

Cedar Pond
Adaptive Management Monitoring Program:
Annual Technical Report
January 2019 to December 2019

FINAL REPORT

September 2020

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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Cover photo: Cedar Pond September 11, 2018
(courtesy of Judy Scanlon)

Acknowledgements:

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Executive Summary

Cedar Pond

Adaptive Management Monitoring Program: Annual Technical Report January 2019 to December 2019

The Town of Orleans Cedar Pond Management Plan¹ was approved in 2016 through a MEPA Certificate from the Massachusetts Secretary of Energy and Environmental Affairs and a Massachusetts Department of Environmental Protection (MassDEP) Superseding Order of Conditions. The Superseding Order of Conditions required regular monitoring of the pond for a minimum of three years in support of the Management Plan goals: 1) restore water quality, 2) restore a herring run, and 3) protect the adjacent Atlantic White Cedar wetland. The regulatory approvals also required regular reporting of monitoring results in a semi-annual memorandum and an annual report. The approvals also required coordination with the Massachusetts Division of Marine Fisheries (MassDMF) to manage the fishway connection between the pond and the downstream Rock Harbor Creek. The Town selected Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) to implement the management plan, complete the monitoring, coordinate with MassDMF, and provide the regular reports on progress toward meeting the Management Plan goals.

In order to attain the Cedar Pond restoration goals, a series of initial management steps were recommended in the Management Plan. These steps included: a) returning the pond to brackish conditions (target goal of 1 to 4 parts per thousand salinity), b) limiting summer nutrient contributions from the large seasonal flock of double-crested cormorants by removing the regional power lines strung over the pond, and c) addressing the nutrient additions (*i.e.*, regeneration) from the pond sediments. Following the approvals, a MassDMF Fishway Operations and Maintenance Plan was developed in coordination among Town, MassDMF and CSP/SMAST staff to implement board heights at the pond outlet to slowly return the pond to brackish conditions.

Part of the regular review and reporting of monitoring results was to consider potential modifications to management activities to better achieve the management goals. Monitoring during 2018 was reviewed in an annual report,² and follow-up discussions among the Town, MassDMF, and CSP/SMAST management partners led to modifications in how the Fishway Plan board heights and configurations were managed during 2019. In addition, 2019 was also the first year where the water quality impacts of reducing cormorants roosting on the power lines over the pond were monitored. The Town succeeded in obtaining consensus to move the lines in 2017 and the key lines were removed in 2018. This annual report reviews Cedar Pond

¹ Eichner, E., B. Howes, and D. Schlezinger. 2013. Cedar Pond Water Quality Management Plan. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 54 pp.

² Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 42 pp.

monitoring during 2019 and uses that information to recommend additional potential changes in management strategies.

The initial Cedar Pond management efforts were focused on restoring brackish water conditions and working to have the power lines moved. In the Management Plan, CSP/SMASST recommended that a low-cost step for returning the pond to brackish conditions would be reinstallation of boards at the pond outlet; natural watershed groundwater inputs would slowly return the pond to brackish salinity that existed prior to 2007. At the time of local approval of the Management Plan, the Town asked CSP/SMASST to develop an initial target elevation height for the re-installation of boards at the pond outlet.³ The MassDMF Fishway Plan approved the initial reinstallation height, but also required reductions in the board heights during the summer to encourage anadromous (*e.g.*, herring) fish passage. The Town began working with all stakeholders to move the power lines in 2015 and was eventually successful in 2017 in reaching an agreement with Eversource. Power lines were relocated to Locust Road, which is located south of the pond, in 2018.

The process of re-installing the boards and the associated water quality monitoring of the pond was begun in November 2017. CSP/SMASST staff began monitoring to establish baseline conditions just prior to the re-installation of the boards and the boards were re-installed on January 4, 2018. Monitoring conducted in 2017 and 2018 was reviewed in the 2018 Annual Report,⁴ following a semi-annual Technical Memorandum in September 2018. Semi-annual reports include a brief summary of six months of water quality and stream monitoring and board adjustments. Typically, CSP/SMASST, MassDMF, and Town staff review the semi-annual results and decide whether adjustments in board management are warranted. Similar discussions occur following the availability of the annual report. The Fishway Plan includes flexibility to adjust the board heights depending on monitoring results.

This 2019 Annual Report reviews all data collected in 2019, including data presented in the 2019 semi-annual Technical Memorandum, which was presented to the Town in September 2019⁵ This report also includes recommendations for adjustments in management strategies to better attain the Management Plan goals. Findings from the collected data included:

- Higher board heights during the 2018/2019 winter allowed shallow (between the surface and 1.2 m) salinity readings to begin the monitoring period in April at ~5 ppt or just above the Management Plan target range of 1-4 ppt. Shallow and deep salinity

³ CSP/SMASST Technical Memorandum: Board Height Recommendation for Cedar Pond Outlet. October 10, 2014. From: Howes, B., E. Eichner, R. Samimy, J. Ramsey, and S. Kelley. To: George Meservey, Town of Orleans, Director of Planning & Community Development and Carolyn Kennedy, Chair, Marine and Fresh Water Quality Task Force. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 13 pp.

⁴ Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 42 pp.

⁵ CSP/SMASST Technical Memorandum: Cedar Pond Adaptive Management Monitoring Program: 2019 Semi-Annual Report. September 9, 2019. From: Howes, B., E. Eichner, and D. Schlezinger. To: Carolyn Kennedy, Chair, Marine and Fresh Water Quality Committee and George Meservey, Town of Orleans, Director of Planning & Community Development. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 17 pp.

concentrations in April 2019 were ~10 ppt and ~1 ppt lower than the respective 2018 concentrations.

- Shallow dissolved oxygen (DO) concentrations were acceptable in the late summer (mid-August through October 2019). These concentrations were greater than the MassDEP regulatory minimum (5 mg/L) and contrasted with anoxic concentrations at the same depth during the same period in 2018. Deep concentrations remained anoxic and unacceptable throughout the April to November 2019 monitoring period. Review of temperature and salinity differences in the water column showed that the improved shallow 2019 DO concentrations were linked to stronger stratification within the water column throughout most of the monitoring period and accompanying isolation of the high nutrient bottom waters below the well-mixed, upper, high DO shallow layer.
- Alterations in the board configurations in 2019 did not reduce tidal and saltwater inputs. Installation of an additional autonomous water level recorder at the pond inlet showed that once board elevations were lowered to address fish passage, all high tides in the creek north of Route 6 reached Cedar Pond. This finding is the same as in 2018 and salinity reading began at lower levels than 2018, but increased at the same rate in both 2018 and 2019.
- Just as DO concentrations continued to show impaired conditions, water column total nitrogen, total phosphorus, and chlorophyll concentrations remained high and indicative of impaired conditions. However, shallow 2019 TN and TP concentrations were lower than those in 2018. These lower concentrations were due to two factors: 1) strong stratification and water column mixing of deep high concentrations into the upper water only occurring outside of the summer management period and 2) reduced TN and TP inputs in 2019 from cormorants roosting on the wires above the pond primarily during August, September, and October.
- Improved shallow water column conditions in 2019 led to reduced TN and TP export to Rock Harbor. Although TN and TP export remained higher than during the Massachusetts Estuaries Project 2002/2003 monitoring, the respective 2019 exports were 19% and 35% less than in 2018 due to management of the salinity structure of the pond in 2019.

