35 mg/L at the sentinel station. The TMDL identifies the main sources of controllable nitrogen in the West Falmouth watershed and their relative contributions as the Wastewater Treatment Facility (WWTF) (61%), septic systems (20%), fertilizer and stormwater (8%). However, a significant upgrade to the town's WWTF was completed in 2005, achieving a nitrogen effluent limit of nearly 3 mg/L and considerably reducing the nitrogen load from the WWTF to West Falmouth Harbor and making septic systems the largest controllable source. Despite these efforts, this embayment is not expected to meet the TMDL and water quality standards unless further action is taken to reduce nitrogen.

Phytoplankton and other particles of algae is food for shellfish but also an unwanted symptom of eutrophication that leads to cloudy water and eelgrass die-off. As algae dies, it also sinks to the bottom, creating undesirable organic-rich sediment that is often referred to as muck. One key ecosystems service provided by oysters is uptake of particulate organic nitrogen. This form of nitrogen is comprised of the phytoplankton and other algae in the water. Recent studies (Reitsma et al. 2017) report that a harvestable size oyster of 85 mm (3.3-inches) that is grown on the bottom contains 0.32 g of nitrogen. Some studies (Bricker et al. 2015) show that filtering of the water also removes particles containing nitrogen and improves water clarity by depositing them in sediments where some nitrogen is removed by bacteria through denitrification.

The ecological services that oyster beds provide may prove critical to catalyzing the ultimate restoration of the water quality in West Falmouth Harbor. Without clear water, eelgrass cannot

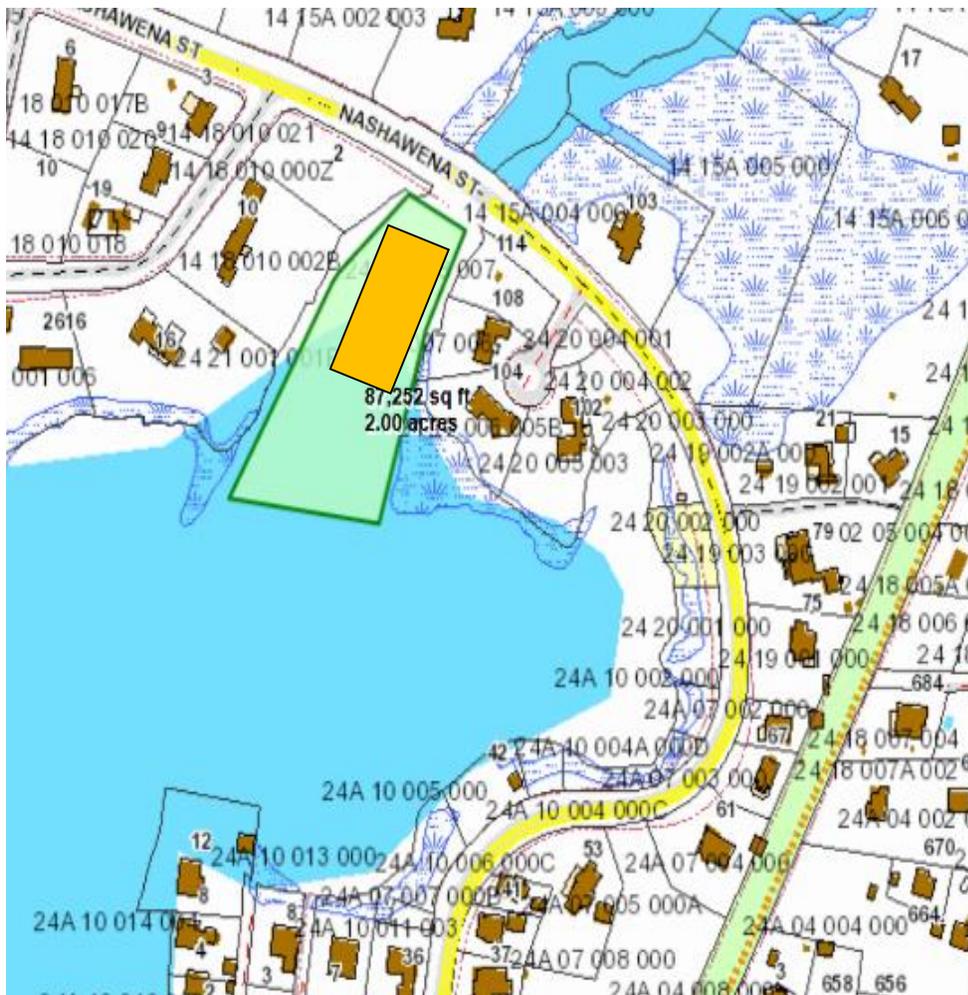
grow. Highly organic sediments that are produced when algae die also inhibit the growth of eelgrass and many bottom dwelling fauna. This project seeks to establish an oyster bed in order to provide a biological filter for the water entering West Falmouth Harbor from Mashapaquit Creek, which is a significant source of nutrients. Estimates of nitrogen uptake attributable to shellfish harvest in this project are found in Section 3.

Oysters are also a significant and valuable source of local food. Once established, the oyster bed in Snug Harbor could provide both a selective relay and harvest area as well as a spawning sanctuary for oysters, which have historically grown well in West Falmouth Harbor. The oysters that are spawned will help support wild commercial and recreational oyster harvesting.

2. Project Description

The project location is shown in Figures 1 and 2.

-  = 2-acre oyster bed location at Snug Harbor
-  = 2016 grow-out area at Snug Harbor



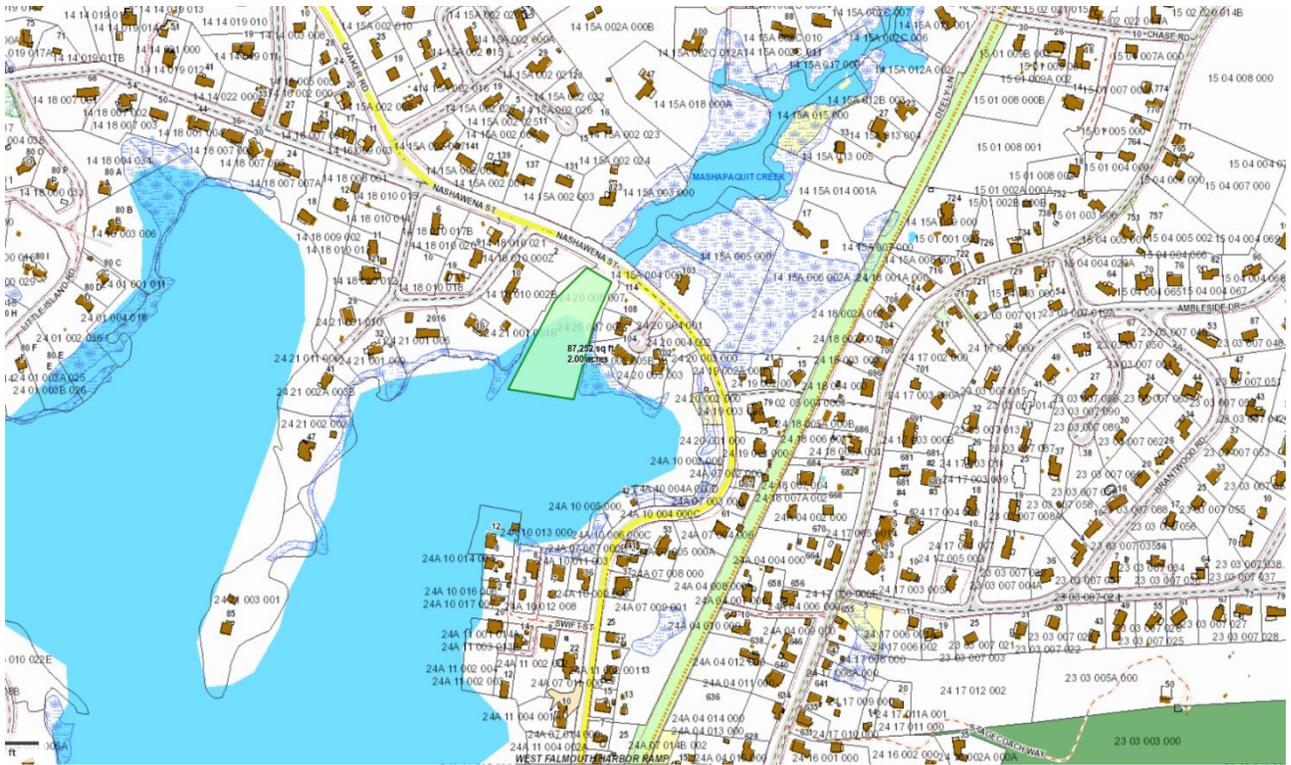


Figure 1. Locus Maps of West Falmouth Oyster Bed Location



Figure 2. Aerial View of West Falmouth Oyster Bed Location

Site Selection (2014, 2015)

Establishing an oyster bed utilizing remote set from hatcheries requires both suitable sites and an effective method for growing. The general location for the establishment of an oyster bed in Falmouth was selected for several reasons, including:

- Observed high rates of water flow and food availability
- Adequate salinity even within Mashapaquit Creek (20 ppt)
- Suitable areas of hard bottom
- Population of wild oysters in this area
- Lack of freezing even during the winter of 2014 when much of West Falmouth Harbor was solid ice

Based on these factors, a preliminary viability study was conducted in July 2014. This exploration involved installing one tray near Nashawena Bridge and 39 floating bags in different locations around the project area. Figure 3 shows the locations of the test sites. Gear was stocked with approximately 1.5 L of oyster singles at a starting size of approximately 12 mm. After approximately six weeks, a visual inspection of the oysters seemed to indicate that those located within Mashapaquit Creek were not thriving and the oysters south of the Nashawena Bridge were growing well. This relative health between oysters in the stations located within Mashapaquit Creek and stations 4A and B was assessed based on a noticeable difference in color. Measurements confirmed these visual inspections. By the end of August, measured oyster growth (starting density of 1.5 L) was as follows:

Stations 1A and 1B: 2.25 L
Stations 2A and 2B: 4 L
Stations 3A and 3B: 8 L
Stations 4A and 4B: 12.5 L

In addition, the areas within Mashapaquit Creek required a boat for access and maintenance and there is only a two-hour window around mid-tide when a work boat can get under the bridge to access this area.



Figure 3. 2014 Preliminary Study Area

Based on these results, the area south of the Nashawena Bridge was selected for continued evaluation and 500 bags of oyster remote set were purchased for the 2015 growing season to confirm the viability of this location for establishing a permanent oyster bed.

Typically, bags of remote set are purchased and directly bottom-planted. Falmouth has found that growing the remote set in floating bags and covered trays off-bottom for the first part of the growing season leads to higher survival and overall oyster density. Keeping the remote set in floating bags and trays also protects the oysters during their early stage of growth. For these reasons, the remote set used in this demonstration was grown in floating bags and trays for one season prior to bottom planting.

During the 2015 evaluation period, oysters grew to an average of 50 mm, mortality was measured at below 5%, and the average number of live oysters per floating bag was approximately 300. Based on these favorable results, both in terms of growth as well as overwintering survival, an implementation project using 1500 oyster remote set bags was planned for 2016. Figures 4 - 6 are photodocumentation of the 2015 pilot study.



Figure 4. Oysters in the Fall of 2015, Prior to Bottom Planting



Figure 5. Oysters Bottom Planted in the Fall of 2015



Figure 6. Left: Oysters in the spring of 2016. Right: Population Counts in the spring of 2016

Project Implementation (2016)

The following steps were taken to implement the 2016 project:

- Assemble floating bags for installation of remote set
- Build cultch bags for remote setting of oysters
- Deliver cultch bags and coordinating with local hatchery to have oyster spat attached to cultch
- Retrieve remote set (oyster spat attached to cultch)
- Install remote set

In April and May, 2016, Falmouth Marine and Environmental Services (MES) staff loaded cultch into mesh bags to create the substrate on which oyster seed is attached. This process involved using a traffic cone as a funnel to efficiently load approximately 10 pounds of clam shell into 10 L mesh bags. Falmouth has been stockpiling clam shell from a local business for several years in anticipation of future projects involving oyster remote set. This shell is clean and dry. In June 2016, 1,500 cultch bags were delivered to ARC (the local hatchery in Dennis, MA). Because ARC was undergoing construction, remote set was not available for pick-up until the last week of July 2016. As soon as the remote set became available, MES staff mobilized to retrieve the 1,500 bags of remote set and began installing it in floating bags on August 3, 2016. Within five days, this remote set had been installed in trays and floating gear.

Approximately 840 floating bags and 30 trays were installed at the project location shown in Figure 1. The floating bags and trays were loaded with approximately 1.5 and 4 remote set bags (respectively). The water surface area taken up by these 840 floating bags using a cinder block anchoring systems is approximately 0.5 acres. As part of its municipal propagation efforts, MES has also developed a system for installing floating bags using helical augers and lines that enables very high density of bags. As seen in Figure 7, more than 4,000 floating bags can be installed per acre. These floating bag densities are highly dependent on flow and food availability.

The purpose of starting the remote set in floating bags was to protect the oysters from predation and fouling during the early phase in their life cycle. Floating bags are widely used across Cape Cod because oysters grow well in them. Low mortality is often measured when using floating bags. At the end of the first growing season, oysters reached an average length of approximately 31 mm. It is likely, based on standard growth rates of oysters, that had remote set been available in late June (as was expected), the oysters would have reached 40 – 50 mm in length.

Operation and maintenance of the floating bag installation included regular flipping of the bags to control fouling. The floating bags were installed so that at low tide, the field could be maintained by foot, greatly reducing the level of effort required for this vital maintenance step. As part of routine maintenance, data was collected on growth rates. Prior to bottom planting, population counts and survival rates were measured.

In October 2016, the remote set oysters were bottom-planted to establish a permanent oyster bed biofilter. The procedure used to bottom plant the oysters involved the following steps:

- Field verification of hard bottom within the Snug Harbor project site

- Marking of these hard bottom areas with buoys
- Systematically emptying strings of floating bags within the marked areas

One challenge with bottom planting is keeping track of where remote set is placed as workers walk on the bottom. A tool was created to enable staff to keep track of where strings of floating bags were emptied within the areas of hard bottom, so that strings of floating bags would be planted across the marked area. This tool included a floating line cut to the approximate width of the planting area that was secured with cinder block anchors and buoys to mark the ends. Once the first string of floating bags was planted, this tool was moved to mark where the second string of bags should be deposited. This approach avoided having staff step on the oysters that had already been put on the bottom, and helped ensure that the area was planted uniformly.

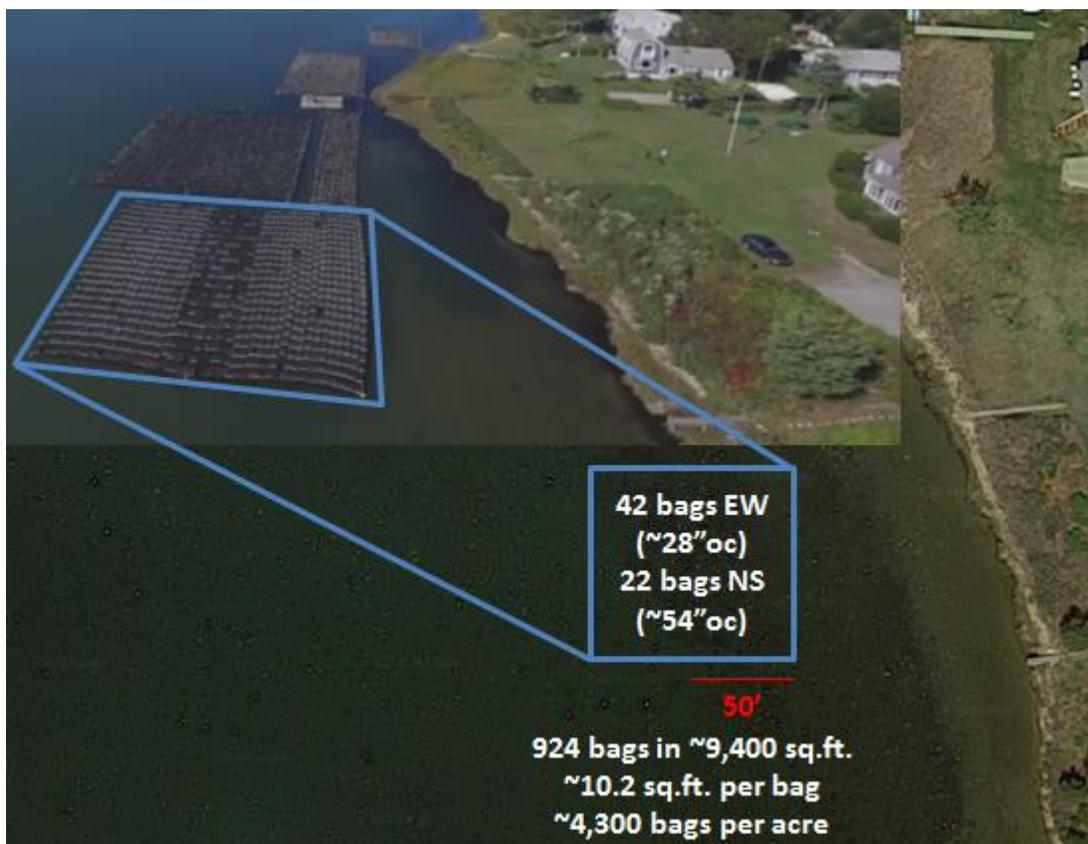


Figure 7. Floating Bag Densities Demonstrated by Municipal Oyster Propagation Operated by the Town of Falmouth in 2016.

Figures 8 - 11 are photodocumentation of the 2016 installation:



Figure 8. 1500 Bags of Remote Set Delivered by Falmouth Staff to Staging Area of Snug Harbor Installation Site



Figure 9. Use of Bobcat by Falmouth Staff to Unload Remote Set



Figure 10. 1500 Bags of Remote Set Being Installed in the Water by Falmouth Staff



Figure 11. Installation of Remote Set in Floating Bags and Trays

3. Population Data and Nitrogen Uptake Estimates

When oyster remote set is first installed, the oyster spat is not visible. As the microscopic seed begins to grow, it is evidenced by small dark spots on the cultch. After installation in 2016, the remote set was monitored weekly to determine when oysters reached a reasonable measurement size. Length measurements of a sample size of 100 oysters began on September 9, 2016. Final lengths were measured on October 21, 2016, prior to bottom planting. Table 1 shows the average measured lengths over the growing season and Figure 12 charts the growth over time.

Table 1. Oyster Remote Set Growth

Date:	9/9/2016	9/23/2016	10/7/2016	10/21/2016
Oyster Size:	mm	mm	mm	mm
Average Length:	15.63	18.73	24.07	30.92

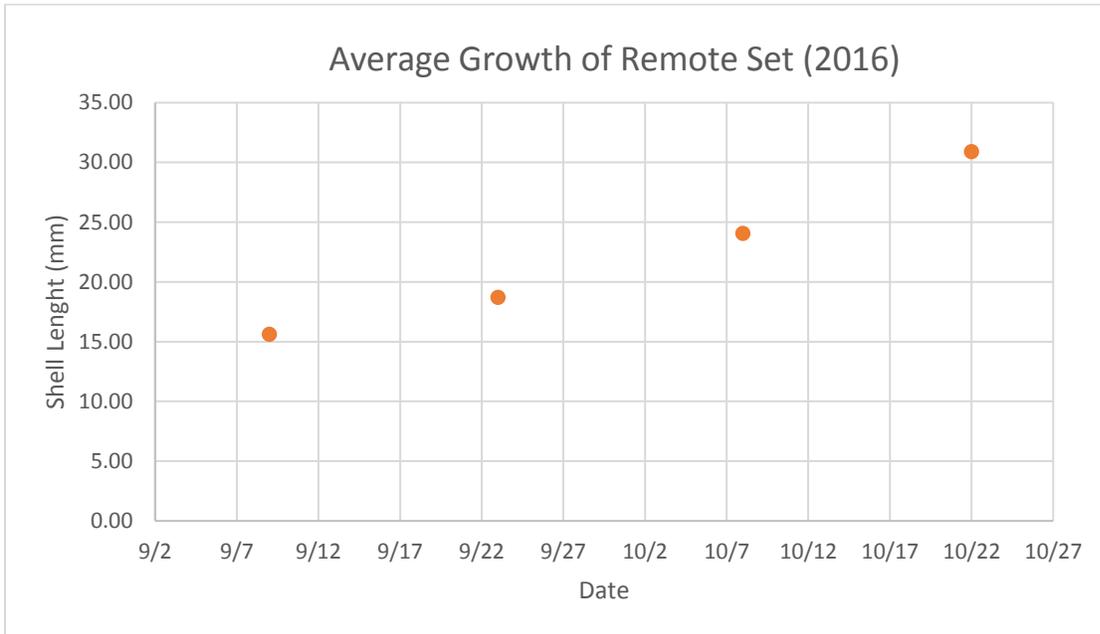


Figure 12. Oyster Remote Set Growth over the Season



Figure 13. Photograph of oysters at the end of October, 2016

A total of 840 floating bags containing 1,300 of the remote set bags and 50 trays containing 200 remote set bags were installed. At the end of the growing season (November, 2016), these oysters were bottom planted in the approximately 3,000 sq. ft. area shown in Figure 14.



Figure 14. 2016 Oyster Bed Planting Area

Prior to bottom planting, five floating bags from three rafts (total of 15 bags) were assessed for both the total oyster population as well as survival. Floating bags were taken from each of the four sides as well as the center of each raft. The entire bag was emptied and all live and dead oysters were counted. The number of live and dead oysters per floating bag was then recorded. The average number of live oysters per floating bag was then calculated to be 296 and the mortality was measured at less than 5%. Please note that this mortality only includes the survival of oysters once they had reached a size where shell was produced. This reported mortality does not include the mortality of spat that never reached the size where shell was visible. Based on these measurements, the estimated population of oysters that was bottom planted in 2016 is approximately 308,000. Mortality will likely reduce the population of planted oysters over time.

Reported mortality for oyster reefs varies widely. There is also a range of published and reported values for annual mortality rates for oysters grown in gear from 2 mm seed to market size. Oyster survival rates vary from one year to another and are impacted both by husbandry practices as well as events of nature. Quality of seed, stocking densities in both nursery and grow-out, disease and weather events can all impact survival. Bricker (2014) and Hudson et al. (2012) propose mortality rates of 55% and 50% respectively, for gear-based aquaculture. The U.S. Department of Agriculture (USDA) Noninsured Crop Disaster Assistance Program uses 44% to 46% as normal mortality rates for oyster aquaculture in their payout calculations. The mortality for an oyster bed in the wild is likely higher than the mortality rate for gear-based aquaculture, especially with respect to predation and weather events. For planning purposes, mortality of an oyster bed is assumed to be 50%.

The value from published literature (Reitsma et al. 2017) for the nitrogen content of Cape Cod oysters that are cultured on the bottom is 0.32 grams per 85 mm oyster. Based on this value, the nitrogen uptake from 308,000 oysters that grow to adult size is 99 kg N (308,000 oysters x 0.32-grams N/oyster). Assuming constant growth over two seasons, half of this nitrogen, or approximately 50 kg would be incorporated into shell and soft tissue per season. The area in which the West Falmouth oyster bed was planted measures approximately 3,000 sq. ft. The planting density was 1.5 - 2 ft² per remote set bag or approximately 100 oysters per square foot. At an estimated 50% mortality, an oyster bed covering one acre could support a population of over 2 million oysters, and uptake over 350 kg N/year.

The first oyster Best Management Practice report from an expert panel in the Chesapeake Bay (Cornwell et al. 2016) indicates that there is scientific agreement regarding nitrogen uptake in oyster tissue. This report also highlights that there are still outstanding questions regarding regulatory credit for nitrogen *removal* from permanent oyster installations. This panel will be addressing the issue of nitrogen-removal from oyster beds and reefs in a future report. The oyster bed that has been initiated in Snug Harbor will be allowed to establish itself for several years, and then strategic harvest may occur to remove the nitrogen contained in the oysters.

4. Budget Estimates for Implementation

Based on updated (2017) cost for the gear and labor required to execute this project, a planning-level budget for developing an oyster bed using 1500 bags of remote set is shown in Table 2. This budget assumes volunteer labor to build the 840 floating bags needed, and that project management will be incorporated into the municipal propagation efforts of the MES department. Specialized monitoring costs are not included.

Table 2. Planning Budget for Oyster Bed Development

Item	Description	Cost
Labor - seasonal position	Installation, operation, maintenance and volunteer coordination	\$ 20,000
Patrol	Enforcement	\$ 2,000
Remote set purchase (1500 bags)	Cost of cultch bags and remote set (spat-on-shell)	\$ 24,000
Gear purchase (includes bags, lines, anchors, etc)	System for 840 floating bags	\$ 11,760
Trays	50 trays	\$ 1,950
Labor to build bags	Volunteers	\$ -
Project management and reporting	MES Department program	\$ -
TOTAL		\$ 59,710

Based on the removal of 50 kg of N per year for 310,000 oysters, and an amortization of the gear, remote set and labor expense over 5 years, the dollars per kilogram of nitrogen removed is \$280/kg N removed.

The initial budget for this grant was amended to allow reallocation of \$2400 to cover a portion of the costs to produce a video (total cost \$3,500) to help meet the outreach goals of the project.

5. Monitoring

Critical water quality parameters were monitored near the oyster grow-out location. Leveraging ongoing collaborations between the Woods Hole Oceanographic Institution and the Buzzards Bay Coalition, monthly water samples were collected for nutrient concentrations, including nitrate, nitrite, ammonium, total dissolved nitrogen and particulate organic nitrogen. Samples were also analyzed for chlorophyll-*a* and phaeopigment concentrations. Total nitrogen at the study site exceeded 1.2 mg/L during both summer 2015 and summer 2016 (Figure 15 left) with chlorophyll-*a* pigment concentrations exceeding 30 µg/L during both summers (Figure 15 right). Discrete measurements of dissolved oxygen concentration reached minimums of ~4 mg/L during both summers monitored.

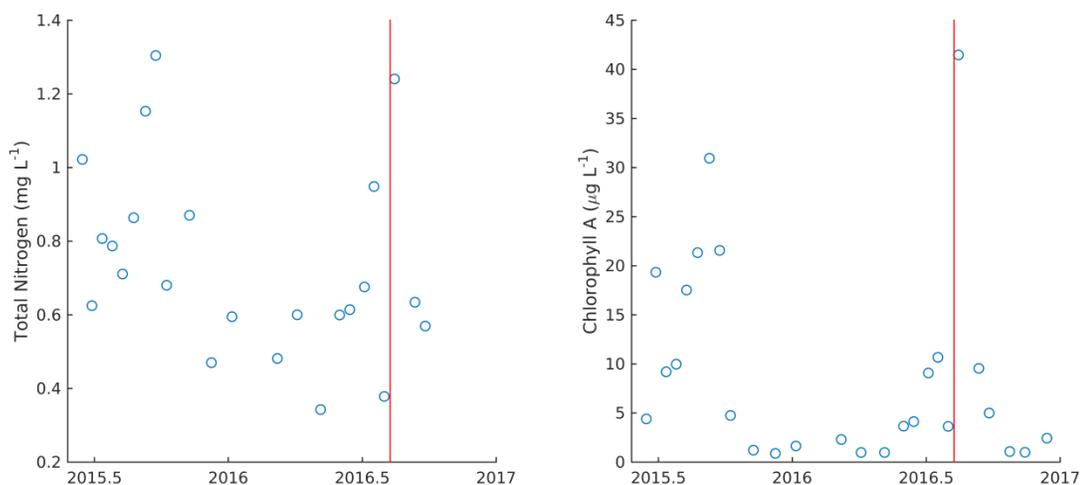


Figure 15. Total nitrogen and chlorophyll A concentration from monthly grab samples near the grow-out location. The vertical red line indicates when the oyster bags were installed.

During summer 2016, a multiparameter datasonde was also installed at the monitoring site that was downloaded, cleaned, and recalibrated every two weeks throughout the summer. The datasonde monitored temperature, salinity, dissolved oxygen, pH, turbidity, and water depth every 30 minutes for the study period. There was a brief hiatus in measurements from late August through early September when the instrument was not collecting data. Daily variations in dissolved oxygen were large and often greater than 10 mg/L (Figure 16). Both extremely low (~ 1 mg/L) and high (>20 mg/L) dissolved oxygen concentrations were observed (Figure 16).

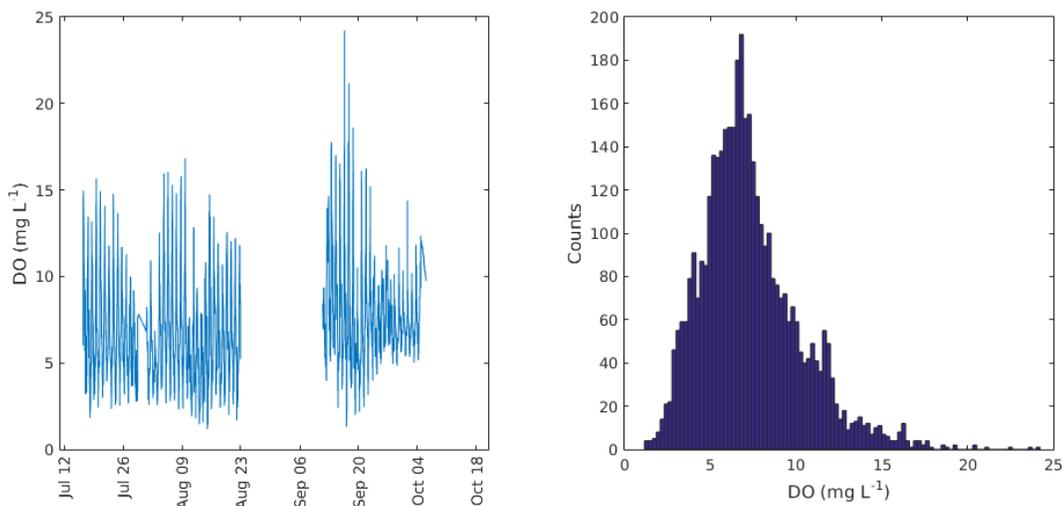


Figure 16. Dissolved oxygen concentration time series and histogram.

