Cedar Pond
Water Quality Management Plan

FINAL REPORT

July 2013

for the

Town of Orleans

Prepared by:

Coastal Systems Group
School for Marine Science and Technology
University of Massachusetts Dartmouth
706 South Rodney French Blvd.
New Bedford, MA 02744-1221

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Town of Orleans
Marine and Fresh Water Quality Task Force
Planning Department

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Cover photo: Cormorants at sunset on NSTAR wires over Cedar Pond August 22, 2012
(courtesy of Carolyn Kennedy)

Acknowledgements:
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Executive Summary

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Cedar Pond is a 6.4 ha (15 acre) surface water body with a 48.4 ha watershed located within the Town of Orleans. The pond receives freshwater primarily through groundwater inflows around its margin, but is also connected to the Rock Harbor estuary through a surface water outlet. The pond has been subject to a variety of inadvertent management actions over at least the past 150 years that have altered its salinity characteristics and associated water quality and aquatic habitats. Aerial photos from 1947 suggest that Cedar Pond was a fresh water pond at that time. Ad hoc management actions over a number of subsequent years have included: a) filling of a portion of the pond for the construction of Route 6, b) siting power lines over the northern portion of the pond, c) removal of boards at the outlet control structure, d) replacement of the Rock Harbor Road culvert, and e) increasing tidal flows resulting from the gradual deterioration of the tidal dike that limited flow to and from the rest of the Rock Harbor system. The loss of the water control structures in the dike increased tidal interaction and converted the system to a brackish, slightly salty, pond. In early 2007 changes to the stream outlet channel caused a significant increase in tidal flows and associated pond salinity levels. This most recent change caused the pond to be converted from a fresh/brackish system with 6.9 ppt surface salinity[1] to a coastal salt pond with 21.8 ppt surface salinity[2].

Review of water quality data collected prior to 2007 show that Cedar Pond on average failed to meet the minimum dissolved oxygen limits in Massachusetts surface water regulations (314 CMR 4) due to high sediment oxygen demand and water column oxygen uptake associated with reoccurring large phytoplankton blooms. This oxygen demand caused a significant fish kill in 2001. More recent water quality data collected in 2009 and 2012, after the most recent stream change, documented that DO impairment has continued under the new, more saline conditions. Another significant fish kill occurred in 2008.

The recent shift from brackish pond to salt pond has, however, raised some key water quality and ecosystem management concerns. Prior to the 2007 change, monitoring conducted under the Massachusetts Estuaries Project, showed that Cedar Pond removed 58% of the nitrogen entering pond from its watershed and, thus prevented it from being discharged into the nitrogen-impaired Rock Harbor estuary. With the conversion to a salt pond, this nitrogen attenuation has ceased and monitoring data collected during the current project indicates that Cedar Pond is actually increasing the load to Rock Harbor above the watershed load during the crucial summer months. In addition, as a salt pond, Cedar Pond is now more sensitive to nitrogen enrichment. These impacts on Cedar Pond and Rock Harbor are greater than those anticipated in the town's Comprehensive Wastewater Management Plan and may require some changes. Additional ecosystem concerns related to the conversion to a salt pond include potential impact on the Atlantic white cedar swamp adjacent to Cedar Pond and loss of the historic herring run and habitat.

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[1] 2002-2004 MEP stream monitoring (Rock Harbor MEP Report; Howes, et al., 2007).
[2] 2012 average measurement from shallow continuous monitoring collected during this project

During the current project, Coastal Systems Program at the School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP-SMAST) was asked by the Town of Orleans and the Orleans Marine and Fresh Water Quality Task Force (OMFWQTF) to collect additional key data on Cedar Pond, synthesize historical pond data and generate recommendations for managing and restoring water quality and habitat health. During the project, CSP-SMAST staff collected: a) sediment cores and incubated them to evaluate sediment nutrient regeneration, b) flow and water quality information for the stream outlet (Cedar Pond Creek), c) continuous dissolved oxygen, chlorophyll, temperature, and water level data within the pond, and d) in-pond water quality profiles and nutrient data. CSP-SMAST staff also reviewed citizen-collected cormorant counts and developed associated nutrient loads.

The data collected during the current project provided more specific detail on the impairments of Cedar Pond. Sediment core data confirmed extremely high sediment oxygen demand and showed how the pond sediments act as a source or sink for nutrients depending on redox conditions that vary during the summer. This data showed that the pond sediments are generally a sink for phosphorus throughout the summer, but are a significant source of nitrogen only during early summer and are a sink that accumulates nitrogen during late summer. Stream data confirmed the temporal variation in sediment nutrient flux, but showed that both phosphorus and nitrogen are exported from the pond with increasing rates between June and August, before moderating somewhat in September. The mass of both nutrients in pond water column measurements also confirmed these interactions. The late summer nutrient export peaks measured in the stream outflow and rise in pond nutrient mass correspond to large increases in the cormorant population that roosts on the power lines above the pond. The collected data suggest the following summer nutrient transitions:

1) nitrogen is released into pond water column by sediment regeneration in early summer raising the mass in the pond and increasing the export to Rock Harbor through the stream outlet,
2) as the cormorant population increases in late July, the sediments become a sink for nitrogen and accumulate available nitrogen from the water column,
3) nitrogen and phosphorus mass in the pond and exported to Rock Harbor increase, however, due to cormorant defecation (the export is greater than watershed inputs) and levels are sustained through September.

Management of water quality in Cedar Pond will require the selection of water quality goals. Effective management will require an initial decision as to salinity regime that will allow for the highest quality environment and restoration of pond resources. Selection of the salinity range for management determines which additional steps are appropriate for restoring water quality and attaining sustainable ecosystem function. Based on an evaluation of pre- and post-2007 water quality conditions and sustainability of key pond resources, *e.g.* herring run and Atlantic white cedar swamp, CSP-SMAST staff recommends that the system be returned to a fresh/brackish salinity regime with a salinity goal between 1 and 4 ppt. This type of salinity regime will 1) restore the nitrogen attenuation capacity in Cedar Pond and protect Rock Harbor, 2) restore the salinity range necessary to support herring spawning in the pond, and 3) protect the adjacent Atlantic white cedar swamp.

Alternative salinity regimes either do not attain the management goals or are structurally difficult to sustain. A completely freshwater system was not recommended because extreme tides associated with storms/hurricanes appear to be able to enter the pond with the present dike

configuration. These types of periodic pulses would have negligible effect if the pond is brackish, but which would cause major habitat degradation if the pond were completely fresh. At the other end of salinity range, the current system is close to the maximum salinity that can be attained and the loss of nitrogen attenuation and herring spawning, increased export of nitrogen above watershed inputs, and threatening of the Atlantic white cedar swamp do not attain sustainable habitat or water quality goals.

Attaining the recommended 1 to 4 ppt salinity goal in Cedar Pond will require a number of sequential steps that should each be followed by monitoring, assessment, and adjustment of subsequent steps. CSP-SMAST staff first recommends a) restoring the boards in the Cedar Pond water control structure to a height that allows only highest tides to enter the pond and b) pumping out the salt water in the deepest portion of the pond. The height of the boards will require more refined evaluation of the elevations around the outlet structure and comparison to existing tidal information. Pumping can be completed in a number of ways, but staff recommends that it be done during low tide, through the existing outlet, and during the winter to minimize downstream impacts on Rock Harbor. Preliminary cost estimates of implementing these steps is less than $15,000 for equipment and monitoring; additional costs would include an elevation survey of the outlet structure and surround area and any efforts to secure permits from various regulatory entities. Monitoring and assessment of the impacts of re-installing the boards and pumping salt water from the deepest portion of the pond will help to guide the extent of subsequent management of the nutrient regeneration from the sediments.

Two other key factors must also be addressed in order to restore water quality in Cedar Pond: a) reducing the cormorant population that roosts on the power lines during late summer and b) addressing sediment regeneration of nutrients. CSP-SMAST staff reviewed the options to control cormorants and recommends the use of a handheld laser to discourage roosting. Available research suggests that initial usage should reduce the roosting populations by up to 90% and these reductions will be sustained with regular monitoring and follow-up laser use. Estimated equipment cost for this task is approximately $1000 to $2000 depending on strength and laser type with additional potential costs associated with personnel to operate the laser and monitor bird roosting following use. Sediment nutrient regeneration can be addressed using aeration or, if return to very low salinity conditions is successful, an alum treatment. Each of these approaches is dependent on changes in current water quality conditions and given that changing the salinity and cormorant population will alter water quality conditions significantly, CSP-SMAST staff recommends that selection of a nutrient regeneration control technique should await monitoring and reassessment of water quality conditions after the implementation of the salinity and bird control management steps.

Overall, water quality conditions in Cedar Pond are currently severely impaired and have largely worsened since the 2007 increase in tidal interaction with Rock Harbor. The increased tidal interaction has allowed greater export of nitrogen and phosphorus from Cedar Pond to Rock Harbor and created increased ecosystem instability. CSP-SMAST staff recommends:

a) returning the pond to brackish conditions (1-4 ppt salinity),
b) reducing the cormorant populations roosting on the power lines that span the pond, and
c) monitoring and assessing the results of management activities to attain these goals before implementing an appropriate strategy to reduce sediment nutrient regeneration.

CSP-SMAST staff is available to assist the Town of Orleans and the Orleans Marine and Fresh Water Quality Task Force to attain water quality goals in Cedar Pond.

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I. Introduction

Cedar Pond is a 6.4 ha (15 acre) surface water body with a 48.4 ha watershed located within the Town of Orleans (Figure 1). The pond receives freshwater primarily through groundwater inflows around its margin, but is also connected to the Rock Harbor estuary through a surface water outlet. The pond has been subject to a variety of inadvertent management actions over at least the past 150 years that have altered its salinity characteristics and associated water quality and aquatic habitats. Aerial photos from 1947 suggest that Cedar Pond was a fresh water pond at that time. Ad hoc management actions over a number of subsequent years have included: a) filling of a portion of the pond for the construction of Route 6, b) siting power lines over the northern portion of the pond, c) removal of boards at the outlet control structure, d) replacement of the Rock Harbor Road culvert, and e) increasing tidal flows resulting from the gradual deterioration of the tidal dike that limited flow to and from the rest of the Rock Harbor system. The loss of the water control structures in the dike increased tidal interaction and converted the system to a brackish, slightly salty, pond. In early 2007 changes to the stream outlet channel caused a significant increase in tidal flows and associated pond salinity levels. This most recent change caused the pond to be converted from a fresh/brackish system to a coastal salt pond.

Review of water quality data collected prior to 2007 show that Cedar Pond on average failed to meet the minimum dissolved oxygen limits in Massachusetts regulations (314 CMR 4) due to high sediment oxygen demand and water column oxygen uptake associated with reoccurring large phytoplankton blooms.[3] This oxygen demand caused a significant fish kill in 2001, which included herring and white perch. More recent water quality data collected in 2009 and 2012, after the most recent stream change, documented that DO impairment has continued under the new, more saline conditions.[4] Another significant fish kill occurred in 2008.

Even with poor pond water quality, however, data collected from the Rock Harbor system during the Massachusetts Estuaries Project (pre-2007) showed that the brackish Cedar Pond was highly protective of Rock Harbor, removing 58% of the watershed nitrogen it received and significantly mitigating the watershed nitrogen load to the nitrogen-sensitive harbor.[5] The MEP assessment also indicated that Rock Harbor is impaired and will require further watershed nitrogen reductions to restore the harbor and meet state surface water regulations. For these reasons, the Town of Orleans has targeted the Cedar Pond watershed for sewer collection of wastewater during the final phase of the town's Comprehensive Wastewater Management Plan.[6] Given the recent changes in the pond's salinity, however, there are concerns that that the pond's ability to attenuate nitrogen entering from the watershed has been significantly reduced and increased loads are reaching Rock Harbor. These shifts have both water quality and financial implications for the Town's ability to meet the Rock Harbor nitrogen threshold and address Cedar Pond's water quality habitat impairments.

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[3] Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. Cape Cod Commission. Barnstable, MA.

[4] Schlezinger, D. and B. Howes. October 29, 2009. Cedar Pond Autonomous Mooring Results, Summer 2009. Coastal Systems Program Technical Memorandum, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA.

[5] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2007. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

[6] Wright-Pierce. December 2010. Town of Orleans Comprehensive Wastewater Management Plan and Single Environmental Impact Report. Andover, MA.

Figure 1. Cedar Pond Locus in the Town of Orleans, MA

Cedar Pond is located in northern Orleans, south of Route 6 and west of Town Cove. The stream outlet from Cedar Pond flows under Route 6 and discharges into the Rock Harbor estuary. Rock Harbor straddles the town boundary between the Towns of Orleans and Eastham. The MEP outlet stream gauge location is also indicated by the yellow triangle.

The Coastal Systems Program at the School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP-SMAST) has been asked by the Town of Orleans to assist the town in developing a water quality and habitat management strategy for Cedar Pond. Development of this strategy requires the collection of additional key new data (sediment nutrient regeneration and water quality conditions under the current high salinity regime) on Cedar Pond and synthesis of historical data to support site specific recommendations for managing and restoring water quality and habitat health.

Once this information was developed, CSP-SMAST was tasked with developing three (3) potential management options: 1) restoration of salinity conditions to those prior to 2007, 2) maintenance of salinity conditions as they currently exist, and 3) a preferred management strategy developed through coordination with the Town. The overall effort to develop and review the management options will be coordinated with the Town of Orleans Marine and Fresh Water Quality Task Force (OMFWQTF) and the Town of Orleans, Director of Planning & Community Development. This Management Plan summarizes the data review and water quality management options for Cedar Pond.

II. Historic Management and Assessments of Cedar Pond

Water quality conditions in Cedar Pond have been the subject of a number of inadvertent management decisions over a number of decades. National Park Service ortho-photographs from 1947 show direct connections of Cedar Pond to an adjacent cranberry bog (on the site of the current Stop and Shop plaza) (Figure 2). Since even brackish waters would harm cranberry plants, the connection of this bog to Cedar Pond suggests that the pond was fresh at that time. The 1947 ortho-photo also shows farmland behind the dike on Rock Harbor Creek; this dike had a flapper valve that prevented tides from reaching the farmland. Comparison of this ortho-photo with current conditions (see Figure 1) also shows that Cedar Pond was approximately 17 acres in area. Comparison of these aerial photographs also shows that construction of Route 6 filled approximately two acres worth of the pond. This filling reduced the surface area of Cedar Pond from 17 acres to its current 15.1 acres. Sometime after the Route 6 construction, electrical lines were also strung over the length of the pond. During summer these power lines are a nightly roosting spot for an extensive aquatic bird population, which bird census data indicate are mainly cormorants. Daily populations of up to 600 birds have been counted. In 2004, pen boards were removed at the Cedar Pond outlet control structure. In December 2005, the tide control structure (weir) that had been installed to replace a flapper valve at the dike was severely damaged by a winter storm.[7] During January 2007, debris in the creek leading to Cedar Pond was cleared by volunteers mostly by hand, but also through use of a "mini-excavator." It was noted that "When all the heavy work was done, water flowed freely into Cedar Pond on the incoming high tide."[8] The culvert under Rock Harbor Road was repaired between November 2008 and January 2009, although its diameter was not increased (personal communication, Mark Budnick, Town of Orleans, 7/13). Within available monitoring history, surface salinity readings in Cedar Pond have increased from 6.9 ppt[9] to 21.8 ppt[10].

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[7] Kelley, S.W. July, 2010. Rock Harbor Creek Restoration Feasibility Study. Completed for Cape Cod Commercial Hook Fisherman's Association. Applied Coastal Research and Engineering, Inc. Mashpee, MA.

[8] Friends of Pleasant Bay Newsletter. January 2007.

[9] 2002-2004 MEP stream monitoring (Howes, *et al.*, 2007).

[10] 2012 average from shallow continuous monitoring collected during this project

Figure 2. 1947 National Park Service ortho-photograph of Cedar Pond area.
Photo shows original extent of Cedar Pond and the adjacent wetlands along the western shoreline prior to the construction of Route 6. Also shows cranberry bogs and likely hydroconnection between bogs and Cedar Pond, as well as the historic dike that had a flapper valve that prevented tidal flows up Cedar Pond Creek to Cedar Pond.

All of these changes have altered the water quality conditions within Cedar Pond, but water quality data only exists to document impacts over the last 15 years. Recent water quality sampling of Cedar Pond was begun in 2001 as part of the Pond and Lake Stewardship (PALS) snapshot. The PALS snapshot, which recently completed its 12th year this past summer, is coordinated by CSP-SMAST and the Cape Cod Commission and involves a once-a-yearsampling using a standard sampling protocol. The early PALS snapshot data for Cedar Pond includes total phosphorus, total nitrogen, and chlorophyll-*a* concentrations, as well as somewhat spotty salinity readings. OMFWQTF members expanded their sampling frequency during 2002 while using the same sampling protocol and conducted two to nine sampling runs each summer between 2002 and 2007. PALS samples were collected in each subsequent year through 2012.

In 2007, Cape Cod Commission staff completed a review of OMFWQTF fresh water pond monitoring, but also included a more refined review of the data from the brackish Cedar Pond.[11] This refined Cedar Pond water quality review found that:

1) available salinity readings ranged between 6 and 18 ppt (shallow low salinity and high salinity in the deepest waters),
2) temperature stratification was minimal (no temperature resistance to mixing),
3) dissolved oxygen stratification was significant with consistently high concentrations at 0.5 and 1 m depths and consistently anoxic (<1 mg/L) concentrations in 2 and 3 m depths,
4) transparency (Secchi depth) is consistently low (averaged 1 m or 30% of total pond depth),
5) nitrogen to phosphorus ratios indicated nitrogen limitation or co-limitation depending on the depth (upper station ratio averaged 23, deep station ratio averaged 12), and
6) phosphorus loading from the project-delineated watershed contributed an estimated annual phosphorus load of 12.9 kg, while the sediments contributed an estimated 12 to 32 kg.