The 2019 monitoring results largely confirmed the lessons of 2018: a) reduced salinity in Cedar Pond can improve water quality conditions and b) salinity reductions can be sustained by installation of the boards at the pond outlet. Reduction of cormorant roosting through the relocation of the power lines also appeared to be reflected in improved water quality.

Lowering board heights to provide potential fish passage continues to seasonally increase salinity in the pond and makes it more of a challenge to attain the salinity goals in the Management Plan and restore water and habitat quality. The higher level of boards during the 2018/2019 winter allowed the pond to start the 2019 monitoring period at a lower salinity level, but lowering the boards allowed salinity levels to increase at the same rate as 2018. Installation of an autonomous water level sensor at the inlet showed that board elevations attained the water levels in the Fishway Plan approximately half of the time. **Perhaps board heights could be increased slightly to allow lower tidal salinity inputs while also allowing adequate fish passage**

(perhaps attaining the Fishway Plan target for 10% of the time). No fish have been observed entering or leaving the pond during more than 30 visits to the Cedar Pond inlet during 2018 and 2019. It is recommended that the Town work with MassDMF to see if further flexibility in board heights can be implemented to keep salinity levels at lower concentrations.

Overall, 2019 readings showed more progress toward attaining the Management Plan goals. Cedar Pond remains impaired and with poorer water and habitat quality than existed in 2002/2003 and pre-2007, but 2019 readings were better than 2018. Shallow water quality conditions were notably improved with acceptable DO in late summer and lower nutrient levels, due to salinity management and the removal of inputs from roosting cormorants. Spring salinity readings almost attained the Management Plan target range and stream export of nitrogen to the Rock Harbor Estuary was reduced. Challenges remain about sustaining lower salinity levels and improved water quality conditions, as well as addressing deep water quality impairments once shallow improvements are sustained.

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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 has been subject to a series of *ad hoc* management decisions over the last few decades, including filling a portion of the pond to build Route 6, running regional electrical lines over the pond, removing boards at the outlet control structure, replacing the Rock Harbor Road culvert, and increasing tidal flows into the pond from Rock Harbor.

In response to citizen-collected data indicating poor water quality in Cedar Pond, the Town began work with the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) to develop a management plan to restore acceptable water quality within the Pond. The Town of Orleans Cedar Pond Management Plan was reviewed and approved by appropriate Town Committees, including the Board of Selectmen and the Conservation Commission and then the state in 2016.⁶ The management plan recommended a series of management steps to attain three goals for Cedar Pond: 1) restore water quality, 2) restore a herring run, and 3) protect the adjacent Atlantic White Cedar wetland.

The state regulatory approvals of the Management Plan required regular monitoring following the implementation of initial management steps for a minimum of three years, reporting of monitoring results in Semi-Annual and Annual Reports, and coordination with the Massachusetts Division of Marine Fisheries (MassDMF) to manage the fishway connection between the pond and Rock Harbor Creek. Following the approvals, a MassDMF Fishway Operations and Maintenance Plan was developed in coordination among Town, MassDMF and CSP/SMAST staff. The Fishway Plan included raising and lowering of boards at the Pond inlet to facilitate fish passage throughout the summer.

The Cedar Pond Management Plan included an adaptive management approach that followed a strategy of implementing management steps and using continuing monitoring to adjust future management steps to attain the plan goals. Initial management steps included: a) reinstallation of boards at the pond outlet to slowly allow the pond to return to brackish conditions [target goal of 1 to 4 parts per thousand (ppt) salinity],⁷ b) moving the regional power lines that were strung over the pond to remove summer nutrient contributions from the large seasonal roosting flock of double-crested cormorants, and c) addressing the internal nutrient regeneration from the pond sediments. These steps were based on the data review in the Management Plan that included water column data collected between 2000 and 2012 and supplemental data collection in 2012 to address known data gaps, including stream flow and pond water quality, nutrient regeneration from pond sediments, and cormorant counts and timing of roosting.

The initial Cedar Pond management efforts were focused on attaining the return of historic brackish water salinity and working to move the power lines. In 2018, the outlet boards were re-installed. Discussions on moving power lines began in 2015 and the Town was eventually successful in 2017 in reaching an agreement with Eversource. Replacement lines have now been installed along Locust Roads, which is located south of the pond, and the preferred lines for cormorant roosting have been removed.

⁶ Eichner, E., B. Howes, and D. Schlezinger. 2013. Cedar Pond Water Quality Management Plan. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 54 pp.

⁷ CSP/SMAST Technical Memorandum: Board Height Recommendation for Cedar Pond Outlet. October 10, 2014. From: Howes, B., E. Eichner, R. Samimy, J. Ramsey, and S. Kelley. To: George Meservey, Town of Orleans, Director of Planning & Community Development and Carolyn Kennedy, Chair, Marine and Fresh Water Quality Task Force. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 13 pp.