From the existing monitoring data, the new oyster bed does not show a measurable impact on nutrient and chlorophyll-*a* concentrations. The oysters were not installed at the study site until early August. This means that while the impact of adult oysters may be measurable, likely the small-sized oysters installed late in the season would not yet have had an impact on water column nutrients. These data do provide important baseline information from before and after the installation to assess the future impacts of the new oyster bed on West Falmouth Harbor.

6. Summary and Recommendations

Key findings of this project include:

- Survival of remote set is high in floating bags. Of the oysters that grew on the cultch to a size where shell was visible, mortality was less than 5%. The survival of spat was not measured.
- Oysters grew from spat to over 30 mm from August to October. This growth over a three-month, warm-weather period is similar to the amount of growth of oyster singles that were grown by the MES Department for municipal propagation.
- The estimated nitrogen uptake in shell and soft tissue for this installation is almost 50 kg per year for 308,000 oysters. Some additional nitrogen may be filtered out of the water column and deposited in sediments (not quantified in this study).
- Costs in terms of dollars per kilogram of nitrogen harvested: \$272
- The program's outcomes also highlight the importance of site selection and viability testing as critical first steps in planning.
- Due to the visibility of this location, many people stop and ask questions when staff is working on this project. This provides an excellent opportunity to discuss environmental issues and the role of shellfish in water quality improvements. There is a great deal of public support for this project.
- Several public outreach presentations during the planning and implementation phases of this project have been made, including:
 - Presentations at two meetings sponsored by EPA/SNEP (August and October, 2016)
 - Presentation to West Falmouth Village Association meeting (June, 2016)
 - Periodic updates at Falmouth Water Quality Management Committee meetings
 - “From Town To Table: Falmouth Oysters” video posted on Vimeo at <https://vimeo.com/210045949> and the Falmouth MES Facebook page, and has been presented at various venues, including a Massachusetts Shellfish Offices Association meeting, Trinity College, Falmouth Fisherman’s Association and Cape Cod

Cooperative Extension. Showing this video to Falmouth's Fall 2017 Town Meeting and the Cape Cod Commission's OneCape conference in June 2017 are also planned.

- Additional presentations are planned once this project report is finalized

Based on the lessons learned, it is recommended that the population and survival of this oyster bed in this area of Snug Harbor be evaluated in the fall of 2017, and scale-up to a one-acre oyster bed be considered.

7. References

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Appendix 3.2: Shellfish Aquaculture

- Draft Rotational Aquaculture Plan

Falmouth, MA Rotational Aquaculture Plan, including:
Executive Summary
Literature Review
Habitat and Resource Assessment
Engineering and Planning for Proposed License Sites
Other Elements (including municipal roles and economic benefits)

August 3, 2017

Executive Summary

Falmouth is a special place. Over the past 50 years, development has compromised estuarine water quality and led to significant loss of invaluable marine habitat. These salt ponds, estuaries and harbors are the critical nurseries and rookeries for shellfish and finfish as well as birds and mammals that form the basis of a complex food web. Estuarine habitats also the home to harvestable species of both commercial and recreational value. Within our lifetime, we can start to return Falmouth's estuaries to the vibrant ecosystem that brought us here to work and play in the first place. Shellfish propagation is a key component of this restoration effort.

The Falmouth Rotational Aquaculture Plan has several goals, including:

- Develop a plan for the town's estuarine resources which benefits all users these area, both economically and environmentally
- Balance the harvest goals of commercial, recreational, senior, and family diggers with aquaculture growers
- Strive to balance the need and distribution of benefits associated with aquaculture development locally
- Explore and develop innovative approaches to municipal planning and propagation
- Provide an estimate of the economic and social benefits of local aquaculture to help provide a rationale for town expenditures
- Provide guidance on helping to meet regulatory water quality goals using private aquaculture and municipal propagation

Shellfish aquaculture operates within a public resource with multiple user groups. The purpose of this plan is to both define specific locations that are potentially suitable for private shellfish aquaculture and to present an approach for managing these aquaculture sites in a way that does not negatively impact other stakeholders. A Shellfish Working Group was formed to provide input to this plan and includes representatives of Town departments such as Marine and Environmental Services and Conservation Commission, Town committees, growers, neighbors and other user groups. Through this interactive, stakeholder-driven process, a preliminary set of sites that are potentially suitable for shellfish aquaculture has been identified. In addition, this plan includes an implementation strategy for these aquaculture sites based on the concept of Rotational Aquaculture License Sites (RALS) and concurrent municipal propagation of commercially important species such as quahogs. The overall nitrogen-removal of this program has also been quantified.

This plan includes the following Sections:

Section 1: Literature Review:

This section presents the results of the literature review of aquaculture plans from other areas and was used to determine the sections contained in this plan.

Section 2: Resource Assessments and Potential Aquaculture Development Areas

Section 2 presents the results of resource assessments derived from the following sources:

- Division of Marine Fisheries (DMF) Shellfish Suitability Areas
- DMF Designated Shellfish Growing Area Maps
- MA Department of Environmental Protection (MA DEP) Eelgrass Maps
- Shellfish Habitat Assessment Maps for West Falmouth Harbor, Childs/Eel River and Green Pond
- Draft Green Pond Harbor Management Plan (July 2009)
- Massachusetts Estuaries Project Reports (dates vary)
- GIS maps of boat landings, yacht clubs, moorings and other public use areas

From these information sources, existing conditions have been summarized on a series of maps, and potential areas for aquaculture have been identified. Using a customized decision support tool, the Falmouth Shellfish Working Group and other stakeholders reviewed these potential aquaculture sites. Section 2 also details the approach used to evaluate these sites and the results of this process.

Section 3: Description of multi-user and Rotational Aquaculture License Site (RALS) model for potential aquaculture sites

This section presents a RALS model for aquaculture license sites that links areas for private oyster farming with enhanced municipal quahog propagation. Other species such as quahogs and scallops can also be proposed for farming within these license sites. Area requirements, permitting steps and other features of this program are included.

Section 4: Planning estimates for the potential for nitrogen-removal of the Rotational Aquaculture Plan

This section estimates the number of both oysters and quahogs that can be grown using the RALS model described in Section 3, as an example. Other commercially-important species may also be grown. Based on the preliminary areas that have been identified in this plan for aquaculture and municipal quahog propagation, planning-level estimates for the nitrogen-removal that these shellfish quantities represent are presented.

Section 5: Other Issues

Several planning considerations are discussed in Section 5:

- Infrastructure needs and mooring consolidation
- Role of municipal propagation
- Economic and other benefits

Section 6: Next Steps

Several public meetings were held to review this plan. A fact sheet was prepared for distribution at these public meetings to summarize the objectives and regulatory context of this plan (Appendix A). ADA areas were adjusted based on comments made at these meetings and the maps in Section 2 reflect this input. Section 6 summarizes the questions that were raised that relate to the implementation phase of this plan.

Key aspects of the Falmouth Rotational Aquaculture Plan include:

- The town is trying to expand aquaculture AND increase municipal propagation for wild harvest AND address aesthetic concerns of neighbors AND meet regulatory requirements AND remove nitrogen in a quantifiable way for TMDL-compliance AND address the costs of implementing this plan.
- Expanding private aquaculture into estuaries using the rotational system makes sense for everybody. Growers benefit by having ideal growing locations; the local economy benefits from creation of new businesses and jobs; local restaurants benefit from the increased supply of local shellfish; commercial harvesters benefit by an enhanced wild resource; taxpayers benefit by a reduced cost of infrastructure to remove nitrogen from the water; and all residents, taxpayers and businesses benefit from the removal of microalgae to help clean up these impaired waterbodies. We believe these benefits can be attained without an undue burden to neighbors and other users of the waterways because placement of aquaculture areas has been carefully planned and moves annually so that no one area on the water is permanently affected.
- Without a rotational system, private aquaculture would only be allowed to expand in much less desirable offshore locations because:
 - Nine of fifteen estuaries in Falmouth are conditionally approved for shellfishing, and have historically enjoyed productive bottom for wild harvesting -- traditional, private aquaculture is prohibited in these locations. The rotational system we are proposing addresses this issue from a regulatory perspective and thus opens these areas for private aquaculture; and
 - Of Falmouth's fifteen estuaries, two are open for shellfishing and have historically had productive bottom. Private aquaculture cannot be located in areas with productive bottom. There are possibly one or two small sections of these estuaries are not productive areas, significantly limiting the potential for private aquaculture here. The rotational system accomplishes the goal of allowing private aquaculture to expand into these two open estuaries in Falmouth.
- The rotational system requires an operations manager to serve as a liaison with neighbors, to ensure transitions are managed and permit conditions are enforced. Someone from the Town needs to be both in the field and available to assist administratively for this level of commercial activity within our coastal ponds. This manager will also need to ensure the biomass of shellfish for nitrogen-removal is quantified and the quahogs are planted, maintained and harvested at appropriate times. This is a full-time job that is a direct result of expanding aquaculture in town.

The Falmouth Rotational Aquaculture Plan seeks to benefit all users of the town's estuaries, both economically and environmentally and balance the harvest goals of commercial, recreational, senior, and family diggers with aquaculture growers and town water quality goals.

Section 1: Literature Review

The purpose of the literature review is to ensure that the Falmouth Rotational Aquaculture Plan includes a comprehensive list of topics and methods. Plans from both coastal communities in Massachusetts as well as plans from other states were evaluated. Literature search was performed by:

- Conducting an internet search for “aquaculture shellfish plan”, plus name of 15 towns on Cape Cod separately
- Requesting a list of towns with aquaculture plans from the MA Division of Marine Fisheries, East Coast Shellfish Growers Association, and Cape Cod Cooperative Extension
- Discussing with Falmouth Marine and Environmental Services staff
- Phone/in person interviews (summarized below) with:
 - Tessa Getchis Connecticut Sea Grant
 - Sebastian Belle, Maine Sea Grant
 - Perry Raso, Ocean State Aquaculture Association
 - David Beutel, RI Coastal Resources Management Council
 - Gregg Rivara, Cornell Cooperative Extension

Aquaculture plans from several coastal towns in southeast Massachusetts were identified. While coastal towns have regulations related to municipal propagation and wild harvest, only the towns listed below have specific plans related to private aquaculture. The following is a bibliography for these Aquaculture Plans:

- Barnstable, MA Shellfish Aquaculture Study (1998) and Three Bays Shellfish Master Plan (2016)
- Dennis, MA Coastal Resources Plan section of the Local Comprehensive Plan (2002)
- Duxbury, MA Aquaculture Management Plan (January 12, 2009)
- Orleans, MA Phase I: Orleans Shellfish Operations and Program Expansion Plan (June 2015)

Based on discussion with staff at Sea Grant programs in Connecticut, Maine, Rhode Island and New York, several state and county-level planning efforts were identified. The following is a bibliography for these plans:

- A Guide to Marine Aquaculture Permitting in Connecticut (2008)
- Rhode Island Shellfish Management Plan (2014)
- The Suffolk County Shellfish Aquaculture Lease Program Management Plan (August, 2009)
- U.S. Atlantic Coast State Shellfish Aquaculture Permitting Information prepared by Paul Zajicek Division of Aquaculture, Florida Department of Agriculture and Consumer Services

The contents of these town and state-level plans are summarized below and elements and methods that are relevant to Falmouth’s Rotational Aquaculture Plan are identified.

Barnstable, MA Shellfish Aquaculture Study (SAS, 1998) and Three Bays Shellfish Master Plan (SMP, 2016)

The Barnstable SAS identifies “areas of least conflict” throughout the town where shellfish aquaculture would be compatible with other uses. To identify these areas, the Barnstable Department of Natural Resources formed a volunteer Public Advisory Group (PAC) to identify and study shellfish aquaculture and multi-user group issues. Members of the PAC represented the spectrum of user groups of the town’s coastal resources. These

stakeholders provided information and assessments regarding how the granting of aquaculture leases in different areas might impact the other current uses of the water. A consideration of biological suitability or water quality impacts were not part of this assessment.

Factors that were considered:

- Historic and presently productive shellfish habitat
- Recreational and commercial shellfish harvesting areas
- Shellfish relay areas
- Public shellfish propagation project areas
- Navigation channels
- Mooring fields
- Existing licensed aquaculture sites
- DMF shellfish area classifications
- Anadromous fish runs

Using a consensus approach, the PAC develop draft policies and recommendations for areas throughout Barnstable where private aquaculture would be of minimal impact to other uses. The plan includes maps of the “areas of least conflict” but does not include any details for the factors that were considered. This plan was adopted by Barnstable Town Council. The current lease areas in Barnstable were permitted based on this document.

The Three Bays SMP included the following sections:

- Introduction
- Background: including historical data and reports and a description of current shellfish Initiatives in Three Bays (both municipal propagation and private aquaculture)
- Analysis of food availability and minimum carrying capacity for shellfish based on Massachusetts Estuaries Project water quality data sets and other environmental assessments, and discussions with town Department of Natural Resources and growers
- Quantification of area available for shellfish propagation using GIS analysis of acreage and “Areas of Least Conflict” from 1998 Aquaculture Plan
- Quantification of the overall potential for nitrogen-removal of the shellfish plan

Recommended elements from Barnstable’s plans to include in Falmouth’s Plan:

- Factors that were considered (mooring fields, existing aquaculture sites, DMF shellfish areas, anadromous fish runs, habitat and resource assessments, food availability, available acreage)
- Maps showing “areas of least conflict”
- Quantification of the nitrogen-removal expected

Dennis Coastal Resources Plan (CRP)

In 2001, the Town of Dennis established an Aquaculture Development Area (ADA) in Cape Cod Bay. While not part of an explicit aquaculture plan, the decision to site private aquaculture in this area was made based on several factors. This beach already allowed access for automobiles and horses, and the flats were not a

productive shellfish harvest area. This area is currently managed through local shellfish regulations. In addition, the Dennis CRP includes the following sections:

- Mapping of current coastal areas
- Inventory of town landings/water access
- Goals and policies for protecting public rights of fishing, fowling and navigation, development in FEMA velocity zones, minimize traffic in critical wildlife and plant habitats, and improve coastal water quality to enable shellfishing and swimming and protect shellfish and finfish habitat.
- List of action items with responsible parties

Recommended elements from Dennis' plan to include in Falmouth's Plan:

- Inventory of town landings and water access
- List of action items with responsible parties

Duxbury Aquaculture Management Plan (January 12, 2009)

Sections:

1. Goals and objectives
 - A key reason for developing this plan is the Board of Selectmen moratorium on either the extension of existing shellfish leases to the maximum allowed area of 3 acres, or the permitting of additional shellfish leases.
2. Background on current aquaculture regulations and practices and current lease areas
3. Benefits of aquaculture industry to town
 - Economic multiplier citations provided
4. Impacts of aquaculture industry to town
 - Identification of which town infrastructure (such as boat landings) the aquaculture industry is currently using
 - Suggestions for how to reduce multi-use issues, such as use of rafts for sorting, culling and bagging; consistent and clear buoys that mark lease areas and a waterways guide for boaters that highlights locations of lease areas)
5. Description of existing lease program
6. Discussion of the future of the shellfish lease program
7. Summary of existing knowledge of Duxbury Bay ecology
 - General, qualitative (no carrying capacity estimates made)
 - Recommends a site-specific survey of the Bay's capacity to support shellfish populations
 - References support hypothesis that shellfish aquaculture improves ecological conditions
8. Summary of current uses of Duxbury Bay
9. Discussion of sustainable aquaculture practices for existing lease-holders
 - Need for off-season storage
 - Effect of moratorium on current lease-holders
 - Size of additional areas that should be licensed, including rationale
10. Discussion of licensing new aquaculture areas

- Priority is given to allowing existing industry to mature, and expand to the 3-acre maximum size that was allowed prior to moratorium
- Limited-entry fishery model discussed (new leases are granted when old leases are relinquished)
- Need to study impacts of additional lease areas

Recommended elements from Duxbury’s plan to include in Falmouth’s Plan:

- Benefits and impacts of aquaculture industry to the town (economic, environmental)
- Summary of existing knowledge of waterbody ecology
- Summary of current uses of waterbodies
- Numerical estimate for additional lease acreage

Orleans, MA Phase I: Orleans Shellfish Operations and Program Expansion Plan (June 2015)

This plan contains the following sections:

- Quantification of the current and historic production from private aquaculture operations in Orleans
- Assessment of whether these leases are making a measurable impact on water quality
- Summary findings from a Shellfish Forum held on June 6, 2015 to review proposed sites for increased shellfish propagation (municipal propagation) in Pleasant Bay and Town Cove
- Action items and responsible parties

Recommended elements from Orleans’ plan to include in Falmouth’s Plan:

- Summary of input from public hearings
- List of action items with responsible parties

Related activities from other towns

While not formalized in a planning document, Provincetown and Truro are planning to double the area where commercial aquaculture is licensed. Each town now has a 25-acre Aquaculture Development Area (ADA). Truro plans to add 25 more acres adjacent to its existing site, while Provincetown is seeking to add acreage parallel but not adjacent to its site. Because of whale entanglement issues, floating gear will not be permitted in the expanded Truro area, but Provincetown will be expanding into shallower waters that will likely allow the use of floating gear. Whale entanglement issues are not an issue in shallower waters. Any private aquaculture lease within the ADAs still require permits from the local Board of Selectmen and Conservation Commission and, as well as Division of Marine Fisheries and U.S. Army Corps of Engineers.

Summary of Information from Other States

Outside Massachusetts, the permitting authority for aquaculture leases is typically at the state level. Discussions with regulators as well as staff from the Cooperative Extension/Sea Grant programs in Rhode Island, Connecticut and Maine provided insight into the evolution of several state programs. In addition, a comprehensive review of

the state-level aquaculture lease programs for the east coast is detailed in the report entitled “U.S. Atlantic Coast State Shellfish Aquaculture Permitting Information”. Elements of these approaches have been reviewed for the purpose of informing the Falmouth Rotational Aquaculture Plan. A synthesis of these conversations and related documents is included below.

The lease programs of different states include one or more of the following:

- Maps showing areas within which aquaculture leases may be permitted. These areas are determined after an analysis of natural resources, hydrodynamic/benthic characteristics and potential use conflicts
- Size limits on lease area
- Different classifications of leases (commercial, experimental/commercial viability, recreational, limited-purpose)
- Annual use fees, typically on a per acre basis (from \$5 [MA] – \$500 [NH] per acre)
- Limits on the number of leases allowed per application
- Shellfish production and reporting requirements
- Renewal periods and renewal fees
- Performance bonds
- Information and filing fees that must be submitted with lease applications
- Public hearing and abutter notification requirements for lease applications
- Permits from other agencies (local, state and/or federal)

As the Town of Falmouth establishes permitting requirements and other requirements for aquaculture, the specific permitting requirements from these programs may be useful to consider.

State-specific Planning in Connecticut, Maryland, Maine, New York and Rhode Island

The Connecticut Department of Agriculture (DOA) regulates the permitting of aquaculture lease sites in state waters. Areas considered suitable for gear-based aquaculture have not been mapped. When an applicant applies for a given location, this area is then publicly advertised and sealed bids are submitted. A threshold requirement for applying for an aquaculture lease is that the areas proposed for private shellfish planting and cultivation must not interfere with any established rights of fishing. Several other permitting authorities are also involved, including the state’s Department of Environmental Protection’s Office of Long Island Sound Programs and the Army Corp of Engineers. Towns, cities or boroughs are required to set up municipal Shellfish Commissions to manage both wild shellfish resources as well as aquaculture in waters outside the state’s jurisdiction. These local Commissions do not have the authority to permit structures, including gear within the coastal waters located inside their “town line”. This authority rests with the state DOA, with local Commission comments included as part of the state’s permitting process. Local Commissions have the authority for leasing commercial shellfish grounds that have no associated structures or gear and must develop a comprehensive management plan that includes a process for permitting these areas.

In Maine, the state Department of Marine Resources administers the permitting process. Specific aquaculture areas are not mapped. It is up to applicants during the permitting process to present information showing the merits of any site to be considered for a lease. Multiple categories of leases are available, from experimental to large scale commercial.

Maryland’s Department of Natural Resources (DNR) was reorganized in 2009 to proactively promote shellfish aquaculture and streamline the permitting process. To help identify suitable lease sites and create the proper

maps to accompany an application, the state developed an aquaculture siting tool. This tool is an interactive online map viewer that displays both environmentally sensitive areas as well as potential conflicts with existing commercial and recreational uses. Although growers can apply for as much acreage as they believe they need, they must provide production plans. When granted, leases then include planting requirements that must be met annually and proof of insurance. Nonresidents and business entities are also allowed to apply for leases.

In New York, the state regulates lands under water except for coastal ponds, which are controlled by towns. Recent regulatory changes have given Suffolk County control of areas previously regulated by the state. The County now controls the location, extent and intensity of aquaculture in approximately 100,000 acres in Peconic Bay and Gardiners Bay. The Suffolk County Shellfish Aquaculture Lease Program Management Plan (2009) describes implementation details of the County program for both new and existing growers. New shellfish farms are permitted as either five or ten-acre parcels. These new leases are limited to a total of 60 additional acres per year for ten years, in addition to the current area or 2.9% of the area under County lease jurisdiction.

A key feature of this program is the Shellfish Cultivation Zone map which defines the specific areas where shellfish leases can be issued, under the phasing constraints listed about. This map was developed by reviewing environmental and other data to guide lease siting, such as:

- Habitat and resource assessments
- Shellfish productivity and abundance
- Water quality data
- Socioeconomic data
- Maritime traditions

Multiple stakeholder meetings with individuals as well as groups were held to inform this mapping effort. Through proactive mapping of possible lease areas, clear limits on lease size and number, and a streamlined permitting pathway, the County both promotes private aquaculture and explicitly manages use conflicts. The program also provides non-commercial shellfish cultivation leases for experimental, educational, and shellfish resource restoration purposes to municipalities, researchers, and non-profit organizations. Lease applicants must also obtain a shellfish culture permit from NYSDEC. The towns of Islip, Babylon and Brookhaven control the majority of underwater lands in Great South Bay and are currently developing lease programs for this area that will likely be patterned after the Suffolk County approach.

In Rhode Island (RI) the Coastal Resources Management Council (CRMC) regulates all waters that are submerged and permits aquaculture activities within these waters, including coastal ponds. Aquaculture is not allowed in intertidal areas. Towns may submit Harbor Management Plans for waters adjacent to the town, where they can comment on aquaculture. The CRMC approves these Harbor Management Plans, which are expected to be consistent with the 2014 RI Shellfish Management Plan (SMP).

The SMP is a state-level comprehensive plan for shellfish, with a focus on preserving and enhancing the wild stock of species such as quahogs, soft-shelled clams, oysters, blue mussels and other native species. The SMP was developed as a collaborative effort amongst regulators, scientists, commercial interests, non-profit organizations and citizens over a two-year period. Large sections of this plan are dedicated to summarizing the scientific understanding related to wild shellfish populations in the state, in order to develop management recommendations to protect and enhance these wild shellfish resources. Although the SMP does not include specific regulations, it contains numerous recommendations that were developed by this broad group of stakeholders that worked together as a team to draft this plan.

Key features of the Rhode Island SMP include:

- Clearly articulated goals and objectives for the state’s shellfish resources in general and the planning process in particular
- An identification of urgent issues and early action items accomplished through the SMP process
- Detailed descriptions of the physical, biological, social, and economic aspects of Rhode Island’s shellfish resource, including information on the standing stock of select species
- Summary of the status of both wild harvesting and aquaculture, with an identification of trends
- Summary of regulations pertaining to shellfish in RI
- Policy and management recommendations, including an Adaptive Management Approach
- Development of use maps developed by stakeholders during several facilitated workshops

These maps document and highlight the myriad of human uses and activities currently occurring within Narragansett Bay and the coastal ponds. The goals of mapping human uses were to examine how the Bay and coastal ponds are used and by whom, and also to better understand utilization patterns and interactions. Furthermore, the effort aimed to enhance existing tools and resources available to state agencies to inform management decisions about water-related uses.

Recommended elements from state plans to include in Falmouth’s Plan:

- Maps showing appropriate areas for aquaculture evaluated and finalized through a stakeholder process
- Clearly articulated goals for the Town’s shellfish resources

The outline below incorporates the recommended elements from the aquaculture plans and other planning documents reviewed, as well as the specific requirements from Falmouth’s Request for Proposals for its aquaculture plan.

Section 2. Resource Assessments and Potential Aquaculture Areas

Section 2A. Planning Area

Falmouth is home to 14 estuaries with Massachusetts Estuaries Project Reports. The following are included in the Falmouth Rotational Aquaculture Plan:

1. Megansett Harbor
2. Rands Canal
3. Fiddlers Cove
4. Wild Harbor
5. West Falmouth Harbor
6. Quissett Harbor
7. Salt Pond
8. Falmouth Harbor
9. Little Pond
10. Great Pond
11. Green Pond
12. Bournes Pond
13. Waquoit Bay
 - Childs River/Eel Pond
 - Seapit River

Estuary delineation is consistent with the Massachusetts Estuaries Project (MEP) mapping conventions. The specific sites recommended for aquaculture within these waterbodies are described in Section 2, including the process used for initial site evaluations. Oyster Pond is not included because it is maintained at a salinity of approximately 5 parts per thousand which will not support shellfish growth.

Falmouth's Rotational Aquaculture Plan concentrates on locations *within the Town's estuaries* for private growing operations. Note that sites in Megansett Harbor and Great Pond are associated with offshore locations due to the seasonal nature of harvesting. Seed grown in these conditionally-approved areas is required to move to open areas to be grown to harvestable size. Focusing aquaculture in the Town's estuaries benefits commercial wild harvesters, aquaculture growers and Town as a whole. These advantages include:

- Linking aquaculture sites to locations for enhanced municipal propagation of hard clams and other species
- Removing some of the nitrogen that is polluting these eutrophic waterbodies
- Providing locations to aquaculture growers with better growing conditions relative to offshore sites in Buzzards Bay and Vineyard Sound, such as:
 - Higher food availability, which allows a higher density of shellfish to be grown and lowers the overall gear required for a given number of shellfish
 - Warmer waters, creating a longer growing season
 - Protected and more safe working conditions

- Easier access

Falmouth's estuaries are rich in algae, which is both a problem and a resource. In terms of water quality, algae are a symptom of nitrogen enrichment. For filter-feeding shellfish, algae are food. Bringing filter-feeders into estuaries to remove algae benefits all the users of these natural resources and is an important part of the Town's Comprehensive Wastewater Management plan. Growers benefit by farming areas with ideal conditions for shellfish cultivation, which reduces the time-to-market for their product, and lowers overall costs per unit of shellfish sold. Commercial harvesters benefit by having enhanced propagation occur concurrent with aquaculture activities. The specific permitting approach that enables these key stakeholders to all profit from enhanced aquaculture in Falmouth is detailed in Section 3.

Section 2B. Data Sources

This habitat and resource assessments conducted for each of the estuaries discussed in this report are based on data from the following sources:

- Division of Marine Fisheries (DMF) Designated Shellfish Growing Area Maps
- DMF Shellfish Suitability Area Maps
- MA Department of Environmental Protection (MA DEP) Eelgrass Maps
- Massachusetts Estuaries Project Reports (MEP, dates vary)
- Town of Falmouth Recreational and Commercial Shellfish Areas
- Shellfish Habitat Assessment Maps for West Falmouth Harbor, Childs/Eel Pond and Green Pond
- Draft Green Pond Harbor Management Plan (July 2009)
- Falmouth Geographic Information System (GIS)

Specific data is sourced as described below.

Information regarding the classification of shellfish growing areas, as well as locations of suitable habitats and eelgrass beds comes from DMF. According to the MassGIS website, DMF's Shellfish Suitability Areas "delineate areas that are **believed** to be suitable for shellfish based on the expertise of the Massachusetts Division of Marine Fisheries (DMF), the opinion of local Massachusetts Shellfish Constables, and information contained in maps and studies of shellfish in Massachusetts. The areas covered include sites where shellfish have historically been sighted, but may not currently support any shellfish. **The shellfish suitability areas were not verified in the field and the boundaries were not surveyed.**" (emphasis added). DMF classifies these potential shellfish growing areas for management with respect to harvest for direct human consumption, in accordance with the National Shellfish Sanitation Program. Classifications include approved, conditionally approved, restricted, conditionally restricted and prohibited. Sections of Falmouth's estuaries fall into one of three classifications: approved, conditionally approved or prohibited. Falmouth Harbor is classified as restricted. Approved areas are open year-round for the harvest of shellfish stock for human consumption. Conditionally approved areas close during certain periods of the year due to environmental factors. During these closed periods, harvest of shellfish is prohibited. In prohibited areas, harvest of shellfish is not permitted. Current aquaculture regulations prohibit private aquaculture in areas that are conditionally approved and/or prohibited.