This Orleans Ponds report also noted that Cedar Pond was failing to meet minimum water quality standards in the state Surface Water Regulations[12], recommended that management strategies should be developed and these strategies should include quantifying and reviewing the impact of the tides and the sediments on the pond's water quality.

In early years of the OMFWQTF pond monitoring, the Massachusetts Estuaries Project (MEP) project team also began gathering data that would subsequently be used for the MEP ecosystem assessment of the Rock Harbor estuary.[13] This data gathering included CSP-SMAST monitoring of the flow and water quality in the creek discharging from Cedar Pond into Rock Harbor. Weekly water samples and flow measurements were collected from the creek between September 2002 and August 2003. These flows from Cedar Pond showed low tide salinity that ranged between 6.9 and 11.1 ppt and reflect the surface concentrations in the pond. Average measured freshwater outflow was 1,271 m^3/d with a total nitrogen export out of the pond of 1.09 kg/d. Comparing the projected nitrogen load from the Cedar Pond watershed with the measured

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[11] Eichner, E. October, 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. Final Report. For the Town of Orleans Marine and Fresh Water Quality Task Force and Barnstable County. Cape Cod Commission. Barnstable, MA. 80 pp.

[12] 314 CMR 4. Massachusetts Surface Water Quality Standards. Massachusetts Department of Environmental Protection.

[13] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2007. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

nitrogen load in the creek, MEP staff estimated that Cedar Pond was removing/attenuating 58% of its incoming watershed nitrogen load. In addition, the overall MEP assessment concluded that the Rock Harbor estuary, specifically the Rock Harbor basin, was impaired by nitrogen enrichment and that existing TN concentrations needed to be reduced from 0.686 mg/L to a recommended 0.50 mg/L TN threshold level. MassDEP has not developed a TMDL based this threshold because it is awaiting "additional funding to incorporate Cedar Pond"[14], as tidal flows were established post-MEP assessment and the pond is now part of the estuarine system. MEP assessments are required to show at least one option to attain the TN threshold and the threshold attainment scenario in the MEP Rock Harbor Report assigned a 69% nitrogen loading reduction to the main Rock Harbor subwatershed, but no additional nitrogen removal required within the Cedar Pond subwatershed given that the pond was already removing 58% of its watershed load.

After the 2007 creek changes, there was some concern about how conditions might have been altered in Cedar Pond. To help address this, CSP-SMAST was asked by the Town to install two continuous recording instruments in Cedar Pond during the summer of 2009. These YSI 6600 sondes recorded dissolved oxygen, temperature, salinity, chlorophyll-*a*, and water level readings at one meter and 2.5 m above the pond bottom between June 16 and September 10, 2009.[15] This data collection did not include accompanying laboratory water quality samples, but these readings generally found:

1) warming of the whole pond as the summer progressed, but with a distinct (~5ºC) difference between surface and bottom temperatures,
2) weaker salinity stratification than previous readings with higher bottom salinity (23-26 ppt) and lower surface salinity (18-21 ppt) with peaks associated with increased water surface elevation (likely due to monthly high tides),
3) higher surface chlorophyll-*a* concentrations, a phytoplankton bloom in August, and a September crash with transfer of pigment (and likely particulate carbon and nitrogen) to deeper waters,
4) surface dissolved oxygen concentrations that are generally greater than atmospheric equilibration (>100% saturation) which are indicative of an extensive phytoplankton population,
5) hydrogen sulfide levels rose to reach the sonde (0.75 m depth) around August 15, which is indicative of excessive sediment oxygen demand and hypoxic conditions, and
6) water elevations that are weakly tidal with a range of ~0.3 m and peaks influenced by larger spring tides every 14-15 days or so.

III. Current Project Data Collection

During review of the available historic Cedar Pond data, CSP-SMAST staff indicated that additional key information was necessary in order to develop effective management strategies for Cedar Pond. This data collection was incorporated into the current project and tasks included: a) stream water quality, streamflow, and pond water quality monitoring under current higher salinity

[14] Massachusetts Department of Environmental Protection. 2012. Massachusetts Year 2012 Integrated List of Waters, Proposed Listing of the Condition of Massachusetts' Waters Pursuant to Sections 305(b), 314 and 303(d) of the Clean Water Act.

[15] Coastal Systems Program Technical Memorandum. October 29, 2009. Cedar Pond Autonomous Mooring Results, Summer 2009. From David Schlezinger, Sr. Scientist, and Brian Howes, Director, Coastal Systems Program, SMAST-UMD. To George Meservey, Director of Planning Department, Town of Orleans.

conditions and b) sediment core collection and incubation. Results from this data collection are summarized in this section.

III.A. Cedar Pond Stream and Pond Monitoring

CSP-SMAST was charged with collecting continuous flow and weekly water quality data within the outflow stream from Cedar Pond to the upper reach of Rock Harbor Creek at the location where the MEP flow gauge was previously installed (see Figure 1) and to collect monthly water quality profiles within the main basin of Cedar Pond. In addition, CSP-SMAST staff installed continuously recording instruments in the pond at a surface mixed layer depth (~1 m) and near the bottom (~2.7 m). The moored instruments collected time-series measurements of dissolved oxygen (mixed layer only), temperature, salinity, chlorophyll-*a*, and water depth every 15 minutes. The mixed layer instrument recorded from June 5 to September 6, 2012, while the bottom depth sonde recorded from May 31 to August 26, 2012.

Measurements at the stream gauge were collected according to the same sampling protocols used during the MEP gauging effort, in order to facilitate comparison between the two datasets. A vented calibrated water level gauge was installed at the MEP gauge location that continuously recorded water level readings. The vented transducer automatically corrects for changes in atmospheric pressure. The transducer was "fixed" within the deepest part of the creek channel. While the transducer was in the field, water levels at the sensor were measured manually at approximately weekly intervals to confirm the calibration over the course of the deployment.

Creek and pond water quality samples were collected on the same dates as the stream gauge checks. Samples were collected using USEPA/MassDEP-approved, MEP procedures and samples were assayed at the SMAST Coastal Systems Analytical Facility Laboratory according to lab analysis and sample handling procedures described in the SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (2003), which is also approved by the MassDEP. Stream water quality samples were collected 15 times between June 5 and September 20, 2012. Pond profile samples and readings were collected five times between June 5 and September 6, 2012. Assay of Cedar Pond and stream samples included: total nitrogen, total phosphorus, chlorophyll-*a*, pH, and alkalinity. Detection limits for SMAST laboratory analytes and field data collection are listed in Table 1.

Monitoring in 2012 shows that surface water outflow from Cedar Pond increased substantially since the January 2007 opening, but all of the increase is due to tidal interactions. Streamflow at the gauge location during the MEP measurement period (September 2002 and August 2003) was about a third that of 2012. However, the MEP flows reflected only freshwater discharge (1,271 m^3/d[16]) and not total volumetric discharge., Salinity readings in surface water outflow during the MEP measurement period averaged 7.5 ppt , while these readings averaged 20.9 ppt in 2012 (consistent with 21.8 ppt in surface pond water). However, the total volumetric flow was much higher in 2012, averaging 3,613 m^3/d between June 13 and September 20 (Figure 3). Correcting the 2012 discharge for entrained saltwater, produces a 2012 freshwater discharge (1,246 m^3/d) that is similar to the 2003 freshwater discharge (1,197 m^3/d) for the same summer interval.

[16] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2007. Rock Harbor MEP Report.

Table 1. Field and laboratory reporting units and detection limits for water samples analyzed at the SMAST Coastal Systems Analytical Facility Laboratory and field data collected at Cedar Pond				
Parameter	**Reporting Units**	**Detection Limit**	**Accuracy (+\-)**	**Measurement Range**
Pond Field Measurements				
Temperature	ºC	0.5°C	± 0.3 ºC	-5 to 45
Dissolved Oxygen	mg/l	0.5	± 0.3 mg/l or ± 2% of reading, whichever is greater	0 – 20
Secchi Disk Water Clarity	meters	NA	20 cm	Disappearance
Salinity	ppt	NA	± 0.2 ppt	0-35 ppt
Laboratory Measurements – SMAST, UMass Dartmouth				
Alkalinity	mg/l as $CaCO_3$	0.5	80-120% Std. Value	NA
Chlorophyll-*a*	µg/l	0.05	80-120% Std. Value	0-145
Nitrogen, Total	µM	0.05	80-120% Std. Value	NA
pH	Standard Units	NA	80-120% Std. Value	0 - 14
Phosphorus, Total	µM	0.1	80-120% Std. Value	NA
Note: All laboratory measurement information from SMAST Coastal Systems Analytical Facility Laboratory Quality Assurance Plan (January, 2003)				

The freshwater discharge measurements are also consistent with the MEP water balance model based on USGS modeled watershed area and recharge rate. The balance between the watershed modeled flows and the measured flows also means that the creek outlet is the predominant outflow conduit for watershed inputs to Cedar Pond and that groundwater outflow along the downgradient shoreline was negligible and that the increase in flow between 2003 and 2012 is due to increased tidal interactions between Cedar Pond and the Rock Harbor estuary.

The increased tidal water moving in and out of Cedar Pond is the cause of both the increase in pond water salinities and the decreasing difference between surface and bottom readings. The four 2012 monthly salinity profiles collected by CSP-SMAST showed average salinity readings in the shallow, middle, and bottom water column samples of 21.5 ppt, 22.6 ppt, and 23.3 ppt, respectively. As would be expected, the fresher, less dense water is above the saltier, denser water just as in the past, but the difference between the surface and bottom has declined.

These current conditions are the result of a progression that seems to have been ramped up by the 2007 opening. Prior to the 2007 opening (between 2001 and 2006) average surface and bottom salinity were 8.6 and 16.4 ppt, respectively (Figure 4). Since the opening, the average surface (18.4 ppt) and bottom (21.1 ppt) salinity are both significantly higher (both $\rho<0.005$). These higher salinities have also decreased the differences between the shallow and bottom salinities. Prior to the opening, the average difference between the shallow and bottom salinities was 7.7 ppt. After the opening, the difference decreased significantly ($\rho<0.00005$) to an average of 2.7 ppt. These readings show that Cedar Pond became more saline throughout its whole water column after the January 2007.

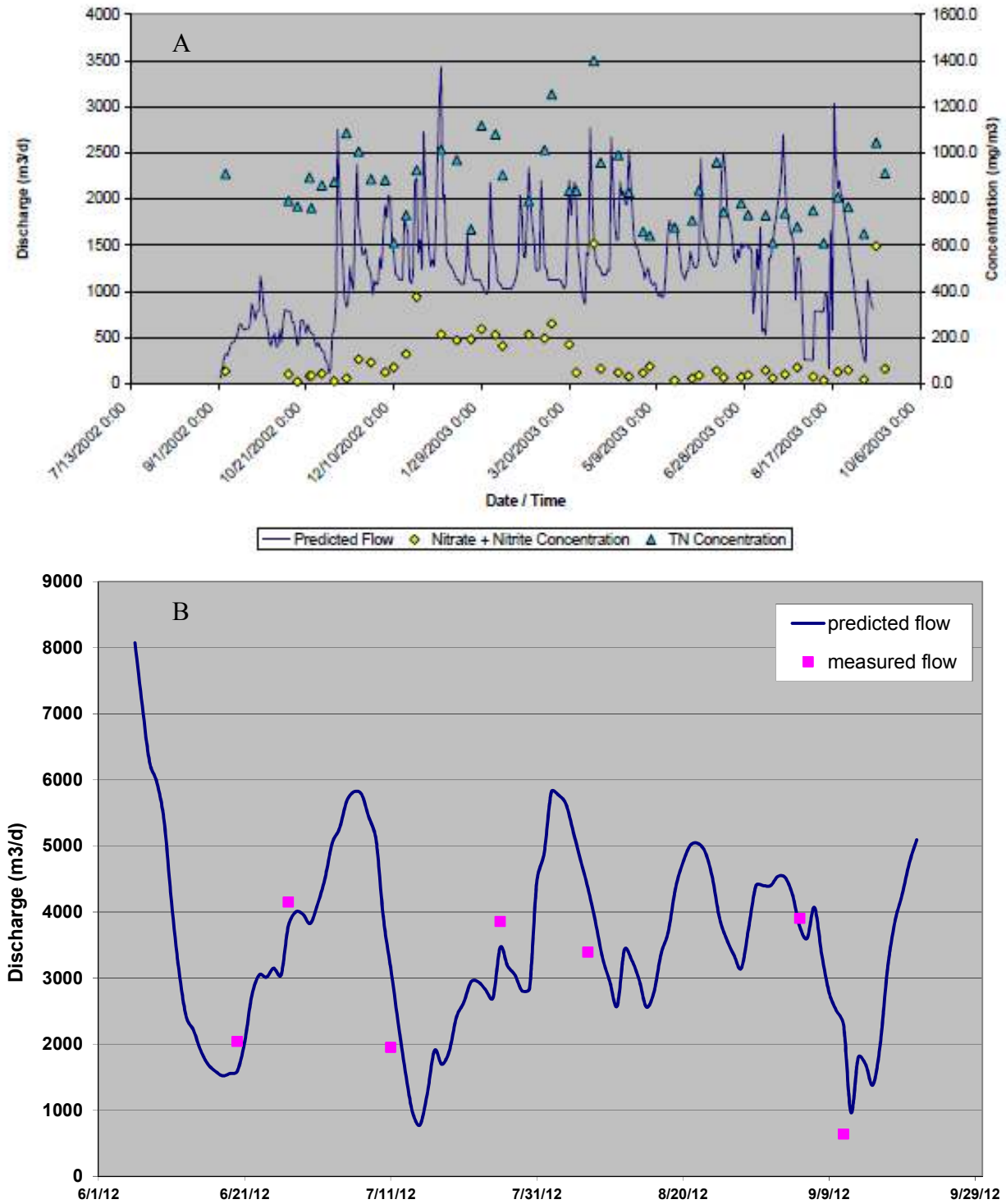

Figure 3. Measured outflow from Cedar Pond in outlet creek (2002/2003 and 2012). *A* shows measured and predicted outflow between September 2002 and August 2003 during MEP assessment of Rock Harbor (modified from Figure IV-7 in Howes, *et al.*, 2007). Average outflow during this period was 1,271 m3/d. *B* shows measured and predicted 2012 outflow between June 13 and September 20. Average outflow during this period was 3,613 m3/d. Correction for salinity differences shows that freshwater discharge during the two periods is the same.

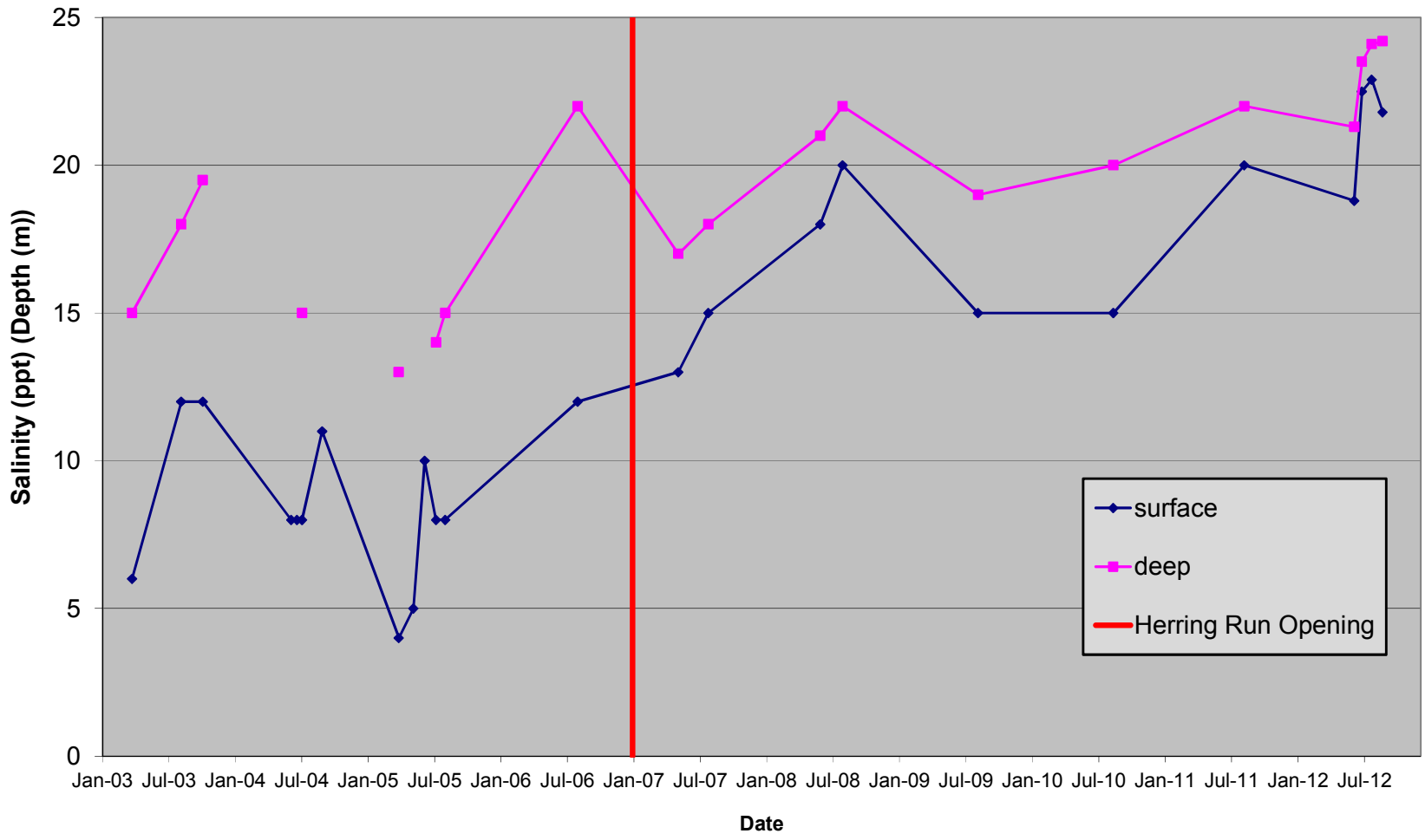

Figure 4. Historic Salinity in Cedar Pond.
Surface and bottom salinity readings are shown from April 2003 through September 2012. The red line shows the January 2007 opening of the Cedar Pond Creek to allow greater tidal interaction with Cedar Pond. Prior to the opening, average surface and bottom salinity were 8.6 and 16.4 ppt, respectively. After the opening, average surface (18.4 ppt) and bottom (21.1 ppt) salinity are significantly higher ($\rho<0.005$). The difference between the shallow and bottom salinities also decreases after the January 2007 opening. Prior to the opening, the average difference between the shallow and bottom salinities was 7.7 ppt. After the opening, the difference decreases significantly ($\rho<0.00005$) to an average of 2.7 ppt.