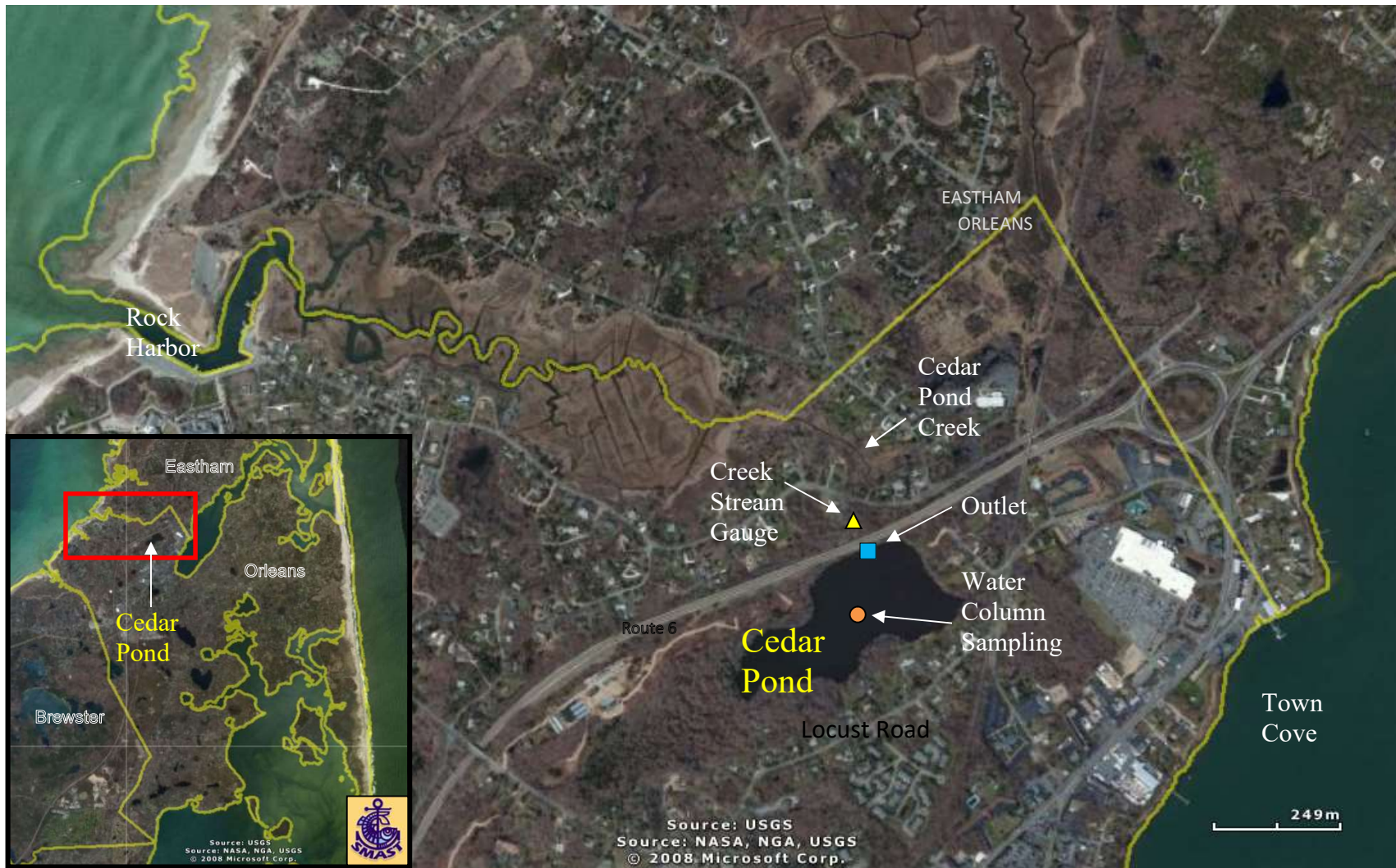


Figure 1. Cedar Pond Locus in the Town of Orleans, MA. Cedar Pond is located in northern Orleans, south of Route 6 and west of Town Cove. The Pond is connected to the Rock Harbor estuary on Cape Cod Bay via Cedar Pond Creek. The creek leaves the pond through a weir at the pond outlet (blue square), flows under Route 6 and Rock Harbor Road, and through a salt marsh to Rock Harbor. Creek flow and water quality have been measured several times at the same location (yellow triangle) and the pond has been sampled regularly since 2000 at the same deep location (orange circle).

The process of re-installation of the boards and the associated water quality monitoring of the pond was begun in November 2017 and boards were re-installed at the beginning of January 2018. Monitoring results reviewed in the 2018 Cedar Pond Annual Report showed that reduced salinity improved water quality conditions and that salinity reductions could be sustained by installation of the boards at the pond outlet.⁸ Monitoring also showed that as board heights were reduced to allow immigration of spawning fish, salinity levels increased and water quality conditions deteriorated again. Monitoring during this period also showed that no spawning fish were observed during multiple visits to the Cedar Pond channel.

During the 2018/2019 winter, the outlet boards were left at a relatively high elevation and this led to notable water quality improvements. Salinity monitoring in April 2019 showed that shallow readings had decreased to the 5 to 7 ppt range.⁹ These salinities were only slightly higher than the Management Plan goal and equivalent to some readings collected between 2001 and 2005. Salinity readings began to rise in mid-May when another board was removed at the outlet and shallow water (1.2 m depth) continuous DO readings developed anoxic conditions at the same time. In addition, no fish were noted immigrating into the pond in the 2019 spring, which was two consecutive springs without any fish noted coming into the pond.

Based on the monitoring results available in the 2019 Semi-Annual Tech Memo, Town, CSP/SMAST, and MassDMF discussed further options within the Management Plan and the Fishway Operations and Maintenance Plan to improve water quality in Cedar Pond. These discussions led to an agreement 1) to leave the boards at their height as of July 2019 and continue on-going monitoring, 2) evaluate ways to ensure fish out-passage beginning in mid-August, 3) review collected 2019 data in the annual report and look again at adaptations to the board management to meet fish passage goals. In November/December 2019, further discussions were had regarding preliminary 2019 data. As a result of these discussions, it was decided that efforts would be made to maintain a higher board elevation through the 2019/2020 winter and then try to limit water flow in spring 2020 by notching boards while also maintaining the higher overall board elevation. It was thought that the notch in the boards would still allow fish passage while restricting inflow.

This Annual Report includes a comprehensive review of all data collected during 2019, including the data summarized in the 2019 Semi-Annual Tech Memo. This report also includes recommendations for adjustments in management strategies to better attain the Management Plan goals.

II. Background

Cedar Pond receives freshwater primarily through groundwater inflows around its margin, but is also connected to the Rock Harbor estuary through a surface water outlet. Saltwater flows into

⁸ Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 42 pp.

⁹ CSP/SMAST Technical Memorandum: Cedar Pond Adaptive Management Monitoring Program: 2019 Semi-Annual Report. September 9, 2019. From: Howes, B., E. Eichner, and D. Schlezinger. To: Carolyn Kennedy, Chair, Marine and Fresh Water Quality Committee and George Meservey, Town of Orleans, Director of Planning & Community Development. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 17 pp.

the pond through the outlet during the highest tides and the pond discharges water through the outlet to Rock Harbor during each tide as the high tide recedes.

When regular monitoring of the pond began in 2001, the pond was brackish with lower salinity waters (~7 ppt) floating on top of deeper, higher salinity waters (~15 ppt). Significant changes to the stream outlet channel in early 2007 caused a notable increase in tidal inflows and began to increase salinity levels throughout the pond water column. This most recent *ad hoc* management change caused the pond to be converted from a brackish system to a coastal salt pond; prior to the start of Management Plan remedial actions, shallow salinities had more than doubled, averaging 16.9 ppt, while deep waters averaged 20.9 ppt.

Review of water quality data collected prior to 2007 showed that Cedar Pond was impaired with dissolved oxygen concentrations regularly failing to meet the minimum DO limits in Massachusetts surface water regulations (314 CMR 4) due to high sediment and water column oxygen demand and also with frequent large phytoplankton blooms.¹⁰ Extreme oxygen demand events 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 changes to the downgradient stream channel, documented that DO impairment has continued and become more extreme under the new, increasingly more saline conditions.¹¹ Another significant fish kill occurred in 2008.

Extensive water quality monitoring conducted for the 2007 Massachusetts Estuaries Project (MEP) assessment of Rock Harbor also showed that Cedar Pond had impaired water quality,¹² but also showed that it was removing 58% of the watershed nitrogen flowing through it and, therefore, was lowering the watershed N load to Rock Harbor.¹³ Stream monitoring in 2012 after the pond had become more saline showed that the nitrogen attenuation in the pond had been eliminated and that during the 2012 summer, the pond was adding nitrogen to the stream flow and was exporting up to more than 3X the watershed nitrogen inputs.¹⁴ The extra nitrogen exports were from a combination of sediment regeneration and roosting cormorant inputs.