The delineation of habitats that are appropriate for specific shellfish species are based on the DMF Designated Shellfish Suitability Maps, with additional field verification from the town shellfish constable. Ten species of shellfish are included in the DMF assessments:

- American Oyster
- Bay Scallop
- Blue Mussel
- European Oyster
- Ocean Quahog
- Quahog
- Razor Clam
- Sea Scallop
- Soft-shelled Clam
- Surf Clam

The areas shown on DMF's maps include sites where shellfish have been observed since the mid-1970's, but may not currently support any shellfish. They are believed to be suitable for shellfish based on the expertise of DMF and local Shellfish Constables, input from commercial fishermen, and other studies. DMF advises that site specific surveys should be conducted to verify habitats because habitats and water quality change over time. Site specific surveys shellfish surveys have been conducted in West Falmouth Harbor, Little Pond, Green Pond, and Childs/Eel Pond and these data are included as part of this review.

The DEP Eelgrass Mapping Project began in 1994 to provide systematic and comprehensive documentation of the aerial extent of the state's eelgrass resources. These data also show the extent of habitat loss over several decades. The MEP Reports are a comprehensive review of the water quality of Falmouth's estuaries. Information on parameters such as nitrogen species, chlorophyll-*a*, dissolved oxygen and sediment type is derived from these reports. Relevant habitat and infrastructure information for Green Pond also came from the Draft Green Pond Harbor Management Plan. Infrastructure and public use areas were obtained using the town's GIS system and field visits. The purpose of this resource assessment was to identify possible areas for shellfish aquaculture.

Section 2C. Decision Support Tool for Estuary Evaluations

To facilitate a systematic and objective evaluation of Falmouth's estuaries for private aquaculture license sites, a Decision Support Tool was developed. The process of customizing this Decision Support Tool for the Falmouth Rotational Aquaculture Plan occurred over two workshop meetings with the Shellfish Working Group (SWG). This tool includes a number of criteria that address the environmental, land use and other characteristics of each estuary.

The initial ranking system was designed as a point-based system to quantify how well each location met a specific criterion. If an estuary was fully suitable based on the criterion being ranked it was assigned a numerical value of 3, if the site was mostly suitable based on the criterion being ranked it was assigned a ranking of 0, and

if the site was unsuitable it was assigned a ranking of -3. Using this initial approach, the SWG reviewed ranked three initial sites, including Megansett Harbor, Rands Canal and Fiddlers Cove based on water quality data from the MEP Reports, eelgrass maps from MA DEP, shellfish suitability and other GIS maps from DMF, preliminary sediment data and information provided by Town staff and SWG members.

During this ranking exercise, it was determined that the criteria were better evaluated as threshold issues, using a yes/no or high/medium/low ranking system. The Decision Support Tool was revised based on this input and each of Falmouth’s estuaries was then ranked using this approach. Figure 1 shows the final criteria that were used.

Criteria
Overriding/threshold considerations
Prohibited area
Lack of space (due to eelgrass, moorings, navigation)
Aesthetic/abutter compatibility (gear type)
Use conflict (navigation, boating, swimming, other)
Currently used for municipal oyster propagation
Successful shellfish cultivation likely (environmental)
Implementation Factors
Private landowner partner needed
Grow-out to harvestable size allowed (DMF)
Wild harvest area
Start/end of private growing season
Public access available
Nitrogen removal benefits

Figure 1. Decision Support Tool Criteria

2C.1: Definitions

Prohibited area: the harvesting of shellfishing is not allowed due to bacterial and other considerations. These areas are considered inappropriate for private aquaculture.

Lack of space: an assessment of whether the amount of waterbody surface area is sufficient for private aquaculture, and whether expansion potential exists. Key considerations are presence of eelgrass, moorings, navigation channels and other proximate uses.

Aesthetic /abutter compatibility (gear type): the visual impression that the project will have on vistas around the site and the likelihood that private aquaculture can occur without significant objections from adjacent landowners and residents.

Use conflict: the likelihood that the proposed shellfish demonstration can occur without impeding the other activities currently taking place at proposed demonstration sites. This criteria seeks to evaluate whether there will be strong objections from the community of people who use the waters nearby. The lack of space criterion (above) is more area-based, while this criterion seeks to understand stakeholder perceptions.

Currently used for municipal oyster propagation: the presence of a successful program for municipal propagation was discussed and it was concluded that these existing Town programs were more appropriate than private aquaculture in West Falmouth Harbor, Falmouth Harbor and Little Pond. Bournes Pond seemed suitable for both private aquaculture as well as continued municipal propagation.

Successful shellfish cultivation likely: the environmental conditions needed to support shellfish growth are available. Key parameters include chlorophyll a , dissolved oxygen (DO), and salinity, and absence of a population of predators (or the ability to control through the use of gear).

Private landowner partner needed: the need for abutting landowner because of access issues or because the estuary was created by dredging and the land under the water is privately-owned.

Grow-out to harvestable size allowed: certain sites are not always open to shellfishing, which requires a relay out of the area for grow-out to harvestable size.

Wild Harvest area: there are populations (standing stock) of species that are currently harvested, so aquaculture activity in this location cannot be permanent.

Public access available: locations are available from which aquaculture sites can be accessed, operated and maintained.

Start of growing season: the month in which the conditional area closes to the wild harvest of shellfish, allowing private aquaculture to operate without impacting this activity.

Nitrogen-removal benefits: the relative role of shellfish in meeting the target nitrogen-removal goal as calculated in the MEP Reports. If the estuary is part of the Town's Comprehensive or Targeted Wastewater Management Plan (CWMP/TWMP), or if the nitrogen-reduction target is less than 1500 kg N/year, the estuary was ranked HIGH for this criterion.

2C.2: Qualitative Ranking for Each Criterion

Each of the criterion reviewed was ranked using either a yes/no or high/medium/low assessment. For the overriding/threshold considerations, certain rankings were used to determine whether a particular estuary should be removed for consideration for private aquaculture as follows:

- Prohibited area criterion: if ranked YES, this criterion takes estuary off list for private aquaculture areas, with note that if classification changes, estuary could be re-reviewed for aquaculture
- Lack of space criterion: if ranked YES, this criterion takes estuary off list for private aquaculture areas

- Aesthetic/abutter compatibility criterion: If ranked LOW, this criterion takes estuary off list for aquaculture areas
- Use conflict criterion if ranked HIGH, this criterion takes areas of estuary off list for aquaculture areas
- Currently used for municipal oyster propagation: If ranked YES, this criterion takes estuary off the list for aquaculture areas
- Successful shellfish cultivation likely: if ranked NO, this criterion takes estuary off list for aquaculture areas

Criteria important to implementation were also evaluated to guide future planning and ranked as follows:

- Private landowner partner needed (YES/NO)
- Grow-out to harvestable size (YES/NO)
- Wild harvest (YES/NO)
- Public access available (NEAR/MID/NO) indicating distance from public access
- Start of growing season (MONTH) helps gage when private aquaculture operations can begin seasonally
- Nitrogen-removal benefits (HIGH/LOW) relate to the target nitrogen load reductions from the MEP Reports

2C.3: Results of Decision Support Tool Evaluations

Appendix A contains the Decision Support Tool results. Based on the ranking of the various criteria in the Decision Support Tool, the following estuaries are initially found to be appropriate for private aquaculture:

1. Megansett Harbor
2. Rands Canal
3. Quissett Harbor
4. Great Pond
5. Bournes Pond
6. Waquoit Bay
 - Childs River/Eel Pond
 - Seapit River

Municipal oyster propagation occurs in these estuaries:

1. West Falmouth Harbor
2. Falmouth Harbor
3. Little Pond
4. Green Pond
5. Bournes Pond

Table 1 summarizes the acreage and percent of waterbody that the potential aquaculture areas shown in Figures 1 - 12 represent.

Table 1: Summary of Potential Areas for Aquaculture by Estuary

Potential Aquaculture Site	Total Waterbody Area (acres)	Approximate Area of Polygon (acres)	Percent of Waterbody	Map Name
Megansett Harbor	540	4.0	1%	Megansett Harbor, Fiddlers Cove and Rands Canal
Rands Canal	10	0.25	2%	Megansett Harbor, Fiddlers Cove and Rands Canal
Quissett: Off National Academy	100	2.0	2%	Quissett Harbor
Upper Great Pond: East		1.0		Little Pond, Great Pond
Upper Great Pond: West		2.5		Little Pond, Great Pond
Lower Great Pond: North		3.0		Little Pond, Great Pond
Lower Great Pond: South		3.5		Little Pond, Great Pond
Great Pond (All)	269	10.0	4%	
Bournes Pond: Conditional Area		2.5		Bournes Pond
Bournes Pond: Northeast		11.0		Bournes Pond
Bournes Pond: South		2.5		Bournes Pond
Bournes Pond (All)	153	16.0	10%	
Eel Pond: Northwest (Off Eel River Rd)		0.5		Waquoit Bay and Eel Pond
Eel Pond: Southwest		1.0		Waquoit Bay and Eel Pond
Eel Pond: Off Seacoast Shores		1.0		Waquoit Bay and Eel Pond
Eel Pond: Washburn Northwest		4.0		Waquoit Bay and Eel Pond
Eel Pond: Washburn Mid		3.0		
Eel Pond: Washburn Southwest		5.0		
Eel Pond: Cove in Washburn		2.5		Waquoit Bay and Eel Pond
Eel Pond: Off Seapit Road		2.0		Waquoit Bay and Eel Pond
Eel Pond Offshore		5.0		Waquoit Bay and Eel Pond
Eel Pond (All)	278	24.0	9%	
Waquoit Bay Main (All)	679	0.0	0%	Waquoit Bay and Eel Pond

Each of Falmouth’s twelve estuaries is described in detail in Section 2D, and includes a discussion of the evaluation made for private aquaculture.

Section 2D. Estuary Discussions and Evaluations

Megansett Harbor

Figure 1 shows eelgrass beds, DMF classifications of shellfish growing area and habitat, key infrastructure (such as public landings) and mooring fields. Other unique public use features such as swimming beaches, boatyards and yacht clubs are also marked.

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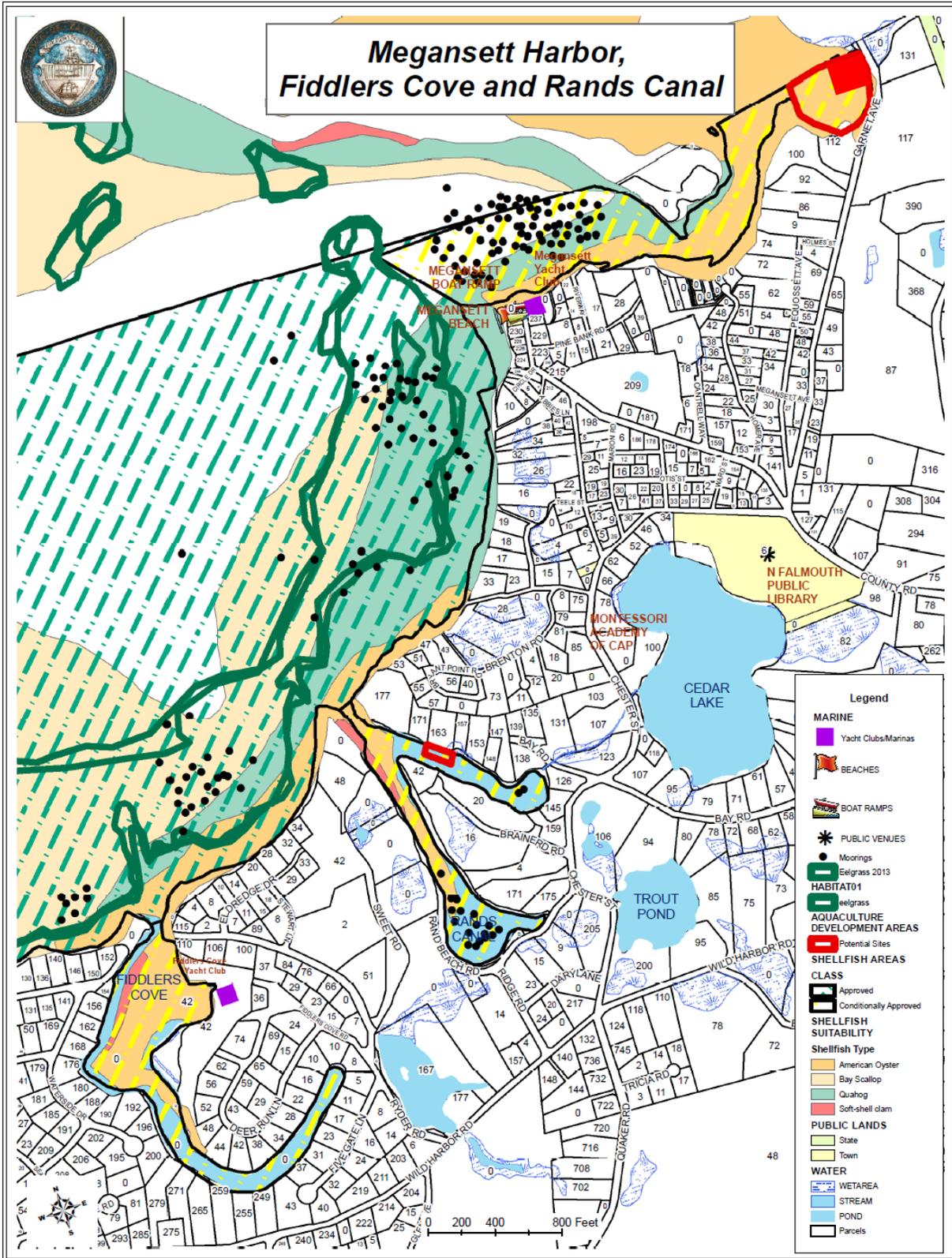


Figure 1. Megansett Harbor, Rands Canal and Fiddlers Cove: Map of Habitat, Infrastructure, Public Uses and Potential Aquaculture Areas

Key findings from this habitat and resource mapping, as well as a review of environmental conditions documented in the MEP Report for Megansett/Squeteague Harbor (2015) include:

Eelgrass and Sediment Type

As shown in Figure 1, much of the Megansett main basin contains eelgrass beds. Historically, these beds were much larger, and included an area in Squeteague Harbor. Areas that do not presently contain eelgrass, nor have a history of eelgrass include the western shore off Pequossett Ave (southern extension of Lawrence Island) and the channel into Squeteague Harbor. The bottom sediment in these areas is mostly sand.

Shellfish/finfish

As shown in Figure 1, DMF Shellfish Growing Area maps classify most of Megansett Harbor as approved, with the channel that enters Squeteague Harbor as conditionally approved. There is an active population of oyster drills, conch and starfish throughout this area, which is considered suitable habitat for quahogs and sea scallops. It is likely that oysters would also grow here. Commercial and recreational wild harvest of quahogs occurs in Megansett Harbor.

Infrastructure/Public Uses

Megansett Harbor is a multi-use recreation area. As shown in Figure 1, on the west side of County Road, there is a public beach, boat landing with ramp and parking lot with approximately 40 parking spaces. Megansett Yacht Club is located on the east side of County Road. There are 80 private moorings and 3 boatyard/yacht club moorings in the inner harbor and 93 private moorings in the outer harbor. Private moorings are administered through the town. The channel into Squeteague Harbor is narrow and surrounded by shallow sand flats. This recreation area is heavily used in the summer for boating, sailing lessons, and swimming.

Water Quality

Certain water quality parameters including total nitrogen (TN), chlorophyll-*a* (Chl-*a*) and dissolved oxygen (DO) are reported in the MEP Report for Megansett/Squeteague Harbor. Chl-*a* concentrations, which are an indicator of phytoplankton food availability varies widely from day to day in this system (between 3 ug/L and 46 ug/L in Megansett Harbor and 4 ug/L and 32 ug/L in Squeteague Harbor). In Megansett Harbor, data loggers were installed at three monitoring stations over a 42-day period during July, August and September. Average Chl-*a* concentrations of 7 ug/L, 5.3 ug/L and 4.7 ug/L are reported, with levels below 5 ug/L 59% of the deployment period. In Squeteague Harbor, data loggers were also installed at three monitoring stations in July. Average Chl-*a* concentrations of 11.8 ug/L, 11.2 ug/L and 11.6 ug/L are reported, with levels below 5 ug/L an average of 3% of the deployment period, which varied from 26 to 41 days. These data are collected 10 cm off the bottom in 15-minute intervals. Surface water Chl-*a* concentrations may be different from bottom water. According to the MEP Report, bottom water dissolved oxygen concentrations do not typically decline below 4 mg/L. This indicates that oxygen should not be a limiting factor in shellfish propagation.

Table 2. Executive Summary Table from MEP Report for Megansett Harbor

Table ES-2. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the Thresholds Loads for the Wild Harbor estuarine system in Falmouth, Massachusetts.						
Sub-embayments	Present Watershed Load ¹ (kg/day)	Target Threshold Watershed Load ² (kg/day)	Direct Atmospheric Deposition (kg/day)	Benthic Flux Net ³ (kg/day)	TMDL ⁴ (kg/day)	Percent watershed reductions needed to achieve threshold load levels
Megansett Harbor	18.978	15.760	5.556	-23.545	-2.229	-17.0%
Megansett Channel	3.699	3.422	0.386	-0.669	3.140	-7.5%
Squeteague Harbor	9.263	8.741	1.000	0.146	9.888	-5.6%
Combined Total	31.940	27.924	6.942	-23.545	10.799	-12.6%

(1) Composed of combined natural background, fertilizer, runoff, and septic system loadings.
 (2) Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentration identified in Table ES-1.
 (3) Projected future flux (present rates reduced approximately proportional to watershed load reductions).
 (4) Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.

Target nitrogen removal for Megansett Harbor: $(31.94 \text{ kg/day} - 27.924 \text{ kg/day}) = 4.016 \text{ kg/day} \times 365 \text{ days/yr} = 1,466 \text{ kg/yr}$

Based on Table 2, approximately 1,470 kg N per year must be removed for Megansett Harbor to meet the regulatory standard for TN.

Discussion of Decision Support Tool Evaluation

Figure 1 shows a potentially suitable area for shellfish aquaculture off the shore between Homer Ave and Garnet Avenue (~4 acres). This specific area near Squeteague Harbor subembayment are considered appropriate for private aquaculture based on the six Overriding/Threshold Consideration criteria. In summary: this location is not within a prohibited area; this site does not impinge on eelgrass, moorings and navigation channels; aesthetic concerns are not ranked high; use conflicts are not ranked high; municipal propagation of oysters does not occur in this area; and it is likely that shellfish could be successfully cultivated at this location. Key implementation considerations include: shellfish cannot be grown to harvestable size; sections are used for wild commercial harvest so a survey for productive bottom is needed; the closure period within which private aquaculture could occur is moderate (between July 1 and September 30); public access for boat launching is nearby and there is a public boat landing; and the value of shellfish cultivation for nitrogen-removal is high.

The seed that is cultivated in these conditional areas must be moved to open grow-out areas after the first growing period that is determined by the closure period for wild harvesting. These final grow-out areas may either be within existing offshore grants, or be in new licensed sites in Buzzards Bay that will be identified as part of the permitting process.

Rands Canal/Fiddlers Cove

Figure 1 shows eelgrass beds, DMF classifications of shellfish growing area and habitat, key infrastructure (such as public landings) and mooring fields. Other unique public use features such as swimming beaches and yacht clubs are also marked.

Key findings from this habitat and resource mapping, as well as a review of environmental conditions documented in the MEP Report (2013) for Rands Canal/Fiddlers Cove include:

Eelgrass and Sediment Type

As shown in Figure 1, much of area outside the entrance to Fiddlers Cove and Rands Canal in Buzzards Bay contains eelgrass beds. Neither estuary currently contains eelgrass beds, nor do these systems have a history of eelgrass. The bottom sediment along the shore and in the center closest to Buzzards Bay is mostly sand, with soft sediment found in the middle and closer to the head of these systems.

Shellfish/finfish

As shown in Figure 1, DMF Shellfish Growing Area maps classify both Rands Canal and Fiddlers Cove as conditionally approved. Fiddler Cove and Rands Canal are considered suitable habitat for quahog and soft-shelled clam. Rands Canal is also considered suitable for oysters, which would likely grow in Fiddlers Cove as well, as a natural set of oysters was observed on the rip-rap in 2015. A fish ladder for alewife was built at the head of Rands Canal (east), where the Canal connects to a stream under Bay Road. The town does not have any commercial and/or recreational wild harvest areas within Rands Canal or Fiddlers Cove.

Infrastructure/Public Uses

Rands Canal and Fiddlers Cove are manmade, boat basins that are about 100 feet wide, with no public access from the land. There are approximately 33 private docks in Fiddlers Cove and six in Rands Canal. There are 5 boatyard moorings and 15 private moorings in Rands Canal. Private moorings are administered through the town. There is a private marina located in Fiddlers Cove, with a private upweller located under one of the docks. This area is heavily used for boating in the summer.

Water Quality

Certain water quality parameters including total nitrogen (TN), chlorophyll-*a* (Chl-*a*) and dissolved oxygen (DO) are reported in the MEP Report for Rands Canal and Fiddlers Cove. Chl-*a* concentrations, which are an indicator of phytoplankton food availability varies widely from day to day in these systems (between 4 ug/L and 45 ug/L in Fiddler's Cove and 3 ug/L and 25 ug/L in Rands Canal). In Fiddlers Cove, data loggers were installed at two monitoring stations over a 41-day period during June, July and August. Average Chl-*a* concentrations of 15.2 ug/L and 10.5 ug/L are reported, with levels below 5 ug/L 2% of the deployment period. In Rands Canal, data loggers were installed at two monitoring stations in July. Average Chl-*a* concentrations of 8.3 ug/L and 6.2 ug/L are reported, with levels below 5 ug/L an average of 24% of the 26 -day deployment period. Periodic algae

blooms occurred during the data collection period in both systems. These data are collected 10 cm off the bottom in 15-minute intervals. Surface water Chl-*a* concentrations may be different from bottom water.

According to the MEP Report, bottom water dissolved oxygen concentrations do not typically decline below 4 mg/L in either Fiddlers Cove or Rands Canal. This indicates that oxygen should not be a limiting factor in shellfish propagation.

Table 3. Executive Summary Table from MEP Report for Rands Canal and Fiddlers Cove

Table ES-2. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the Thresholds Loads for the Fiddlers Cove and Rands Harbor estuarine systems in Falmouth, Massachusetts.						
Sub-embayments	Present Watershed Load ¹ (kg/day)	Target Threshold Watershed Load ² (kg/day)	Direct Atmospheric Deposition (kg/day)	Benthic Flux Net ³ (kg/day)	TMDL ⁴ (kg/day)	Percent watershed reductions needed to achieve threshold load levels
Rands Harbor	6.074	4.410	0.142	0.582	5.134	-27.4%
Fiddlers Cove	4.332	3.368	0.184	1.208	4.760	-22.2%
Combined Total	10.406	7.778	0.326	1.790	9.894	-25.2%
(1) Composed of combined natural background, fertilizer, runoff, and septic system loadings. (2) Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentration identified in Table ES-1. (3) Projected future flux (present rates reduced approximately proportional to watershed load reductions). (4) Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.						

Target nitrogen removal for Rands Harbor (Canal): $(6.074 \text{ kg/day} - 4.410 \text{ kg/day}) = 1.664 \text{ kg/day} \times 365 \text{ days/yr} = \sim 607 \text{ kg/year}$

Target nitrogen removal for Fiddlers Cove: $(4.332 \text{ kg/day} - 3.368 \text{ kg/day}) = 0.964 \text{ kg/day} \times 365 \text{ days/year} = \sim 352 \text{ kg/year}$

Based on Table 3, approximately 607 kg N per year must be removed for Rands Canal and about 352 kg/N per year for Fiddlers Cove to meet the regulatory standard for TN.

Discussion of Decision Support Tool Evaluation

Figure 1 shows a potentially suitable area for shellfish aquaculture in Rands Canal. This specific area is to be determined based on landowner partner and is considered appropriate for private aquaculture based on the six Overriding/Threshold Consideration criteria. In summary: this location is not within a prohibited area; this site does not impinge on eelgrass, moorings and navigation channels; aesthetic concerns are not ranked high; use conflicts are not ranked high; municipal propagation of oysters does not occur in this area; and it is likely that shellfish could be successfully cultivated at this location. Key implementation considerations include: a private landowner partner is needed due to the ownership structure of this dredged basin; shellfish cannot be grown to harvestable size; sections are used for wild commercial harvest so a survey for productive bottom is needed; the closure period within which private aquaculture could occur is moderate (between May 1 and September 30); public access for boat launching is reasonably close and there is a public boat landing; and the value of shellfish cultivation for nitrogen-removal is high.

Wild Harbor/Wild Harbor River

Figure 2 shows eelgrass beds, DMF classifications of shellfish growing area and habitat, key infrastructure (such as public landings) and mooring fields. Other unique public use features such as swimming beaches and yacht clubs are also marked.

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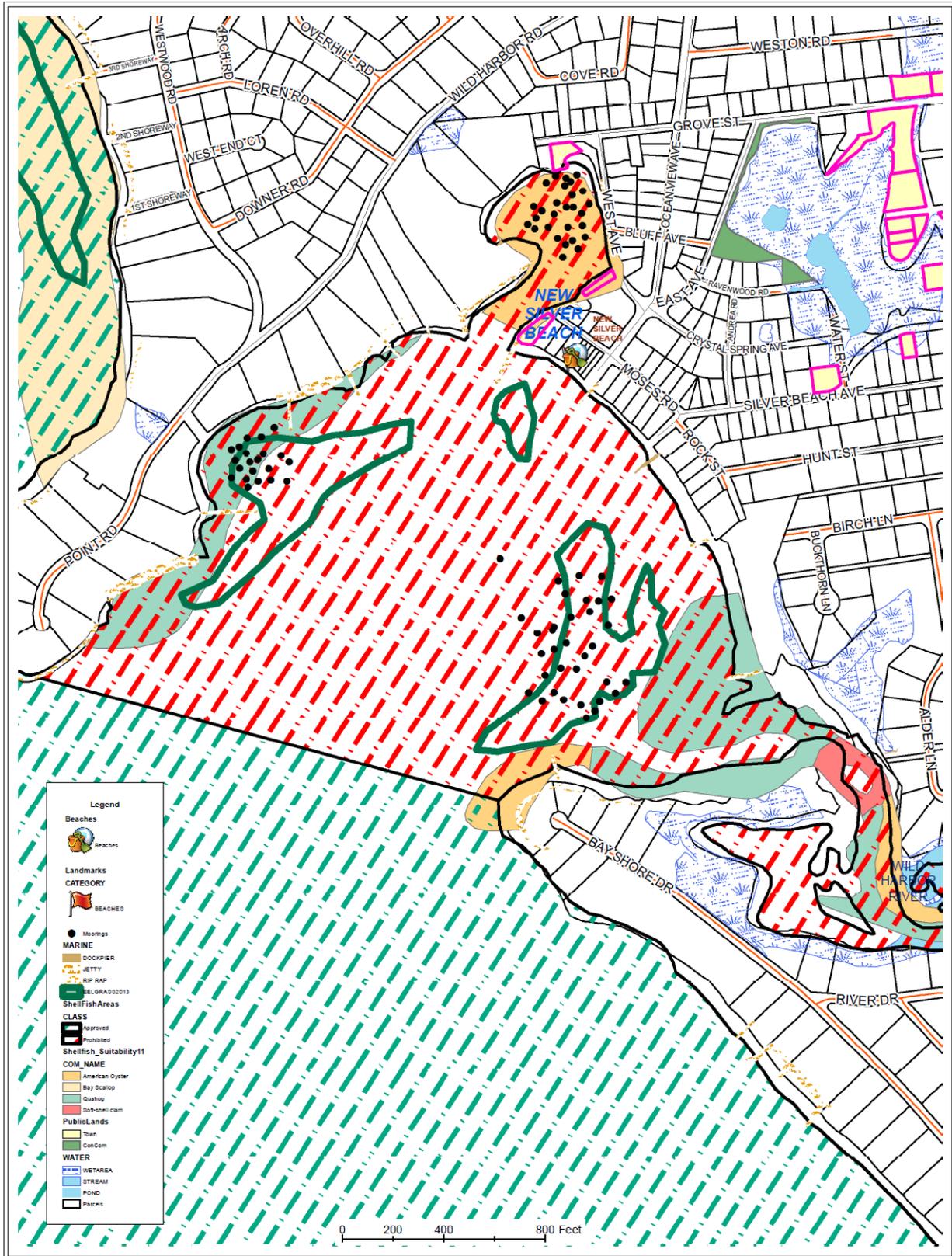


Figure 2. Wild Harbor and Wild Harbor River: Map of Habitat, Infrastructure and Public Uses

Key findings from this habitat and resource mapping, as well as a review of environmental conditions documented in the MEP Report for Wild Harbor include:

Eelgrass and Sediment Type

As shown in Figure 2, eelgrass is found along the shores of Wild Harbor, but the beds are smaller than the historic areal coverage. Sediment is mostly sandy. The inner Wild Harbor boat basin is a manmade feature created by dredging and bulkhead construction. Eelgrass has not been found historically in this relatively deep, depositional basin. Sediment is fine grained and rich in organic matter (muck). There is not a record of eelgrass in Wild Harbor River because it is predominantly a salt marsh. As is the case with most salt marsh systems, the Wild Harbor River sediment is rich in organic matter and becomes very shallow at low tide.