Comparison of the 2009 and 2012 time-series data confirms both the increase in pond-wide salinity and reduction in salinity differences with depth, as well as indicating that these changes continued into the 2012 study period. In 2009 (June 16 to July 15), the average difference in salinity between the top and bottom was 3.7 ppt (Figure 5).[19] During the same period in 2012, the average salinity difference had decreased to 1.7 ppt. Review of the 2012 salinity data also shows differences among the months: June 2.15 ppt, July 1.43 ppt, and August 1.71 ppt. The decrease in difference between June and July may be due, in part, to decreased groundwater levels as the summer progressed.[20] The 2012 continuous salinity readings had a minimum 0.1 ppt difference between the two sensors. The decreases in the salinity differences in the pond provide less resistance to mixing of the whole water column.

Temperatures readings also show a trend toward a more isothermic water column and, hence, potentially easier mixing of the water column. Average temperatures throughout the water column are higher after the 2007 opening with significantly higher ($\rho<0.01$) temperature in the deepest waters: the average 3 m depth temperature prior to 2007 was 17.1°C and was 22.5°C after 2007 (Figure 6). The average difference between the highest and lowest temperatures in pond profiles also decreased significantly ($\rho<0.00005$) with an average difference of 6.4°C prior to the 2007 and an average difference of 2.3°C after 2007. This warming of the deepest waters and the decrease in temperatures between the warmest and coolest waters is likely related to greater surface water temperatures due to higher tidal exchange. Since the average salinities and temperatures after the 2007 opening have lessened the difference between the top and bottom waters, periodic mixing may eventually occur as smaller temperature and salinity differences take less wind energy to mix the entire water column and oxygenate the bottom waters.

The deeper mixing of the water column has increased dissolved oxygen (DO) concentrations in Cedar Pond at the mid-water depths, but not the deep basin. The greater mixing has allowed increased access of the water column to atmospheric oxygen. Easier access to this source of additional oxygen has somewhat diminished the impact of sediment oxygen demand in the water column. Prior to the January 2007 opening, anoxic conditions (DO<1 mg/L) in the pond generally existed 1.5 m and deeper. Dissolved oxygen concentrations in shallower waters gradually moved toward an equilibrium with atmospheric oxygen at the surface (*i.e.*, August/September surface average of 98% saturation) (Figure 7). Average August/September DO concentration at 1.5 m prior to the opening was 1 mg/L (11% saturation), while after the opening, the average at 1.5 m met the DEP 6 mg/L limit and anoxic water had generally been reduced to depths greater than 2.5 m. An exception to this in the available data is the 2009 sonde data where it appears that anoxic waters rose to the depth of instrument (average 0.75 m) after a phytoplankton bloom and the associated hydrogen sulfide poisoned the DO sensor (Figure 8). These types of anoxic events would likely be associated with fish kills if they reach the surface and show that while snapshot readings and average conditions show some improvement primarily in mid-waters, but short-term periodic events appear to re-create the pre-opening anoxic conditions. These data indicate that the sediment oxygen demand and secondary water column oxygen uptake are sufficient to create low oxygen conditions throughout most of the water column during periodic low mixing conditions (*e.g.*, quiescent or cloudy conditions).

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[19] Schlezinger, D. and B. Howes. October 29, 2009. Cedar Pond Autonomous Mooring Results, Summer 2009.

[20] USGS groundwater levels at BMW-22, which is the closest of the long-term water level wells in the area, declined throughout 2012. data from http://nwis.waterdata.usgs.gov/ma/nwis/gwlevels/?site_no=414630070014901&agency_cd=USGS&

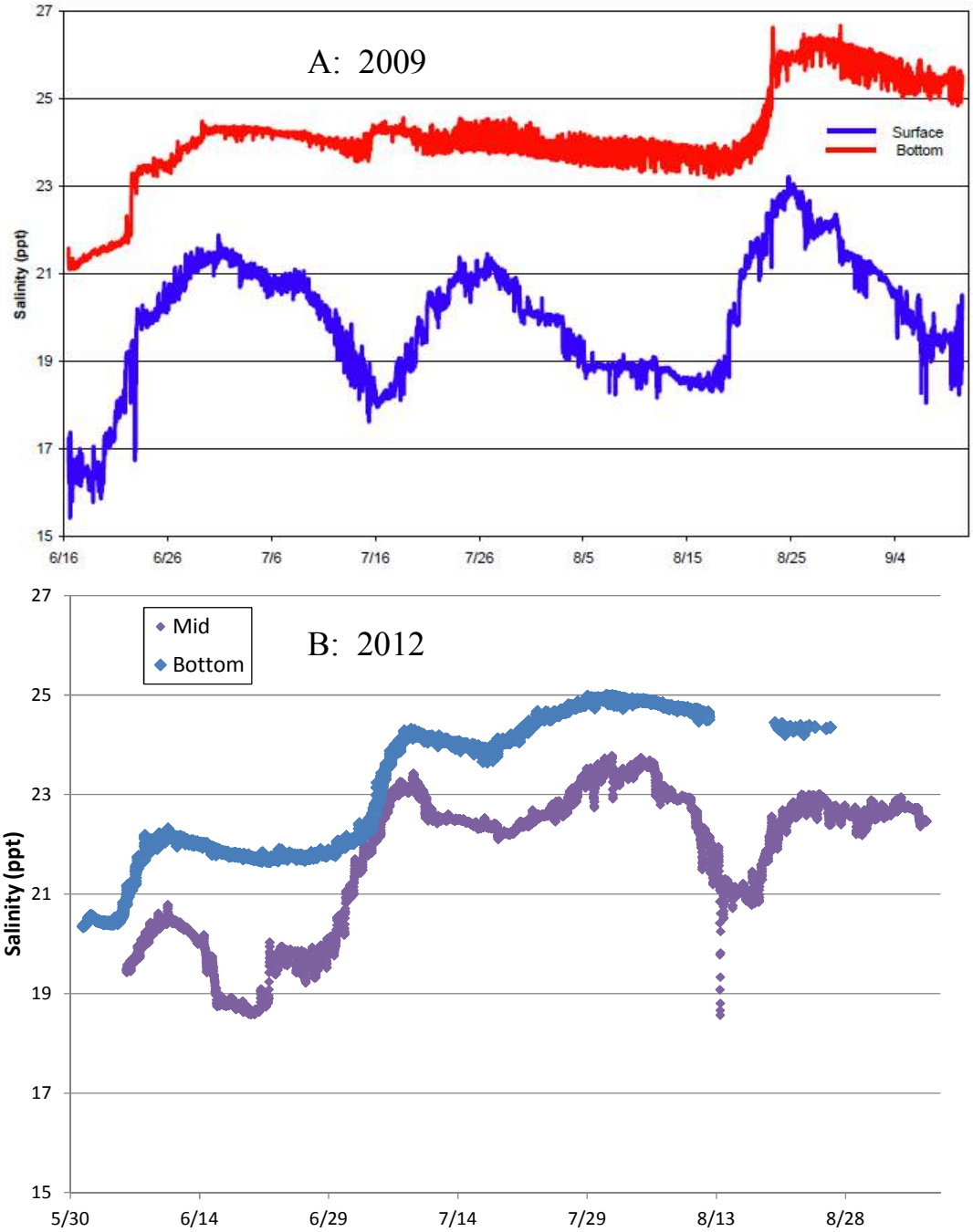

Figure 5. 2009 and 2012 Continuous Salinity Readings in Cedar Pond.
Time-series salinity records from Cedar Pond during 2009 (*A*: June 16 to September 10) and 2012 (*B*: June 5 to September 6). Sensors were placed at average depths of 0.75 m and 2.35 m in 2009 and 1.16 m and 2.75 m in 2012. Salinity measurements were synchronized and recorded at 15 minute intervals. Average salinity difference at two depths during an equivalent time period was 3.71 ppt in 2009 and 1.72 ppt in 2012. The 2012 difference is generally sufficient to prevent vertical mixing and full ventilation of bottom waters. Since the degree of summer salinity (and temperature) stratification is diminishing, resistance to wind-aided mixing is also diminishing.

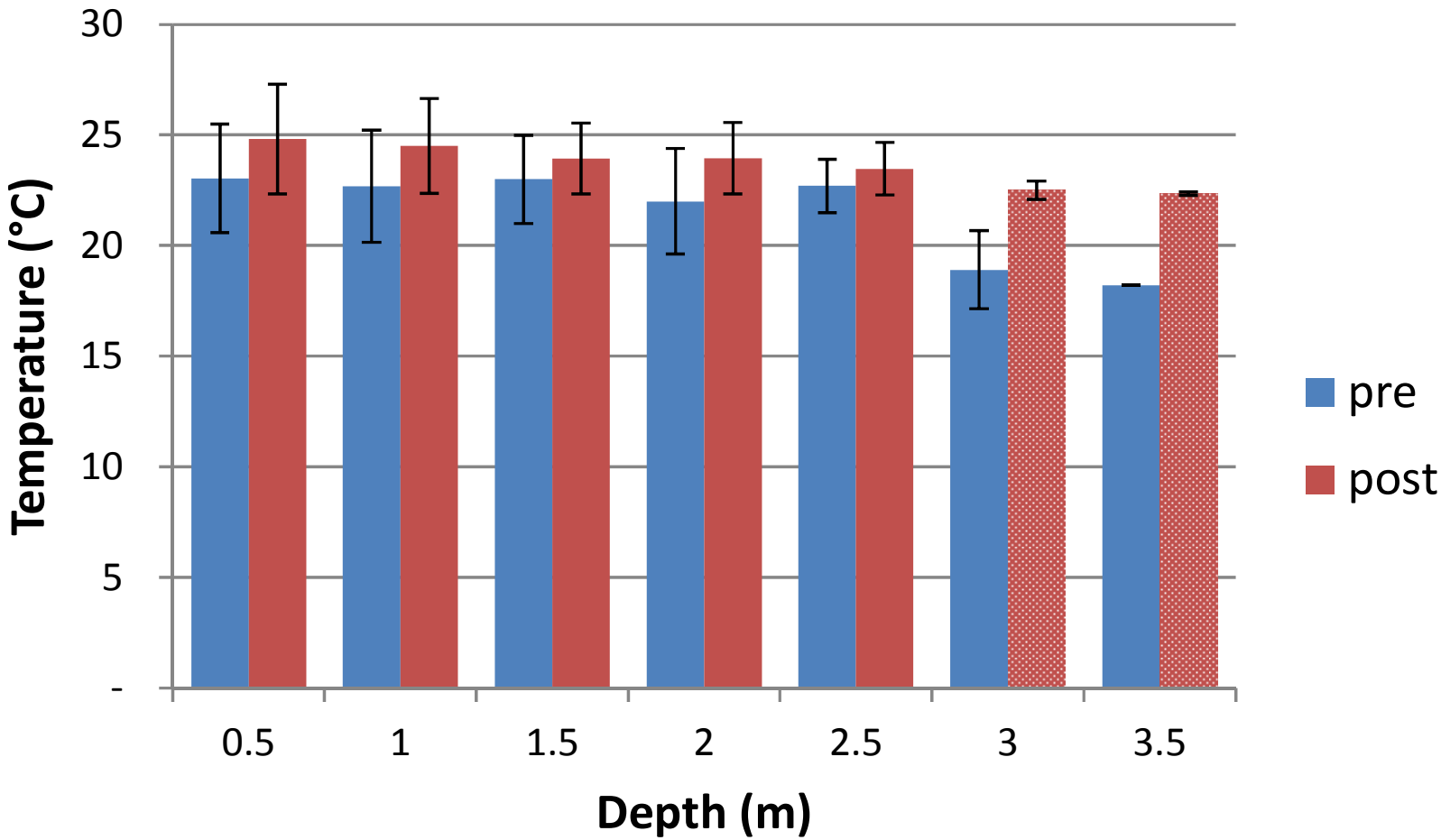

Figure 6. Average Water Temperatures in Cedar Pond (August/September readings): Pre- and Post-Jan 2007 opening. Average water column temperatures at 0.5 m increments within the Cedar Pond water column are shown both before the January 2007 opening ("pre") and after ("post"). Averages are based on readings in August and September. Error bars indicate one standard deviation. Average temperatures at 3 m and 3.5 meters are significantly higher ($\rho<0.01$) after the 2007 opening. This warming of the deepest waters is likely to both increased input of warmer tidal waters and increased likelihood of water column mixing.

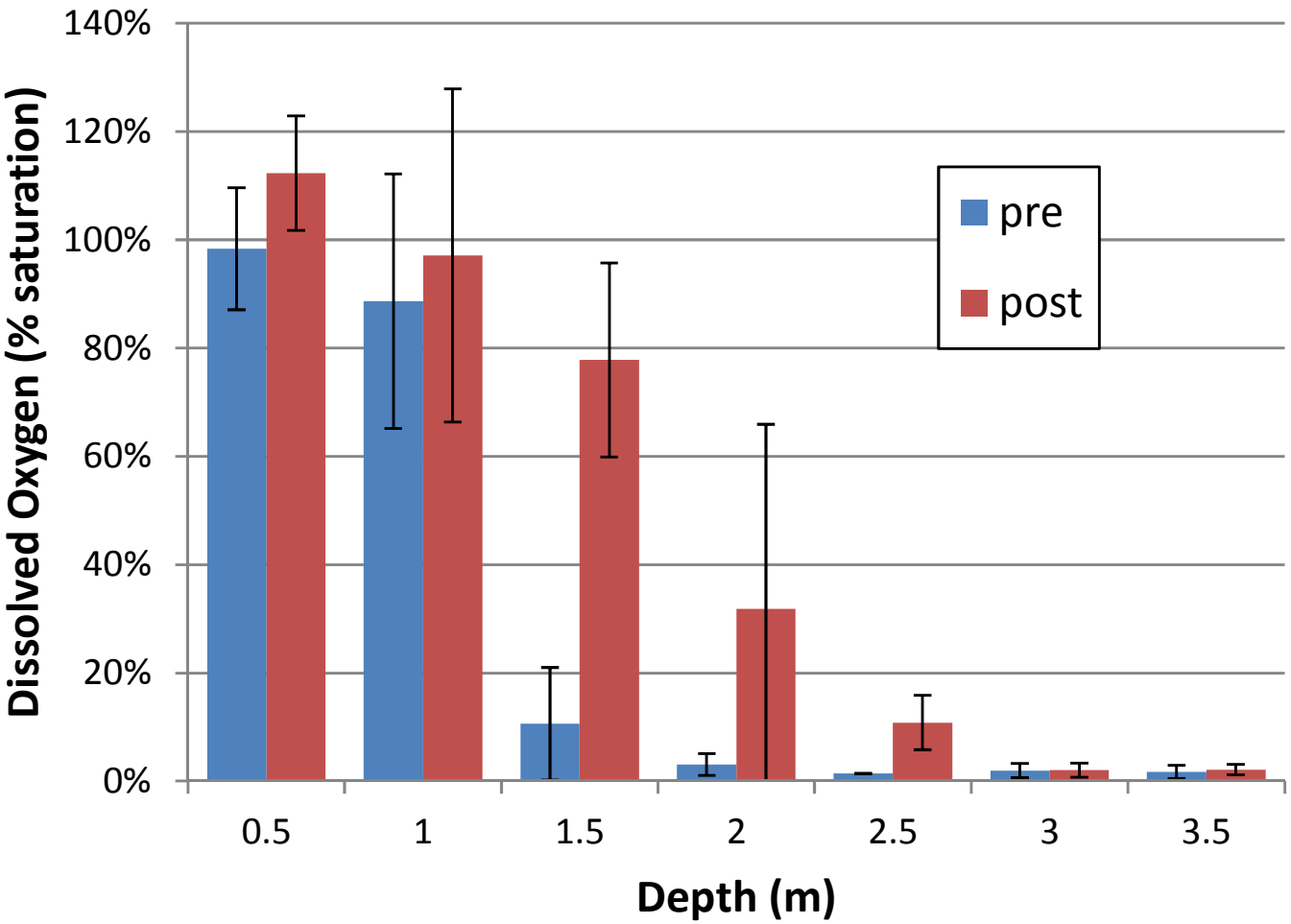

Figure 7. Average DO (% saturation) in Cedar Pond (August/September readings): Pre- and Post-Jan 2007 opening. Average water column dissolved oxygen (% saturation) at 0.5 m increments within the Cedar Pond water column are shown both before the January 2007 opening ("pre") and after ("post"). Averages are based on readings in August and September. Error bars indicate one standard deviation. Surface and 1.5 m % saturation is significantly ($\rho<0.05$) higher post-opening. Increase in surface concentrations is likely due to greater nutrient availability (*e.g.*, more photosynthesis), while the increase at the mid depths are likely due to deeper mixing of atmospheric oxygen due to tidal and wind action. Deepest waters were consistently anoxic (<1 mg/L DO) in both pre- and post-opening records.