Because of the water quality impairments in Cedar Pond, the Town of Orleans had originally targeted the Cedar Pond watershed for sewer collection of wastewater during the final phase of the town's Comprehensive Wastewater Management Plan (CWMP).¹⁵ Given the Town's efforts to implement the Cedar Pond Management Plan, the recently amended CWMP has recommended that the Town review the results of the Cedar Pond management options and then

¹⁰ Eichner, E. 2007. Review and Interpretation of Orleans Freshwater Ponds Volunteer Monitoring Data. Cape Cod Commission. Barnstable, MA.

¹¹ CSP/SMASST Technical Memorandum: Cedar Pond Autonomous Mooring Results, Summer 2009. October 29, 2009. From: Schlezinger, D. and B. Howes. School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA.

¹² *e.g.*, regular low or anoxic dissolved oxygen concentrations (regularly below MassDEP regulatory minimums), high nitrogen, phosphorus, and chlorophyll concentrations.

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. SMASST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA.

¹⁴ See Table 3 in Eichner, E., B. Howes, and D. Schlezinger. 2013. Cedar Pond Water Quality Management Plan.

¹⁵ Wright-Pierce. December 2010. Town of Orleans Comprehensive Wastewater Management Plan and Single Environmental Impact Report. Andover, MA.

re-assess whether alternative solutions should be pursued within the Cedar Pond and Rock Harbor watersheds.¹⁶

III. Cedar Pond Adaptive Management Program 2019 Results

The 2016 approval of the Cedar Pond Management Plan required three years of monitoring, adjustment of management strategies, and regular reporting on the impact on water quality in Cedar Pond. Monitoring strategies implemented in 2018 included changes in board management at the pond outlet and relocation of some of the wires strung across the pond to reduce the number of roosting cormorants and their N and P contributions to the pond in late summer.

The CSP/SMASST portion of the implementation of the Cedar Pond Adaptive Management Plan has focused primarily providing the Town with: a) regular, reliable water quality monitoring of the pond water column, b) measurement of stream flow into and out of the pond, c) measuring water level fluctuations, d) working with the Town and MassDMF to track board heights at the outlet, water level over the boards, fish observations and other Town activities specified in the MassDMF Fishway Operations and Maintenance Plan, and e) providing the Town with the regular semi-annual and annual reports required in the approval of the Management Plan. Monitoring during the 2019 calendar year is summarized in this section.

III.A. Board Height and Water Levels

Increasing the board height at the Cedar Pond outlet was selected through the Management Plan as a low-cost approach to slowly decrease the salinity in the pond to the 1 to 4 ppt goal and improve water and habitat quality. Boards at the pond outlet would be managed to limit, but not eliminate, high tide flooding of the pond and allow natural groundwater inputs to gradually return salinity levels to the brackish conditions that had allowed natural nitrogen attenuation¹⁷ and support a restored habitat for a healthy herring run.

Management of the board height is complex because pond water levels are impacted by a number of fluctuating factors including surrounding groundwater levels, high tide inputs, and seasonal variations in rainfall and evapotranspiration. Boards had long been in place at the Cedar Pond outlet, but had been completely removed just prior to development of the Management Plan. As part of the initial implementation of the Management Plan, CSP/SMASST was asked by the Town to determine an initial board height. After reviewing past pond and tidal elevation data collected between 2001 and 2012, CSP/SMASST staff recommended an initial board elevation of 1.45 m NAVD88.¹⁸

During the discussion of the Fishway Operations and Maintenance Plan, this elevation was seasonally modified. As a result of these discussions, the board height was to be adjusted to allow at least 6 inches (0.15 m) of water depth to flow over the top board from March 15 to June 30 in order to facilitate river herring migration into the pond. Beginning on July 1 and lasting until November 15, the board height would be raised to allow at least 2 inches (0.05 m) of water depth to flow over the top board to allow juvenile herring to leave the pond.

¹⁶ AECOM Technical Services, Inc. 2016. Amended Comprehensive Wastewater Management Plan. Town of Orleans, MA.

¹⁷ Documented in 2002-2003 monitoring for the MEP Rock Harbor assessment

¹⁸ CSP/SMASST Technical Memorandum: Board Height Recommendation for Cedar Pond Outlet. October 10, 2014.

After one year of board movements and the subsequent review of the 2018 YR1 monitoring results, Town, DMF, and CSP/SMAST staff discussed options to better attain the Management Plan goal of reduced salinity to accelerate accompanying water quality remediation, while still providing a potential fish migration pathway. As a result, it was agreed that in 2019 YR2 a new board configuration should be used: maintaining higher board heights and limiting the opening to a 6-inch notch. The Fishway Plan water heights would be maintained, but would be measured over the bottom of the notch opening. It was also agreed in these discussions, that water level and pond salinity monitoring results would be reviewed in late summer 2019 to see if further adjustments were required to facilitate the exit of juvenile fish from the pond. After again meeting in late June 2019, Town, DMF, and CSP/SMAST staff agreed to leave the boards in their current configuration at the time. A follow-up discussion in November 2019 led to the Town removing the notch and adding additional boards. The Town then slightly reduced the board level in December 2019 to manage pond water level.

In order to monitor the water and board elevations and note fish counts, Town and CSP/SMAST staff visited the outlet on 17 visits in 2019, with most of them concentrated between March and July 2019. Town staff recorded water elevations above the boards, adjusted the board heights as appropriate, and noted presence of any fish (Table 1). CSP/SMAST staff visited the outlet for regular maintenance of the autonomous water level device installed there and also recorded the elevation of the bottom of the notch and the top of boards during selected site visits using a GNSS/GPS with RTK enabled. No fish were noted migrating into or out of the pond at the outlet during any of the 2019 Town or CSP/SMAST visits. No fish were noted during any inlet visits during 2018 either.¹⁹

The autonomous water level recorder was installed at the weir on May 23, 2019 and failed on September 24, 2019 (it was later replaced). Installation of this device was the result of the 2019 YR2 adaptive management discussions among CSP/SMAST, MassDMF, and the Town. During these discussions, it was acknowledged that water levels at the outlet and the middle of the pond where the other water level recorders were deployed required some refinement. CSP/SMAST offered to install the third device at the outlet and it was programmed to record water levels every 10 minutes.

Comparison of the water levels at the inlet and the center of the pond showed that the readings at the outlet had much greater fluctuations than what was measured near the center of the pond (Figure 2). This type of pattern is often seen in other settings as the impact of significant changes near a pond inlet are dampened as they spread over the whole pond surface.