Shellfish/Finfish

As shown in Figure 2, DMF Shellfish Growing Area maps classify both Wild Harbor and Wild Harbor River as prohibited. These areas are considered suitable habitat for quahogs, with a small section at the entrance to Wild Harbor River suitable for soft-shelled clams. The town does not have commercial and/or recreational wild harvest area within the Wild Harbor system.

Infrastructure/Public Uses

Wild Harbor is a multi-use recreation area. As shown in Figure 2, at the end of Ocean View Avenue, there is a public beach, and small parking lot. Wild Harbor Yacht Club is located off Wild Harbor Road and abuts Grove Street to the south. There are 2 yacht club moorings and 36 private moorings in the Wild Harbor boat basin. Private moorings are administered through the town. This recreation area is heavily used in the summer for boating, sailing lessons, and swimming. Wild Harbor River is used by non-motorized boats, primarily by abutters due to lack of public access.

Water Quality

Certain water quality parameters including total nitrogen (TN), chlorophyll-*a* (Chl-*a*) and dissolved oxygen (DO) are reported in the MEP Report for the Wild Harbor System. Chl-*a* concentrations, which are an indicator of phytoplankton food availability varies widely from day to day in both the inner and outer harbor (between 2 ug/L and 30 ug/L). In Wild Harbor, data loggers were installed at two monitoring stations over a period ranging from 28 to 41 days during June, July and August. These two locations have very different patterns of Chl-*a* availability, with average concentrations of 9.4 ug/L reported in the inner harbor and 3.8 ug/L in the outer harbor. Chl-*a* levels fall below 5 ug/L 12% of the deployment period in the inner harbor and 84% of the deployment period in the outer harbor. These data are collected 10 cm off the bottom in 15-minute intervals. Surface water Chl-*a* concentrations may be different from bottom water.

According to the MEP Report, bottom water dissolved oxygen concentrations do not typically decline below 4 mg/L in the inner harbor and 5 mg/L in the outer harbor. This indicates that oxygen should not be a limiting factor in shellfish propagation.

Table 4. Executive Summary Table from MEP Report for Wild Harbor

Table ES-2. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the Thresholds Loads for the Wild Harbor estuarine system in Falmouth, Massachusetts.						
Sub-embayments	Present Watershed Load ¹ (kg/day)	Target Threshold Watershed Load ² (kg/day)	Direct Atmospheric Deposition (kg/day)	Benthic Flux Net ³ (kg/day)	TMDL ⁴ (kg/day)	Percent watershed reductions needed to achieve threshold load levels
Wild Harbor	10.326	4.552	1.033	-10.232	-4.647	-55.9%
Wild Harbor River	11.825	10.062	0.447	-0.359	10.150	-14.9%
Dam Pond Stream	1.507	1.507	--	--	1.507	0.0
Combined Total	23.658	16.121	1.480	-10.591	7.010	-31.9%

(1) Composed of combined natural background, fertilizer, runoff, and septic system loadings.
 (2) Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentration identified in Table ES-1.
 (3) Projected future flux (present rates reduced approximately proportional to watershed load reductions).
 (4) Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.

Wild Harbor: $(10.362 \text{ kg/day} - 4.552 \text{ kg/day}) = 5.774 \text{ kg/day} \times 365 \text{ days/yr} = \sim 2108 \text{ kg/year}$

Wild Harbor River: $(11.825 \text{ kg/day} - 10.062 \text{ kg/day}) = 1.763 \text{ kg/day} \times 365 \text{ days/yr} = \sim 643 \text{ kg/year}$

Target nitrogen removal for Wild Harbor System: $(23.658 \text{ kg/day} - 16.121 \text{ kg/day}) = 7.537 \text{ kg/day} \times 365 \text{ days/yr} = \sim 2751 \text{ kg/year}$

Based on Table 4, approximately 2751 kg N per year must be removed for Wild Harbor to meet the regulatory standard for TN.

Discussion of Decision Support Tool Evaluation

Figure 2 is a summary map that does not show any suitable areas for shellfish aquaculture in the Wild Harbor system. Because this area is closed to shellfishing and is a heavily used boat basin, there is lack of space and use conflicts are ranked high. This area would best support additional Town upwellers.

a busy boat basin,.

West Falmouth Harbor

Figure 3 shows eelgrass beds, DMF classifications of shellfish growing area and habitat, key infrastructure (such as public landings) and mooring fields. Other unique public use features such as swimming beaches and yacht clubs are also marked. A field assessment of sediment type has been completed for West Falmouth Harbor and is also included.

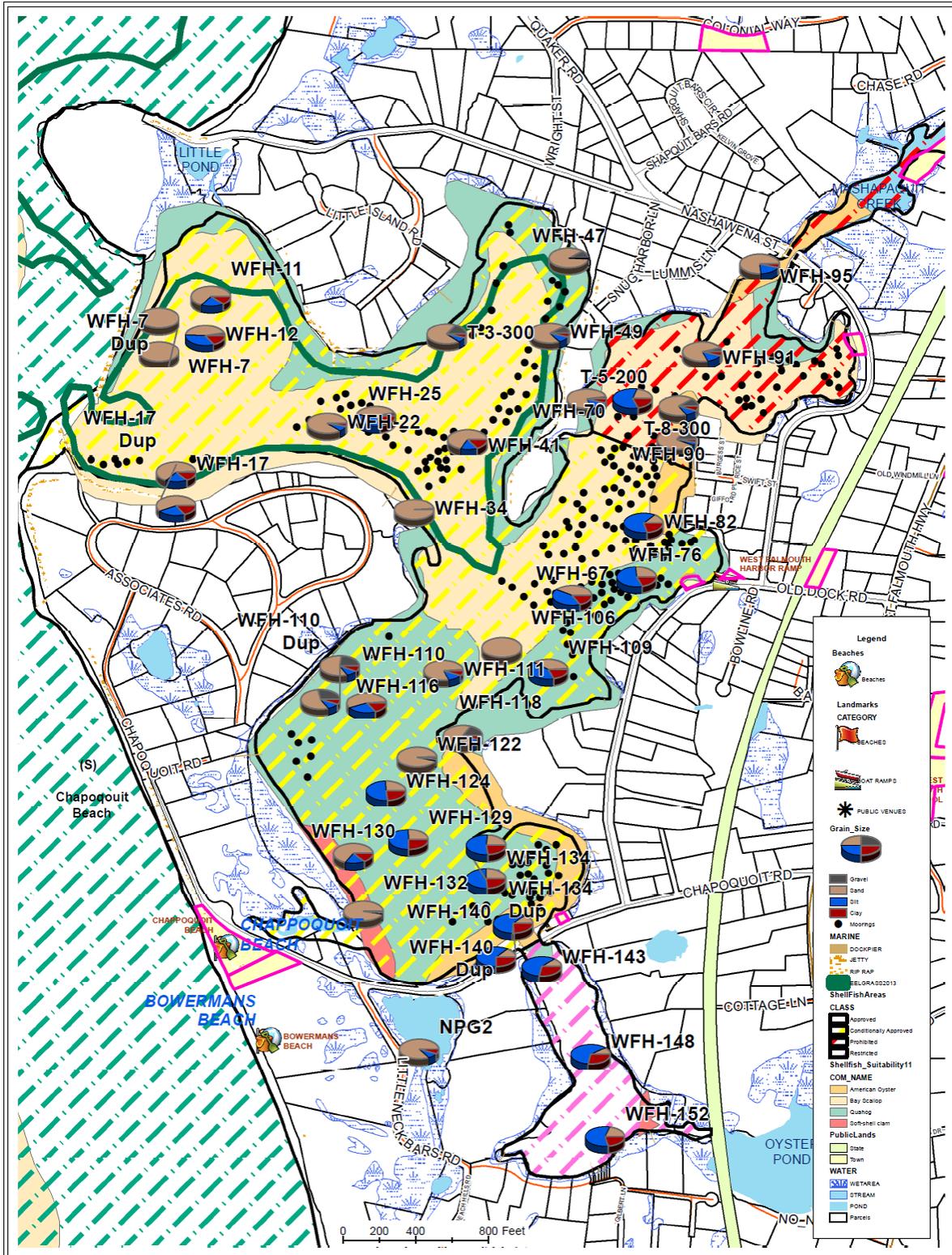


Figure 3. West Falmouth Harbor: Map of Habitat, Infrastructure and Public Uses

Key findings from this habitat and resource mapping, as well as a review of environmental conditions documented in the MEP Report for West Falmouth Harbor include:

Eelgrass and Sediment Type

As shown in Figure 3, Eelgrass beds are found in patches throughout West Falmouth Harbor. Historically, eelgrass beds were larger and contiguous. Sediment in many areas is fine grained and rich in organic matter (muck). There is sandy bottom in a few sections of West Falmouth Harbor, most notably near Chapoquoit Island.

Shellfish/finfish

As shown in Figure 3, DMF Shellfish Growing Area maps classify the main basin of West Falmouth Harbor as conditionally approved, Snug Harbor as prohibited and Harbor Head as restricted. These areas are considered suitable habitat for quahogs and oysters. Commercial and recreational wild harvest of quahogs and oysters occurs in several areas within West Falmouth Harbor. Additional detail on sediment types is available for West Falmouth Harbor from a habitat assessment that was conducted in 2008. The GIS layer that was developed to summarize the results of this data collection effort is included in Figure 3.

Four species of shellfish were assessed as part of this work, including: quahogs (*Mercenaria mercenaria*), bay scallops (*Argopecten irradians*), American oysters (*Crassostrea virginica*), and soft shell clams (*Mya arenaria*). Prior to the start of field efforts, the entire Harbor area was gridded into north/south and east/west transects spaced 100 feet apart using a large scale orthophoto image. Each intersection was assigned a number (WFH1 – WFH750) and was considered a potential sampling station. Of the 750 potential sampling sites, 125 were randomly selected and 25 specifically chosen (for larger areas missed by random selection or special focus areas) for analysis of shellfish and eelgrass presence or absence (150 stations). The shoreline areas were also surveyed by wading at 100 foot intervals along 100-, 200-, and 500- foot long linear transects that ran parallel to the shore, and were sampled at a distance of 100 feet from mean high water if possible. Each of these linear transects included one “shore normal” transect which ran perpendicular to the shore, with sampling stations at the intertidal area as well as the mid-point of one transect station (e.g. Transect 1 at the 300-foot station was sampled at 50 feet from shore, 25-feet from shore, and at the intertidal area). A total of seventeen (17) linear transects with three (3) to eight (8) stations each were sampled for shellfish throughout the Harbor system, for a total of 120 shoreline transect stations. A total of 270 stations were sampled for shellfish throughout the West Falmouth Harbor area. Ten shellfish stations representing all areas of the West Falmouth Harbor system were chosen for analysis of one benthic grab to determine absence/presence of benthic species indicative of disturbed or healthy habitat conditions.

Sediment type and oxygen conditions were also evaluated using the apparent Redox Potential Discontinuity (aRPD) depth method. Oxidized benthic sediments are light in color, then turn darker as the sediments show signs of anoxic conditions. The change between light to dark sediment is termed the aRPD depth. In general, anoxic or hypoxic sediments will have no or shallow aRPD depths, respectively, and more oxygenated sediments will have deeper aRPD depths. Samples were analyzed for total organic carbon (TOC) and grain-size.

Infrastructure/Public Uses

West Falmouth Harbor is a multi-use recreation area. As shown in Figure 3, There is a town dock and boat ramp off Old Dock Road, and a public beach with a large parking lot at the end of Chapoquoit Road. The harbor side of Chapoquoit beach is also a popular area. Chapoquoit Yacht Club is located off Associates Road. There are 9 boatyard/yacht club moorings and 268 private moorings in West Falmouth Harbor (95 in the inner harbor and 173 in the outer harbor). Private moorings are administered through the town. This recreation area is heavily used in the summer for boating, sailing lessons, and swimming.

Water Quality

Certain water quality parameters including total nitrogen (TN), chlorophyll-*a* (Chl-*a*) and dissolved oxygen (DO) are reported in the MEP Report for West Falmouth Harbor. Chl-*a* concentrations, which are an indicator of phytoplankton food availability varies widely from day to day in both Snug, and the outer harbor (between 2 ug/L and 22 ug/L). In West Falmouth Harbor, data loggers were installed at three monitoring stations over a period of 22 days in July. Two loggers are in the outer harbor and one is in Snug Harbor. Two of these three locations have comparable patterns of Chl-*a* availability, with average concentrations of 7.64 ug/L reported in Snug harbor and 5.28 ug/L in the south basin of the outer harbor. The north basin of the outer harbor has an average Chl-*a* of 4.01 ug/L. Chl-*a* levels do not fall below 5 ug/L during the deployment period in Snug Harbor but do fall below 5 ug/L in the northern section of the outer harbor. These data are collected 10 cm off the bottom in 15-minute intervals. Surface water Chl-*a* concentrations may be different from bottom water.

According to the MEP Report, bottom water dissolved oxygen concentrations do not typically decline below 4 mg/L in either Snug Harbor or the outer harbor. This indicates that oxygen should not be a limiting factor in shellfish propagation.

The MEP Report for West Falmouth Harbor was finalized in 2006, prior to substantial improvements to the town's wastewater treatment facility (WWTF). This report assumes that 70% of the load to West Falmouth Harbor comes from the WWTF. Equipment upgrades at the WWTF have reduced the nitrogen concentration of the WWTF's effluent from the 23.5 mg N/L that was used for load calculations in the MEP Report to 3 mg N/L. A new MEP model run is required to determine the actual nitrogen-removal target based on this change, as well as other factors.

Table 5: Summary Table from MEP Report for West Falmouth Harbor

Table VIII-3. Comparison of sub-embayment total watershed loads (including septic, runoff, and fertilizer, and the WWTF) used for modeling of present and threshold loading scenarios of the West Falmouth Harbor system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.			
sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Outer West Falmouth Harbor	1.690	1.359	-19.6%
Inner West Falmouth Harbor	10.386	5.301	-49.0%
Harbor Head	1.085	0.592	-45.5%
Oyster Pond	1.359	0.718	-47.2%
Snug Harbor	9.570	3.715	-61.2%
Mashapaquit Creek	17.649	6.844	-61.2%

Target nitrogen removal for West Falmouth Harbor System: $(41.739 \text{ kg/day} - 18.529 \text{ kg/day}) = 23.21 \text{ kg/day} \times 365 \text{ days/yr} = \sim 8472 \text{ kg/year}$

Discussion of Decision Support Tool Evaluation

Figure 3 is a summary map that does not show suitable areas for shellfish aquaculture. Because West Falmouth is a busy boat basin, there is lack of space and use conflicts are ranked high. This area is also fully utilized for the Town’s highly successful program for municipal propagation of quahogs and oysters by bottom planting (no gear required). For these threshold considerations, aquaculture leases are not recommended in this harbor.

Quissett Harbor

Figure 4 shows eelgrass beds, DMF classifications of shellfish growing area and habitat, key infrastructure (such as public landings) and mooring fields. Other unique public use features such as swimming beaches and yacht clubs are also marked.

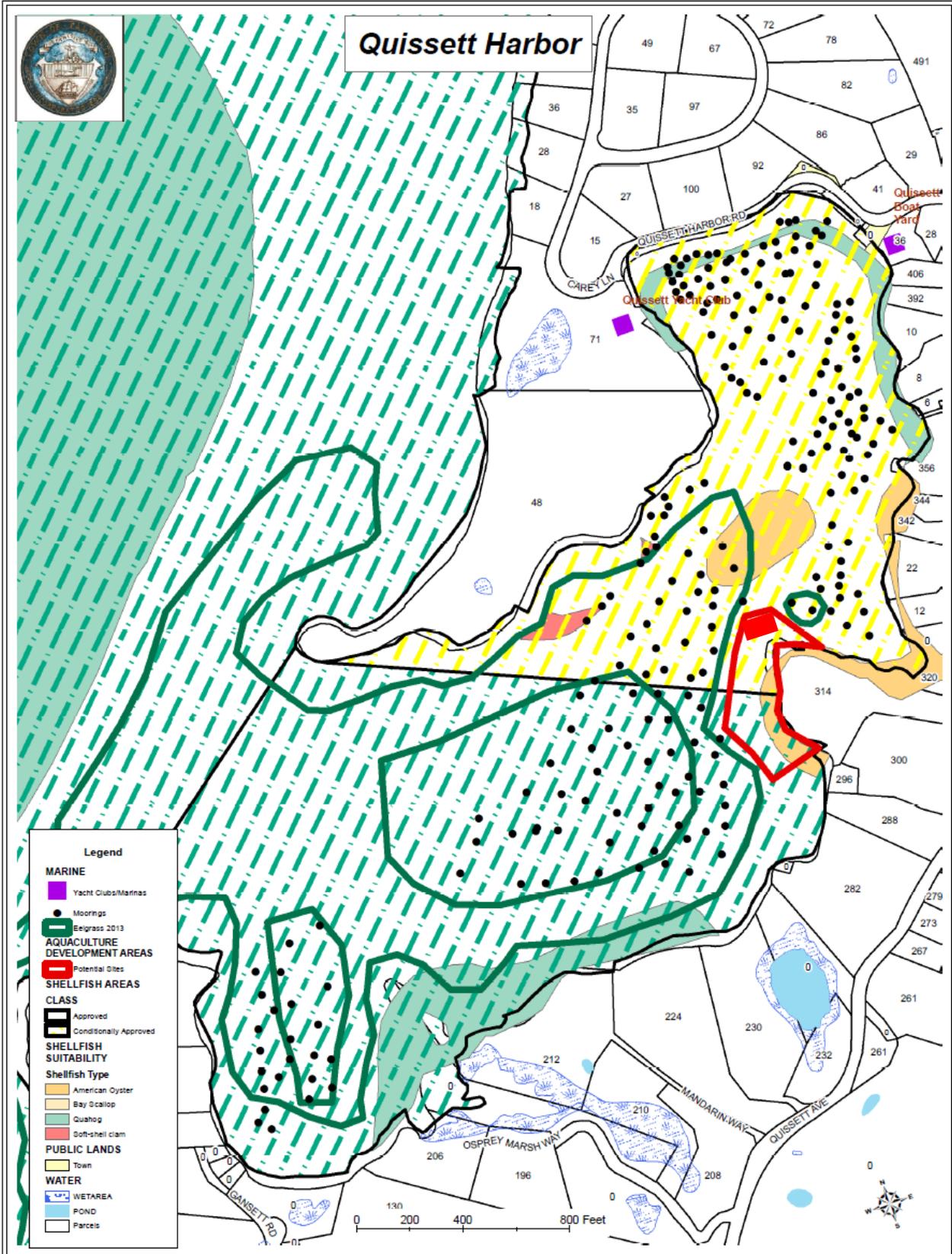


Figure 4. Quissett Harbor: Map of Habitat, Infrastructure, Public Uses and Potential Aquaculture Areas

Key findings from this habitat and resource mapping, as well as a review of environmental conditions documented in the MEP Report for Quissett Harbor include:

Eelgrass and Sediment Type

As shown in Figure 4, eelgrass beds are found throughout outer Quissett Harbor. There is not a historic record of eelgrass in the inner harbor. The main loss of eelgrass is documented for the transition area between the outer to the inner harbor. Sediment in the main basin of the inner harbor is fine grained and rich in organic matter (muck). The outer harbor and areas closer to shore have a more hard, sandy bottom.

Shellfish/finfish

As shown in Figure 4, DMF Shellfish Growing Area maps classify inner Quissett Harbor as conditionally approved and outer Quissett Harbor as approved. These areas have active oyster drill populations and are considered suitable habitat for quahogs, soft-shelled clams and oysters. Commercial and recreational wild harvest of quahogs, soft-shelled clams and oysters occurs in both inner and outer Quissett Harbor.

Infrastructure/Public Uses

Quissett Harbor is a multi-use recreation area. As shown in Figure 4, there is a town dock and private boatyard off Quissett Harbor Road, and a beach managed by Quissett Land Trust and Salt Pond Area Bird Sanctuaries with a very small parking lot at the end of Quissett Harbor Road. Quissett Yacht Club is also located at the end of Quissett Harbor Road. There are 103 boatyard/yacht club moorings and 133 private moorings in Quissett Harbor. Private moorings are administered through the town. This recreation area is heavily used in the summer for boating, sailing lessons, and swimming.

Water Quality

Certain water quality parameters including total nitrogen (TN), chlorophyll-*a* (Chl-*a*) and dissolved oxygen (DO) are reported in the MEP Report for the Quissett Harbor System. Chl-*a* concentrations, which are an indicator of phytoplankton food availability varies widely from day to day in both the inner and outer harbor (between 2 ug/L and 21 ug/L). In Quissett Harbor, data loggers were installed at two monitoring stations over a 24-day period in July. These two locations have comparable patterns of Chl-*a* availability, with average concentrations of 10.6 ug/L reported in the inner harbor and 6.5 ug/L in the outer harbor. Chl-*a* levels fall below 5 ug/L 9% of the deployment period in the inner harbor and 36% of the deployment period in the outer harbor. These data are collected 10 cm off the bottom in 15-minute intervals. Surface water Chl-*a* concentrations may be different from bottom water.

According to the MEP Report, bottom water dissolved oxygen concentrations do not typically decline below 4 mg/L in either the inner or outer harbor. This indicates that oxygen should not be a limiting factor in shellfish propagation.

Table 6. Executive Summary Table from MEP Report for Quissett Harbor

Table ES-2. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the Thresholds Loads for the Quissett Harbor estuary system, Town of Quissett, Massachusetts.						
Sub-embayments	Present Watershed Load ¹ (kg/day)	Target Threshold Watershed Load ² (kg/day)	Direct Atmospheric Deposition (kg/day)	Benthic Flux Net ³ (kg/day)	TMDL ⁴ (kg/day)	Percent watershed reductions needed to achieve threshold load levels
SYSTEMS						
Quissett Harbor (Main)	1.458	1.458	0.928	-3.159	-0.773	0.0%
Quissett Harbor (Upper)	1.921	1.192	0.409	3.840	5.441	-38.0%
System Total	3.379	2.650	1.337	0.681	4.668	-21.6%
(1) Composed of combined natural background, fertilizer, runoff, and septic system loadings. (2) Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentration identified in Table ES-1. (3) Projected future flux (present rates reduced approximately proportional to watershed load reductions). (4) Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.						

Quissett Harbor (main): 0 kg/day

Quissett Harbor (upper): $(1.921 \text{ kg/day} - 1.192 \text{ kg/day}) = 0.729 \text{ kg/day} \times 365 \text{ days/yr} = \sim 266 \text{ kg/year}$

Target nitrogen removal for Quissett Harbor system: $(3.379 \text{ kg/day} - 2.65 \text{ kg/day}) = .729 \text{ kg/day} / \sim 266 \text{ kg/year}$

Based on Table 6, approximately 266 kg N per year must be removed for Quissett Harbor to meet the regulatory standard for TN.

Discussion of Decision Support Tool Evaluation

Figure 4 is a summary map that shows a potentially suitable area for shellfish aquaculture, including:

- Area off the National Academy of Sciences property (approximately 3 acres)

These specific areas within the overall Quissett Harbor estuarine system are considered appropriate for private aquaculture based on the six Overriding/Threshold Consideration criteria. In summary: these locations are not within an area prohibited to shellfishing; these sites do not impinge on eelgrass, moorings and navigation channels; aesthetic concerns are not ranked high; use conflicts are not ranked high; municipal propagation of oysters does not occur in these areas; and it is likely that shellfish could be successfully cultivated at these locations. Key implementation considerations include: shellfish cannot be grown to harvestable size within the inner harbor; some sections of this estuary are used for wild commercial harvest so a survey for productive bottom is needed; the closure period within which private aquaculture could occur is moderate (between July 1 and September 30; public access for boat launching is not nearby and there is no public landing, but a skiff might be able to be kept on the Town dock; and the value of shellfish cultivation for nitrogen-removal is high.

Falmouth Harbor/Little Pond

These estuaries are included in the Rotational Aquaculture Plan because they are key nursery areas for the town's shellfish propagation program. ADAs are not recommended in Falmouth Harbor or Little Pond.

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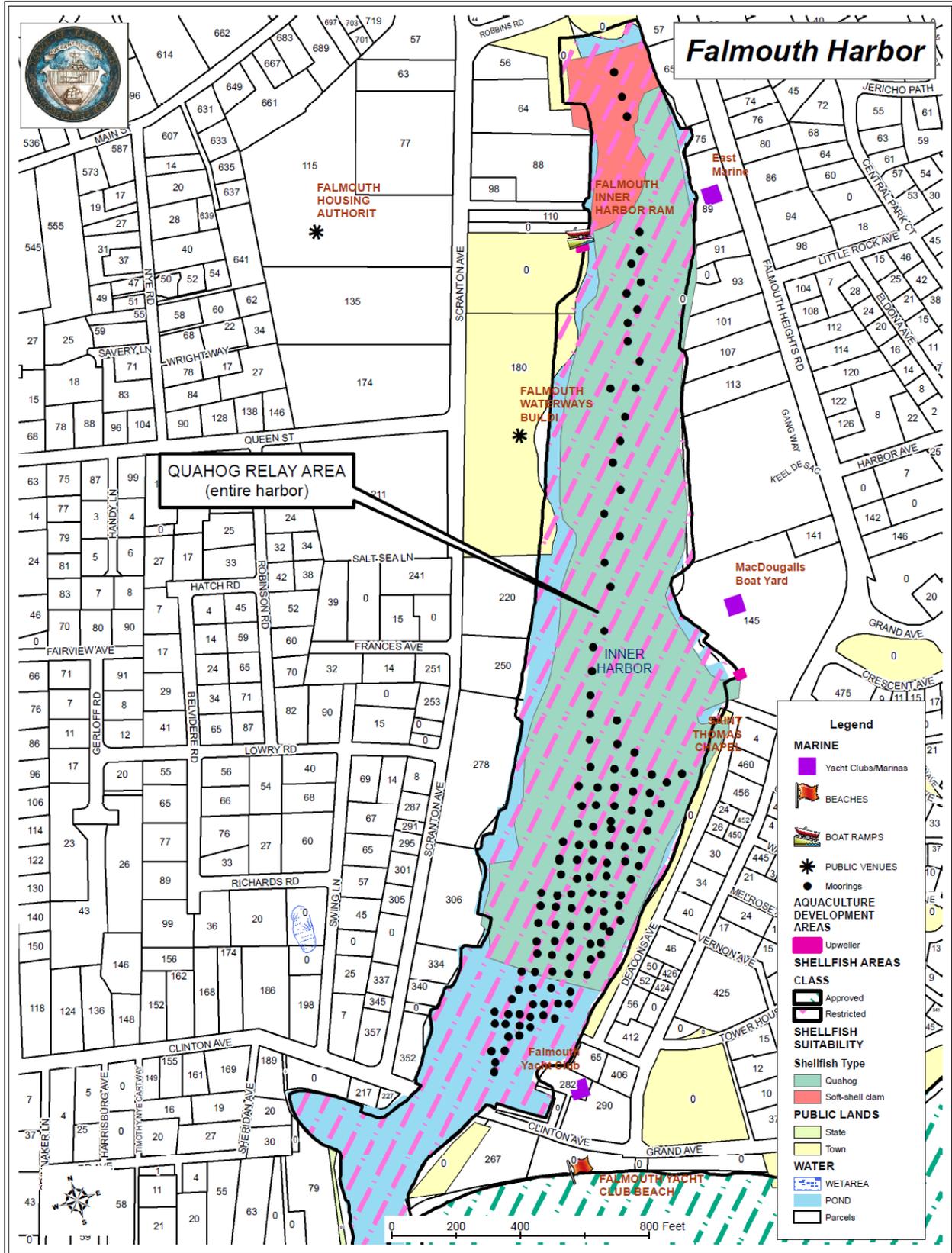


Figure 5. Falmouth Harbor: Map of Habitat, Infrastructure and Public Uses

Eelgrass and Sediment Type

As shown in Figure 5, Falmouth Harbor has never contained eelgrass habitat because it is a manmade system formed by the opening of a fresh pond in 1907 to create a protected harbor for boats. As shown in Figure 6, Little Pond has a patch of eelgrass in the middle of the lower basin, near the inlet opening.

Shellfish/finfish

As shown in Figures 5 and 6, DMF Shellfish Growing Area maps classify Falmouth Harbor as restricted and Little Pond as prohibited. Falmouth Harbor is considered suitable habitat for quahogs and soft-shelled clams and Little Pond is considered suitable habitat for soft-shelled clams. Commercial and recreational wild harvest of quahogs, soft-shelled clams and oysters does not occur in either Falmouth Harbor or Little Pond.

Infrastructure/Public Uses

Falmouth Harbor is a multi-use recreation area. As shown in Figure 5, there is a town marina and public boat ramp as well as two private marinas and a yacht club. There are 36 boatyard/yacht club moorings and 75 private moorings in Falmouth Harbor. Private moorings are administered through the town. This recreation area is heavily used in the summer for boating, sailing lessons, and swimming. The town operates a shellfish propagation center at Falmouth Harbor with five large upwellers. There is an additional Town upweller at MacDougall's Boatyard.