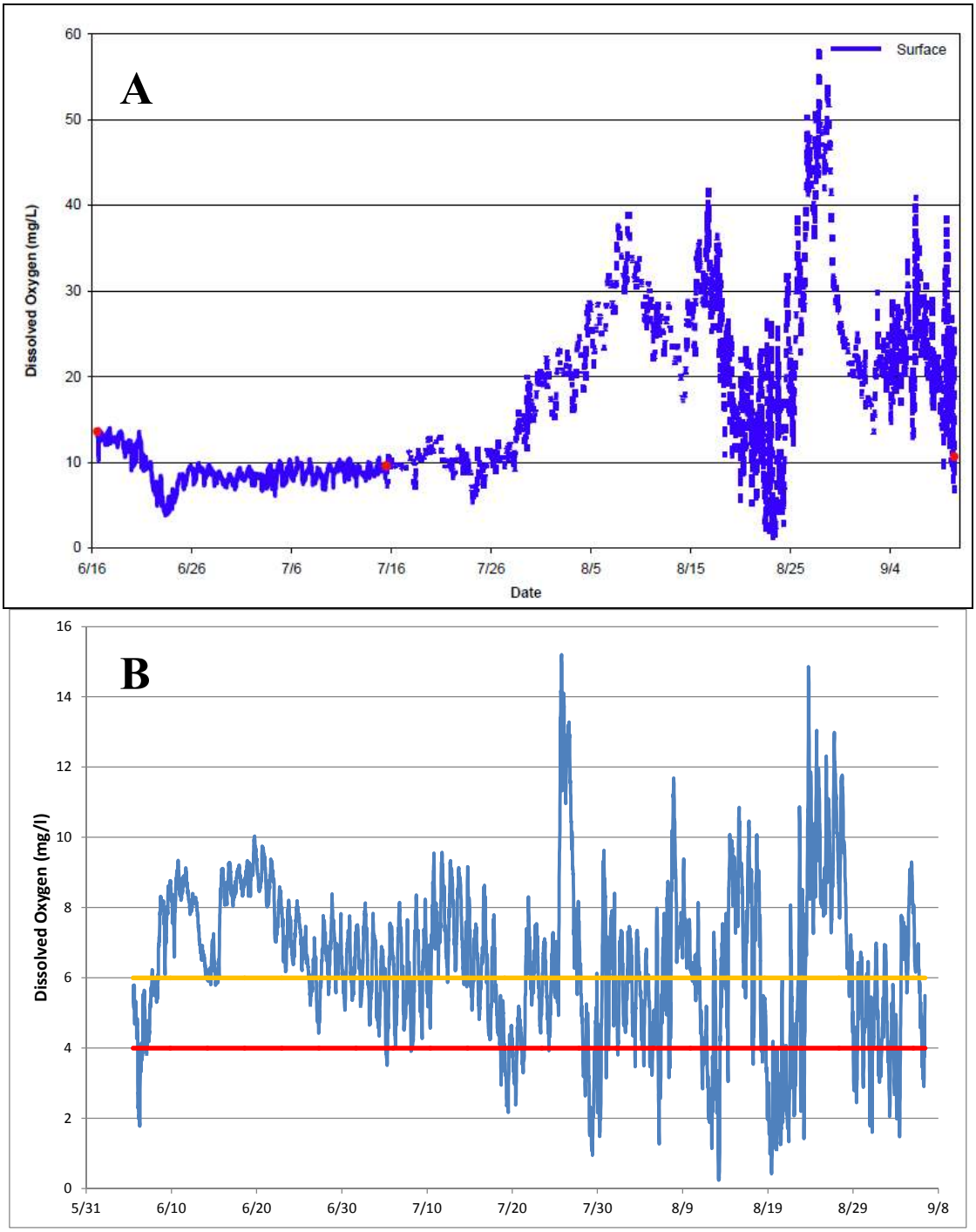

Figure 8. 2009 and 2012 Continuous Dissolved Oxygen Readings in Cedar Pond. Sonde instruments were deployed in Cedar Pond during 2009 (*A*: June 16 to September 10) and 2012 (*B*: June 5 to September 6). The sondes were placed at average depths of 0.75 m in 2009 and 1.16 m in 2012. DO was recorded at 15 minute intervals. The DO sensor in the 2009 placement suggests a large phytoplankton bloom in late July followed by low oxygen and poisoning of the sensor by hydrogen sulfide in late August. At roughly the same time in 2012, the DO readings became more variable.

Average dissolved oxygen concentrations at 2.5 m and deeper are anoxic during both pre- and post-opening periods, reinforcing that sediment oxygen demand is still creating water quality impairments.

Review of the time-series DO data in 2009 and 2012 show highly variable oxygen concentrations at ~1 meter depth both between the years and during the period of recording. In 2009, DO concentrations before the end of July were generally very high (average % saturation = 122%), while in July 2012 average % saturation was 89%. DO concentrations greater than atmospheric equilibrium (>100%) are usually indicative of extensive phytoplankton photosynthesis adding oxygen to the water column. The 2012 saturation indicates greater impact of sediment oxygen demand and/or less photosynthesis. Review of the 2012 DO concentrations show that minimum concentrations became more prevalent later in the summer: DO less than 6 mg/L (DEP regulatory minimum) were 19%, 45%, and 49% of the readings in June, July and August, respectively. Concentrations less than 4 mg/L, which is usually indicative of organism stress, increased from 2% in June to 11% in July and then to 21% in August (see Figure 8). It is also important to note that the sondes were place at relatively shallow depths (0.75 m in 2009 and 1.16 m in 2012); low oxygen conditions should be relatively uncommon at these depths because of the easy availability of photosynthetic and atmospheric oxygen.

Review of nutrient (nitrogen and phosphorus) measurements show that the increased mixing and greater availability of oxygen after the January 2007 opening was associated with higher nitrogen levels in Cedar Pond surface waters. Average total phosphorus (TP) in the surface waters is essentially the same before and after the opening: average June to September concentrations are 81 µg/L and 86 µg/L, respectively (Figure 9). In contrast, average surface total nitrogen (TN) concentrations are significantly ($\rho<0.02$) higher after the opening: average June to September concentrations are 0.63 mg/L and 0.94 mg/L, respectively. Both of these TN concentrations are higher than the 0.5 mg TN/L threshold recommended for Rock Harbor.[22] Water column concentrations just above the sediments have a different pattern. Average TN concentrations in the deep waters are not significantly different before and after the opening: average June to September concentrations are 2.0 mg/L and 1.6 mg/L, respectively. On the other hand, average TP concentrations in the deep waters are significantly ($\rho<0.03$) lower after the opening: average June to September concentrations are 442 µg/L and 213 µg/L, respectively.

These concentration differences also translate into significant changes in nutrient masses within Cedar Pond. Since the majority of the pond volume is shallower than 2 m depth, the changes in surface concentrations have the most impact on the mass of TP and TN in the pond and the most potential on transfer of Cedar Pond nutrients to Rock Harbor. When these concentration differences are combined with the pond volumes, the average TN mass in Cedar Pond increased slightly after the 2007 opening, but not significantly. However, the mass was shifted to the shallower waters; the percentage of the overall mass in the shallow waters (<2 m in depth) increased significantly ($\rho<0.0001$) from 60% to 76% (Figure 10). The average TP mass also was shifted to the shallower waters after the 2007 opening; the percentage of the overall mass in the shallow waters (<2 m) significantly ($\rho<0.01$) increased from 52% to 69%. However, the average summer total TP mass in the pond also decreased, from 16.5 to 12.2 kg.

[22] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2007. Rock Harbor MEP Report.

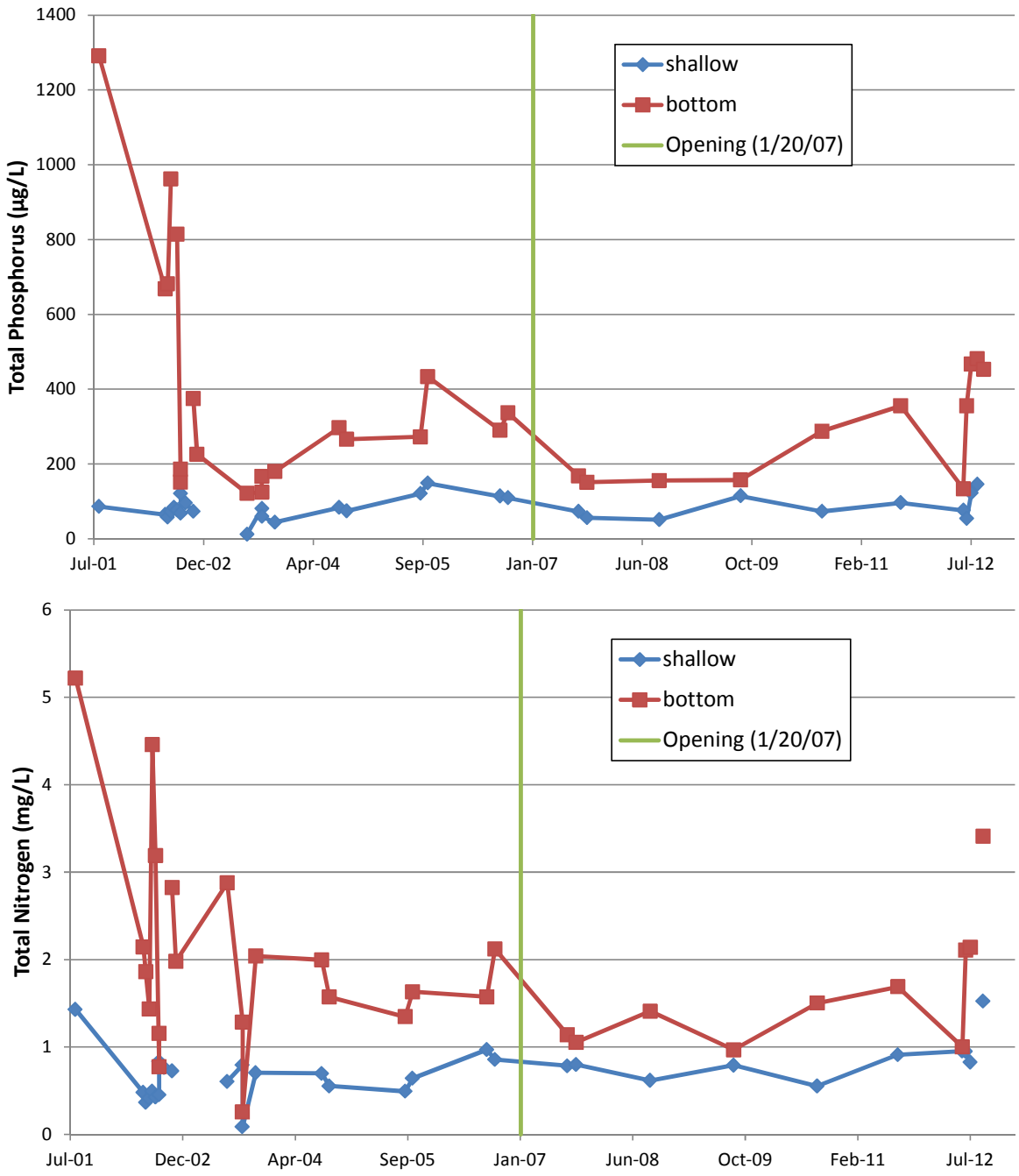

Figure 9. TP and TN concentrations in Cedar Pond: Pre- and Post-Jan 2007 opening. Average surface total phosphorus (TP) in the summer (June to September) before and after the 2007 opening were 81 µg/L and 86 µg/L, respectively. Average deep summer TP concentrations were significantly ($\rho<0.03$) lower after the opening: 442 µg/L and 213 µg/L, respectively. Average surface summer total nitrogen (TN) concentrations are significantly ($\rho<0.02$) higher after the opening: 0.63 mg/L and 0.94 mg/L, respectively. These surface concentrations are both higher than the 0.5 mg TN/L threshold recommended by the MEP for Rock Harbor. Average deep summer TN concentrations are not significantly different before and after the opening: 2.0 mg/L and1.6 mg/L, respectively. Graphs do not include data outliers.

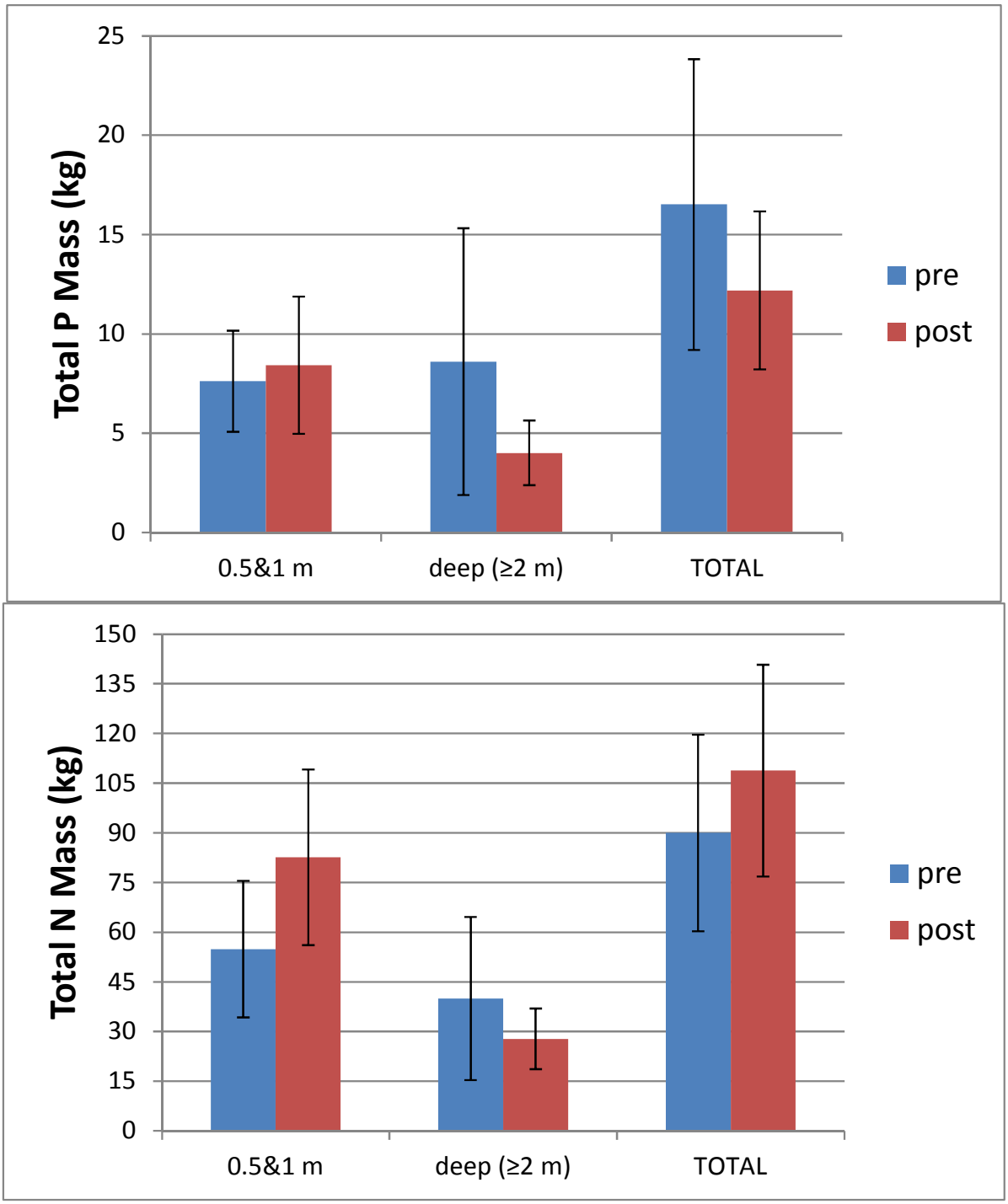

Figure 10. TP and TN mass in Cedar Pond: Pre- and Post-Jan 2007 opening. Average total mass of TP in Cedar Pond decreased from 16.5 kg to 12.2 kg after the 2007 opening with a significant increase ($\rho<0.01$) in the percentage of the mass in surface waters (52% to 69%). Average total mass of TN increased slightly after the 2007 opening, but not significantly. However, the portion of TN mass in the shallow waters (<2 m in depth) significantly increased ($\rho<0.0001$) from 60% to 76%. Averages are based on 27 TP and 29 TN sampling dates. Error bars are one standard deviation.

The shift of more nitrogen to the shallower portions of the water column has increased the shallow chlorophyll-*a* (Chl-*a*) concentrations (Figure 11) and decreased the summer Secchi clarity (Figure 12). Chl-*a* assays were conducted only as part of the PALS monitoring prior to the 2007 opening, so project staff compared August/September Chl-*a* concentrations before and after the 2007 opening. Average surface concentrations increase from 12.9 µg/L to 18.2 µg/L. This increase is not statistically significant ($\rho<0.05$), largely because of the large variability in the post-opening concentrations (max=31.3 µg/L, min=5.0 µg/L). Increased fluctuations in water quality parameters are usually associated with unstable, highly eutrophic ecosystems.[23] These increases in Chl-*a* concentrations are consistent with the increased surface TN concentrations and are likely the result of greater upward mixing of nutrient rich mid and bottom waters causing blooms. These increases in phytoplankton have also produced less clear surface waters; Secchi clarity has significantly ($\rho<0.01$) decreased. Pre-opening clarity averaged 1.01 m and 30% of total depth, both of which are representative of impaired conditions. Post-opening clarity decreased to an average of 0.82 m and 23% of total depth.

The increase in nitrogen and decrease in phosphorus in the water column has altered the ratios between nitrogen and phosphorus, which determine the key eutrophying nutrient, but the nutrient ratios are still in the range where phytoplankton blooms and water quality conditions have the potential to worsen due to additions of either nutrient, depending on the magnitude and timing of the addition. Prior to the 2007 opening, the shallow N/P ratio was 15.7, while after the opening the ratio increased to 22.1. As a rule of thumb, if the ratio between nitrogen and phosphorus is greater than 16, phosphorus is the nutrient limiting phytoplankton production.[24] However, growth in systems close to 16 can shift back and forth depending on the forms of the nutrients (*e.g.*, inorganic forms are more quickly utilized).[25] The increase in chlorophyll-*a* concentrations in Cedar Pond after the 2007 opening suggest that both nitrogen and phosphorus management would be required to control eutrophication under current conditions.