Comparison of the inlet water levels with board heights showed that the Fishway goal of 6 inches over the notch was attained approximately half of the time between mid-May and the end of September. Based on 2019 elevation data collected by CSP/SMAST staff, the elevation of bottom of the notch in the inlet boards was 1.48 m NAVD88 when the inlet device was installed on 5/23. This elevation was the same as it was in April (see Table 1). In late May/early June, the boards were lowered and the bottom of the notch elevation was at 1.24 m NAVD88 on 6/19. This elevation was also measured in late July and late August readings by CSP/SMAST staff.

¹⁹ Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018.

Table 1. Cedar Pond Board Height Log: 2019. Town and CSP/SMAST staff visited the pond outlet on 17 dates. Town staff noted outflow over the boards, the pond water level on the gauge at the outlet and whether fish were present. Town staff also adjusted the board heights to attain the water level goals of the Cedar Pond Fishway Operations and Maintenance Plan (source: Nate Sears, Natural Resources Manager, Town of Orleans). CSP/SMAST staff visited the outlet when maintaining the water level recorder installed there and measured the elevation of a) the bottom of the board notch, b) the top of the boards, and c) the pond surface elevation on most visits. All elevations measured by CSP/SMAST staff were determined in NAVD88 meters using a GNSS/GPS with RTK enabled. The first CSP/SMAST elevations measured the bottom of the notch at 1.48 m NAVD88 on April 25. After board removals in June, the recorded bottom of the notch elevation on June 19 was 1.24 m NAVD88. The bottom of the notch remained at this elevation until the notched board was removed in November.

Reporting	Date	Time	Low Tide	Outflow (inches of water over boards)		Water Level (ft)	Fish noted	Board adjustment	CSP/SMAST Elevations (m NAVD88)		
				initial	final				Bottom Notch	Top of Boards	Pond Elevation
Town	3/17/19	8:40	14:10	2	2	2.6	No fish	placed notch board			
Town	3/25/19	15:00	9:21	3	3	2.8	No fish	none			
Town	3/31/19	11:23	14:24	0	3	2.3	No fish	one 6" board removed			
Town	4/19/19	10:30	5:41	0	0	2.3	No fish	none			
CSP/SMAST	4/25/19	11:59							1.48	1.65	1.53
Town	4/30/19	14:00	15:07	5	5	2.1	No fish	none			
Town	5/14/19	13:00	14:09	3	3	2.0	No fish	none			
CSP/SMAST	5/22/19	11:03							1.48	1.65	1.47
Town	5/24/19	10:00	10:06	0	3	1.9	No fish	one 4" board removed			
Town	6/4/19	8:30	6:38	0	5	1.7	No fish	one 4" board removed			
Town	6/18/19	8:30	6:41	5	5	1.7	No fish	none			
CSP/SMAST	6/19/19	11:05							1.24	1.44	1.33
Town	7/10/19	13:20	12:25	5	5	1.7	No fish	none			
CSP/SMAST	7/15/19	11:30							1.24	1.37	1.37
CSP/SMAST	8/28/19	13:30							1.24	1.40	1.29
CSP/SMAST	11/7/19	12:30						notch board removed		1.73	1.40
Town	12/16/19 week							Boards lowered to 2.36 ft on the gauge (~1.5 m NAVD88)			

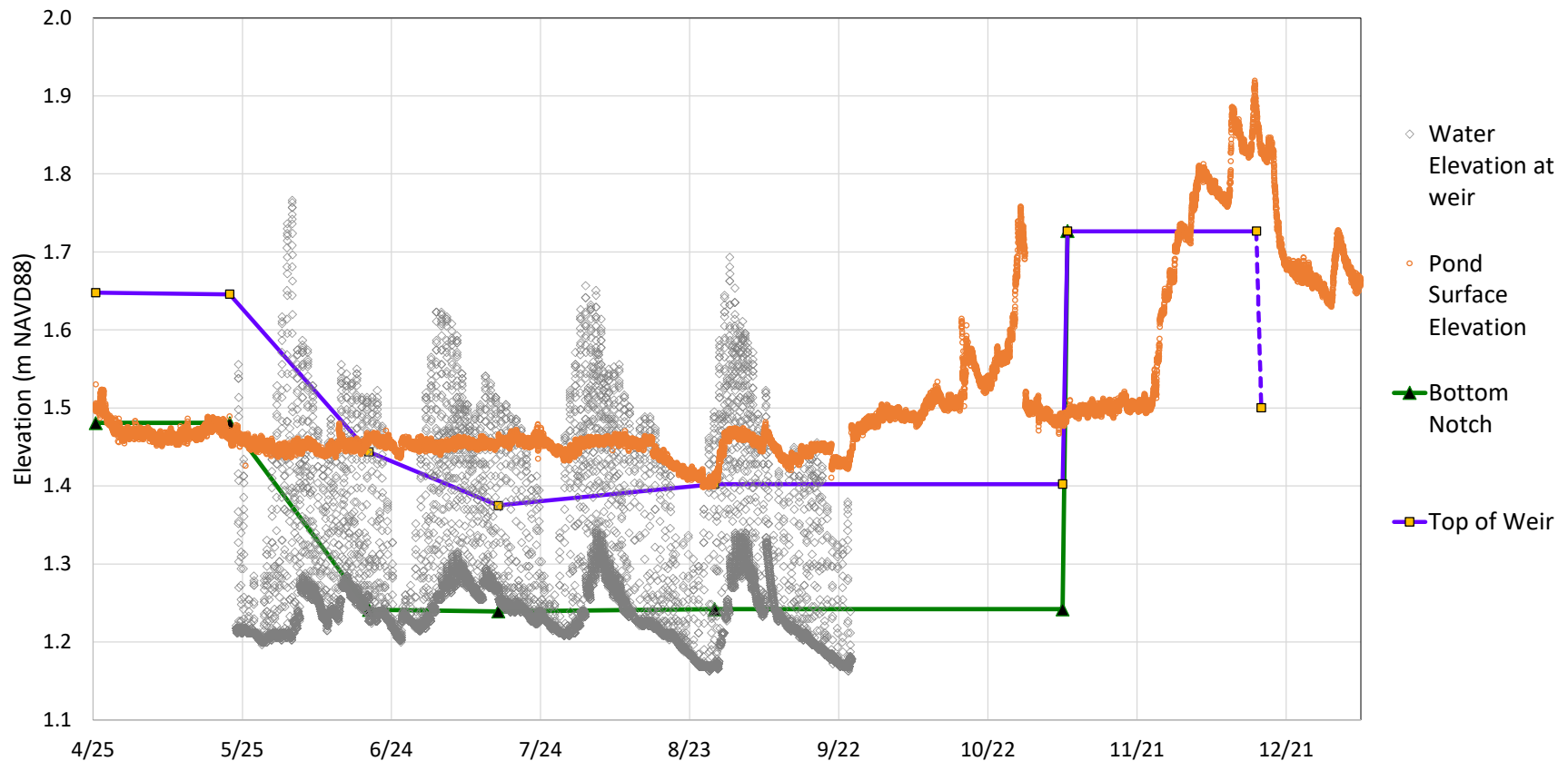


Figure 2. Cedar Pond 2019 Water Levels and Inlet Board Heights. CSP/SMAST staff installed an autonomous recording device programmed to record water levels every 10 minutes at the pond outlet on May 23, 2019. The device recorded readings until September 24, when its battery failed. Staff recorded elevations beginning April 25 for the top of the boards in the weir, as well as the bottom of the notch opening in the boards when it was installed. The notch was first installed on March 17 and was removed on November 7, when weir boards were also raised to 1.73 m NAVD88. Boards were lowered again to approximately 1.5 m NAVD88 during the week of December 16 (dashed line). Comparison of the water levels at the center of the pond and the outlet show that outlet levels varied over a wider range, which would be consistent with the relatively small input being distributed over the large surface area of the pond. Comparison of the bottom of notch elevations and outlet water levels showed that outlet water levels were greater than the 1.24 m NAVD88 bottom of the notch elevation 44% of the time during the overall deployment. This comparison also shows that all tides with their accompanying high salinity reached the pond once the boards were lowered to 1.24 m NAVD88.