There is one public access point into Little Pond, at Spring Bars Road. Internal combustion engines are not allowed in Little Pond but paddlers enjoy this waterbody. The town operates a shellfish farm in Little Pond at the end of Brockton Street. These oysters are only grown in Little Pond until they reach 2-inches and then are bottom-planted in other estuaries for recreational and commercial harvest after a depuration period.

Water Quality

The MEP Report for the Falmouth Harbor and Little Pond Systems present goals for the nitrogen-removal required to restore water quality and ecosystems health.

Table 7. Executive Summary Table from MEP Report for Falmouth Inner Harbor

Table ES-2. Present Watershed Loads, Thresholds Loads, and the percent reductions necessary to achieve the Thresholds Loads for the Falmouth Harbor estuary system, Town of Falmouth, Massachusetts.						
Sub-embayments	Present Watershed Load ¹ (kg/day)	Target Threshold Watershed Load ² (kg/day)	Direct Atmospheric Deposition (kg/day)	Benthic Flux Net ³ (kg/day)	TMDL ⁴ (kg/day)	Percent watershed reductions needed to achieve threshold load levels
SYSTEMS						
Upper Harbor	2.573	1.888	0.219	0.629	2.736	-26.6%
Lower Harbor	3.860	2.832	0.219	0.632	3.683	-26.6%
Morse Culvert	0.764	0.764	--	--	0.764	0.0%
System Total	7.197	5.484	0.438	1.261	7.183	-23.8%
(1) Composed of combined natural background, fertilizer, runoff, and septic system loadings. (2) Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentration identified in Table ES-1. (3) Projected future flux (present rates reduced approximately proportional to watershed load reductions). (4) Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.						

Falmouth Harbor: $(7.197 \text{ kg/day} - 5.484 \text{ kg/day}) = 1.713 \text{ kg/day} \times 365 \text{ days/yr} = \sim 625 \text{ kg/year}$

Target nitrogen removal for Falmouth Harbor: $\sim 600 \text{ kg N/year}$

Table 8. Load Summary Table from MEP Report for Little Pond

Table VIII-3. Comparison of sub-embayment total attenuated watershed loads (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Little Pond system. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.			
sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Little Pond	13.022	2.603	-80.0%
Surface Water Sources			
Little Pond Stream	6.052	2.755	-54.5%

Little Pond: $(13.022 \text{ kg/day} - 2.603 \text{ kg/day}) = 10.419 \text{ kg/day} \times 365 \text{ days/yr} = \sim 3,800 \text{ kg/year}$

Little Pond Stream: $(6.052 \text{ kg/day} - 2.755 \text{ kg/day}) = 3.297 \text{ kg/day} \times 365 \text{ days/yr} = \sim 1,200 \text{ kg/year}$

Target nitrogen removal for Little Pond: $\sim 5,000 \text{ kg N/year}$

Based on Tables 7 and 8, approximately 600 kg N and 5,000 kg N per year must be removed for Falmouth Harbor and Little Pond (respectively) to meet the regulatory standard for TN. The Little Pond sewer project removes all the septic nitrogen from the lower watershed and part of the septic nitrogen from the upper watershed. Sewering of the lower watershed removes 80% of the nitrogen load (MEP pg 117). Sewering of the lower

watershed and part of the upper watershed, combined with fertilizer reductions, removes approximately 88% of the nitrogen load. The remaining load to be removed is 600 kg N/year.

Discussion of Decision Support Tool Evaluation

Figures 5 and 6 do not show any suitable areas for shellfish aquaculture. Falmouth Harbor is restricted to shellfishing, supports six town upwellers, is a busy boat basin with lack of space, and use conflicts are ranked high. Little Pond is closed to shellfishing, has limited public access and supports an oyster nursery for municipal propagation. For these reasons, private aquaculture sites are not recommended within these two waterbodies.

Great Pond

Figures 6 and 7 show eelgrass beds, DMF classifications of shellfish growing area and habitat, key infrastructure (such as public landings) and mooring fields. Other unique public use features such as swimming beaches and yacht clubs are also marked.

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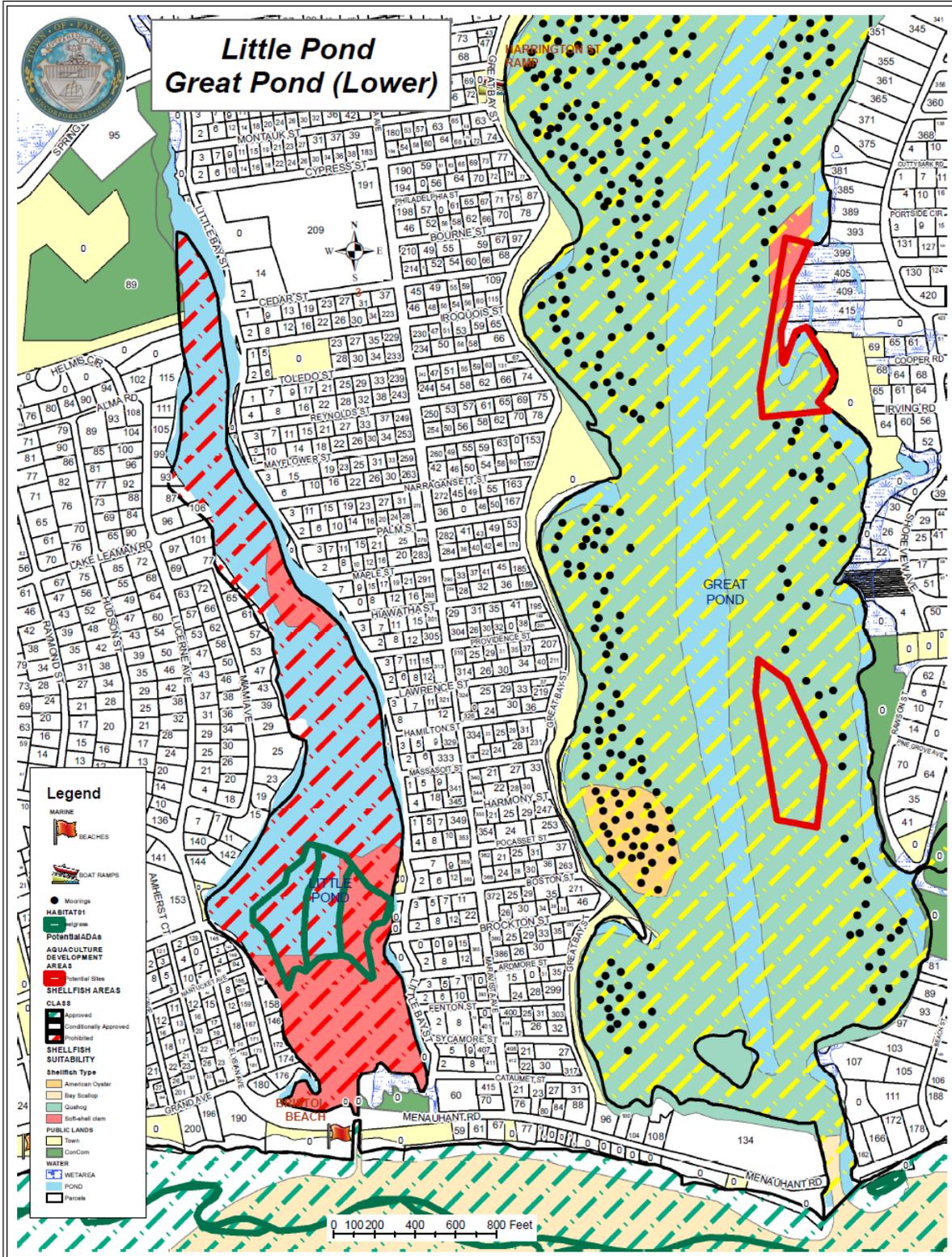


Figure 6. Little Pond and Lower Great Pond: Map of Habitat, Infrastructure, Public Uses and Potential Aquaculture Areas

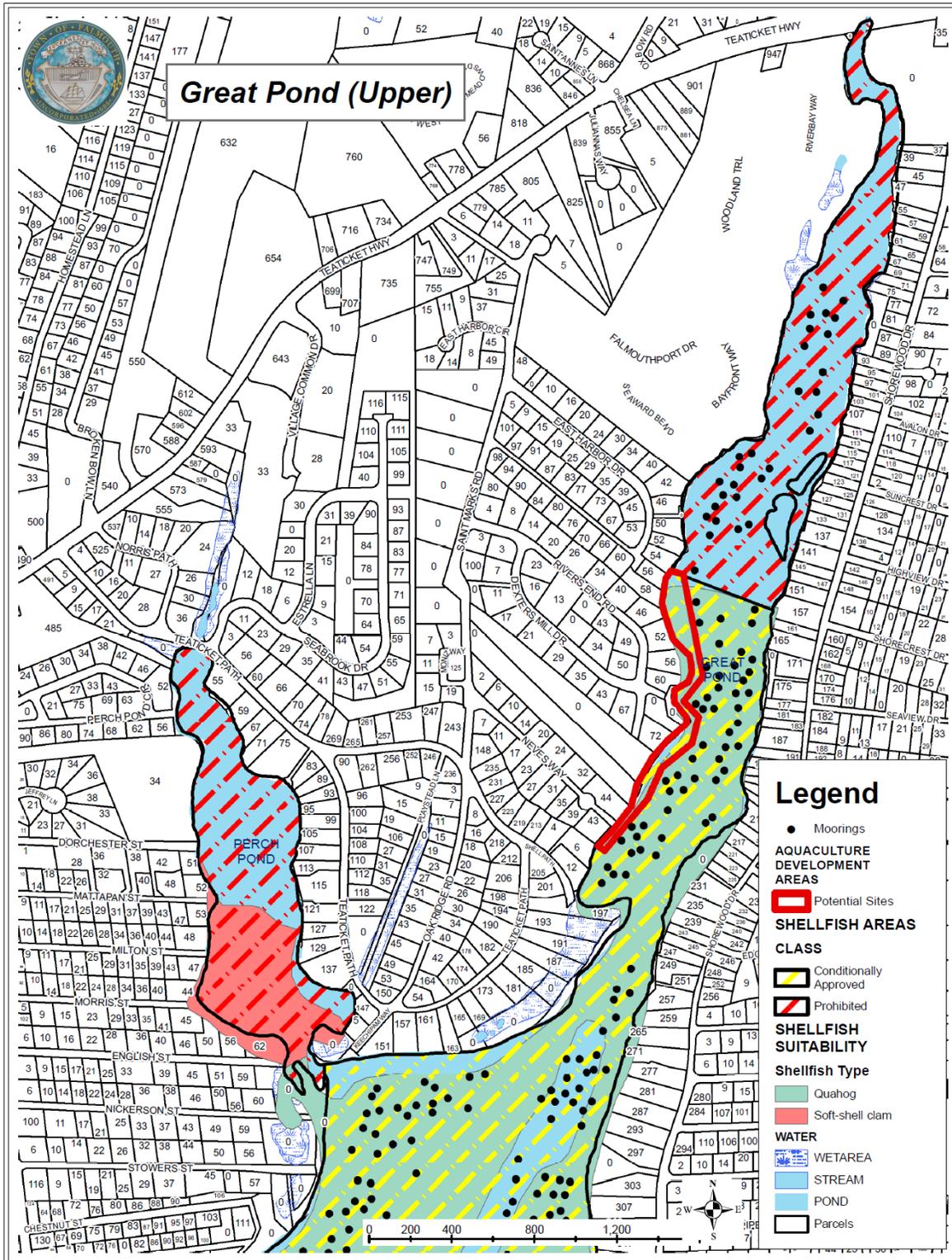


Figure 7. Upper Great Pond: Map of Habitat, Infrastructure, Public Uses and Potential Aquaculture Areas

Key findings from this habitat and resource mapping, as well as a review of environmental conditions documented in the MEP Report for Great Pond include:

Eelgrass and Sediment Type

As shown in Figures 6 and 7, currently, there is a small amount of eelgrass in Great Pond, mainly along the shore. Historically, a bed of eelgrass was found near the inlet. Sediment is predominantly fine grained and rich in organic matter (muck), with some sandy areas near the town boat landing.

Shellfish/finfish

As shown in Figures 6 and 7, DMF Shellfish Growing Area maps classify Great Pond as conditionally approved except for the area north of East Harbor Drive as well as Perch Pond which are classified as prohibited. Great Pond is considered suitable habitat for quahogs and soft-shelled clams. Commercial and recreational wild harvest of quahogs occurs in several areas within Great Pond.

Infrastructure/Public Uses

Great Pond is a multi-use recreation area. As shown in Figure 6, there is a town dock and boat ramp located off Harrington Street, with a small parking lot. This recreation area is heavily used in the summer for boating, town-run sailing lessons, and swimming.

Water Quality

Certain water quality parameters including total nitrogen (TN), chlorophyll-*a* (Chl-*a*) and dissolved oxygen (DO) are reported in the MEP Report for the Great Pond System. Chl-*a* concentrations, which are an indicator of phytoplankton food availability varies widely from day to day in Great Pond (between 1 ug/L and 70 ug/L). Data loggers were installed at two monitoring stations over a 27-day period in July. These two locations have comparable patterns of Chl-*a* availability, with average concentrations not reported. Chl-*a* levels do not fall below 5 ug/L during any of the deployment period in the upper pond and 22% of the deployment period in the lower pond. These data are collected 10 cm off the bottom in 15-minute intervals. Surface water Chl-*a* concentrations may be different from bottom water.

According to the MEP Report, bottom water dissolved oxygen concentrations are less than 3 mg/L in the upper pond 29% of the deployment period and less than 3 mg/L for 17% of the time in the lower pond, indicating a periodic anoxic bottom-water environment. These findings should be verified using updated data.

Table 9. Load Summary Table from MEP Report for Great, Green and Bournes Pond

Table VIII-3. Comparison of sub-embayment total attenuated watershed loads (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Ashumet Valley systems. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.			
sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Great Pond	25.00	3.72	-85.1%
Perch Pond	5.38	0.90	-83.2%
Green Pond	18.55	6.35	-65.8%
Bournes Pond	9.61	1.31	-86.4%
Israels Cove	2.05	0.27	-86.8%
Surface Water Sources			
Coonamessett River (Great Pond)	22.63	15.09	-33.3%
Backus Brook (Green Pond)	3.81	3.81	0.0%
Bournes Brook (Bournes Pond)	3.29	1.97	-40.3%

Great Pond (main): $(25 \text{ kg/day} - 3.72 \text{ kg/day}) = 21.28 \text{ kg/day} \times 365 \text{ d/y} = 7767 \text{ kg/yr}$

Perch Pond: $(5.38 \text{ kg/day} - 0.9 \text{ kg/day}) = 4.48 \text{ kg/day} \times 365 \text{ d/y} = 1635 \text{ kg/yr}$

Coonamessett River $(22.63 \text{ kg/day} - 15.09 \text{ kg/day}) = 7.54 \text{ kg/d} \times 365 \text{ d/y} = 2752 \text{ kg/yr}$

Target nitrogen removal for Great Pond system: ~12,000 kg N/year

Based on Table 9, approximately 12,000 kg N per year must be removed for Great Pond to meet the regulatory standard for TN.

Discussion of Decision Support Tool Evaluation

Figures 6 and 7 are summary maps that shows potentially suitable areas for shellfish aquaculture, including:

- Along the eastern shore of upper Great Pond (~1.0 acres)
- Along the western shore of upper Great Pond (~2.5 acres)
- Off the western shore of lower Great Pond near Cooper Road (~3.5 acres)
- Off the western shore of lower Great Pond near Ramon Street (~3.5 acres)

These specific areas within the overall Great Pond estuarine system are considered appropriate for private aquaculture based on the six Overriding/Threshold Consideration criteria. In summary: these locations are not within a prohibited area; these sites do not impinge on eelgrass, moorings and navigation channels; aesthetic concerns are not ranked high; use conflicts are not ranked high; municipal propagation of oysters does not occur in this area; and it is likely that shellfish could be successfully cultivated at this location. Key implementation considerations include: shellfish cannot be grown to harvestable size; sections are heavily used for wild commercial harvest so a survey for productive bottom is needed; the closure period within which private aquaculture could occur is moderate (between May 1 and October 31); public access for boat launching is

nearby and there is a public boat landing at Harrington Street; and the value of shellfish cultivation for nitrogen-removal is high.

The seed that is cultivated in these conditional areas must be moved to open grow-out areas after the first growing period that is determined by the closure period for wild harvesting. These final grow-out areas may either be within existing offshore grants, or be in new licensed sites in Vineyard Sound that will be identified as part of the permitting process.

Green Pond

Figures 8 and 9 show eelgrass beds, DMF classifications of shellfish growing area and habitat, key infrastructure (such as public landings) and mooring fields. Other unique public use features such as swimming beaches and yacht clubs are also marked.

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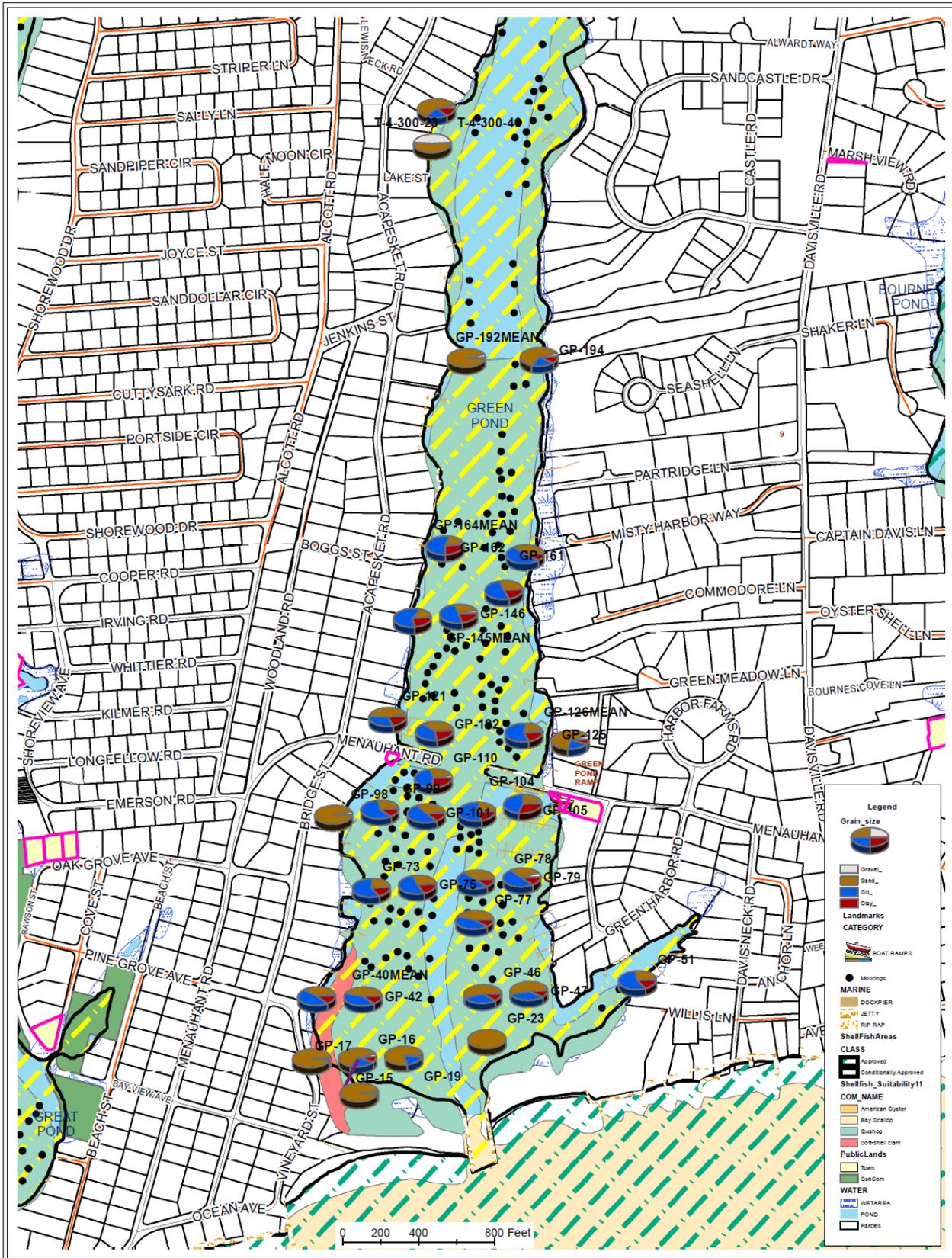


Figure 8. Lower Green Pond: Map of Habitat, Infrastructure and Public Uses

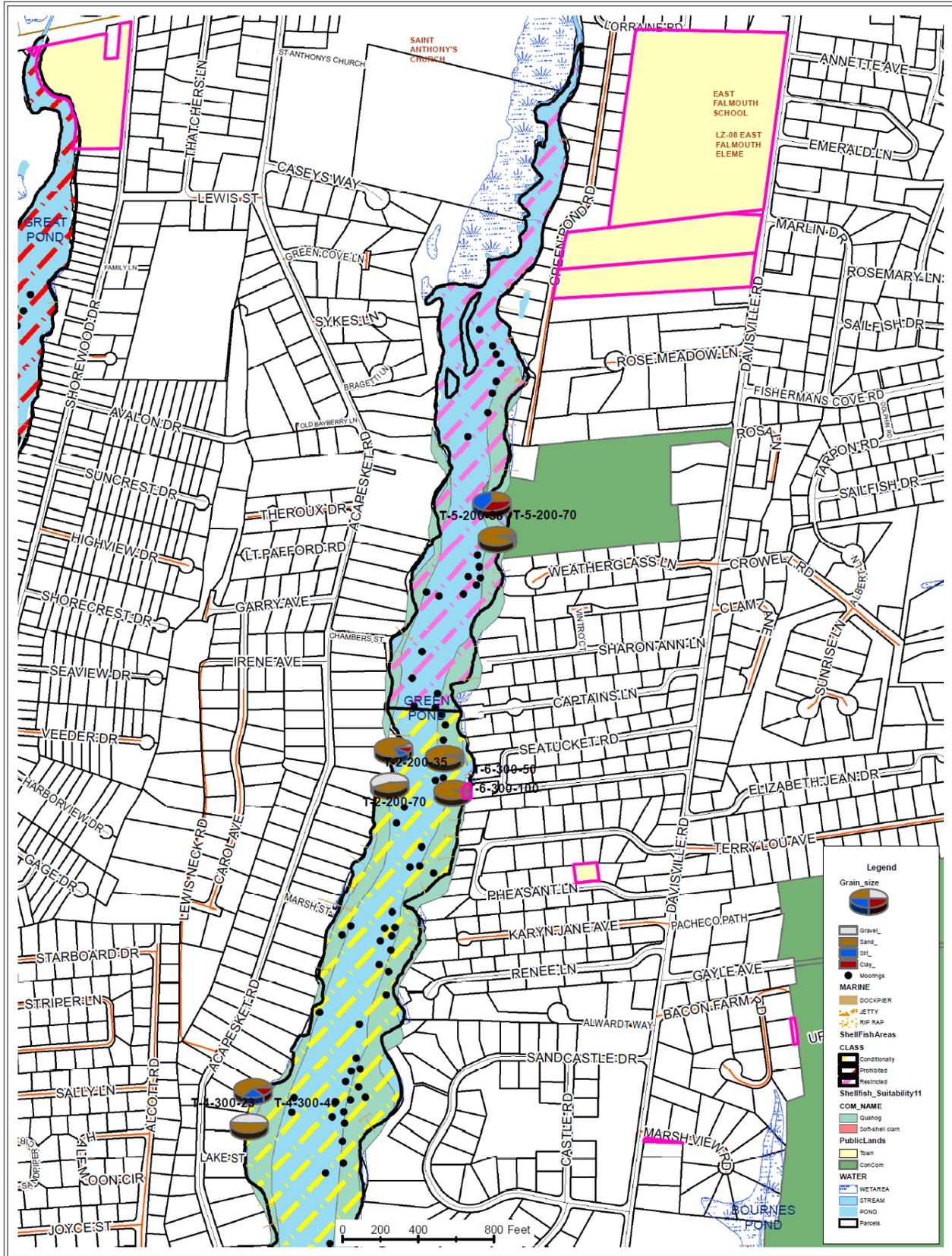


Figure 9. Upper Green Pond: Habitat, Infrastructure and Public Uses Map

Key findings from this habitat and resource mapping, as well as a review of environmental conditions documented in the MEP Report for Green Pond include:

Eelgrass and Sediment Type:

As shown in Figures 8 and 9, currently, there is no eelgrass in Green Pond although historically eelgrass grew throughout the pond south of route 28. Additional information on eelgrass and sediment types is available from the detailed habitat assessments that were conducted as part of preparing the draft Green Pond Harbor Management Plan (GPHMP). The environmental assessment completed for the Draft Green Pond Harbor Management Plan included physical, chemical and biological data as follows:

- Depth (bathymetry)
- Sediment grain size
- Total organic carbon (TOC)
- Apparent redox potential discontinuity (aRPD) layer depth
- Invertebrate indicator species abundance and distribution
- Shellfish abundance (high, medium and low)
- Presence/absence of eelgrass

Data for shellfish abundance, aRPD and eelgrass was collected at 158 stations, grain size and TOC data were taken at 40 stations and benthic indicator species data were obtained at 10 stations. To establish data collection sites, Green pond was divided into upper habitat and lower habitat using the demarcation on the Massachusetts GIS website where MA DEP designated the lower pond (south of Jenkins Street) as suitable habitat for quahogs as well as soft-shell clams, while designating only the shoreward edges of the upper reaches (north of Jenkins Street) as suitable for soft-shell clams. Prior to the start of field efforts, the lower pond was gridded on a paper map into north/south and east/west transects spaced 100 feet apart. Each intersection was assigned a number (GP1 – GP204) and was considered a potential sampling station. Of the 204 potential sampling sites, 80 were randomly selected and 20 specifically chosen (for larger areas missed by random selection) for analysis of shellfish and eelgrass presence or absence (100 stations). The upper reaches were sampled at 100 foot intervals along 500 foot long transects. The transects ran parallel to the shore, at a distance of 100 feet from mean high water if possible. In addition, each transect included one “shore normal” transect which ran perpendicular to the shore, with sampling stations at the intertidal area as well as the mid-point of one transect station (e.g. Transect 1 at the 300-foot station was sampled at 50 feet from shore, 25-feet from shore, and at the intertidal area). A total of seven (7) transects with eight (8) stations each were sampled for shellfish in the upper reaches (56 stations). Additionally, to field-verify the transition between the upper and lower reaches portrayed by MA DEP, a central rake haul transect was sampled.

At each station in the lower pond where eelgrass may have been present, an underwater investigation of the area was performed using a view box. No eelgrass was present. At each station sampled for shellfish, sediment was collected for the analysis of grain-size and total organic carbon (TOC). From the 156 stations, forty stations along cross-pond transects were selected to have the sediment samples analyzed for grain-size and TOC, with five duplicate samples run for QA/QC purposes (total of 45 samples). Ten sites were selected randomly from the shellfish stations for analysis of a 0.04 m² Van Veen benthic grab for the presence or absence of species indicative of poor or stressed habitat.

The GIS layer that was developed to summarize the results of this data collection effort is included in Figure 6. The draft GPHMP concludes that north of the Green Pond bridge is unlikely to be a suitable habitat for eelgrass, even when water quality has improved. South of the bridge, eelgrass recolonization is expected to be slow. Most of the sediment is fine grained and rich in organic matter (muck), with some sandy areas near the pond inlet and along the Green Pond bridge where the town currently relays oysters as part of its municipal propagation program.

Shellfish/Finfish:

As shown in Figures 8 and 9, DMF Shellfish Growing Area maps classify Green Pond as conditionally approved except for the area north of Rose Meadow Lane which is prohibited. Green Pond is considered suitable habitat for quahogs and soft-shelled clams. Commercial and recreational wild harvest of quahogs and oysters occurs in several areas within Green Pond.

According to the draft GPHMP, the highest value shellfish habitat is currently located south of the bridge, and moderate value shellfish habitat is near the shoreline throughout much of the pond. The central areas of the pond and the extreme northern end of the pond are considered low value shellfish habitat (Figure 9). Alewife run into Mill Pond from Green Pond.