III.B. Cedar Pond Sediment Nutrient Regeneration (Cores and Incubation)

Review of the water quality data shows that the sediments in Cedar Pond are a significant contributor to the nutrients in the pond and consume significant amounts of dissolved oxygen during summer. In order to quantify these contributions directly and evaluate potential future management options, CSP/SMAST staff collected and incubated sediment cores at various depths around the pond to evaluate nutrient regeneration from the sediments under oxidizing and reducing conditions.

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[23] *e.g.,* Eichner, E.M. 2004. Flax Pond Water Quality Review. Final Report to the Town of Harwich. Cape Cod Commission. Barnstable, MA.

[24] Redfield, A.C., B.H. Ketchum, and F.A. Richards. 1963. The influence of organisms on the composition of sea-water, in The Sea, (M.N. Hill (ed.). New York, Wiley, pp. 26-77.

[25] USEPA. 2001. Nutrient Criteria Technical Guidance Manual. Estuarine and Coastal Marine Waters. EPA-822-B-01-003.

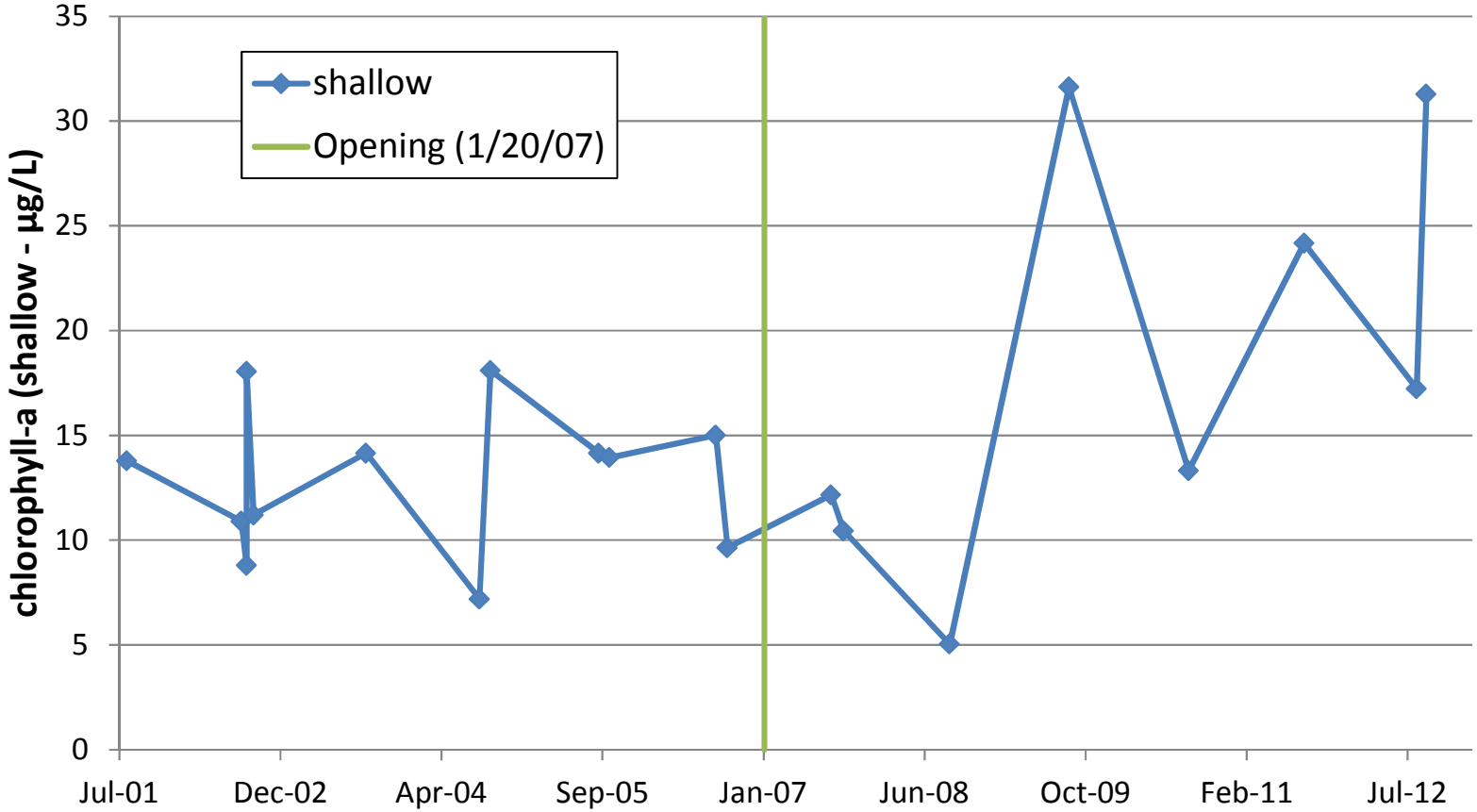

Figure 11. Chlorophyll-*a* in Cedar Pond: Pre- and Post-Jan 2007 opening.
Average surface concentrations during August/September increase from 12.9 µg/L to 18.2 µg/L before and after the 2007 opening, respectively. August and September concentrations are used because most pre-opening concentrations are from the PALS snapshots which always took place in August/September. The increase is not statistically significant at the $\rho<0.05$ level. Surface concentrations demonstrate greater fluctuation post-opening, which is consistent with impaired ecosystems.

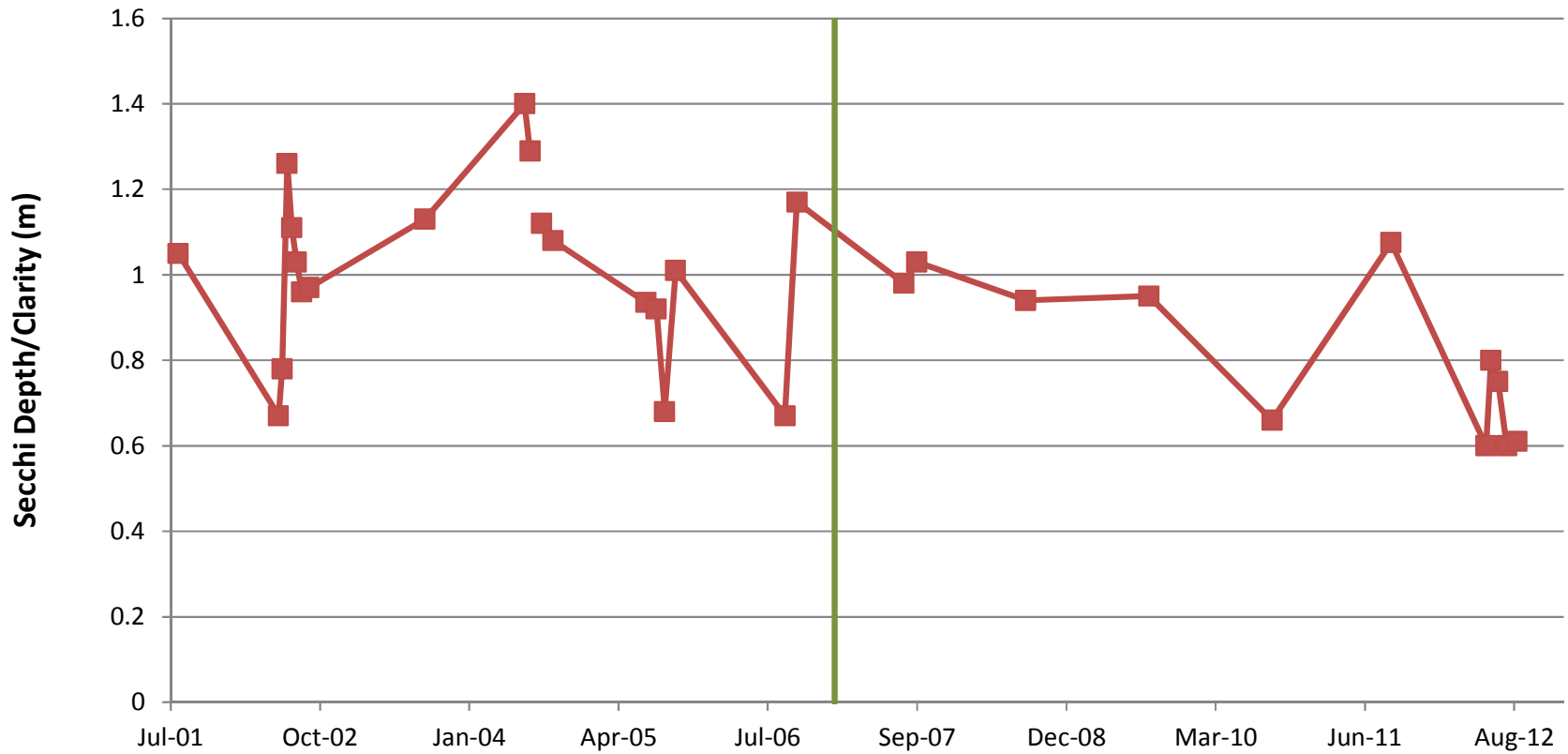

Figure 12. Secchi Depth/Clarity in Cedar Pond: Pre- and Post-Jan 2007 opening.
Average Secchi clarity has significantly ($\rho<0.01$) decreased after the January 2007 opening. Pre-opening clarity averaged 1.01 m and 30% of total depth, both of which are representative of impaired conditions. Post-opening clarity decreased to an average of 0.82 m and 23% of total depth. Green line indicates the January 20, 2007 opening.

Sediments are an active repository of past nutrient loadings to surface waters. Inorganic forms of nutrients (*e.g.*, nitrate-nitrogen or ortho-phosphate) enter the pond surface waters via surface and groundwater inflows from the watershed. These inorganic forms are usually quickly utilized by phytoplankton living in the pond and, as such, are converted into less bioavailable organic forms. Phytoplankton are subject to grazing herbivores, which release portions of the nutrients that were in the phytoplankton back into the water column. However, a significant amount of the phytoplankton "particles" settle to the bottom and are incorporated into the sediments, where decomposition occurs regenerating some of the nutrients in the same inorganic bioavailable nutrient forms that originally entered the pond.

In general the fraction of the phytoplankton/organic nutrients that reaches the sediments is based on the residence time of water in the system and the velocity which the water is exchanged. Once the nutrients settle to the sediments, the organic matrix they are bound in will be subject to bacterial degradation, chemical transformations, and, in oxygenated basins, invertebrate resuspension. These sediment actions can release inorganic or dissolved organic nutrient forms back into the water column or result in burial and removal from the water column cycle. The cumulative impact of all these interactions is complex, so the direct measurement of sediment-water column exchange helps to understand current and future contributions by the sediments to pond nutrient budgets.

Sediment cores were collected from Cedar Pond by SCUBA divers at eight locations on July 26, 2012 (Figure 13). Core locations were selected to represent the various depths and areas (*e.g.*, under the power lines) within Cedar Pond. Cores were transported and incubated under *in situ* conditions to determine both aerobic and anoxic nutrient regeneration. Prior to incubation bottom water was collected from the Pond at each core site and filtered to replace the headspace water over the sediment cores During incubation, time course measurements of total dissolved nitrogen, nitrate+nitrite, ammonium, inorganic phosphorus, and total dissolved phosphorus were made. During coring events standard handling, incubation, and sampling procedures were followed based on the methods of Jorgensen (1977), Klump and Martens (1983), and Howes (1998). Rates of sediment nutrient release were determined from linear regression of analyte concentrations through time. All analyses were completed at the Coastal Systems Analytical Facility, School for Marine Science and Technology (SMAST), University of Massachusetts Dartmouth using standard methods for analysis and sediment geochemistry.

Sediment incubation results showed nutrient regeneration is largely depended on aerobic *vs.* anaerobic conditions, location and water depth of the cores site within the Pond (Table 2). All cores had sediment oxygen demand rates that are among the highest recorded for southeastern Massachusetts coastal basins. The highest demand was found in sediments under the power lines (Core #3). The deepest core locations (Cores #1 & 2) were anaerobic at the time of collection, so sediment oxygen demand could not be determined.

Sediments generally released ammonia-nitrogen at similar rates under aerobic or anaerobic conditions. The largest release of nitrogen was from the shallow, eastern portion of the pond (Cores #5 & 6). The aerobic nitrogen release rate (118 mg $N/m^2/d$) in these cores is slightly higher than the release measured by the MEP (80 mg $N/m^2/d$) in the Rock Harbor

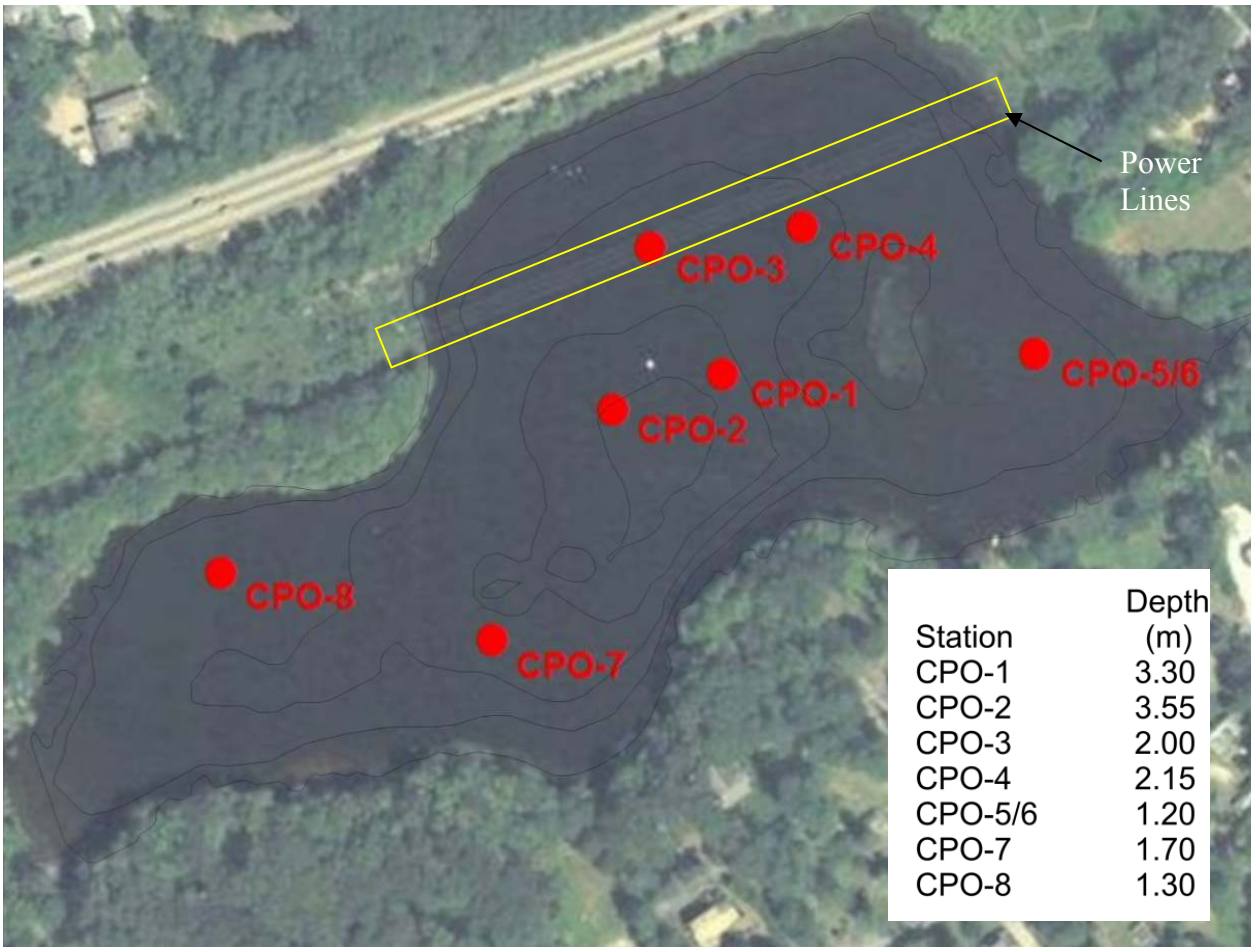

Figure 13. Cedar Pond Sediment Core Locations.
Sediment cores were collected by SCUBA divers from eight locations on July 26, 2012 from the locations indicated by the red dots. Cores were incubated under using standard procedures, including aerobic, chemical transition, and anoxic conditions. Water depths at core collection sites are shown in the associated table.

Table 2. Cedar Pond Sediment Core Analysis.

Sediment water column exchange of nutrients and oxygen uptake under aerobic and anaerobic conditions. Core sites locations are shown in Figure 13. All values are release (+) or uptake (-) in milligrams per square meter per day. Cores were incubated at *in situ* water temperatures at the time of collection.