While the 6 inch water level over the boards was not noted on any of the Town visits, the autonomous recordings showed the inlet water level was 6 inches (0.15 m) above the 1.24 m NAVD88 bottom of the notch elevation in 44% of the water level readings collected at the outlet during the device deployment.

The inlet readings also show that all high tides reached the pond once the boards were lowered to 1.24 m NAVD88 in mid-June. This impact was also noted in 2018, when lowering the boards to Fishway Plan targets between March through June resulted in all tides reaching the pond during that period. The higher percentage of high tides reaching Cedar Pond corresponded with a rise in water column salinity during both 2018 and 2019 (see discussion below).

III.B. Water Quality Monitoring

Water quality monitoring included regular collection of salinity and water quality samples within the water column and dissolved oxygen and temperature profiles, as well as the installation of two continuous monitoring devices at two depths in the deepest basin and another device and regular monitoring of Cedar Pond Creek, just north of the pond outlet. All water quality monitoring was conducted by CSP/SMASST staff.

CSP/SMASST staff collected water column samples and profiles on eight (8) dates in 2019: April 18, May 22, June 19, July 15, August 15, September 24, October 29, and November 25. On each date, temperature, dissolved oxygen (DO), and salinity profiles were collected and water quality samples were collected at a minimum of three depths in the water column. Stream measurements of volumetric flow and nutrient levels were collected approximately every two weeks as part of continuous stream monitoring that began November 3, 2017. During 2019, stream samples and flow readings were collected 21 times with continuous water level recordings collected at the same location. The stream monitoring site was the same site used during both the MEP assessment and the data collection for development of the Pond Management Plan. The continuous water column monitoring devices were installed April 25, 2019 at shallow (1.2 m) and deep (3.6 m) depths and were programmed to record DO, temperature, salinity, chlorophyll a, and depth readings every 15 minutes. The devices were removed on October 29, 2019. All collected water quality samples were assayed at the Coastal Systems Analytical Laboratory at SMASST/UMASS Dartmouth.

III.B.1. Water Column Profiles: Salinity, Temperature, Dissolved Oxygen

Temperature and dissolved oxygen profiles generally showed some slight differences from 2018, while salinity profiles showed significant, but temporary, reductions due to the boards being left at a higher elevation throughout the winter. Salinity profiles showed that the first 2019 profile on April 18 had shallow water salinity concentrations of ~5 ppt with a significant increase beginning at 1.5 m depth and rising to 13.8 ppt at 3.5 m (Figure 3). These April 2019 shallow concentrations were ~5 ppt less than comparable April 2018 readings and only slightly greater than the target Management Plan salinity range (1 to 4 ppt).²⁰ This reduction also provided some sense of the timeframe (3 to 4 months) required for groundwater inputs to lower salinity levels to the Management Plan targets.

²⁰ Eichner, E., B. Howes, and D. Schlezinger. 2013. Cedar Pond Water Quality Management Plan.

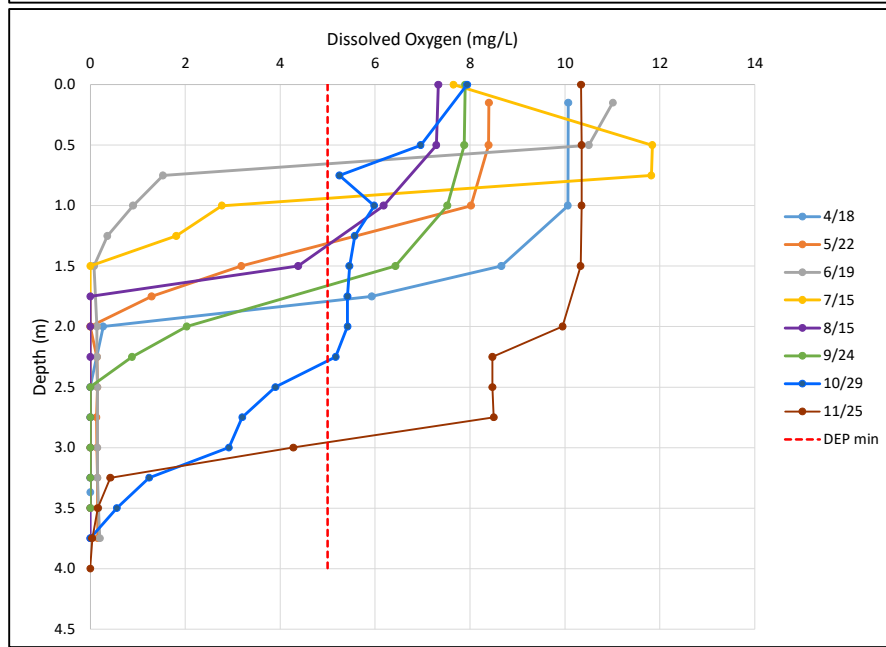
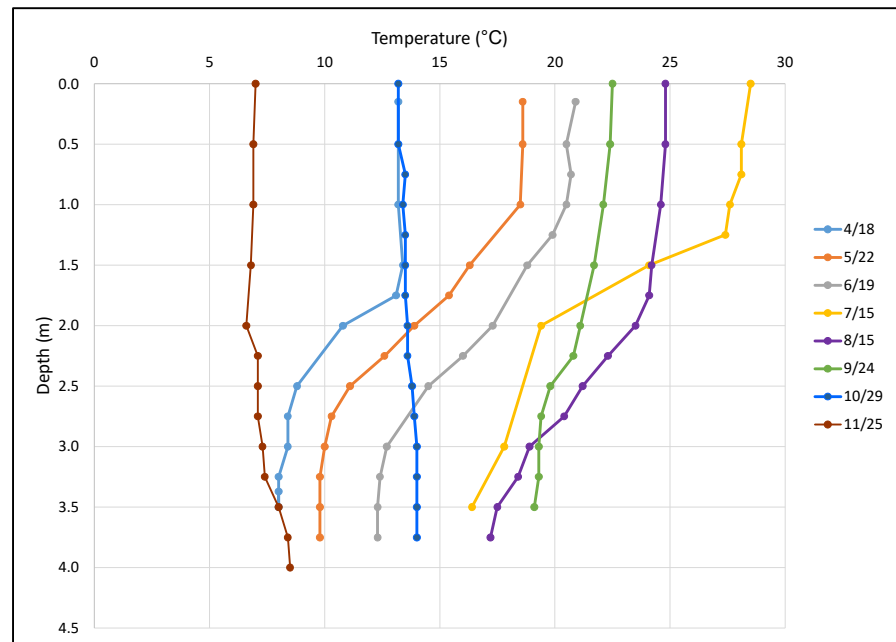
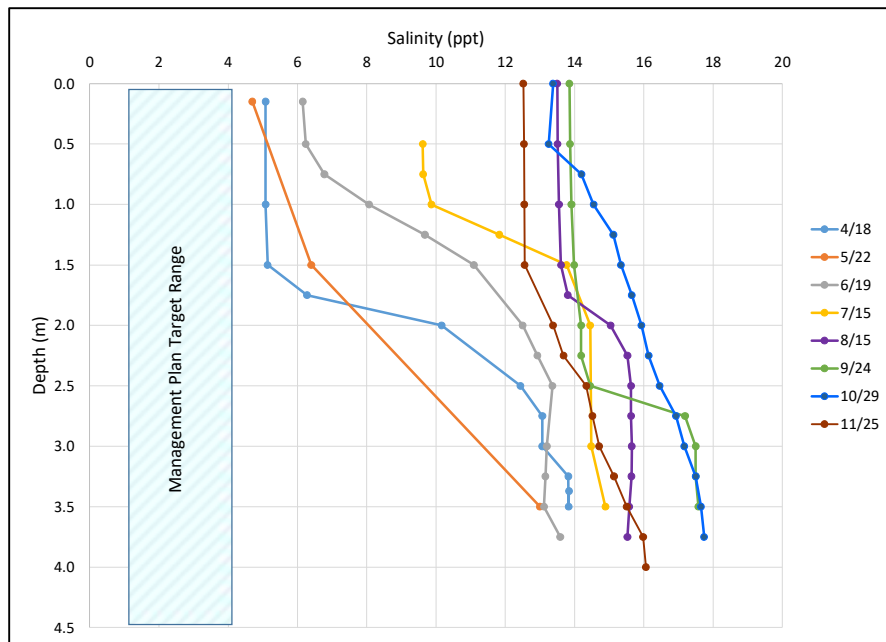