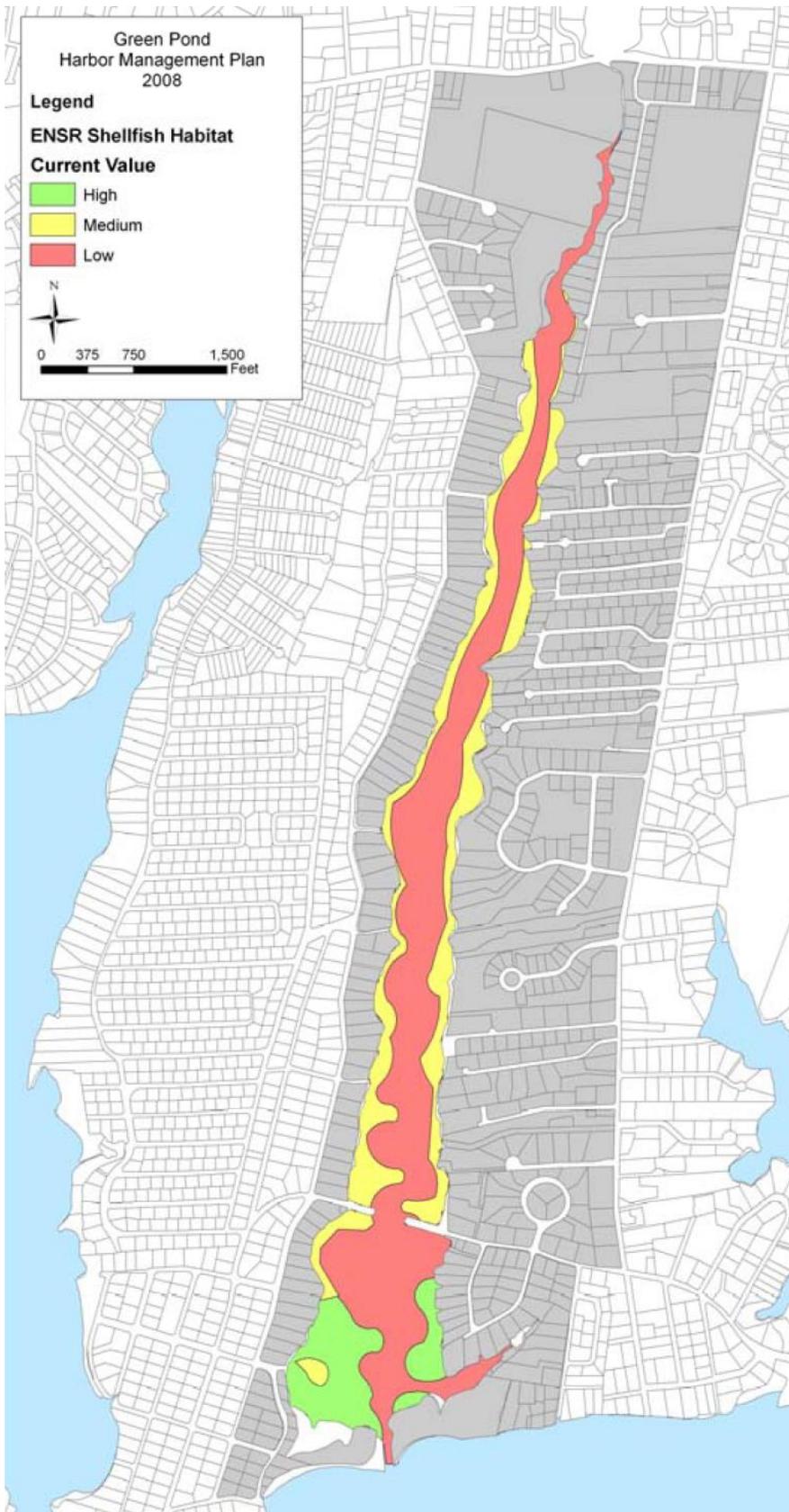


Figure 10. Relative value of shellfish habitat in Green Pond

Infrastructure/Public Uses

Great Pond is a multi-use recreation area. As shown in Figure 8, there is a town dock and boat ramp, and a parking lot with spaces for 19 vehicles with boat trailers and two vehicle spaces as well as a private marina. There are 328 private moorings in Great Pond. Private moorings are administered through the town. This recreation area is heavily used in the summer for boating, and swimming. The Department of Marine and Environment maintains an upweller at the boat landing.

Water Quality

Certain water quality parameters including total nitrogen (TN), chlorophyll-*a* (Chl-*a*) and dissolved oxygen (DO) are reported in the MEP Report for the Green Pond System. Chl-*a* concentrations, which are an indicator of phytoplankton food availability varies widely from day to day in Green Pond (between 10 ug/L and 120 ug/L, with values at 5 ug/L close to the inlet). Data loggers were installed at three monitoring stations over an approximately 27-day period in July and August. These three locations have comparable patterns of Chl-*a* availability, with average concentrations not reported. Chl-*a* levels did not fall below 5 ug/L during any of the deployment period anywhere in the pond. These data are collected 10 cm off the bottom in 15-minute intervals. Surface water Chl-*a* concentrations may be different from bottom water.

According to the MEP Report, bottom water dissolved oxygen concentrations are seldom less than 4 mg/L in Green Pond. This indicates that oxygen should not be a limiting factor in shellfish propagation. These findings should be verified using updated data.

Table 10. Load Summary Table from MEP Report for Great, Green and Bournes Pond

Table VIII-3. Comparison of sub-embayment total attenuated watershed loads (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Ashumet Valley systems. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.			
sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Great Pond	25.00	3.72	-85.1%
Perch Pond	5.38	0.90	-83.2%
Green Pond	18.55	6.35	-65.8%
Bournes Pond	9.61	1.31	-86.4%
Israels Cove	2.05	0.27	-86.8%
Surface Water Sources			
Coonamessett River (Great Pond)	22.63	15.09	-33.3%
Backus Brook (Green Pond)	3.81	3.81	0.0%
Bournes Brook (Bournes Pond)	3.29	1.97	-40.3%

Green Pond (main): $(18.55 \text{ kg/day} - 6.35 \text{ kg/day}) = 12.2 \text{ kg/day} \times 365 \text{ d/y} = 4453 \text{ kg/yr}$

Backus Brook: 0 kg/day

Target nitrogen removal for Green Pond system: ~4500 kg N/year

Based on Table 10, approximately 4,500 kg N per year must be removed for Green Pond to meet the regulatory standard for TN.

Discussion of Decision Support Tool Evaluation

Figures 8 and 9 are summary maps that do not show suitable areas for shellfish aquaculture. Because Green Pond is a busy boat basin, there is lack of space, and use conflicts are ranked high. This is also a highly successful area for municipal propagation of quahogs and oysters by bottom planting (no gear required). For these reasons, private aquaculture sites are not recommended for this harbor.

Bournes Pond

Figure 11 shows eelgrass beds, DMF classifications of shellfish growing area and habitat, key infrastructure (such as public landings) and mooring fields. Other unique public use features such as swimming beaches and yacht clubs are also marked.

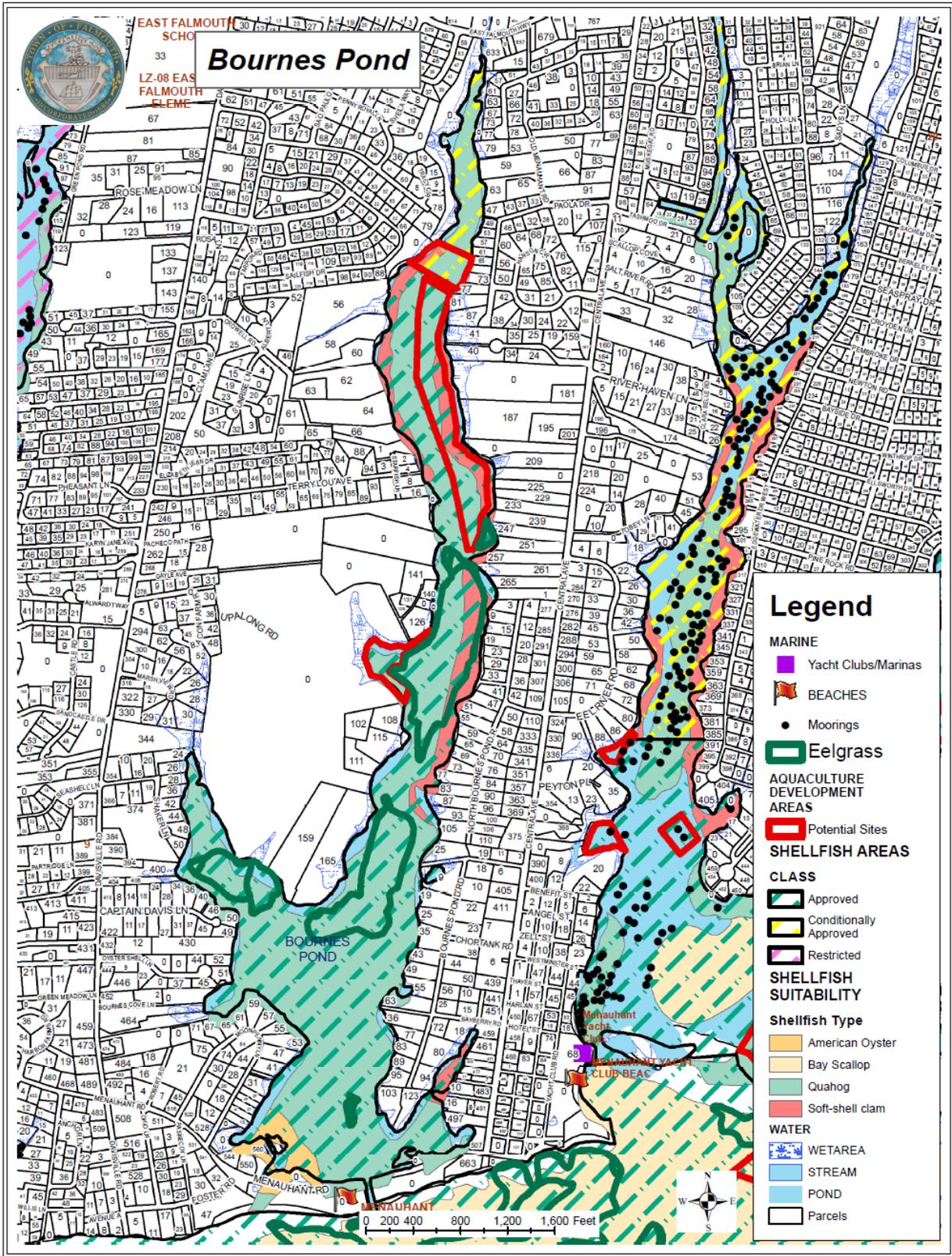


Figure 11. Bournes Pond: Map of Habitat, Infrastructure, Public Uses and Potential Aquaculture Areas

Key findings from this habitat and resource mapping, as well as a review of environmental conditions documented in the MEP Report for Bournes Pond include:

Eelgrass and Sediment Type

As shown in Figure 11, currently, there are eelgrass beds along the shore throughout the middle section of Bournes Pond. Sediment is predominantly fine grained and rich in organic matter (muck), with some sandy areas in the center of the middle section of the pond.

Shellfish/finfish

As shown in Figure 11, DMF Shellfish Growing Area maps classify Bournes Pond as approved except for the area north of Sailfish Drive which is conditionally approved. Bournes Pond is considered suitable habitat for quahogs and soft-shelled clams. Commercial and recreational wild harvest of quahogs and soft-shelled clams occurs in several areas within Bournes Pond.

Infrastructure/Public Uses

Boat access to Bournes Pond is limited by the height of the bridge over the inlet. As shown in Figure 11, off Pacheco Path, there is a parking area and a path for public access to the water, but there is no boat ramp. There are 16 private moorings in Bournes Pond. Private moorings are administered through the town.

Water Quality

Certain water quality parameters including total nitrogen (TN), chlorophyll-*a* (Chl-*a*) and dissolved oxygen (DO) are reported in the MEP Report for the Bournes Pond System. Chl-*a* concentrations, which are an indicator of phytoplankton food availability varies widely from day to day in Green Pond (between 5 ug/L and 55 ug/L). Data loggers were installed at two monitoring stations over an 27-day period in July and August. Data for one logger is presented, with average concentrations not reported. Chl-*a* levels fell below 5 ug/L a de minimis 1% of the deployment period. These data are collected 10 cm off the bottom in 15-minute intervals. Surface water Chl-*a* concentrations may be different from bottom water.

According to the MEP Report, bottom water dissolved oxygen concentrations are less than 3 mg/L in the upper pond 34% of the deployment period and less than 3 mg/L for 4% of the time in the lower pond, indicating a periodic anoxic bottom-water environment. These findings should be verified using updated data.

Table 11. Executive Summary Table from MEP Report for Bournes Pond

Table VIII-3. Comparison of sub-embayment total attenuated watershed loads (including septic, runoff, and fertilizer) used for modeling of present and threshold loading scenarios of the Ashumet Valley systems. These loads do not include direct atmospheric deposition (onto the sub-embayment surface) or benthic flux loading terms.			
sub-embayment	present load (kg/day)	threshold load (kg/day)	threshold % change
Great Pond	25.00	3.72	-85.1%
Perch Pond	5.38	0.90	-83.2%
Green Pond	18.55	6.35	-65.8%
Bournes Pond	9.61	1.31	-86.4%
Israels Cove	2.05	0.27	-86.8%
Surface Water Sources			
Coonamessett River (Great Pond)	22.63	15.09	-33.3%
Backus Brook (Green Pond)	3.81	3.81	0.0%
Bournes Brook (Bournes Pond)	3.29	1.97	-40.3%

Bournes Pond (main): $(9.61 \text{ kg/day} - 1.31 \text{ kg/day}) = 8.3 \text{ kg/day} \times 365 \text{ d/y} = 3030 \text{ kg/yr}$

Israels Cove: $(2.05 \text{ kg/day} - 0.27 \text{ kg/day}) = 1.78 \text{ kg/d} \times 365 \text{ d/y} = 650 \text{ kg/yr}$

Bournes Brook: $(3.29 \text{ kg/day} - 1.97 \text{ kg/day}) = 1.31 \text{ kg/d} \times 365 \text{ d/y} = 482 \text{ kg/yr}$

Target nitrogen removal for Bournes Pond system: $\sim 4000 \text{ kg N/year}$

Based on Table 11, approximately 4,000 kg N per year must be removed for Bournes Pond to meet the regulatory standard for TN.

Discussion of Decision Support Tool Evaluation

Figure 11 is a summary map that shows potentially suitable areas for shellfish aquaculture, including:

- Within the conditionally-approved area (~2.5 acres)
- 50-feet off the eastern shore (~11 acres)
- Off the western shore of Sea Farms (2.5 acres)

The sand flat located near Pacheco Path is part of the Town’s municipal propagation program and should not be included in the ADA.

These specific areas within the overall Bournes Pond estuarine system are considered appropriate for private aquaculture based on the six Overriding/Threshold Consideration criteria. In summary: these locations are not within an area prohibited to shellfishing; these sites do not impinge on eelgrass, moorings and navigation channels; aesthetic concerns are not ranked high; use conflicts are not ranked high; municipal propagation of oysters does not occur in these specific areas; and it is likely that shellfish could be successfully cultivated at these locations. Key implementation considerations include: shellfish can be grown to harvestable size; some sections of this estuary are used heavily for wild commercial harvest so a survey for productive bottom is needed; there is no closure period; public access for boat launching is minimal, there is no public boat landing

into this estuary and the height of the bridge at the inlet limits boat size to small skiffs; and the value of shellfish cultivation for nitrogen-removal is high.

Waquoit Bay including Eel Pond

Waquoit Bay is a designated Area of Critical Environmental Concern (ACEC). Figure 12 shows eelgrass beds, DMF classifications of shellfish growing area and habitat, key infrastructure (such as public landings) and mooring fields. Other unique public use features such as swimming beaches and yacht clubs are also marked.

DRAFT

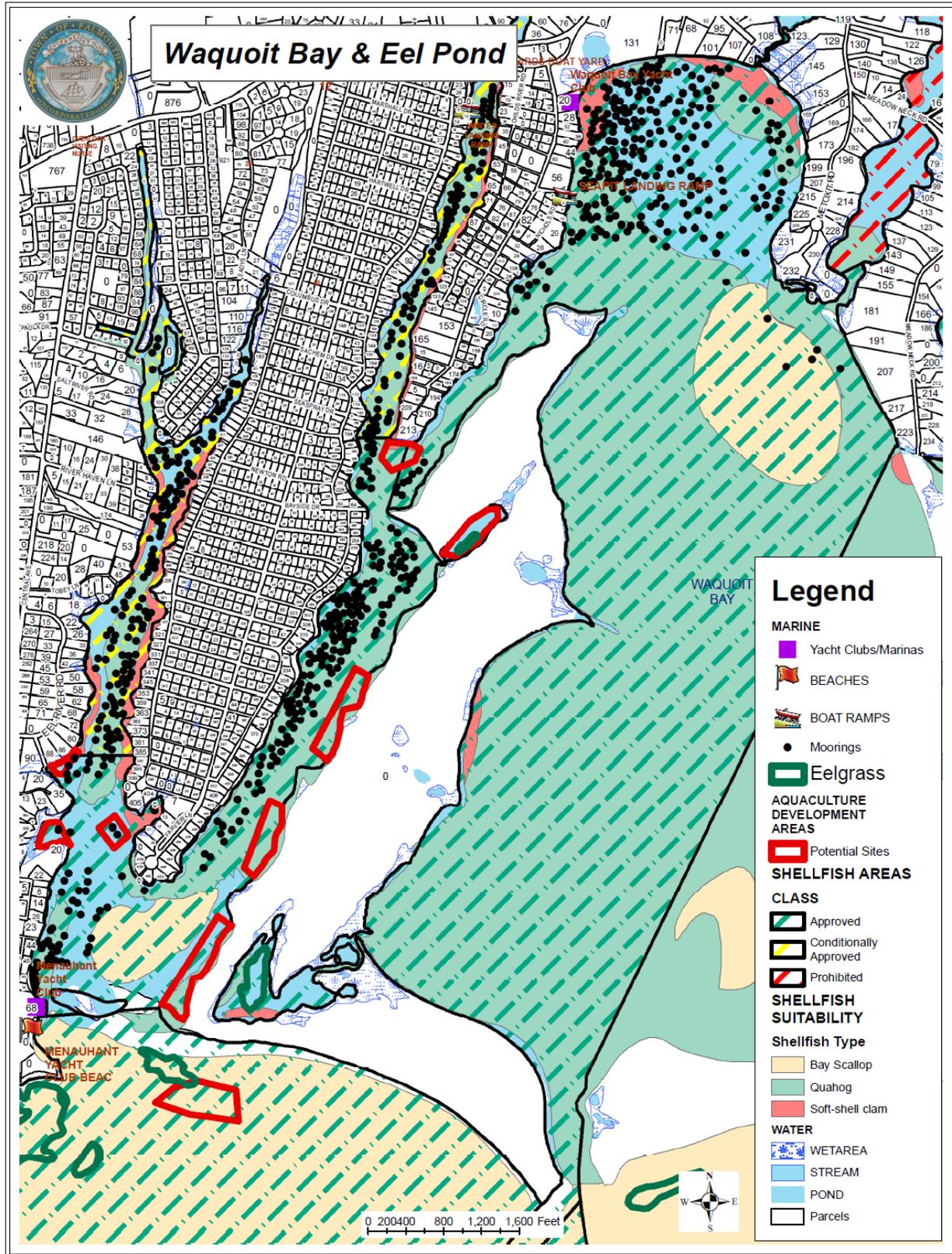


Figure 12. Waquoit Bay and Eel Pond: Map of Habitat, Infrastructure, Public Uses and Potential Aquaculture Areas

Key findings from this habitat and resource mapping, as well as a review of environmental conditions documented in the MEP Report for Waquoit Bay include:

Eelgrass and Sediment Type

As shown in Figures 12, currently, there are no eelgrass beds in Eel Pond or Waquoit Bay with a small patch in Hamblin Pond. Historically Waquoit Bay supported eelgrass in the northern basin with large fringing beds near the inlet. In Eel Pond and the Childs and Seapit River, significant eelgrass existed 60 years ago. There is not a past record of eelgrass in the northern section of the Childs River. Sediment is predominantly fine grained and rich in organic matter (muck), with some sandy areas in the middle section of the bay along the shore. In some areas, the bottom is covered with a mat of macroalgae.

Shellfish/finfish

As shown in Figures 12, DMF Shellfish Growing Area maps classify Waquoit Bay as approved except for the Quashnet/Moonakis River which is prohibited. Eel Pond as approved except for the areas north of Newton Road to the west and Seaspray Drive to the east which are conditionally approved. Eel Pond and Waquoit Bay are considered suitable habitat for quahogs and soft-shelled clams. Commercial and recreational wild harvest of quahogs, soft-shelled clams and scallops (occasionally) occurs in several areas within Eel Pond and Waquoit Bay. Commercial and recreational wild harvest of quahogs and soft-shelled clams occurs in several areas within Waquoit Bay. There is a private aquaculture lease in the Seapit River.

Infrastructure/Public Uses

The Waquoit Bay system is a National Estuarine Research Reserve and a multi-use recreation area. As shown in Figures 12, there are two public boat landings, both located off Route 28. White's Landing accesses the Childs River and is located off White's Landing Road. There is a large dirt parking lot nearby. Waquoit Bay Landing is located on Waquoit Landing Road. There is also a yacht club and a private marina near White's Landing. Washburn Island, a popular camping area, is only accessible by boat.

There are 5 boatyard/yacht club moorings and 221 private moorings in Waquoit Bay 144 private moorings in Eel River (pond) east, 5 yacht club moorings and 169 private moorings in Eel River (pond) west, 12 boatyard moorings and 82 private moorings in the Childs River and 17 private moorings in the Seapit River. Private moorings are administered through the town. This recreation area is heavily used in the summer for boating, sailing lessons and swimming.

Water Quality

Certain water quality parameters including total nitrogen (TN), chlorophyll-*a* (Chl-*a*) and dissolved oxygen (DO) are reported in the MEP Report for the Waquoit Bay System. Chl-*a* concentrations, which are an indicator of phytoplankton food availability varies widely from day to day in the Childs River/Eel Pond system (between 5 ug/L and 55 ug/L). The Waquoit Bay main basin (including data from the upper, mid and lower basin) ranges between 2 ug/L and 14 ug/L, with lower concentrations in the lower basin. Data loggers were installed at three monitoring stations over a period of between 22 and 42 days in July, August and September. These three

locations have comparable patterns of Chl-*a* availability, with average concentrations of 15.3 ug/L reported in the upper Bay, 6.8 ug/L mid-Bay and 5.4 ug/L in the lower Bay. Chl-*a* levels were below 5 ug/L, 0%, 11% and 64% of the deployment period, with concentrations declining closer to the inlet. These data are collected 10 cm off the bottom in 15-minute intervals. Surface water Chl-*a* concentrations may be different from bottom water.

In the Childs/Eel Pond system, data loggers were installed at three monitoring stations over a 24-day period in July, August and September. These three locations have varying degrees of Chl-*a* availability, with average concentrations of 6.2 ug/L reported in Eel Pond near the inlet, 23.3 ug/L in the Childs River and 17.4 ug/L at the “Eel River” station located north of the fork with the Seapit River.

According to the MEP Report, bottom water dissolved oxygen concentrations in both the main basin of Waquoit Bay and the Childs Eel Pond system are seldom less than 5 mg/L, with concentrations lower than 3 mg/L occurring less than 5% of the deployment period. This indicates that oxygen should not be a limiting factor in shellfish propagation.

Table 12. Executive Summary Table from MEP Report for Waquoit Bay System

Table ES-2. Present Watershed Loads, Threshold Loads, and the percent reductions necessary to achieve the Threshold Loads for the Waquoit Bay system.						
Sub-embayments	Present Watershed Load ¹ (kg/day)	Target Threshold Watershed Load ² (kg/day)	Direct Atmospheric Deposition (kg/day)	Benthic Flux Net ³ (kg/day)	TMDL ⁴ (kg/day)	Percent watershed reductions needed to achieve threshold load levels
WAQUOIT BAY SYSTEM						
groundwater sources						
Waquoit Bay	2.088	2.088	11.956	-56.779	-42.735	0.0%
Childs River - upper	12.019	4.076	0.455	-4.291	0.240	-66.1%
Eel Pond - east branch	2.170	0.820	1.011	19.480	21.310	-62.2%
Eel Pond - south basin	0.523	0.523	0.663	-4.632	-3.445	0.0%
Eel Pond - west branch	16.337	8.808	0.890	-2.900	6.798	-46.1%
Quashnet River	2.773	1.497	0.252	9.496	11.245	-46.0%
Hamblin Pond	4.381	0.953	1.529	5.712	8.194	-78.2%
Little River	1.096	0.211	0.156	2.554	2.922	-80.7%
Jehu Pond	3.912	1.025	0.674	6.897	8.596	-73.8%
Great River	3.671	0.997	1.307	14.222	16.526	-72.8%
Sage Lot Pond	2.753	1.622	0.471	-2.726	-0.633	-41.1%
surface water sources						
Childs River	10.622	4.115	-	-	4.115	-61.3%
Quashnet River	20.507	13.469	-	-	13.469	-34.3%
Red Brook	8.014	2.096	-	-	2.096	-73.8%
Waquoit Bay System Total	90.866	42.300	19.364	-12.967	48.697	-53.4%
(1) Composed of combined natural background, fertilizer, runoff, and septic system loadings.						
(2) Target threshold watershed load is the load from the watershed needed to meet the embayment threshold concentrations identified in Table ES-1.						
(3) Projected future flux (present rates reduced approximately proportional to watershed load reductions).						
(4) Sum of target threshold watershed load, atmospheric deposition load, and benthic flux load.						

Waquoit Bay System:

$$(90.1 \text{ kg/day} - 42.3 \text{ kg/day}) = 47.8 \text{ kg/day} \times 365 \text{ d/y} = 17,447 \text{ kg/yr}$$

From 208 Plan Update Appendix 8C:

- Total Reduction Target = 20,954 kg N/year
- Falmouth share = 11,198 kg N/year (53%)
- Mashpee/Sandwich share = 9,756 kg N/year (42%/5%)

Based on Table 12, approximately 11,200 kg/N per year must be removed *by Falmouth* for Waquoit Bay to meet the regulatory standard for TN.

Discussion of Decision Support Tool Evaluation

Figure 12 is a summary map showing potentially suitable areas for shellfish aquaculture, including:

- Along the western shore of Eel Pond west off Eel River Road (~0.5 acres)
- Along the western shore of Eel Pond west, south of the above site (~1.0 acre)
- Off the eastern side of Seacoast Shores (~1.0 acre)
- Along the western shore of Washburn Island (three sites: ~4.0, 3.0 and 5.0 acres, from north to south)
- With the cove in Washburn Island (~2.5 acres)
- Off the end of Seapit Road (~2.0 acres)
- Offshore, outside the groin at Eel Pond (~5.5 acres)

These specific areas within the overall Waquoit Bay/Eel Pond estuarine system are considered appropriate for private aquaculture based on the six Overriding/Threshold Consideration criteria. In summary: these locations are not within an area prohibited to shellfishing; these sites do not impinge on eelgrass, moorings and navigation channels; aesthetic concerns are not ranked high; use conflicts are not ranked high; municipal propagation of oysters does not occur in these areas; and it is likely that shellfish could be successfully cultivated at these locations. Key implementation considerations include: shellfish can be grown to harvestable size; some sections of this estuary are used heavily for wild commercial harvest so a survey for productive bottom is needed; there is no closure period; public access for boat launching is adequate and there are public boat landings available; and the value of shellfish cultivation for nitrogen-removal is high.

Figure 13 shows the boundary map for the Waquoit Bay National Estuarine Research Reserve (WBNERR) and Area of Critical Environmental Concern (ACEC). Eel Pond is not part of these protected areas.

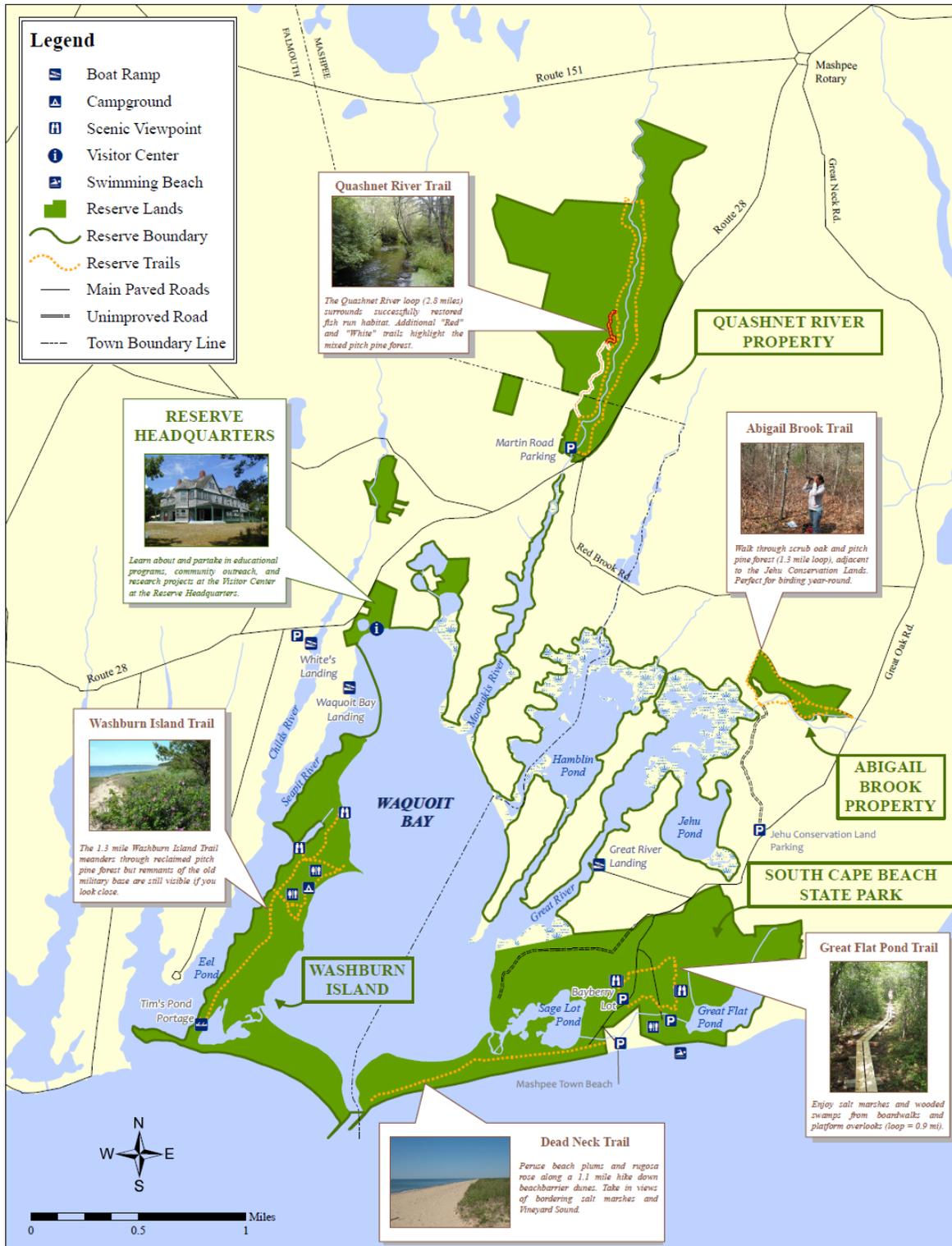


Figure 13: Waquoit Bay National Estuarine Research Reserve (WBNER) and Area of Critical Environmental Concern (ACEC) Boundary

Section 3. Rotational Aquaculture License Sites (RALS)

Section 3A. Background

Falmouth's estuaries are a public resource where both families and commercial fishermen have harvested shellfish for centuries. Many other recreational activities such as boating and swimming are popular in these areas as well. As an overabundance of nitrogen has degraded water and sediment quality, shellfish populations have declined. As early as 1974, the Town's Shellfish Constable George Souza was experimenting with raising quahogs in West Falmouth's Quahog Pond for municipal propagation. His goal was to seed West Falmouth Harbor with quahogs and create more productive areas for wild quahog harvesting throughout the Town's "flats". News of his experiment, likely one of the first municipal propagation efforts on Cape Cod, was published in the November 11, 1975 edition of the Falmouth Enterprise. By 1998, the Town had installed an upweller on the Town dock in West Falmouth and was growing 1.5 million quahogs annually that were bottom-planted for commercial and recreational harvest. Today, the Town's municipal propagation program continues the mission of Mr. Souza to maintain and enhance the population of quahogs for public harvest. The Town has planted an average of 3.5 million quahogs that were started from seed annually over the past four years, not including the many bushels of quahogs relayed from one waterbody to another. There is also interest in developing viable methods for propagating other species such as scallops.