Core Sites	Water Depth	Sediment O2 Uptake		Nitrogen							
				Aerobic						Anaerobic	
				Ammonia Nitrogen		Nitrate Nitrogen		Total Nitrogen		Ammonia Nitrogen	
		(mg O2 m-2d-1)		(mg N m-2d-1)		((mg N m-2d-1)		(mg N m-2d-1)		(mg N m-2d-1)	
	(meters)	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
1,2	3.3-3.55	Anaerobic		43.0	10.8	7.9	2.2	28.3	9.9	47.8	12.0
3	2 - directly under wires	-4,370	335	58.5	7.9	-0.1	0.0	50.4	6.8	65.0	8.7
4	2.15	-3,440	243	75.3	7.3	0.1	0.0	84.6	8.9	83.6	8.1
7,8	1.3-1.7 W	-2,380	152	65.9	3.0	-0.2	0.3	57.0	6.7	73.2	3.4
5,6	1.2 E	-2,380	137	104.5	5.1	1.0	0.2	118.0	13.9	116.1	5.7

		Phosphorus					
		Aerobic		Chemical Release		Anaerobic	
Core Sites	Depth	Total Phosphorus		Total Phosphorus		Total Phosphorus	
		(mg P m-2d-1)		(mg P m-2d-1)		(mg P m-2d-1)	
	(meters)	Mean	s.e.	Mean	s.e.	Mean	s.e.
1,2	3.3-3.55	18.6	1.9	9.3	0.8	3.9	0.7
3	2 - directly under wires	9.8	4.1	11.7	1.3	2.3	1.5
4	2.15	-2.1	1.5	7.8	1.0	1.4	1.7
7,8	1.3-1.7 W	-0.8	1.0	8.4	0.6	5.3	0.7
5,6	1.2 E	-3.0	2.5	11.2	1.6	6.8	1.5

basin.[30] These rates are both very high for natural systems (*i.e.*, not associated with concentrated contamination/disposal sites). Sediment oxidation-reduction status is more important for phosphorus binding/release, so considerable differences were observed under anaerobic *vs.* aerobic conditions. Phosphorus release under aerobic conditions is controlled by available sediment ferric iron, with significant release due to chemical changes at the onset of anaerobic conditions. This transition phase is generally dominated by rapid reduction and solubilizing of iron, breaking iron/phosphorus bonds and liberating of phosphorus. This phase is typically very rapid with a pulse-like release of phosphorus that lasts for many days and is followed by a relative constant release due to anaerobic degradation of organic matter. In Cedar Pond, the shallower sediments (<2 m) generally absorb phosphorus under aerobic conditions with the exception of the sediments under the power lines (Core #3), which had high P release rates. During the chemical release transition phase, all cores released phosphorus at similar rates (7.8 to 11.7 mg $P/m^2/d$). During the subsequent anaerobic phase, all cores continued to release phosphorus, but at a reduced rate (1.4 to 6.8 mg $P/m^2/d$). These transitions are consistent with other sediment studies and biogeochemical theory.

Integration of these results with pond oxygen, nitrogen and phosphorus cycling must include information on water depth at the core locations, the nutrient content of pond water column, the settling rate of particulate nutrients, and oxygen distribution in pond bottom waters. Combining all this information allows determination of the level of net uptake and release of nutrients from the overall sediment component of the pond. As indicated in Figure 8, oxidation-reduction status of the pond water column is relatively stable during the early summer (June/July) then enters a period (late July through early September) where conditions are much more variable. The longer term, historic dissolved oxygen data show that the early summer water column is usually aerobic to ~2 m depth and anaerobic in the deepest portion. In later summer, the anaerobic conditions rise above the 2 m depth. Sediments (and the cores) collected near this depth are in a redox transition zone during the summer. Based on these readings and the earlier, historic data, project staff grouped the areas of the pond sediments by the water depths presented in Table 2 **(**Figure 14). Based on the oxygen distribution and sediment regeneration data, it appears that the sediments throughout the pond are a net sink for phosphorus during both the early and late summer, but a net source of nitrogen during the early summer and a net sink of nitrogen during the late summer (Figure 15).

III.C. Cormorants

As mentioned in Section II, electrical lines were extended over Cedar Pond after portion of the pond was filled to construct Route 6. These electrical lines are parallel to Route 6 and are strung over approximately 220 m of the water sheet. The lines have become a favorite nightly resting spot for cormorants during the summer. Over the past two decades, the Town of Orleans has tried a number of tactics to scare the birds away.[31] More recently, volunteers have counted the birds in order to provide some insights into their likely contributions to the nutrient loads and water quality impairments of the pond.

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[30] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2007. Rock Harbor MEP Report.

[31] *e.g.*, "Cormorants are back – it's a blast. Orleans to use rockets to scare birds from Cedar Pond. May 1, 1999. Cape Cod Times.

Figure 14. Sediment Areas used to determine whole pond sediment regeneration rates.
Apportionment of pond bottom areas used to estimate whole pond sediment regeneration based on the sediment regeneration rates in Table 2. Red area has depths greater than 3 m and is anaerobic throughout the summer. Orange area is western portion of the pond from the shoreline out to the 2 m depth contour. Purple area is eastern portion of the pond from the shoreline out to the 2 m depth contour. Green area is the pond bottom under the power lines and the black area is depths between 2 and 3 m.

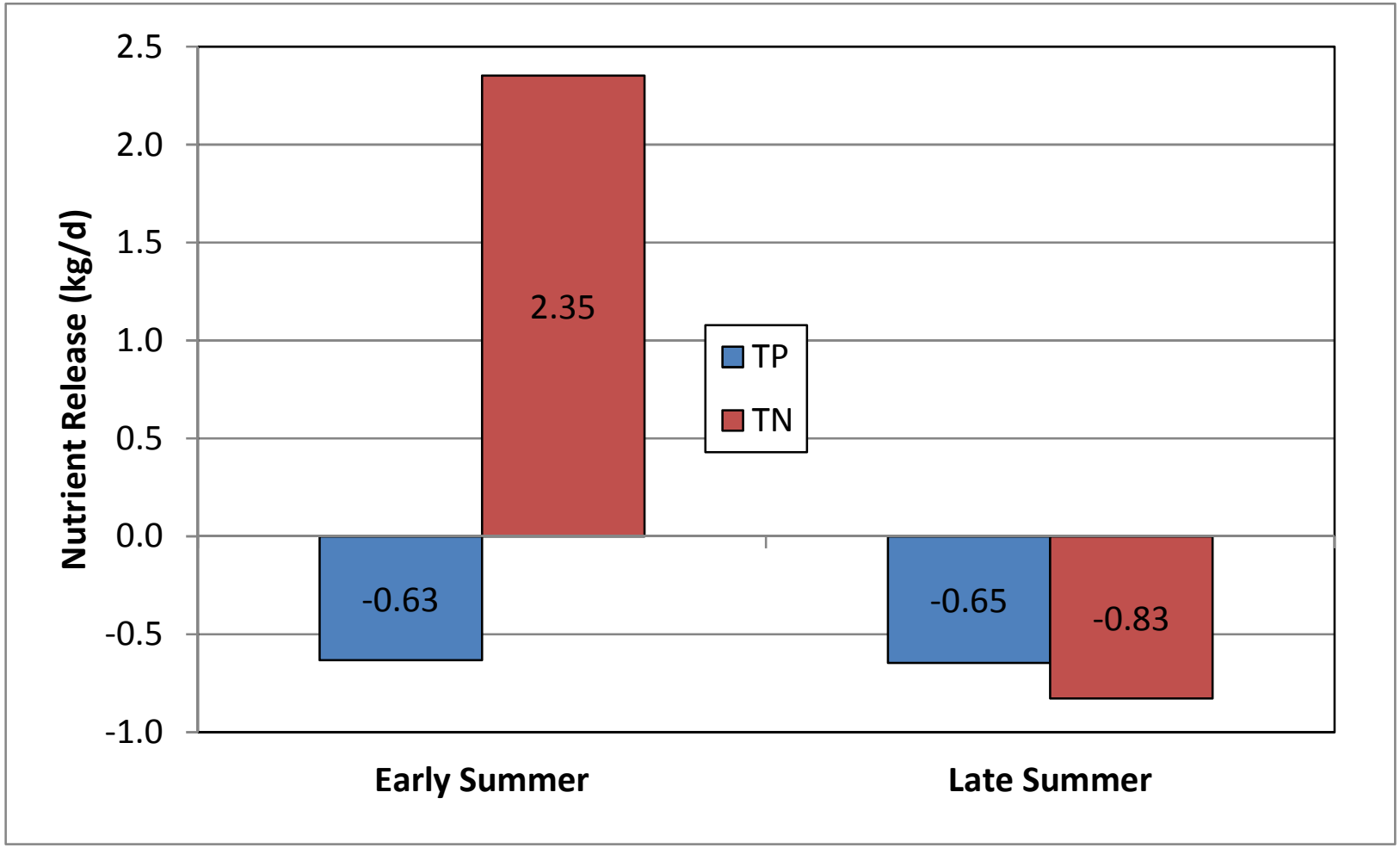

Figure 15. Whole Pond Net Sediment Nutrient Release or Uptake (Summer 2012)
Based on sediment core incubation and collected and historic water quality data, Cedar Pond sediments are a net sink for phosphorus throughout the summer, removing 0.63 to 0.65 kg/d. During the early summer, Cedar Pond sediments are a significant source of nitrogen, adding 2.35 kg/d. Later in the summer, the sediments become a net sink and remove 0.83 kg/d.

During April through September over both 2011 and 2012, volunteers have regularly counted birds, *e.g.* double-crested cormorants (*Phalacrocorax auritus*), on the electrical lines over Cedar Pond. All counts occurred at dusk. Highest counts occurred in August and September, although birds were noted on almost all census dates (Figure 16). Highest average counts were in August and September with the highest daily count of 600 on October 5, 2012. Counts during November 2012 showed that the flocks had dwindled to a few individuals, due to migration. During both years, double-crested cormorants (DCC) counts tripled in late July and then were stable into August and September. Counts during 2012 were much higher than those observed in 2011.

These counts are consistent with DCC behavior. DCC are migratory, typically arriving in Massachusetts in late March/early April and with most leaving the state in late September/early October.[32] DCC generally congregate where food is readily available, which is near aquatic systems as their diet consists of a variety of fish and crustaceans. Since they often congregate in large groups, their excrement can be appreciable and a number of studies have documented water quality impacts from individual colonies[33] and/or the impacts of colonies on soil conditions.[34] However, direct deposition of excrement in surface waters has not been widely researched.

In the interest of developing an estimate of the potential nutrient loading to Cedar Pond from the roosting DCC population, project staff reviewed available literature to develop a range of nitrogen and phosphorus loads. Wires *et al*. (2001) determined that the body mass of DCC range between 1.2 and 2.5 kg and that daily droppings are 2.25% of the body mass. Marion, *et al.* (1994) also found a similar daily dropping rate of 27 g and droppings were 3.28% N and 14.32% P. Using these percentages, the daily nitrogen load per bird ranges between 0.89 and 1.85 g, while the daily phosphorus load ranges between 3.87 and 8.06 g. Using the Cedar Pond DCC counts from 2012, which are the highest recorded year, the DCC seasonal contribution would be between 39 and 81 kg of nitrogen and between 169 and 352 kg of phosphorus. Since the DCC population nearly triples in August/September, as compared to June/July, N and P loads from the DCC population would also triple during this time. These loads do not account for factors such as volatilization of ammonia, but as it is highly soluble, loss through this mechanism is likely small.

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[32] Wires, L.R., F.J. Cuthbert, D.R Trexel, and A.R. Joshi. May, 2001. Status of the Double-Crested Cormorant (*Phalacrocorax Auritus*) in North America. University of Minnesota. Prepared under contract with US Fish and Wildlife Service.

[33] *e.g.* Klimaszyk, P. 2012. May a cormorant colony be a source of coliform and chemical pollution in a lake? *International Journal of Oceanography and Hydrobiology.* 41(*1*): 67-73.

[34] *e.g.* Breuning-Madsen, H., C. Ehlers-Koch, J. Gregersen and C.L. Løjtnant. 2010. Influence of perennial colonies of piscivorous birds on soil nutrient contents in a temperate humid climate. *Danish Journal of Geography.* 110(*1*): 25-35.

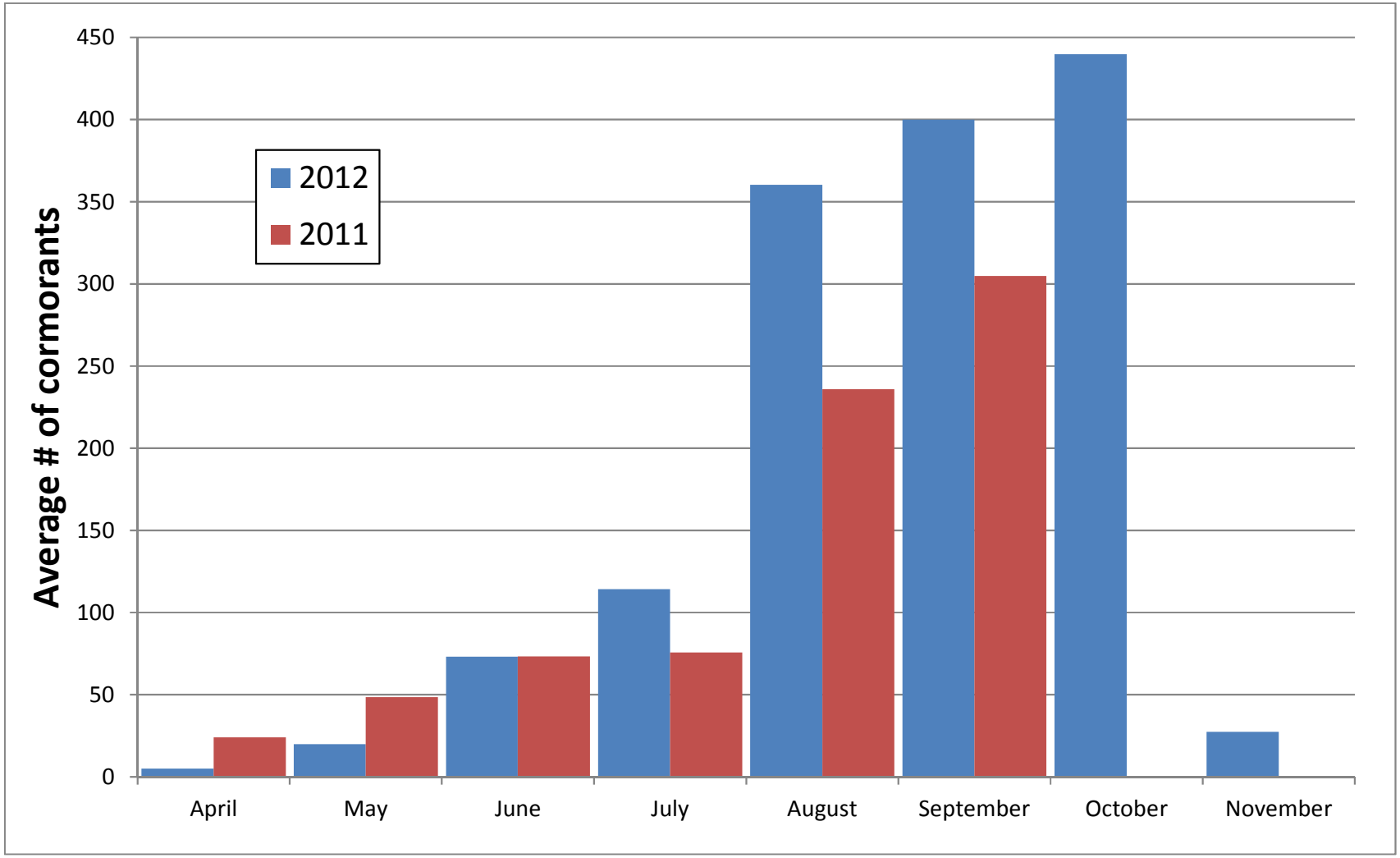

Figure 16. Cormorants on Cedar Pond Power Lines (2011, 2012)
Volunteers counted cormorants roosting on the power lines over Cedar Pond on nearly a daily basis between April and September during 2011 and between April and November during 2012. Daily averages are shown by month. Daily counts show a significant increase during both years during late July.

The August and September population increase has significant water quality impacts. The 2012 water quality data shows that total nitrogen and total phosphorus mass in the pond both nearly double between the July 11 and August 7, with total phosphorus mass increasing to more than triple the June 20 mass (Figure 17). Similarly the flow-adjusted increase in total nitrogen exported from Cedar Pond to Cedar Pond Creek increases by 47% between July and August and the total phosphorus increases by 69% in the same time period (Table 3). Consideration of these measurements suggest that the sediments contribute nutrients to the water column during the early summer and then the DCC population increase significantly adds to the nutrient mass in the pond in the later summer. Both sediments and the cormorants will need to be addressed for a successful water quality restoration strategy.