Figure 3. Cedar Pond 2019 Salinity, Dissolved Oxygen, and Temperature Profiles: April to November. April shallow salinity profile readings were just above the Pond Management Plan target range of 1-4 ppt, due to higher board levels during the 2018/2019 winter. Salinities increased slowly between May and October, but were generally lower than 2018 concentrations due to the lower starting point. Temperature readings followed a similar warming pattern to 2018, but showed larger differences between shallow and deep levels. DO levels were slightly lower than 2018 likely due to greater salinity and temperature stratification, but none of the 2019 profiles had concentrations as low as those in September 2018 and had acceptable DO concentrations in the upper 0.5 m in all profiles and the upper 1.0 m in 6 of the 8 profiles.

As expected, as boards were removed at the pond outlet, shallow salinity levels increased from ~5 ppt in April to 13.8 ppt in September. Deep concentrations increased less starting at 13.8 ppt in April and increasing 17.7 ppt in October. The deeper levels remain high because higher salinity waters coming into the pond sink to the bottom. It is notable, however, that the low salinity starting point in April kept deep 2019 concentrations 2 to 3 ppt less than maximum levels in 2018.²¹

The temperature profiles show that 2019 and 2018 had similar warming patterns during the summer, but 2019 has more pronounced water column differences between shallow and deep temperatures. The April 2019 profile had isothermic temperatures (~13 °C) from the surface to 1.75 m, then decreasing temperatures between 1.75 m and 2.75 m, and relatively isothermic temperatures (~8 °C) from 2.75 m to 3.5 m (see Figure 3). In contrast, the April 2018 profile was relatively isothermic (7 to 8 °C) throughout the water column. Differences between shallow and deep temperatures increased to 7 to 8 °C in the May, June, July, and August 2019 profiles before decreasing in September and becoming isothermic in October and remaining isothermic, but colder, in November. August temperature differences were different enough to prevent mixing of the whole water column, but September shallow and deep temperatures were sufficiently similar to allow mixing throughout the water column. Salinity differences in all profiles were sufficiently different to prevent mixing of the entire water column. Most of the profiles had distinct shallow and deep layers with a sharp transition zone of 0.5 to 1 m. Both the shallow and deep portions of the water column generally had relatively similar salinities (within 1 ppt) that would allow regular mixing. The upper, shallow layer was generally surface to 2 or 3 m depth depending on the profile. The early summer pattern for salinity and temperature was consistent with 2018 when salinity differences prevented water column mixing in the early summer, but the late summer pattern is different: 2018 temperature differences prevented water column mixing, but 2019 late summer shallow and deep temperatures were not sufficiently different to prevent water column mixing.

As would be expected based on the salinity and temperature layering, shallow waters regularly mixed and 2019 DO concentrations were generally acceptable (*i.e.*, greater than the MassDEP minimum), but DO concentrations in deeper waters were regularly less than the MassDEP standard or anoxic (see Figure 3). In April 2019, the DO concentrations deeper than 1.75 m were less than the MassDEP standard; this depth was approximately the bottom of the shallow isothermic, isosaline layer. In subsequent profiles the depth where DO concentrations were first less than the MassDEP standard decreased to 1.3 m (May) then 0.7 m (June) and then moved slightly between 0.9 m and 1.3 in July and August, respectively. In September, when the profiles showed that the water column was less stratified by temperature, but not salinity, the depth increased to ~1.6 m, increased again to ~2.3 m in October, and increased again to ~2.9 m in November. Temperature differences gradually diminished throughout September to November, but salinity differences were maintained based on the profile readings; sonde data showed that transitory periods of similar salinities at 1.5 m and 3.5 m depths that occurred between profile readings beginning in late August (discussed below). The strong salinity stratification, but increasing depth of acceptable DO concentrations suggest that incoming tidal waters were adding DO and creating additional mixing within the water column. These tidal waters would likely find their depth within the pond based on both their temperature and salinity, as well as how they dispersed and mixed into the water column. These injections would tend to be deeper in the water column and would fully saturated DO levels

²¹ Figure 6 in Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018.

that would somewhat address water column oxygen demand. In general, the summer depth of the upper well mixed layer was shallower in 2019 than in 2018 and this was likely related to the stronger temperature and salinity stratification in 2019 which reduced atmospheric replenishment of the oxygen taken up by water column and sediments in the deeper waters. It is notable, however, that 2019 did not have a profile like September 2018 where DO concentrations throughout the water column were less than the MassDEP standard, a clear improvement.