Propagating quahogs and other species and maintaining public access to the areas that have been harvested historically is an important goal of the Town. At the same time, private aquaculture provides an opportunity to promote local food production, foster local jobs and introduce larger quantities of shellfish into the town's impaired estuaries to rapidly improve water quality. To both improve the wild fishery as well as provide opportunities for aquaculture sites in appropriate locations, the Rotational Aquaculture License Site (RALS) model has been developed.

The economic, environmental and practical value of growing shellfish within several of the Town's estuaries is documented in Section 2A. While offshore aquaculture sites are not advantageous for the Town or growers, several historical offshore license sites already exist in Vineyard Sound and Buzzards Bay. As aquaculture planning and implementation moves forward, open water growers should be given right of first refusal on any expansions or new aquaculture license site proposals which are within 1000 feet of their existing aquaculture license site.

Concept Overview

The RALS model provides locations in certain estuaries for private aquaculture for commercial and recreational purposes, while at the same time enhancing these estuaries for wild harvesting through municipal propagation of quahogs and other species. The system works by establishing two to four distinct RALS sub-locations per grower. Only one sub-location is used per year, and the grower moves operations on either a two-year or a four-year rotation. During periods when an area is actively farmed using floating gear, nearby areas are concurrently bottom-planted with quahogs or other species that can be successfully planted and have commercial value such as scallops. Private aquaculture operations are then moved to the next sub-location to allow for wild harvesting of the bottom at the first sub-location. Areas that are municipally propagated are opened for wild harvesting depending on whether the species planted has reached a harvestable size and the

Town's health-related closure schedule. Moreover, all aquaculture activities in RALS within conditionally-approved estuaries are seasonal and are completely removed from all areas during periods when conditionally-approved areas are open for wild shellfish harvesting.

It is expected that DMF permitting for this approach in conditionally-approved areas is possible based on a recent program in Barnstable where aquaculture license-holders are potentially being permitted to grow in areas that are considered productive for commercial wild harvest and are also conditionally-approved. These aquaculture nursery areas are permitted on a seasonal basis, during the wild-harvest closure periods. Locating RALS in open estuaries will be done in a way that does not negatively impact commercial wild harvesters.

The RALS approach involves the following:

- The Town of Falmouth identifies and maps Aquaculture Development Areas (ADAs) and certain RALS within these ADAs
- DMF certifies these areas at the request of the Board of Selectmen (BOS)
- Town applies for permits from Army Corp of Engineers (ACOE) and Conservation Commission
- Individuals who are residents of the Town of Falmouth apply to the BOS for a RALS
 - Three types of license areas are available: Commercial Aquaculture, Introductory Trial Sites for commercial evaluations and Family Gardens
- Municipal propagation of quahogs and other commercially-important species such as scallops occurs in proximity to these areas concurrent with aquaculture operations
- License sites move annually or every two years (either a two or four-year rotation), and in conditionally-approved area only contain gear during periods when these areas are already closed to commercial and recreational wild harvest
- In open areas, the rotation of gear will be structured to allow for wild harvest of the bottom
- Specific terms and expectations for each RALS are a condition of the site license and the propagation permit

The first step in the implementation of ADAs and RALS is to define and site ADAs within appropriate areas of the Town's estuaries. Section 2 describes the process used to define the preliminary ADAs shown in Figures 1 through 12. In general, these areas were determined with the Shellfish Working Group (SWG) using a robust decision-making process. The SWG members represent a broad stakeholder group that includes commercial wild shellfish harvesters, aquaculture farmers, scientists and town staff Department of Marine and Environment and Town Manager's Office and appointed and elected official from the Conservation Commission, Coastal Ponds Committee and Water Quality Management Committee. A public hearing and subsequent meetings with commercial harvesters further refined the ADAs in several estuaries, including Great Pond, Bournes Pond and Waquoit/Eel Pond.

Section 3B. Types and Sizes of Rotational Aquaculture License Sites (RALS)

Within these ADAs, four classifications of RALS are envisioned, allowing for a range of aquaculture activities to occur, including:

- Full-Scale Commercial RALS
- Introductory Trial Sites for commercial evaluations

- Sites for Disabled Veterans
- Family/Recreational Gardening

The number of RALS sub-locations will vary, with more sites allocated to full-scale commercial operations and fewer sub-locations licensed for commercial trials and gardening. Based on the analysis presented in Section 2, sizes for each area could be as follows. This assumes a four-year rotation, and may be adjusted if a two-year rotation is implemented. Other adjustments may be made after discussions during the permitting process with authorities such as DMF and ACOE:

- Full-Scale Commercial RALS Area: maximum of 20,000 sq. ft.
 - In conditionally-approved estuaries:
 - Each grower receives permits for four RALS sub-locations within the conditionally-approved estuary (assuming a four-year rotation) but only one 20,000 sq. ft. site can be used per year (see Figure 14)
 - Each grower covers 20,000 sq. ft. annually
 - Each RALS sub-location of 20,000 sq. ft. will be for growing out seed in its first year only, up to an average size of 1.5 -inches and must be relayed to open areas for final grow-out to harvestable size
 - Each grower also receives permits for locations for final grow-out in open areas (as described below for open areas)
 - Timing and criteria for permit renewal and transfer will be defined during the implementation phase
 - In open estuaries:
 - Each grower receives permits for sixteen RALS sub-locations within an open estuary (assuming a four-year rotation) but only four of the 20,000 sq. ft. RALS sub-locations can be used per year (see Figure 14)
 - Each grower covers 2 acres annually
 - One RALS sub-location is used for first-year growth and the other three RALS sub-locations are used for second-year growth to marketable size.
 - Timing and criteria for permit renewal and transfer will be defined during the implementation phase
- Introductory Trial Sites for commercial evaluations: maximum of 20,000 sq. ft.
 - Each trial grower receives permits for four RALS sub-locations but only one 20,000 sq. ft. site can be used per year (see Figure 14)
 - Each grower covers 20,000 sq. ft. annually
 - This area includes both space for nursery and grow-out
 - These trial areas will change location on either a two or a four-year rotation
 - Timing and criteria for permit renewal and transfer will be defined during the implementation phase
- Sites for disabled veterans: maximum of 20,000 sq. ft.
 - Each disabled veteran receives permits for four RALS sub-locations but only one 20,000 sq. ft. site can be used per year (see Figure 14)

- Each grower covers 20,000 sq. ft. annually
 - This area includes both space for nursery and grow-out
 - These areas will change location on either a two or a four-year rotation
 - Timing and criteria for permit renewal and transfer will be defined during the implementation phase
- Recreational/family garden area: number of oysters that can be grown by an individual will be based on wild harvest limits for oysters or other species grown over a season. This provision allows for recreational harvest of up to 13 bushels of oysters per year. At approximately 300 market-size oysters per bushel, the maximum annual harvest from a recreational or family garden area is no more than 3,900 oysters per year
 - Smaller areas to accommodate mooring-based raft systems will be considered on a site-specific basis

To illustrate this concept based on a four-year rotation, Figure 14 shows how gear may be installed within an ADA. Other time intervals will be explored during the implementation phase.



Figure 14. Conceptual Representation of Four-Year Rotational Aquaculture License Site (RALS) Within ADAs. Left: Nursery/trial areas that are used for both Full Scale Commercial RALS as well as Introductory Trial Sites for commercial evaluations (20,000 sf on a four-year rotation). Right: Full Scale Commercial RALS areas (1.5-acre grow-out sites on a four-year rotation). Two-year rotations may also be evaluated.

RALS should be conditioned to reflect the terms and conditions of this approach and will be finalized during the implementation phase. Specific requirements could include:

- Renewal periods
- Gear requirements
- Minimum required biomass produced in Commercial RALS areas

For example, all RALS could be required to renew after one or two rotational cycles. Because they are located in the Town's coastal ponds, most of which are both conditionally approved and have potentially productive bottom for wild commercial harvesting, these license sites could have specific terms and conditions that are different from Town's standard aquaculture licenses.

Section 3C. Implementation

The general concept of a RALS is to enhance shellfish propagation for wild harvest while at the same time allowing certain areas within an estuary to be periodically used for private aquaculture in floating gear. A pilot phase is envisioned, where approximately two to four RALS are granted to individual growers and the program is monitored and evaluated. The exact number of RALS granted during the pilot phase will be determined prior to permitting. This pilot phase is intended to inform the program structure based on actual implementation. The knowledge gained through practical experience may lead to important modifications that will streamline and enhance the system of granting RALS and propagating quahogs and other species. Full-scale implementation will proceed based on the evaluation and recommendations of the pilot phase.

There are several benefits of the RALS approach:

- Maintains estuary bottom as a public resource for wild harvesting of shellfish
- Increases wild harvest of quahogs and other species by increased bottom-planting
- Allows private aquaculture in areas that have sufficient microalgae, and are warmer than open waters (Dame 2011, Gosling 2003, Lorio and Malone 1994). These are ideal growing conditions for shellfish, improving economic viability for new farms
- Allows private aquaculture in areas that are protected and provide better working conditions for growers
- Maximizes the number of shellfish grown and harvested per unit area of aquaculture farm
- Promotes the cultural benefits of native species by making them more prevalent and thus available for people to experience
- Concentrates the filter-feeding benefits of shellfish into water bodies suffering from the worst nitrogen-impairment and eutrophication
- Accommodates riparian and littoral rights of upland landowners

This program works by having periods when areas that are bottom-planted with quahogs and other species are in proximity to areas that are actively farmed in floating gear, and periods where private aquaculture operations are moved to allow for wild harvesting of the species that were both planted and naturally available. During periods when aquaculture is occurring at a given location, wild harvesting would be prohibited, allowing the field-planted species to reach harvest size. Once the aquaculture operation rotates to a new location, the bottom-planted area would be opened to commercial and recreational harvest based on species size and the Town's health-related closure schedule. To illustrate the RALS approach, a four-year rotation of oyster aquaculture with quahog propagation is given. Other species may be proposed for both farming as well as propagation, and other rotation intervals may be explored.

As an example, the timing of a four-year rotation as shown in Figure 15 is as follows. The four RALS sub-locations that are rotated annually are designated in Figure 15 as RALS #1, RALS #2, RALS#3 and RALS #4. This system works as follows:

Year 1:

RALS Sublocation #1:

- Actively used for aquaculture and municipal propagation
- Closed to wild harvest

RALS #2, RALS #3 and RALS #4 are open to wild harvest of bottom during seasonal opening of estuary. These areas may also be left closed for a spawn season as part of ongoing municipal propagation planning.

Year 2:

RALS Sublocation #2:

- Actively used for aquaculture and municipal propagation
- Closed to wild harvest

RALS #1 area is actively harvested if appropriate size of propagated species is reached

RALS #3 and RALS #4 are open to wild harvest of bottom during seasonal opening of estuary. These areas may also be left closed for a spawn season as part of ongoing municipal propagation planning.

Year 3:

RALS Sublocation #3:

- Actively used for aquaculture and municipal propagation
- Closed to wild harvest

RALS #2 area is actively harvested if appropriate size of propagated species is reached

RALS #1 and RALS #4 are open to wild harvest of bottom during seasonal opening of estuary. These areas may also be left closed for a spawn season as part of ongoing municipal propagation planning.

Year 4:

RALS Sublocation #4:

- Actively used for aquaculture and municipal propagation
- Closed to wild harvest

RALS #3 area is actively harvested if appropriate size of propagated species is reached

RALS #1 and RALS #2 are open to wild harvest of bottom during seasonal opening of estuary. These areas may also be left closed for a spawn season as part of ongoing municipal propagation planning.

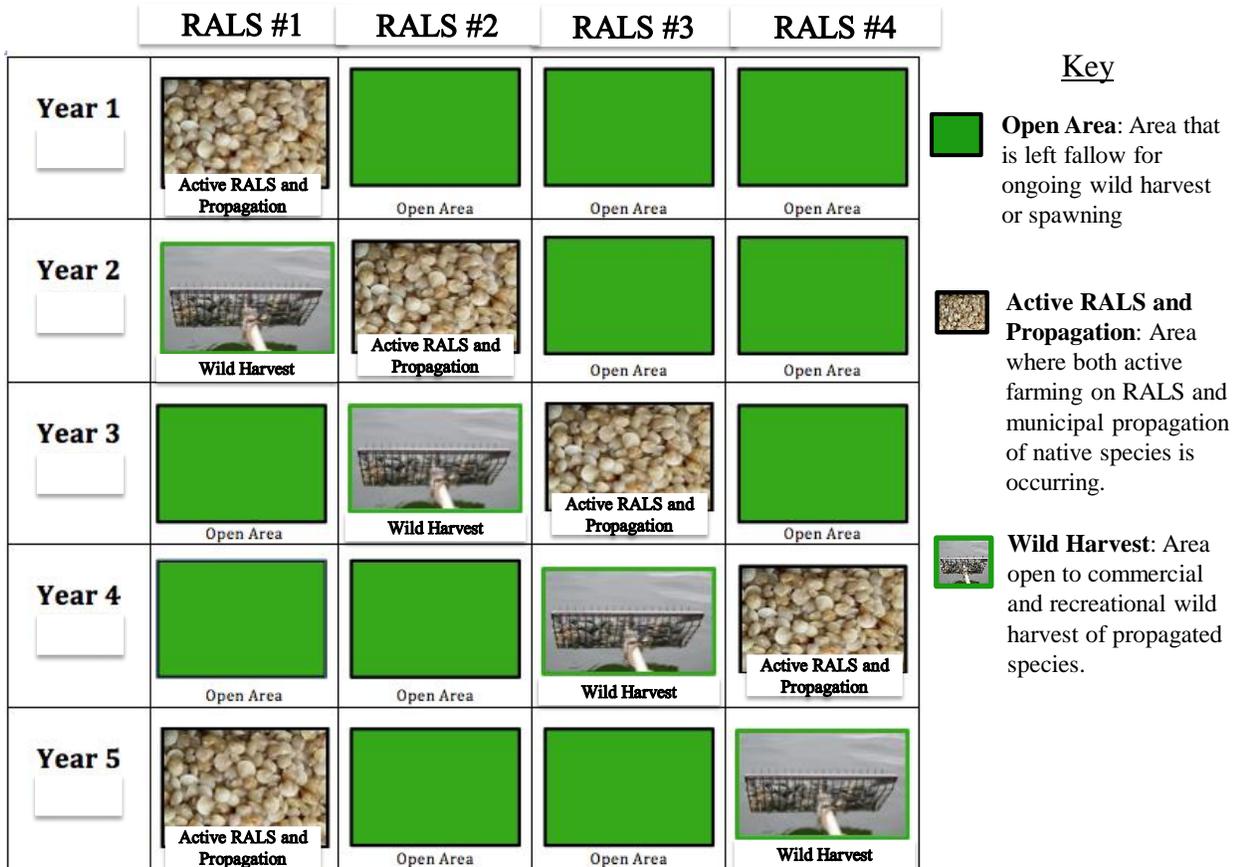
Year 5:

RALS Sublocation #1:

- Actively used for aquaculture and municipal propagation
- Closed to wild harvest

RALS #4 area is actively harvested if appropriate size of propagated species is reached

RALS #2 and RALS #3 are open to wild harvest of bottom during seasonal opening of estuary. These areas may also be left closed for a spawn season as part of ongoing municipal propagation planning.



Martinsen, 2016

Figure 15. Four-year private aquaculture and wild propagation schedule

As part of a grant provided by the Cape Cod Economic Development Council, the Coonamessett Farm Foundation prepared a white paper that outlines this concept with three rotational areas. Given the growth rate of hard clams and other species, four locations may be preferred. The approach of rotating over four sites annually also limits the period when bottom is not available for wild harvest to 25 percent of the time.

During the implementation phase, the timing of the rotations for the pilot phase will be defined.

Section 3D. Additional Space for Each RALS

The amount of biomass that can be grown at a given location is highly dependent on food availability, which includes both algae and particulates. Where the availability of food is not limited, a second factor that influences the biomass that can be grown is the type of gear used. The density of oysters that can be harvested per acre is also impacted by whether bottom planting is possible. If oysters that have already grown for one season (first-year oysters) can be grown to harvestable size on the bottom, stocking densities are much higher than if oysters need to be maintained in floating bags until they reach market size. The Cape Cod Commission Technology Matrix assumes 1 million oysters can be harvested per acre. This likely assumes bottom-planting. Published numbers in the Three Bays Shellfish Master Plan (2016) from Barnstable growers indicate that 400,000 first-year oysters can be grown through bottom-planting to harvestable size on one acre of hard

bottom. Information from an off-Cape growing consortium indicates that between 500,000 and 1 million first-year oysters can be grown to harvest size on one acre of hard bottom.

In Falmouth, oysters are grown in gear for the first year at densities of up to 900 per bag. The configuration of this gear is shown in Figure 16 and scales to approximately 4300 bags per acre.

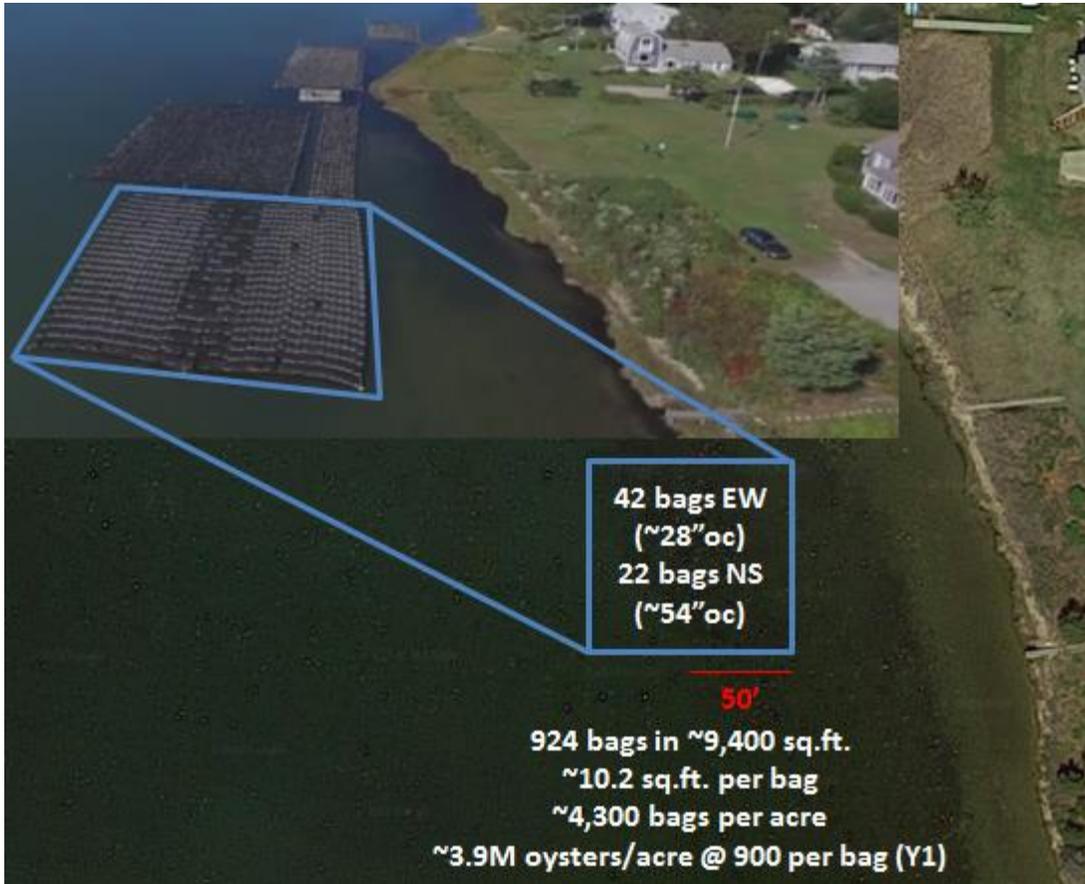


Figure 16. Floating Bag Densities Demonstrated by Municipal Oyster Propagation Operated by the Town of Falmouth in 2016.

Commercial densities may also vary from those planted solely for municipal propagation because growers must focus on producing an oyster with a size and shape that is optimally marketable. Cup shape is a key factor in the wholesale price offered for a crop of oysters. To grow an oyster that develops an appropriately deep cup, two approaches are used: low stocking density of oysters within gear, and tumbling to remove edges. For nutrient removal, shape is not as important as overall growth in total biomass. However, during the Lonnie's Pond Oyster Aquaculture Demonstration in Orleans, approximately 200,000 oysters were grown in 800 floating bags in an area of approximately 9,600 square feet. The end-of-season mass of oysters grown in this area was approximately 10 metric tons, with about half of the oysters at harvestable size. It should be noted that upon inspection by commercial growers and others, these oysters were found to be well-shaped with an acceptably deep cup.

The goals of growing premium grade oysters should be harmonized with the need to maximize oyster biomass density when finalizing gear configurations for the purposes of permitting RALS.

Another consideration when determining the size of RALS is that the ACOE Massachusetts General Permit for Aquaculture limits the amount of floating gear that can be installed on an aquaculture project site. The limits are the greater of 10% of the project area or 20,000 square feet. Thus, if a project is located on a site that is between 20,000 square feet and almost five acres, the total area covered by gear cannot exceed 20,000 sf.

Floating bags are:

- Widely used by growers on Cape Cod
- Able to be installed in high density configurations
- Lightweight, and therefore do not require significant strength to flip in order to control fouling throughout the growing season
- Lower cost for materials per bag than other systems
- Can be rapidly secured or moved in response to a forecast of severe weather
- Useable to grow other species in addition to oysters, such as quahogs to field-plantable size

Floating bags are recommended because they are cost effective and use space efficiently. Oysters grow well in floating bags. Moreover, operation and maintenance effort is low requiring flipping these bags weekly to control fouling. One person can flip the bags. 2017 costs for materials per bag are \$13.30 including the long lines and augers. Larger sized floating systems have higher capital costs per unit, \$32.78 for an OysterGro system and \$42.89 for a LowProGro system. The materials costs for floating bags are less than half the cost of these other methods. Assuming it takes twenty minutes for assembly of a floating bag, even with an allowance for labor, they are the lowest cost gear option. And, the biomass of oysters that can be grown per unit area using floating bags is high. Because they work well in a variety of growing environments, the floating bag growing system is commonly used throughout Cape Cod. However, during the implementation and permitting phase, if it can be demonstrated that a different gear system is both low profile aesthetically and produces the same biomass of shellfish per unit area, it should be considered.

Figure 17 conceptualizes an installation of 400 floating bags in approximately 3800 square feet, which scales to 2100 bags per 20,000 square feet. This configuration is lower density than the format used in Falmouth and other Cape locations. This configuration works where the available food is high, and with the understanding that oysters growing in the center of the field are likely to grow more slowly than those along the edges. In Falmouth's estuaries, the floating bags can be installed in long, narrow strings, which allow for more uniform food availability.

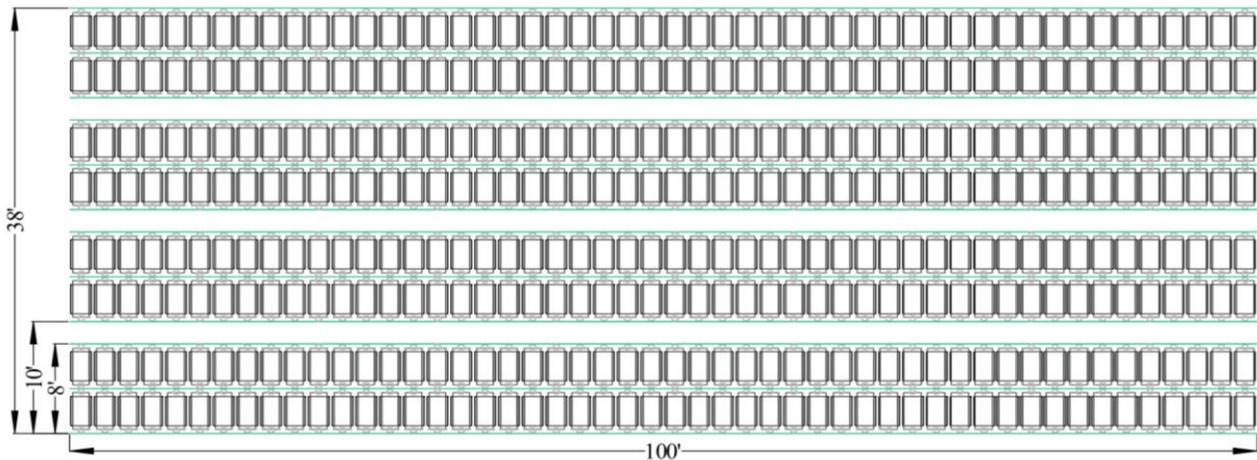


Figure 17. Example of a Floating Bag Layout that Scales 400 bags (above) to 2100 Floating Bags in just under half an acre (20,000 Square Feet)

Based on these demonstrated densities and the ACOE limits, RALS are sized at a half-acre to accommodate the maximum allowable coverage of floating gear.

Table 13 presents the number of RALS and area covered by floating gear for each estuary. The number of acres mapped for ADAs is derived from Figures 1 – 12. The half-acre RALS site for first-year seed is based on the demonstrated gear configuration in Figure 16 and Figure 17. For conditionally-approved estuaries, grow-out to harvestable size after the allowable nursery phase must be outside these waterbodies. For Megansett and Rands, the grow-out areas are located offshore in Buzzards Bay, outside Megansett Harbor. For Quissett, the grow-out area is in Outer Quissett Harbor, and for Great Pond, the grow-out areas could include either the preexisting licenses for offshore sites as well as other offshore sites. The final acreage for grow-out sites will be determined after the final number of nursery areas is determined.

There is a difference between the total acreage covered per grower within a conditional versus open estuary. This difference reflects the fact that grow-out during the second year occurs within the same estuary as the nursery stage. Growing oysters to marketable size requires approximately three times the number of floating bags and space, based on the lower stocking densities that are possible, and a ten percent mortality rate for the first year. Thus, for every half-acre nursery area that is fully utilized, 1.5-acres of grow-out area will be covered with floating bags.

The total acres covered with floating gear is calculated based on the coverage of 0.5 acres per RALS in conditional areas and 2 acres per license site for open areas to reflect the area needed for second year grow-out in the open estuaries.

Table 13 should be reviewed carefully with respect to the total area covered by floating gear.