Table 3. Monthly Stream Export of TN and TP from Cedar Pond (Summer 2012)

Month	Average Outflow	Total Phosphorus Outflow	Total Nitrogen Outflow
	m3/d	kg/d	kg/d
June	3,511	0.16	2.39
July	3,440	0.35	3.93
August	4,196	0.72	7.06
September	3,303	0.61	4.19

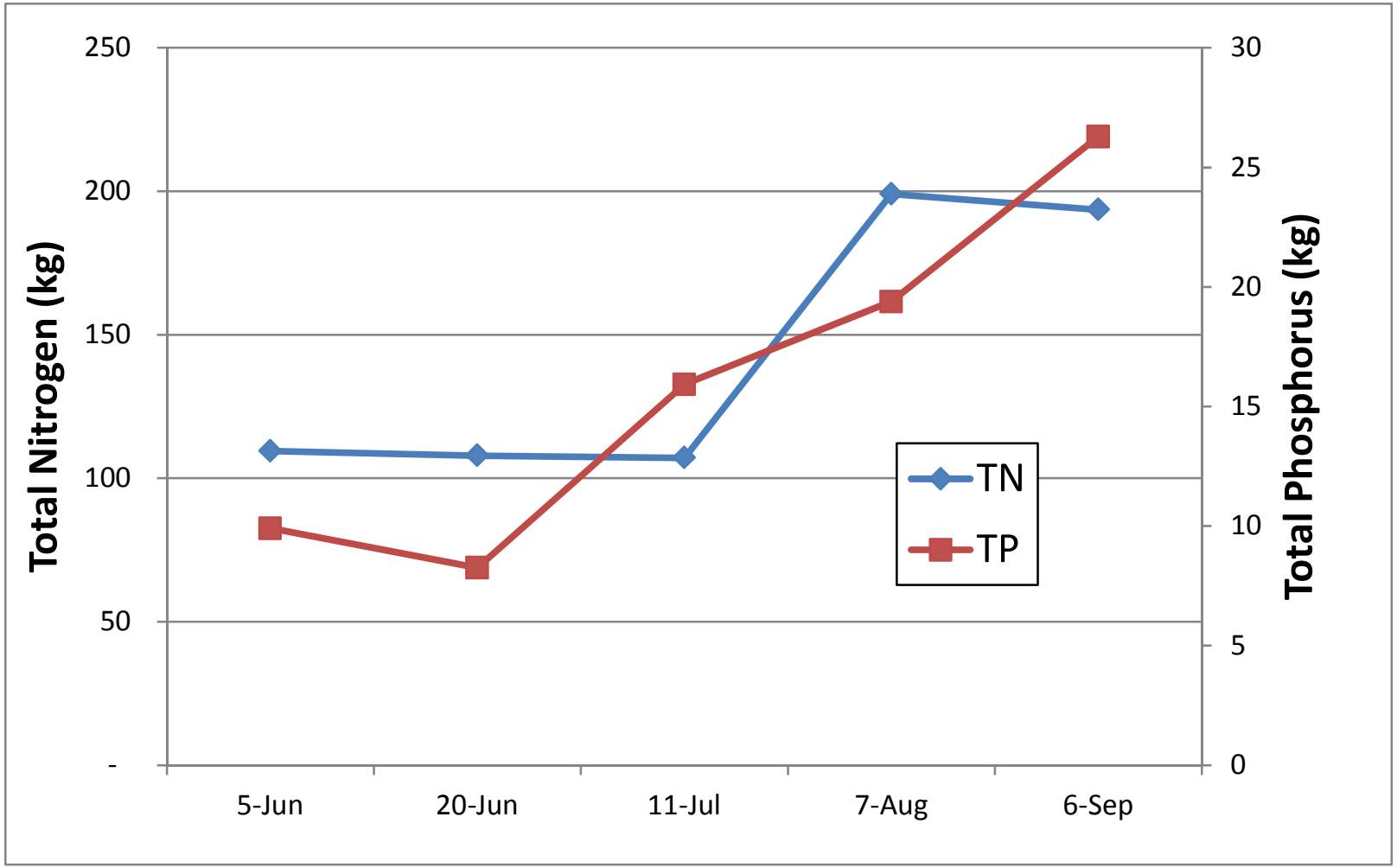

Figure 17. Mass of Total Nitrogen and Total Phosphorus in Cedar Pond during summer 2012
Total nitrogen (TN) is relatively stable during the June and July sampling runs, but increase by 80% between July 11 and August 7. The timing of this increase matches the increase in the cormorant population roosting on the power lines strung across Cedar Pond. Total phosphorus (TP) nearly doubles between June 20 and July 11, which is likely due to decreased dissolved oxygen throughout the pond, and then rises 22% between July 11 and August 7 and then another 36% between August 7 and September 6. TN and TP mass are based on collected water quality samples and bathymetric volumes.

III.D. Cedar Pond Water Levels and Atlantic White Cedar Swamp

Concerns were expressed during the initial scoping of this project that the increased tidal interaction between Rock Harbor and Cedar Pond would increase salinity within the pond increasing the likelihood that the Atlantic white cedar swamp that is located along the western edge of Cedar Pond would periodically receive salt water and be harmed. While there are multiple scenarios for salt water exposure (*e.g.*, storms, extreme tides, spray), the close proximity of the swamp to what is now a marine basin is a legitimate issue. Although this was not a funded task in the project, project staff reviewed the elevations in the area to assess whether exposure to salt water was significant concern.

The Atlantic white cedar swamp is located to the west of an abandoned road, Cedar Pond Road, which is adjacent to the Cedar Pond (Figure 18). The road runs from Locust Road to an overgrown blacktop area within the NStar power lines' right of way. Cedar Pond Road appears to have been constructed with a ditch along the western/swamp side of the road and its construction may have included fill across the edge of Cedar Pond to provide a level surface for the road. The 1947 aerial photograph (see Figure 2) shows that Cedar Pond Road connected Locust Road and Rock Harbor Road prior to the construction of Route 6. Currently, portions of the road surface are intact, but the section abutting Cedar Pond is significantly degraded. There are two culvert pipes that run under the road, a northern culvert pipe that is rusted and partially exposed to the surface amidst broken blacktop and a southern culvert pipe, one end of which can be seen in Cedar Pond.

In order to review the potential interactions between Cedar Pond and the Atlantic white cedar swamp, CSP-SMAST staff collected elevation data in the area of the northern pipe for comparison to Cedar Pond water level elevations. The bottom elevation of the Cedar Pond end of this pipe is 0.91 m, only slightly lower than the end within the swamp, which is 1.01 m (both elevations NAVD88). The southern pipe is submerged in Cedar Pond at one end and the swamp end of the pipe could not be located. At the time of the site visit, which was close to low tide, a small flow of water was discharging through the northern pipe from the swamp side of the road toward Cedar Pond.

In order to evaluate the potential for Cedar Pond water, which is currently saline, to discharge into the swamp, project staff reviewed the water level data collected by the moorings placed in the pond during 2012 and by the stream gauge in Cedar Pond creek. As mentioned previously, water levels within the pond were recorded every 15 minutes June 5 to September 6. Water level over the pond sensor was found to fluctuate between 0.91 m and 1.48 m with an average of 1.16 m (Figure 19). The stream gauge was in place from June 5 to December 18, 2012 and recorded water levels every 10 minutes. Water level elevations at the stream gauge location averaged 1.14 m with a tidal height range of 0.99 m (dry) to 1.68 m (elevations in NAVD88). These water levels appear to be equivalent to those collected in 2008 for ACRE (Kelley, 2010).

Comparison of Cedar Pond water level data and the stream gauge/tidal gauge water level data show that Cedar Pond is very weakly tidal, as seen by the tidal signal of a few centimeters corresponding to the much larger tidal signal at the creek gauge. By far the major water level

Figure 18. Cedar Pond Road and Adjacent Atlantic White Cedar Swamp
Cedar Pond Road separates Cedar Pond from an adjacent Atlantic white cedar swamp. The road is in poor condition and has a ditch along the swamp side. Two pipes appear to connect the ditch to Cedar Pond. The southern pipe is submerged in Cedar Pond and could not be located on the swamp side. The northern pipe is degraded, but was observed to be carrying water from the swamp during the site visit, indicating a pathway for flow into the swamp if the hydraulic gradient were reversed.

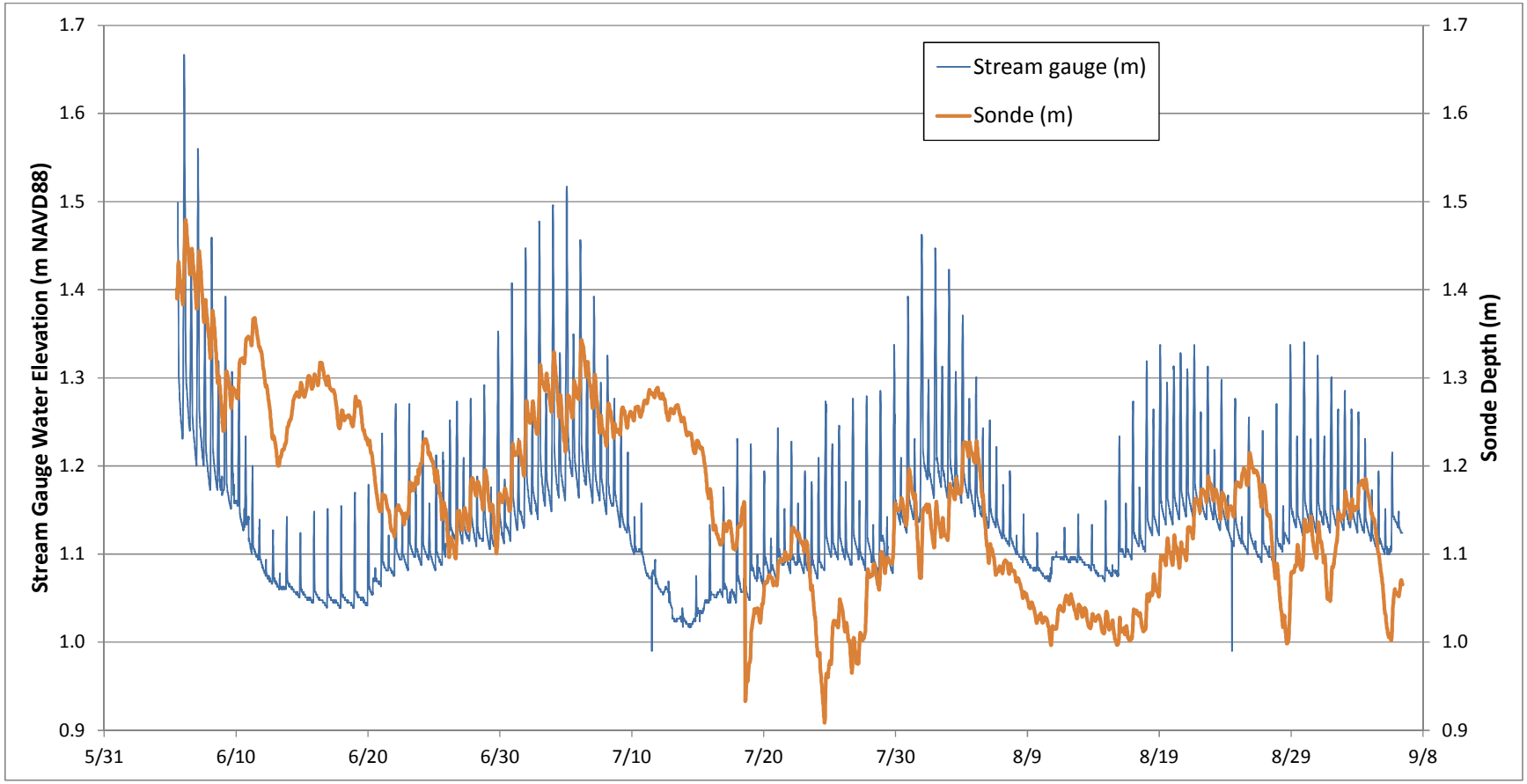

Figure 19. 2012 Tidal Elevation and Depth in Cedar Pond
Water elevations at the Cedar Pond Creek gauge and the depth of Cedar Pond during 2012 are compared. Stream gauge elevations are recorded in meters using the NAVD88 standard, while water depths are in meters, but are not corrected to elevations. Gauge water level elevations averaged 1.14 m with a tidal height range of 0.99 m (dry) to 1.68 m (all data in NAVD88). In-pond sensor depth readings fluctuated between 0.91 m and 1.48 m with an average of 1.16 m. Comparison of the ranges shows that water levels in Cedar Pond generally follow the weekly/monthly trends of the tides in the creek, but do not follow the daily tidal fluctuations. The water level readings also show that there are other factors (likely evapotranspiration) that cause the pond level to drop during rising tidal trends.

changes within the pond tend to follow the larger monthly fluctuations of the tides levels, but do not fluctuate as significantly as the daily tidal fluctuations. The relatively small daily response in Cedar Pond is due to the smaller tidal inflow volume compared to the volume of the pond. The comparison also shows that there are periods where the Cedar Pond water levels are dropping when tidal trends are rising. These periods are likely due to enhanced evapotranspiration transferring water to the atmosphere.

These water level readings also show that water levels in Cedar Pond regularly exceed the elevations that would allow salt water to discharge into the adjacent Atlantic white cedar swamp. Field observations suggest that most to the water discharging toward the swamp would fill the ditch between Cedar Pond Road and the swamp, but it is unclear if there is sufficient flow to impact the swamp plants or the underlying hydrology. Field observations of the plants in the area seem to suggest that salt water is not impacting the swamp; none of the plants seemed to show obvious distress. Groundwater elevations in the swamp may be preventing salt water intrusion and observations during summer conditions may provide other insights. Potential management options to prevent salt water impacts on the swamp could include raising the height of the road or altering the historic pipes to ensuring that flow is only toward Cedar Pond.

IV. Discussion of Management Concerns/Development of Management Recommendations

Management of water quality in Cedar Pond will require the selection of water quality goals. Among the key questions in setting those goals is the salinity regime that is desired for the pond. Selection of this regime will determine which additional steps are appropriate for restoring water quality in the pond. As discussed above, Cedar Pond has been a freshwater pond, a brackish pond, and recently has become a salt pond. Attaining and maintaining each of these conditions has implications for the management steps that will be required, as well as associated ecological, regulatory, and monetary impacts. Consideration of these impacts is discussed in this section.

IV.A. Cedar Pond Salinity

Improving water quality conditions in Cedar Pond favors returning it to a brackish condition. In its current condition as a salt pond, water quality conditions in Cedar Pond are significantly degraded (Table 4). Current conditions include:

a) significant sediment oxygen demand,
b) anoxic bottom waters with hydrogen sulfide,
c) no attenuation of watershed nitrogen, hence additional nitrogen exported to already impaired Rock Harbor,
d) threat of salinity intrusion into Atlantic white cedar swamp,
e) poor water clarity,
f) large phytoplankton blooms, and
g) no herring run.

Most of these current conditions are worse than when the pond was brackish (pre-2007 opening). It should be noted, however, that water quality conditions when the pond was brackish (pre-2007) were also significantly degraded (see Table 4). Conditions in the brackish salinity regime included:

a) significant sediment oxygen demand,

Table 4. Cedar Pond Water Quality Conditions Review Summary			
Issue	High Salinity (Current Conditions)	Brackish (pre-2007)	Fresh (~1947)
Salinity (ppt)	23-24	1-4[a]	0
Salinity Stratification	none[b]	yes	none
Pond Nitrogen Removal	none/net increase[c]	58%[d]	unknown
Total N mass in pond	83 kg surface[e] 109 kg total	60 kg surface 99 kg total	unknown
Phosphorus sediment release/export	Sediments P sink	unknown[f]	unknown
Total P mass in pond	8.4 kg surface[g] 12.2 kg total	7.6 kg surface 16.5 kg total	unknown
Clarity	0.82 m[h]	1 m	unknown
Phytoplankton/Chlorophyll	Higher, and increasing[i]	High, but stable	unknown
Dissolved oxygen: bottom waters	Anoxic >2.5 m[j]	Anoxic >2 m	unknown
Dissolved oxygen: surface waters	Supersaturated[k]	Atmospheric equilibrium	unknown
Herring suitability	Salinity too high	Less than optimal	unknown
Meet MassDEP Water Quality Standards?	No	No	unknown
OVERALL ASSESSMENT	Significantly Degraded	Significantly Degraded	unknown

Notes:

a. Brackish conditions will largely be determined by how much interaction with tides is allowed, 4 ppt is selected as an upper range given its previous permitted use in a restoration project on Cape Cod
b. Current conditions show no significant salinity stratification; pre-2007 opening data average 7.7 ppt difference between surface and deep salinity readings, while post-opening average 2.7 ppt difference
c. Cedar Pond is currently not attenuating watershed nitrogen during the summer and is adding additional nitrogen to the export waters from sediment regeneration and seasonal cormorant populations (MEP N export 1.09 kg/d; June, July, August, and September 2012 N export were 2.39, 3.93, 7.06, and 4.19 kg/d, respectively); peak export in August appears to be due to roosting cormorant increase
d. MEP Rock Harbor assessment (Howes, *et al.*, 2007) determined 58% nitrogen attenuation in Cedar Pond due to measurements in Cedar Pond Creek.
e. Summer average N mass in pond has not increased, but more is in available in surface waters
f. Sediment incubation was not conducted under pre-2007 conditions; whole pond functions as P sink during summer
g. Decrease in average P mass in pond due to increased dissolved oxygen; surface mass the same (large increase in P export during late summer due to roosting cormorant increase)
h. Clarity/Secchi depth June-September averages from pre- and post-2007 opening; significantly lower ($\rho<0.01$) after opening
i. Chlorophyll-a concentration averaged 18.2 µg/L after the 2007 opening and is trending upward; 12.9 µg/L pre-2007 opening and was relatively stable
j. Post-2007 opening increases oxygen: consistently anoxic deeper than 2.5 m throughout summer (June – September); consistently anoxic deeper than 2 m throughout summer pre-2007
k. Post-2007 opening increase in oxygen appears to be due to greater phytoplankton growth and photosynthesis increases dissolved oxygen concentrations above equilibrium with atmospheric concentrations (surface concentrations average 112%); pre-2007 opening concentrations averaged 98% saturation

b) anoxic bottom waters,
c) poor water clarity, and
d) large phytoplankton population.

Cedar Pond in this condition did, however, provide nitrogen attenuation of watershed loads (58% reduction based on MEP measurements) and a degraded, but functioning, herring population (personal communication, Judy Scanlon). Based on a goal of improving water quality in Cedar Pond, returning the pond to more brackish conditions offers more benefits than maintaining current conditions, although additional actions would be required to sustain a moderate to high quality habitat.

Returning the pond to a completely freshwater system would seem to present more hurdles than returning it to a brackish condition. Making the pond completely fresh would require preventing any tidal interaction or storm entry of salt water. Since the pond has not been completely fresh during the period when water quality monitoring has occurred, some of the potential impacts are unknown (see Table 4). Spawning herring, larvae, and juveniles have an optimal salinity range of 0-5 ppt,[38] so a brackish or freshwater system in this range would restore habitat for herring spawning. But creating a freshwater system would require creation of a pathway for spawning fish to reach Cedar Pond, such as a fish ladder or weir that prevents tidal water, but allows herring passage. If maintaining the upper portions of the salt marsh in Rock Harbor is also a goal, than reconstruction of the dike would not be a desirable solution. Eliminating surface water discharge from the pond via Cedar Pond Creek would also tend to increase the residence time of water and nutrients in the pond, which would likely increase nitrogen and phosphorus concentrations and mass in the pond. Without further mitigating steps, this might worsen water quality conditions in the pond. With these considerations in mind, it is recommended that the salinity goal for Cedar Pond should be to return it to a brackish condition. Based on the optimal herring salinity, it is further recommended that the salinity range be 1-4 ppt.

Achieving a brackish salinity of 1-4 ppt in Cedar Pond will require steps to restrict tidal interactions with Cedar Pond Creek and Rock Harbor. Review of the tidal elevations approaching Cedar Pond show that maximum tide height was 1.68 m (NAVD88) and a spot elevation of the pond level at low tide was 1.1 m. As a first step toward restoring brackish conditions in the pond, it is recommended that the town reinstall boards in the Cedar Pond outlet structure. No changes in the structure are recommended initially, but further action will be likely to achieve a stable salinity and allow fish passage. However, initially reinstalling the boards, while monitoring the elevation and salinity will inform any future the long-term structural design. The boards need to be installed at a height that will restrict the tidal influence to only the highest of the tides. It is further recommended that continuous water level and salinity recording devices be placed in Cedar Pond and at the MEP Cedar Pond Creek location to optimize the board elevation.

Based upon similar actions in other salt ponds, it is expected that re-establishing the tidal restriction will result in a gradual freshening of the upper water column in Cedar Pond, with a

[38] Klauda, R.J., S.A. Fischer, L.W. Hall and J.A. Sullivan. 1991. Alewife and blueback herring: *Alosa pseudohaerengus* and *Alosa aestivalis*. In: S.L. Funderburk, J.A., Mihursky, S.J. Jordan and D. Riley, eds., Habitat requirements for Chesapeake Bay living resources, 2nd edition, US EPA, Annapolis, MD, pp. 10-1 to 10-29.

slower freshening of the saltier bottom waters. In order to exchange the bottom waters and allow the deeper waters to freshen, it is recommended that the town work with CSP-SMAST staff to develop and implement a plan to pump deeper, high salinity water out of Cedar Pond. Project staff proposes that this be done over one or two winters to minimize short-term aesthetic impacts and any nutrient stress on Rock Harbor. The pump would operate only during low tide and discharge the water through the existing Cedar Pond Creek outlet. It is approximately 130 m (~430 ft) from the pond outlet to the deepest portion of the pond. This length of hose would be required with a pump sufficient to remove at least 200 gallons per minute (gpm). This rate of pumping approximates the groundwater input into the pond and should allow the salt water to be replaced with freshwater without lowering the level the pond significantly and exposing the nearshore habitats to drying stress. Pumping impacts would need to be monitored and adjusted to ensure stable pond surface elevation. At a 200 gpm pumping rate for a 12 hour tidal cycle, this approach would require approximately one month to exchange the volume greater than 2 m in depth or approximately three months to exchange the volume greater than 1 m. Monitoring during the initial phase and then subsequent monitoring prior to pumping the next winter would allow evaluation of whether pumping would be required in a second winter. Use of larger diameter hoses (1 to 1.5 in) and/or a discharge pipe diffuser would minimize/eliminate downstream scour effects. Preliminary costing of implementing such an approach be less than $15,000 including the purchase of a new pump and hoses, gas to run the pump, personnel costs to tend to the pump, and continuous water level/salinity sensors in the pond and creek. Additional cost savings may be possible through the use of existing town equipment and personnel. A firmer cost estimate can be developed following consultation with town staff.

It is unclear at this point what the full extent of regulatory permits would be required to pursue this course of action, but additional costs may be associated with preparing materials for permitting agencies and securing any permits. Among the known concerns that will need to be addressed are the Wetlands Protection Act (through the town Conservation Commission) and the Inner Cape Cod Bay Area of Critical Environmental Concern (ACEC).[39] Additional considerations may involve the TMDL provisions of the Clean Water Act, the Massachusetts Environmental Policy Act (MEPA) and the Cape Cod Commission. CSP-SMAST staff would be available to assist the town in working out the details associated with implementing this approach.

IV.B. Controlling Cormorant Population on Cedar Pond Power Lines

Changing the salinity regime within Cedar Pond is the first step toward water quality restoration, but it will be insufficient on its own to restore water and habitat quality in the pond. Additional management steps are necessary to restore the water quality and habitat in Cedar Pond. A key step among these needs is reducing or eliminating the large cormorant roosting that occurs in August and September.

As mentioned above, the impact of the cormorant population on the power lines that cross Cedar Pond has been a town concern for at least 20 years. Town staff and OWQTF members have regularly cited difficulties engaging NSTAR, the owner of the power lines, in cormorant management discussions. Water quality data and sediment oxygen demand and phosphorus release collected during this project support the contention that the cormorants are

[39] http://www.mass.gov/dcr/stewardship/acec/acecs/l-innbay.htm

contributing large amounts of organic matter and nutrients to the pond, mainly during the maximum roosting population period from August through September (see Figure 16). Past town cormorant management attempts have had only limited success and have included use of loud noises to disturb or scare the flock.

Cormorants roost on the power lines because of their proximity to their primary food sources in Town Cove, Rock Harbor, and Cape Cod Bay. Options to address the cormorants include scaring them away from the power lines, making the power lines difficult to roost on, and or moving/removing the power lines. Burial of the power lines to remove them as a roosting location would be expensive. Costs of burial of existing lines ("undergrounding") range from $400,000 per circuit mile to $1.6 million per circuit mile depending on the details of the site and materials used.[40] Typically, $1 million per circuit mile is used as a planning estimate. The distance of the power lines at Cedar Pond between Cedar Pond Road and Jones Road is 0.313 miles. Using the typical planning estimate, the cost of burial of the power lines would be $313,000. Additional issues would likely involve working through details with MassHighway to use the Route 6 right-of-way. Routing the lines to the south along Locust Road would be a longer path and, thus, would cost more (est. $650,000).

Given that removing the local cormorant food sources is unrealistic, the remaining option to prevent cormorant contamination of Cedar Pond is to prevent or minimize their roosting on the power lines. Auditory scare tactics, similar to the shotgun blasts previously used, have a number of options (*e.g.*, alarm and distress calls played over loud speakers, exploding shells, automatic gas exploders). Visual scare tactics, such as kites, balloons, reflectors, and lasers, have also been used. Available information has shown that most of these require persistent use and changes in use to be effective. Performance review has also shown that these approaches sometimes succeed initially, but then the bird population becomes desensitized to their presence. Given this track record, but also considering the need to address this issue, the town may want to try some of the more promising, lower cost options and measure their efficacy.

With this in mind, project staff reviewed management options that should provide little or no disturbance of residents around Cedar Pond. Most of these are localized visual scare tactics and among these lasers seem to show the most promise. USDA has specifically evaluated use of lasers on double-breasted cormorants and found that populations were reduced by at least 90% of pretreatment levels after 1-3 days of use.[41] Project staff review of comparable hand-held laser devices range in cost from approximately $1000 to $2000 depending on strength and laser type (*e.g.*, green vs. red wavelengths). Additional costs for implementing this approach would be personnel for use of the laser and on-going monitoring to gauge success. Use of the laser would also require safety procedures to protect travelers on Route 6, any aircraft over the area, and residents from direct exposure to laser light. USDA evaluations of lasers on birds have shown

[40] Shaw Consultants International, Inc. 2010. Study of the Feasibility and Reliability of Undergrounding Electric Distribution Lines in the District of Columbia, Formal Case No. 1026. Submitted to Public Service Commission of the District of Columbia.

[41] Glahn, J. F., G. Ellis, P. Fiornelli, and B. Dorr. 2001. Evaluation of moderate- and low- power lasers for dispersing double-crested cormorants from their night roosts. Proceedings of the Eastern Wildlife Damage Management Conference 9:34- 45.

that they will not harm avian optics; laser usage is considered non-lethal.[42] Additional issues to consider prior to implementing this step would be whether any wildlife permits are required. Project staff recommends that the town consider use of an avian laser to disturb the cormorants on the Cedar Pond power lines during July and August.

IV.C. Reducing the Sediment Nutrient Regeneration within Cedar Pond

Aside from addressing the cormorants and the salinity regime, remediating the water quality in Cedar Pond will also require addressing the in-pond sediment nutrient regeneration. As noted in Figure 15, sediments in the pond currently contribute a significant amount of nitrogen during the early summer. It appears that this release is the cause of the increased nitrogen in the pond water and associated export from the pond to Cedar Pond Creek (see Table 3). This high sediment nutrient release precedes the arrival of the bulk of the cormorant flock (see Figure 16), which further increases the nutrient load to the pond. Under its previous brackish condition, review of pond phosphorus data indicated that the sediments contributed 21-58% of the phosphorus in the water column.[43] Clearly, addressing the sediment nutrient regeneration within the pond is a key factor regardless of the salinity condition of the pond. It should be stressed, however, that the sediment releases represent a recycling of nutrients that previously have been added to the pond, so that it is important to reduce both the nutrient inputs and the nutrient recycling to restore Cedar Pond.

Options to lower sediment nutrient regeneration rates generally involve one of three general options: 1) sediment removal, 2) injection of oxygen or 3) phosphorus inactivation (only in the case of fresh water systems). Project staff reviewed each of these for their applicability to Cedar Pond.

Removal of the sediments would remove the sediment oxygen demand and restore the pond to conditions that existed before any monitoring occurred. However, sediment removal can be technically complicated in inland settings and difficult to permit. Sediment removal from freshwater ponds has not been used extensively in Massachusetts and does not appear to ever have been used on Cape Cod.[44] Dredging in salt water settings is subsidized by Barnstable County,[45] but dredging in Cedar Pond presents a number of regulatory hurdles, including Cedar Pond's location within the Inner Cape Cod Bay Area of Critical Environmental Concern (ACEC).[46] A dredging plan would require at the very least securing a sediment disposal location and testing of the sediments for metals and hydrocarbons. If the dredged material was to be dewatered, a site for this would also have to be secured and assessed. But as the pond is now saline, impacts of salt water discharge and potential leaching from the dewatering and disposal site presents an additional issue not part of typical freshwater pond sediment removal projects. The overall effort would also require difficult permitting with both state agencies and local boards. An estimated cost based on dredging of the portion of the pond greater than 2 m in depth

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[42] United States Department of Agriculture, Animal and Plant Health Inspection Service. 2003. Use of Lasers in Avian Dispersal. APHIS Tech Note.

[43] Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data.

[44] Department of Environmental Protection and Department of Conservation and Recreation. 2004. Eutrophication and Aquatic Plant Management in Massachusetts. Final Generic Environmental Impact Report. Executive Office of Environmental Affairs, Commonwealth of Massachusetts

[45] http://harborm.cape.com/cities/barnstabledredge.shtml

[46] http://www.mass.gov/dcr/stewardship/acec/acecs/l-innbay.htm

would be between $169,000 and $338,000. Finally, unless the nutrient sources are managed prior to sediment removal, the rate of sediment recycling would gradually rebuild to present levels. For these reasons, staff would not recommend dredging of Cedar Pond sediments.

The sediments have significant oxygen demand. Review of the sediment incubation data (see Table 2) indicates that the nitrogen release from the sediments is relatively consistent regardless of sediment redox conditions. In contrast, phosphorus release increases significantly when dissolved oxygen concentrations decline due to the large and rapid chemical release of inorganic phosphorus. Preventing summertime anoxia or reducing the area of bottom affected by anoxia would have a direct positive effect on lowering sediment phosphorus release, while also improving the area of bottom usable as benthic animal habitat. Since sediment oxygen demand is the primary cause of water column oxygen loss, lowering this demand to the level where inputs from the atmosphere and photosynthesis can meet the demand will result in an increased aerobic volume of pond water. In the long term, lowering nutrient inputs will eventually lower sediment oxygen uptake. In the shorter term, lowering the oxygen uptake could be addressed by implementing a bottom water aeration strategy. Use of aeration would be a long term solution that would need to be initiated, monitored, and maintained each year or, perhaps, year-round.

Use of aeration in Massachusetts has largely been confined to freshwater ponds, largely because coastal waters are comparatively shallow and do not tend to have enclosed basins as deep as Cedar Pond. Performance of freshwater aeration, both whole lake and hypolimnetic, has been somewhat mixed.[47] Proper air/oxygen flows, mixing, and adequate characterization of the treated ponds are thought to have led to the most successful installations. Successful installations have no negative impacts on fish, shellfish, or plants. Unsuccessful installations in freshwater ponds have increased the transfer of phosphorus from deep waters to the more productive shallow waters and prompted worse water quality conditions. Aeration of Cedar Pond would likely need to continue until the pond approaches its salinity targets to sustain the herring run and protect the Atlantic white cedar swamp, as well as being complemented by cormorant controls.

Review of the historic water quality data shows aeration in Cedar Pond will initially require nearly year-round operation and design features that address the significant oxygen demand. Review of the entire Cedar Pond dissolved oxygen profile history shows that during the calendar year both the earliest (April) and the latest (November) profiles recorded have had anoxic concentrations at 2 meters and deeper. This finding suggests that aeration would need to operate at least 8 to 10 months per year in order to sustain acceptable dissolved oxygen conditions in the pond. Since the usual area of anoxia is deeper than 2 meters (~2.4 ha/6 acres), aeration will only need to address the volume deeper than this depth. For estimating purposes, if one uses the maximum sediment oxygen demand in Table 2 and the average summer difference in dissolved oxygen concentration between shallow and deep waters, an average daily supply of approximately 240 kg of oxygen is needed to create well-oxygenated conditions in Cedar Pond. It should be noted that in practical terms, this demand would not remain constant if an aeration project was implemented, but this estimate is appropriate for planning purposes. It also should be noted that this demand is unmet by the regular atmospheric mixing; temperature and salinity readings suggest that the entire water column is regularly mixed by available wind energy.

[47] DEP/DCR. 2004. Eutrophication and Aquatic Plant Management in Massachusetts. Final GEIR.

There are various ways to provide aeration to ponds. Options include surface propellers, shoreline compressors with diffusers above or along the bottom, spray irrigation, and rafts that increase circulation. Selection of the best option for Cedar Pond will have include discussions of neighborhood acceptance of visual and noise issues, as well as the efficiency of the treatment. Given the estimated oxygen demand in Cedar Pond, preliminary evaluation of use of a traditional shoreline compressor with diffusers suggest a cost of at least $10,000 to $15,000 for the equipment alone, with annual operating costs on the order of $1,500. In order to address noise issues, shoreline compressors also typically require housing within a soundproofing structure. It may be possible that operation of an aeration system for a number of years combined with control of the cormorant population may eventually reduce some of the sediment oxygen demand and lead to less need for the aeration system, but this would have to be part of a follow-up monitoring program. Given the cost involved and the likely water quality changes that will occur from adjusting the salinity and controlling the cormorants, it is recommended that the town consider evaluating this option only after initial management steps have been taken to address the salinity and cormorant reductions.

Another sediment nutrient regeneration control option to further evaluate after salinity adjustment is underway would be an alum application. Alum applications specifically target phosphorus regeneration and creating more brackish conditions (1-4 ppt salinity) would increase the importance of phosphorus as the primary nutrient to manage for improving water quality in Cedar Pond. Alum applications remove phosphorus from the water column and create a soft barrier over the sediments to limit oxygen demand and control phosphorus regeneration. Phosphorus inactivation in freshwater ponds is typically attained by adding salts of aluminum, iron, or calcium that chemically bind with the phosphorus and form solid precipitates that sink to the bottom of the pond. Aluminum precipitates/solids are insoluble under both aerobic and anaerobic conditions, so alum can be used in anoxic settings. While iron can also be an effective phosphorus control, it is not typically added to Cape ponds with hypoxia because there is usually already sufficient iron present, but the low oxygen is preventing it from binding the phosphorus and forming solids; more iron will not resolve this solubility issue and is chemically prevented from forming iron-phosphorus precipitates. Calcium is similarly not used because the low pHs naturally found in Cape ponds will prevent precipitation of calcium-phosphorus solids; calcium precipitates are more chemically favored at pH's above 8 (Stumm and Morgan, 1981). For these reasons, Cape Cod water conditions typically favor application of aluminum for phosphorus inactivation.

Alum applications, typically a mix of aluminum sulfate and sodium aluminate, have been used at a number of Cape Cod freshwater ponds: Ashumet Pond in Mashpee/Falmouth, Hamblin Pond and Mystic Lake in Barnstable, Long Pond in Brewster/Harwich, and Lovers Lake/Stillwater Pond in Chatham. Review suggests that no alum applications have been completed in brackish conditions on Cape Cod. Follow-up monitoring of each of the Cape applications in freshwater ponds has generally showed reduced phosphorus regeneration and reduced sediment oxygen demand. The Hamblin Pond treatment, which occurred in May 1995, increased dissolved oxygen concentrations above the MassDEP 6 ppm threshold for 4 meters worth of water that was anoxic prior to the treatment and this restoration was sustained through at least 2006 (Eichner, 2008).

Use of an alum application on Cedar Pond is subject to uncertainties given that it efficacy is largely going to be dependent on how fresh the system becomes after implementation of the recommended salinity management steps. During the previous brackish phase, Cedar Pond was generally anoxic during the summer at depths of 1.5 m and deeper. Treating this area with alum would have an estimated cost of $7,000 to $10,000. Similar to the aeration application, it is recommended that the town consider evaluating this option after initial steps have been taken to convert the system back to a brackish salinity conditions and begun management of cormorant roosting.

V. Summary of Recommended Management Steps for Cedar Pond

Given the review of management options and the associated uncertainties, CSP-SMAST staff recommends the following management steps for Cedar Pond:

A. Reduce the salinity in the pond from the current 21-23 ppt to 1-4 ppt through installation of boards in the outlet control structure and pumping of deeper water out through Cedar Pond Creek during low tide or periodically mixing the water and allowing salt removal in normal stream outflow.

B. Reduce the cormorant roosting through the use of hand-held lasers.

C. Monitor the results of salinity adjustment and cormorant roosting on dissolved oxygen and nutrient concentration during the year following their implementation.

D. Depending on water quality characteristics following salinity adjustment and cormorant control and subsequent discussion of community concerns, implement aeration or alum treatment to control nutrient regeneration from the sediments.

As this is a draft plan, CSP-SMAST staff will discuss these recommendations with the Orleans Marine and Fresh Water Quality Task Force and jointly develop a final management plan.

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