Table 13: Preliminary Number of Full Scale Commercial RALS in Estuaries Included for ADAs

	Megansett	Rands	Quissett	Great	Bournes	Eel Pond	Waquoit
Number of acres mapped for ADA	4	NA	2	10	16	24	0
Number of 0.5 acre sites	8	NA	4	20	NA	NA	NA
Number of 2 acre sites	NA	NA	NA	NA	8	12	0
For conditionally-approved estuaries: Number of Rotational Licenses (RL) based on a 4-year rotation with grow-out at a different location (four sites per RL)	2	1	1	5	open	open	open
For open estuaries: Number of RL on a 4-year rotation with grow-out sites within estuary (four sites per RL)	conditional	conditional	conditional	conditional	2	3	0
Total acres covered each year if all Rotational Licenses granted	1	TBD	0.5	2.5	4	6	0
NOTE	0.5 acre covered per grower/YEAR	TBD	0.5 acre covered per grower/YEAR	0.5 acre covered per grower/YEAR	2 acres covered per grower/YEAR	2 acres covered per grower/YEAR	2 acres covered per grower/YEAR
Grow out site	Megansett Outer Harbor	Megansett Outer Harbor	Quissett Outer	Existing License Sites	Bournes	Eel Pond	Waquoit

Section 3E. Quantities of Oysters Grown

The number of oysters grown is different for the three types of RALS

The Full-Scale Commercial RALS are intended for full-scale commercial farming. If the number of floating bags and stocking density is maximized within a nursery area (2100 bags and 500 oysters per bag), approximately 1 million oysters can be grown from seed in the first growing season. With ten percent mortality, this creates approximately 900,000 oysters to be grown in the second year. Stocking densities of as low as 150 oysters per bag are used by growers selling into the premium, half-shell market where a deep cup and smaller ratios of length to width are important features. This quantity of oysters is presented as a maximum practical quantity for determining the area required for second-year operations.

Even for commercial farming, growing almost 1 million oysters is an ambitious undertaking, and requires capital for gear as well as sorting equipment. The labor involved is also significant. Therefore, any production requirements associated with these RALS could be reduced to 500,000 market-size oysters after the third or fourth year. This phasing allows for the sale of smaller quantities of oysters to help pay for the additional gear needed to ramp-up operations.

The commercial trial RALS are intended to allow new growers to experiment, so the production requirements are lower. For commercial trials, growers are expected to harvest 60,000 after the second season and 250,000 oysters by the end of the fourth season. If these production requirements are not met, these sites may be converted to full-scale commercial sites. A total of eight commercial trial sites are planned.

When discussing aquaculture with the general public, the idea of growing “one or two bags off my dock or mooring” is often suggested. Programs in some states allow “oyster gardening” to raise public awareness and inspire public participation. Because of health and safety concerns, this approach is only allowed in Approved waters of Massachusetts (Hickey et al. 2015). Furthermore, any shellfish grown must contribute to the public resource and cannot be grown for personal consumption. The third category of RALS provides a location for oyster gardening in Falmouth that allows for the gardeners to consume what they grow and is centralized and therefore able to be more easily managed by the Town. This area is located in the southeast section of Bourne Pond. Individuals would be allowed to grow the same quantity of oysters or quahogs that they would be allowed to take by wild harvesting. This ensures that these gardens are used for personal consumption only. The benefits of this concept in terms of public engagement and education are enormous.

Section 3F. Cost Sharing Goals

RALS are located within protected, highly advantageous growing areas that are also productive for wild shellfish harvesting. The Department of Marine and Environment requires additional staffing and budget to manage the implementation and oversight of the RALS program and purchase and grow the quahogs and other shellfish species that are a key aspect of this approach. Shellfish also uptake nitrogen, which may reduce the cost of infrastructure to meet regulatory water quality standards in Falmouth’s impaired estuaries. In recognition of these facts, robust discussions on an appropriate cost share structure that apportions some percent of program costs to growers began during the development of this Aquaculture Plan. A full spectrum of options has been discussed, including:

- Surcharges to cover a portion of total program costs
 - Flat fee
 - Percentage of private sale
- In-kind contributions of seed for enhanced wild propagation
- Valuing the cost-reduction associated with nitrogen-uptake by shellfish

The overall principle is to apportion the costs of implementing the RALS program in a manner that incentivizes private growers to invest in large scale aquaculture and provides for reasonable cost recovery to secure benefits to both commercial wild harvesters and taxpayers.

There are several uncertainties related to the costs associated with this program and the avoided costs attributable to shellfish for nitrogen-uptake. It is unknown how many total RALS will be farmed, and the level of effort required to provide in-kind contributions of shellfish. In addition, grant funding is actively being pursued to defray the costs of permitting and pilot-scale implementation of this model program. For these reasons, decision making regarding cost-sharing will occur during the implementation phase of the program, with a maximum expected amount to be paid by growers established prior to the granting of any RALS. This timing is important so that growers can prepare business plans that accurately reflect this potential cost. Fees for commercial trial, disabled veteran, community garden plots and possibly other categories will also be established during the implementation phase.

Section 3G. Permitting

The first step in permitting RALS is to identify areas within the Town's coastal ponds where aquaculture operations would be appropriate. Section 2 presents preliminary recommendations for possible ADA locations. These locations have been reviewed through a robust public process that includes multiple meetings with various stakeholders. The next step is to review these locations through the local, state and federal permitting process.

Current Permitting Process for Individual Aquaculture Licenses

This current permitting process for aquaculture licenses in Falmouth is outlined in Chapter 275, Article III of the Town Code. Key considerations in this permitting process include:

- Applicant applies to Board of Selectmen (BOS) for approval of a "municipal aquaculture license site", referred to in Falmouth as an aquaculture license, and a public hearing is held
- Inshore sites are limited to an initial maximum of three acres, with two acres held in reserve for expansion after the initial five-year period of operation.
- Inshore site licensees may apply for additional acreage in up to five-acre increments after the initial five-year period
- Offshore sites are limited to ten acres for the first five years
- A fifty-foot buffer is required between adjacent sites
- If the license is approved by BOS, they request certification from DMF for this specific location
- Once DMF has certified the location, the applicant applies for an Army Corp of Engineers (ACOE) permit and Conservation Commission determination to place structures on the site
- Once all permits are in hand, DMF issues a propagation permit to the applicant, which gives the applicant permission to grow shellfish

Falmouth's current aquaculture regulations do not allow inshore licenses of more than three acres for the first five years of operations, increasing to an additional two acres after the first five-year period. Licensees may apply for additional acreage after the first five years of operation in up to five acre increments. To permit an aquaculture license in Falmouth, an applicant submits a specific location to the Board of Selectmen who will then hold a public hearing on the proposed spot. Input from the Shellfish Constable is an important consideration in this process. If the Selectmen approve the license, they then request a DMF certification of this site, which includes a biological assessment to determine whether the bottom is considered to be productive for wild species as well as a review of other environmental considerations. Aquaculture licenses cannot be permanently sited in areas with already productive bottom so as not to remove the area from the public resource.

After local approval of a license location and DMF certification, the license holder applies to the Conservation Commission and ACOE. As part of this permitting process, a Management Plan must be submitted. Then, a propagation permit can be issued by DMF. These permits allow the growing of shellfish in the state of Massachusetts. Propagation permits are associated with specific licensed areas and are only issued by DMF after certification and all other permitting. These propagation permits may also have conditions regarding species grown, gear type, minimum production standards, individuals allowed on the site and actions to take in the event of closures. These propagation permits are renewed annually.

Section 3G.1: Permitting and Licensing of Rotational Aquaculture License Sites (RALS) within Designated Aquaculture Development Areas (ADAs)

To streamline the permitting process for growers as well as maintain direct Town management and oversight over this rotational program, the environmental permitting of RALS within designated ADAs could proceed by having the Town initiate Conservation Commission and ACOE permitting after DMF certification of specific license sites. Licensing, as well as DMF certification and propagation permit issuance must be completed on a site-specific basis in connection with a specific individual named on the licenses and permits.

Prior to full scale implementation a pilot phase of implementation is envisioned, which involves the following steps:

- Address the programmatic considerations listed in Section 6 to formalize Town management responsibilities, license conditions and performance metrics for RALS
 - Conditions and other requirements could be added to individual licenses or could be codified in local regulations and referenced on licenses
- Locate specific RALS within one or two estuaries for a pilot-scale implementation project
- Identify applicants who will participate in the pilot project
- Issue licenses to selected individuals by BOS for the RALS identified for the pilot project
- Execution of a Memorandum of Agreement (MOA) with DMF delegating patrol responsibilities to Town
- Survey and certification of the license sites by DMF
 - This process may be expedited for seasonal areas if license is conditioned
- Permitting the gear type(s) allowed on these pilot RALS locations through Conservation Commission and ACOE

ACOE and Cons Com permits should be sought after DMF certifies the site because this certification will determine the threshold suitability of the area for aquaculture. In addition, the DMF Habitat Program is only able to provide comments on the NOI and ACOE applications after the survey is completed. ACOE will likely not consider the applications complete until DMF issues its certification. Following pilot phase permitting and assessment of the pilot project, the Town will begin discussions with the DMF, MEPA and Army Corp of Engineers (ACOE) regarding the preferred approach for full scale implementation and may involve the following:

- Approve the general ADAs and the standards outlined in the plan by the Board of Selectmen
 - This is an internal Town vote and not part of the formal aquaculture permitting process outlined in MGL Chapter 130
- Locate specific RALS within these ADAs
- Identification of specific individuals who will hold the license for the RALS that have been located within these ADAs
- Vote by BOS for the issuance of licenses
- BOS request for site certification of approved licenses from DMF
 - DMF conducts expedited survey to issue its certification
 - Evaluate environmental thresholds that may be triggered
- Town submits application to the ACOE and NOI to Conservation to permit approved gear types on RALS
- Application for 10A permit by harbormaster to cover CH 91 requirements
- 10A, ACOE and Conservation Commission permits are granted to the Town

- Licensed growers then apply to DMF for a propagation permit. This propagation permit gives the applicant permission to grow shellfish within the licensed sites.

For DMF to certify these RALS and for the Town to apply to ACOE and Conservation Commission for permits, a management plan for ADAs and RALS that satisfies the requirement of MGL Chapter 130 sections 57, 59, 131, 91 and possibly MEPA is needed. It will at a minimum include mapped locations, performance metrics for growers to avoid impacts and maximize benefits, timing of licenses, gear types and configurations, and shellfish species. The Town may also establish production requirements. The management plan should also specify areas of municipal propagation within RALS estuaries.

The development of a management plan will streamline the permitting process because it meets the statutory requirements of MGL Chapter 130 for all sites. In addition, if the appropriate conditions are placed on the licenses (for example, licenses are seasonal and only operate during the period when an area is in the closed status) DMF can consider waiving the shellfish survey since this seasonal operation should not impact wild fisheries.

There are several ways for the conditions and other requirements of the management plan to be linked to the ADA and/or RALS licenses:

- A condition can be stated on the licenses for RALS and ADAs requiring that they must be operated in accordance with the management plan
- All of the conditions in the management plan could be repeated on each license
- A new category of aquaculture license for RALS and ADAs could be added to local regulations. These regulations would then enumerate the specific terms and conditions of the management plan, and would also be referenced in the licenses issued by the BOS

The DMF-issued certification will also reiterate the specific terms and conditions from the management plan related to all RALS licenses. The DMF-issued propagation permit for individuals who have a license for a RALS within these ADAs may also include specific terms and conditions in the licenses related to maximum seed size, movement of seed, and other considerations. Once RALS are granted, they can be transferred by vote of the BOS in accordance with MGL CH 130 Section 58 and local regulations, new licensee will need to obtain a DMF propagation permit but will not need new permits from the Conservation Commission and ACOE.

There are several considerations with this approach:

- Permitting of all the ADAs in this Plan may trigger MEPA Review and require an Environmental Impact Report (EIR). A key issue that will be confirmed during the pilot implementation phase is the MEPA and other thresholds that are triggered. The segmentation regulations in CMR 301 will be considered as part of this evaluation.
- If the Town holds the ACOE permit and Conservation Commission Order of Conditions, the range of gear and other growing parameters need to be specified as part of the management plan
- If the Town holds the ACOE and Conservation site permits, all Conservation Commission and ACOE requirements and conditions are the Town's responsibility and liability
- DMF holds the applicant named on the site license and propagation permit responsible for all issues related to these permissions

This approach benefits commercial wild harvesters, growers and the Town as a whole. The RALS is structured to keep the areas currently used for commercial wild harvest open as they have been historically. Commercial

harvesters will still have access to productive bottom during periods when these areas have been opened in the past. Commercial harvesters of wild shellfish also profit from this program because it increases the number of hard clams and other species planted as part of municipal propagation for commercial harvest.

For growers, this approach creates a framework that allows aquaculture operations to occur in estuaries that would typically be off-limits. The RALS framework may be the most practical way for DMF to permit aquaculture in conditionally-approved areas or areas that have productive bottom for commercial harvesting of wild species. This system also streamlines the permitting process for growers significantly, saving the time and expense associated with gaining state and federal approvals for aquaculture.

The Town benefits from this system in several ways. The nitrogen uptake and enhanced denitrification from shellfish is a benefit in terms of avoided costs for infrastructure to remove this cause of eutrophication. At the same time, local jobs and food production is encouraged. In addition, this approach ensures local oversight at the site-management level. This level of local oversight is critical to ensuring that the specific aquaculture operations permitted in the Town's estuaries are operated in ways that are compatible with the multiple uses in these waterbodies. Fees for RALS can also be used to help fund the program, creating a budgetary pathway for enhanced municipal propagation. This program is truly a win-win-win.

If the Town simply designates potential ADAs but does not permit them, the current permitting process is not shortened for the grower and the Town does not maintain management oversight of gear and growing configurations.

Section 3H. Gear Specifications

For permitting of structures within ADAs, both the ACOE and Conservation Commission require gear specifications. Key consideration related to permitting of gear requires that the following be specified:

- Type of sediment in the area where gear will be placed
- Types of underwater structures including anchoring systems that hold gear in place
- Types of floating structures
- Plans that minimized the amount of bottom gear
- A workable Storm Management Plan

The following gear specifications are recommended, as described in detail in Section 3D

- Floating bags (ADPI bags of between 4 mm – 9 mm, floats, clips)
- Longline or other line that creates a tight string along which bags can be attached
- Helical augers to anchor lines in place
- Site specific anchoring system for certain estuaries such as Megansett based on a field survey of bottom types
- Orientation of gear will be determined on a site-specific basis, based on prevailing wind or tide
- Requirement for tight, orderly arrangement of gear within a RALS footprint

Oysters, quahogs, scallops and other species may be grown, as long as the total number of animals is appropriate to the nitrogen-removal objectives of the program. Other gear may be proposed as long as it allows

for comparable overall shellfish densities and is aesthetically in keeping with the floating bag paradigm in terms of profile and neatness.

Section 4: Quantities of shellfish needed to meet water quality goals and overall potential for nitrogen-removal of the Rotational Aquaculture Plan

Table 14 estimates the number of shellfish that can be grown and the kilograms of nitrogen removed using the rotational model described in Section 3 and shown in Table 13. The areas available for oyster aquaculture and municipal quahog propagation are based on the preliminary areas that have been identified for aquaculture in this plan. Oyster biomass is the critical indicator of nitrogen uptake. For these planning-level calculations, the oyster biomass and nitrogen uptake of the first-year nursery areas is assumed to be equivalent to 315,000 market-size oysters. This number of market-size oysters is calculated for an installation of 2100 floating bags in a 20,000 sf area and a final stocking density of 150 oysters per bag. The nitrogen-content of a 3-inch oyster grown off-bottom or cherrystone quahog is based on published values from Woods Hole Sea Grant (Reitsma et al. 2016). For enhanced denitrification, some studies have shown that the nitrogen removed by the increase in denitrification caused by oysters is equal to the mass of nitrogen contained in the oyster (Newell et al. 2005; Kellogg et al 2013). Recent work in Lonnie's Pond, Orleans MA has demonstrated enhanced denitrification caused by oysters is 67% of uptake. SMAST will be studying denitrification in Bournes Pond during the 2017 growing season. The number of quahogs planted is based on a stocking density of 25 per square foot, with broadcasting for final grow-out.

Based on planning-level estimates, the total number of shellfish being grown at full-scale implementation:

- 9.5 million first-year oysters
- 5.7 million oysters to marketable size
- 9.5 million quahogs

The wholesale value of a market-size oyster is approximately \$0.35 and a littleneck quahog is \$0.20. Depending on survival, the economic benefits of this program could be significant.

Table 14: Preliminary Nitrogen Removal Calculations for Estuaries Included for ADAs

	Megansett	Rands	Quissett	Great	Bournes	Eel Pond	Waquoit
Number of acres mapped for ADA	4	NA	2	10	16	24	0
Number of 0.5 acre/20,000 sq. ft. Rotational Aquaculture License Sites (RALS)	8	NA	4	20	32	48	0
For conditionally-approved estuaries: Number of Rotational Licenses (RL) based on a 4-year rotation with grow-out at a different location (four RALS per RL)	2	1	1	5	open	open	open
For open estuaries: Number of RLs on a <u>2-year</u> rotation with grow-out sites within estuary (four RALS per RL)	conditional	conditional	conditional	conditional	4	6	0
Total acres covered each year if all Rotational Licenses granted	1	TBD	0.5	2.5	8	12	0
Total number of first year OYSTERS grown annually per RALS at 500,000/year	1,000,000	500,000	500,000	2,500,000	2,000,000	3,000,000	-
Total Number of second year OYSTERS grown annually per RALS at 315,000/year					1,890,000	1,890,000	1,890,000
Total number of QUAHOGS grown annually per RL at a propagation of 500,000 quahogs per RALS	1,000,000	500,000	500,000	2,500,000	2,000,000	3,000,000	-
Kilograms of nitrogen-removal at .14 grams per oyster or quahogs per year	280	140	140	700	825	1,105	265
Kilograms of nitrogen-removal with enhanced denitrification at 50% of uptake	420	210	210	1,050	1,237	1,657	397

Section 5: Other Issues

Section 5A: Infrastructure Needs and Mooring Consolidation

Key infrastructure needs may include:

- Reconfiguring existing mooring fields to enable space for RALS and increase viable habitat for eelgrass
- Access points to water, including areas to launch a skiff
- Upweller space for growing small (approximately 2-3 mm) seed to a size that can be installed in floating gear
- Storage space for gear
- Overwintering options

Consolidating existing mooring areas has several benefits. It would provide areas within estuaries for RALS in locations where the bottom is likely not currently harvested. It would also reduce the amount of disturbed bottom, which may enable eelgrass to regrow.

Additional upweller locations have also been identified in this plan, including publicly-owned parcels around Wild Harbor. The town could provide options for growers to lease space within tested established overwintering areas and a municipal climate-controlled overwintering facility. These issues could be addressed as part of the implementation phase of this plan.

Section 5B. Role of Municipal Propagation

The Town of Falmouth municipal propagation program approximately 2.5 million oysters and up to 2.5 million quahogs annually. A key feature of the RALS approach is municipal propagation of quahogs and other species as part of the aquaculture siting. This enhances the wild resource while promoting additional aquaculture operations. Municipal propagation will continue in the role of enhancing the wild fishery that was begun decades ago.

In addition, the Town's municipal propagation program can begin to support private and recreational aquaculture by providing:

- Upweller space
- Overwintering options
- Larger seed

Municipal propagation can play an important role in alleviating some of the constraints on the productivity of private aquaculture by providing upweller space for private growers to start small seed. In addition, providing a location that has been proven to be successful for overwintering first-year oysters that have reached approximately 2-inches may also benefit local growers. This will allow seed that is grown in nursery areas to be held in a safe location for second-year grow-out.

There is also a desire to explore the value, appropriateness and permitting of having the town provide intermediate-size shellfish to local growers. This intermediate seed only require a month or two to reach harvest size for commercial sale. To illustrate the value to the grower of intermediate seed, it is assumed that a grower purchases intermediate seed for \$0.20 each, and these oysters are sold for \$0.40 each two months later, during the peak season of August and September. At these prices, a grower using 500 bags with 200 oysters

each would have a net revenue after paying for the seed of \$20,000. The expenses beyond the seed would be minimal and would include a few weeks of work on the water in the summer. There are also questions relating to the impacts to the private sector of municipal sale of intermediate seed. As part of the ongoing work of the Department of Marine and Environmental Services, issues relating to the sale of intermediate seed will continue to be discussed with DMF and others.

There are a number of steps to be accomplished as this plan moves to the permitting and implementation phase that are listed in Section 6, Next Steps. To implement the Rotational Aquaculture Plan, additional staffing for municipal propagation of quahogs and other species, ADA permitting, management and oversight and patrolling will likely be needed.

Section 5C. Economic benefits of local fisheries and aquaculture

Another noteworthy aspect of both commercial shellfishing as well as aquaculture is that they create economic activity in terms of labor wages that enhance the local economy. This benefit to the local economy should not be overlooked in weighing alternative approaches for nitrogen-removal within the Town's estuaries. Using shellfish to remove nitrogen is both advantageous economically and environmentally.

The economic multiplier for local shellfisheries and aquaculture has been estimated at between \$1.79 to \$1.90 for every dollar in wages created (Augusto, Holmes and Barnes 2015, Northern Economics 2014). A multiplier for commercial wild shellfish harvest has been valued at 4.5 (Massachusetts Division of Marine Fisheries 2003). Commercial wild harvesting and shellfish farming create revenue. Much of this revenue will likely be spent on wages and salaries. Based on these multipliers, the increased economic activity generated in the local economy is significant.

CCCE/Woods Hole Sea Grant/SEMAC contracted with the UMASS Center for Marketing Research to conduct an economic survey of the aquaculture industry in Massachusetts. Sample of results include:

- The output of the shellfish aquaculture industry in Massachusetts was valued at approximately \$25.4 million in 2013, which in turn generated approximately \$45.5 million in the Massachusetts economy, or 1.79 times the activity
- Shellfish farmers were responsible for approximately 909 jobs
- Shellfish farmers paid approximately \$11.9 million in wages in 2013. Their economic activity generated additional labor income of \$8.2 million, for a total of approximately \$20.1 million in labor income in MA

The Rhode Island Shellfish Management Plan points out that global aquaculture production is growing, and approximately 50 percent of seafood consumed globally is cultured. The U.S. aquaculture industry produces \$1 billion in seafood, but this is less than 5 percent of the seafood consumed in the U.S. Studies have shown that, done properly, shellfish aquaculture is a sustainable method of food production that also provides important ecosystem services, such as providing critical habitat for juvenile fish and also removing nitrogen from the water.

Local food production is a cornerstone of long-term sustainability because of the reduced energy costs required to ship this food. Moreover, local shellfish production does not use fertilizer, pesticides or feed, making shellfish a uniquely positive crop to farm from an environmental perspective. Shellfish are one of the most practical and valuable crops to grow on Cape Cod. Shellfish aquaculture is a type of local business worth promoting in

Falmouth. There are currently 50 commercial shellfish licenses granted in Falmouth, with a moratorium on any additional commercial licenses because the local wild fishery cannot support more. The enhanced municipal propagation that is envisioned as part of implementing this plan may help alleviate the current resource constraints and allow for more commercial shellfish licenses to be supported.

Section 6. Programmatic Considerations/Next Steps

The draft Falmouth Rotational Aquaculture Plan was presented and reviewed with a wide range of stakeholders through Shellfish Working Group meetings, discussions with the Division of Marine Fisheries, at two Public Hearings and at a Board of Selectmen's meeting. This draft plan reflects comments and suggestions from these sessions. The implementation phase of this program should include these elements:

- Permitting of the overall ADA areas through the Conservation Commission and Army Corp of Engineers (MGL CH 131 and 91)
- Mapping specific areas for several RALS locations for a pilot phase of the program
- Permitting of specific RALS in both open as well as conditionally approved estuaries through the Division of Marine Fisheries
- Development of a MOA between DMF and the Town to establish town patrol requirements for conditionally approved areas
- Finalizing the mechanics of the rotational program at a pilot scale, including:
 - Type and quantity of species to be grown in RALS
 - Final gear specifications
 - Type and quantity of species to be propagated for commercial and recreational harvest
 - Number of years for rotation at each site
 - Transplant locations for second year grow-out in conditionally-approved areas
 - Require gear-removal in conditionally-approved areas
 - Review need for gear-removal in open areas
 - Process and criteria for selecting growers to farm these pilot sites
 - Timing and process for renewing these sites
 - Transfer requirements of these sites (is local residency required for transfer)
 - Municipal management including patrol schedule
- Addressing mooring consolidation if needed to increase RALS sites
- Creating an equitable system for distributing the RALS if demand is greater than the number of sites available at full-scale implementation
- Estimating the costs to growers of starting an aquaculture business on a RALS
- Addressing the cost sharing goals of this program, including an evaluation of the potential avoided costs of infrastructure due to nutrient uptake of shellfish and the availability of nitrogen-trading credits and the state or federal level that can be used. This requires:
 - Calculating the costs of this program
 - Determining the number/species of shellfish that can be grown through this program
 - Defining a way of calculating the avoided infrastructure costs of the nitrogen-removal
 - Researching the availability and mechanics of nitrogen trading that may apply
- Meeting the short-term and long-term staffing and other budgetary needs of the MES department to execute and manage this program

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DRAFT

Fact Sheet

Falmouth Rotational Aquaculture Plan, May 2017

Falmouth is a special place. Over the past 50 years, development has compromised estuarine water quality and led to significant loss of invaluable marine habitat. Our salt ponds, estuaries and harbors are the critical nurseries and rookeries for shellfish and finfish as well as birds and mammals that form the basis of a complex food web. Within our lifetime, we can start to return Falmouth's estuaries to the vibrant ecosystems they once were. Shellfish propagation is a key component of this restoration effort.

Shellfish aquaculture operates within a public resource which has multiple user groups. The overarching goal of the Falmouth Rotational Aquaculture Plan is to meet the needs of all these groups - growers, wild harvesters, neighbors, visitors, mooring holders, and taxpayers. The next steps in the planning process include:

- Presenting this plan to stakeholders, neighborhood groups and the general public; and
- Addressing implementation issues such as overwintering of shellfish and covering the costs of running this program in a way that is fair and equitable.

Below is an executive summary of the regulatory context and the objectives of the Falmouth Rotational Aquaculture Plan which are further detailed in the 80+ report (available online at <http://www.falmouthmass.us/862/Falmouth-Rotational-Aquaculture-Plan>)

- The town is trying to expand aquaculture AND increase municipal propagation for wild harvest AND address aesthetic concerns of neighbors AND meet regulatory requirements AND remove nitrogen in a quantifiable way for TMDL-compliance AND address the costs of implementing this plan.
- Expanding private aquaculture into estuaries using the rotational system makes sense for everybody. Growers benefit by having ideal growing locations; the local economy benefits from creation of new businesses and jobs; local restaurants benefit from the increased supply of local shellfish; commercial harvesters benefit by an enhanced wild resource; taxpayers benefit by a reduced cost of infrastructure to remove nitrogen from the water; and all residents, taxpayers and businesses benefit from the removal of microalgae to help clean up these impaired waterbodies. We believe these benefits can be attained without an undue burden to neighbors and other users of the waterways because placement of aquaculture areas has been carefully planned and moves annually so that no one area on the water is permanently affected.
- Without a rotational system, private aquaculture would only be allowed to expand in much less desirable offshore locations because:

- Nine of fifteen estuaries in Falmouth are conditionally approved for shellfishing, and have historically enjoyed productive bottom for wild harvesting -- traditional, private aquaculture is prohibited in these locations. The rotational system we are proposing addresses this issue from a regulatory perspective and thus opens these areas for private aquaculture; and
- Of Falmouth's fifteen estuaries, two are open for shellfishing and have historically had productive bottom. Private aquaculture cannot be located in areas with productive bottom. There are possibly one or two small sections of these estuaries are not productive areas, significantly limiting the potential for private aquaculture here. The rotational system accomplishes the goal of allowing private aquaculture to expand into these two open estuaries in Falmouth.
- The rotational system requires an operations manager to serve as a liaison with neighbors, to ensure transitions are managed and permit conditions are enforced. Someone from the Town needs to be both in the field and available to assist administratively for this level of commercial activity within our coastal ponds. This manager will also need to ensure the biomass of shellfish for nitrogen-removal is quantified and the quahogs are planted, maintained and harvested at appropriate times. This is a full-time job that is a direct result of expanding aquaculture in town.

The Falmouth Rotational Aquaculture Plan seeks to benefit all users of the town's estuaries, both economically and environmentally and balance the harvest goals of commercial, recreational, senior, and family diggers with aquaculture growers and town water quality goals.

For more information, please contact Sia Karplus, Science Wares, Inc. at sia@sciencewares.com

Appendix B: Segmentation Section of 301 CMR 11

11.01: continued

(c) Segmentation In determining whether a Project is subject to MEPA jurisdiction or meets or exceeds any review thresholds, and during MEPA review, the Proponent, any Participating Agency, and the Secretary shall consider the entirety of the Project, including any likely future Expansion, and not separate phases or segments thereof. The Proponent may not phase or segment a Project to evade, defer or curtail MEPA review. The Proponent, any Participating Agency, and the Secretary shall consider all circumstances as to whether various work or activities constitute one Project, including but not limited to: whether the work or activities, taken together, comprise a common plan or independent undertakings, regardless of whether there is more than one Proponent; any time interval between the work or activities; and whether the environmental impacts caused by the work or activities are separable or cumulative. Examples of work or activities that constitute one Project include work or activities that:

- meet or exceed one or more review thresholds on an area previously subject to a Land Transfer, provided that not more than five years have elapsed between the Land Transfer and the work or activities; and
- construct more than one structure (such as more than one single family dwelling) and appurtenant structures, facilities, and other improvements on a site, unless a plan for the subdivision or other legal division creating or allowing separate lots or parcels was definitively approved or endorsed in accordance with applicable statutes and regulations prior to the effective date of 301 CMR 11.00.