III.B.2 Water Column Continuous Recordings: DO, temperature, salinity, and chlorophyll a

Regular monthly profile samplings of key nutrient related water quality parameters throughout the water column provide valuable insights into habitat quality, but often fail to capture rapid or periodic changes and miss transitory, but meaningful ecological events between snapshots. The monitoring included in the implementation of the Management Plan addressed this issue through the use of autonomous recording devices that measure DO, salinity, chlorophyll a and water depth every 15 minutes. Based on 2019 recordings, the shallow and deep devices were at respective average depths of 1.2 m and 3.6 m, which were approximately the same depths as the 2018, as well as deployment of devices installed in 2009, 2012, and 2015 as part of partial prior pond assessments.²²

Review of the chlorophyll sensor reading found that they were unreliable compared to the analysis of water samples; the optical sensors at both depths seem to be confounded by interferences, likely from fluorescence from organic materials. Sensors used for measuring *in situ* fluorescence (generally a reliable proxy measurement of chlorophyll) cannot distinguish between phytoplankton-derived chlorophyll and the many bacterial accessory pigments found in anoxic environments. Because anoxic conditions were often measured in Cedar Pond at both chlorophyll sensors (see below), fluorescence of non-phytoplankton pigments confounded the continuous chlorophyll measurements at both depths.

Comparison of the temperatures at the shallow and deep devices provide insights into whether the water column between the sensors was likely to mix or not (Figure 4). Beginning in mid-May, the difference between the two temperatures was sufficient to prevent water column mixing (consistent with the temperature profiles) with the shallow temperature approximately 7°C higher than the deep reading throughout most of the summer. In mid-September, the difference between the shallow and deep temperatures narrowed again and thermal mixing could occur if not for on-going salinity stratification. This is a similar pattern and timing to what was measured in 2018,²³ but the average shallow temperature in 2018 was ~2°C higher (Figure 5). As in 2018, the changes in board heights appeared to have no significant impact on temperature readings.

Salinity readings in 2019 were also generally lower than 2018, but increased at approximately the same rate during the summer as greater tidal flows through the outlet were allowed as the boards were removed. As noted in the salinity profiles (see Figure 3), at the time of the 2019 installation of the recording devices, shallow and deep salinities were ~5 ppt and ~15 ppt, respectively (Figure 6).

²² CSP/SMASST Technical Memorandum: Cedar Pond Continuous Monitoring. January 14, 2016. From: Howes, B., E. Eichner, and D. Schlezinger. To: George Meservey, Town of Orleans, Director of Planning & Community and F Development and Carolyn Kennedy, Chair, Marine and Fresh Water Quality Task Force. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 6 pp.

²³ Figure 6 in Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018.

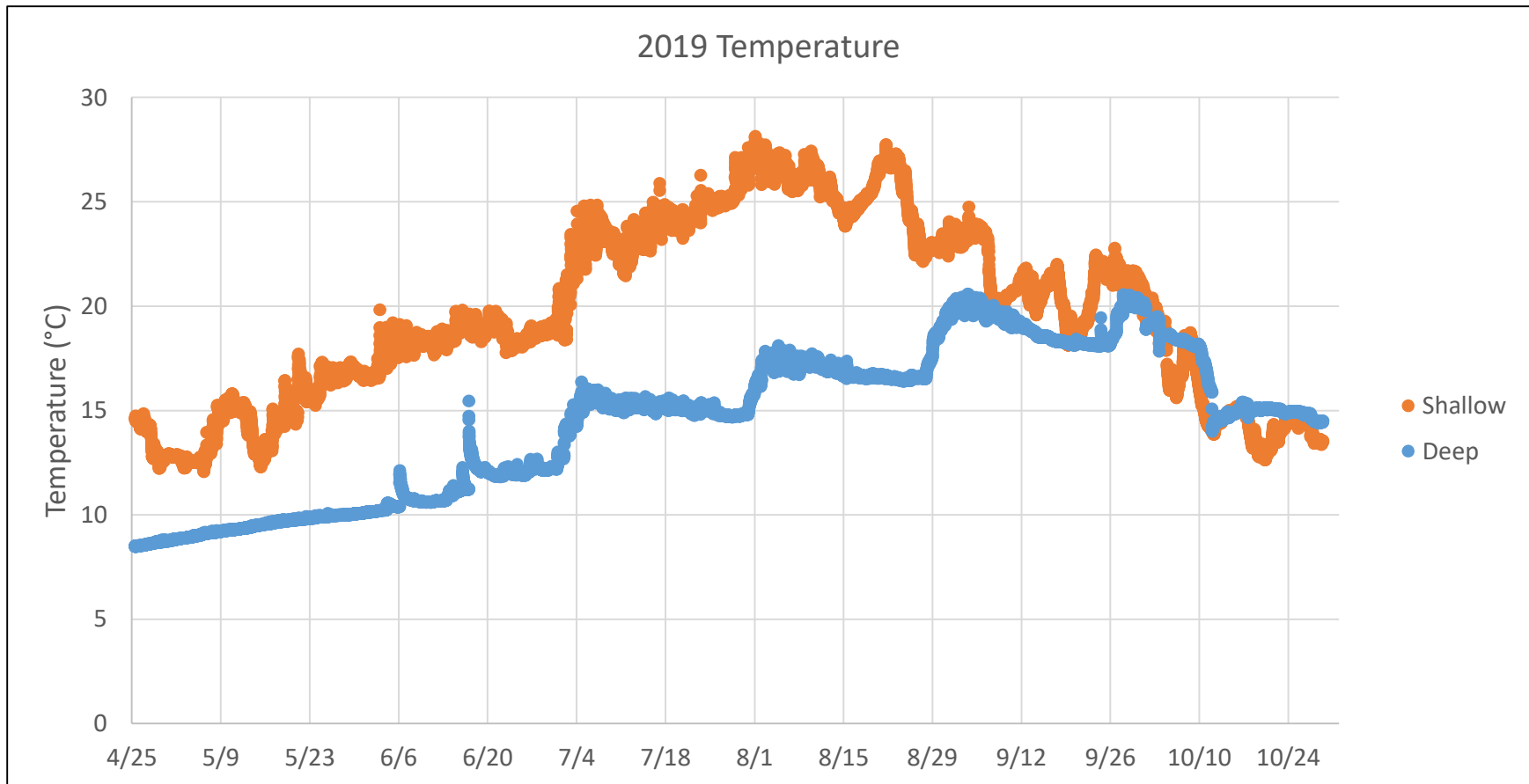


Figure 4. Cedar Pond 2019 Continuous Temperature Readings (April 25 to October 29). Both devices recorded temperature readings every 15 minutes and were located in the main basin at averages depths of 1.2 m and 3.6 m. Shallow temperatures were approximately 7°C higher than the deep reading until mid-September. From mid-May to mid-September, temperature differences at the two depths were sufficient to prevent mixing of the water column. Average shallow and deep temperatures over the entire deployment period were 19.71°C and 14.51°C, respectively.

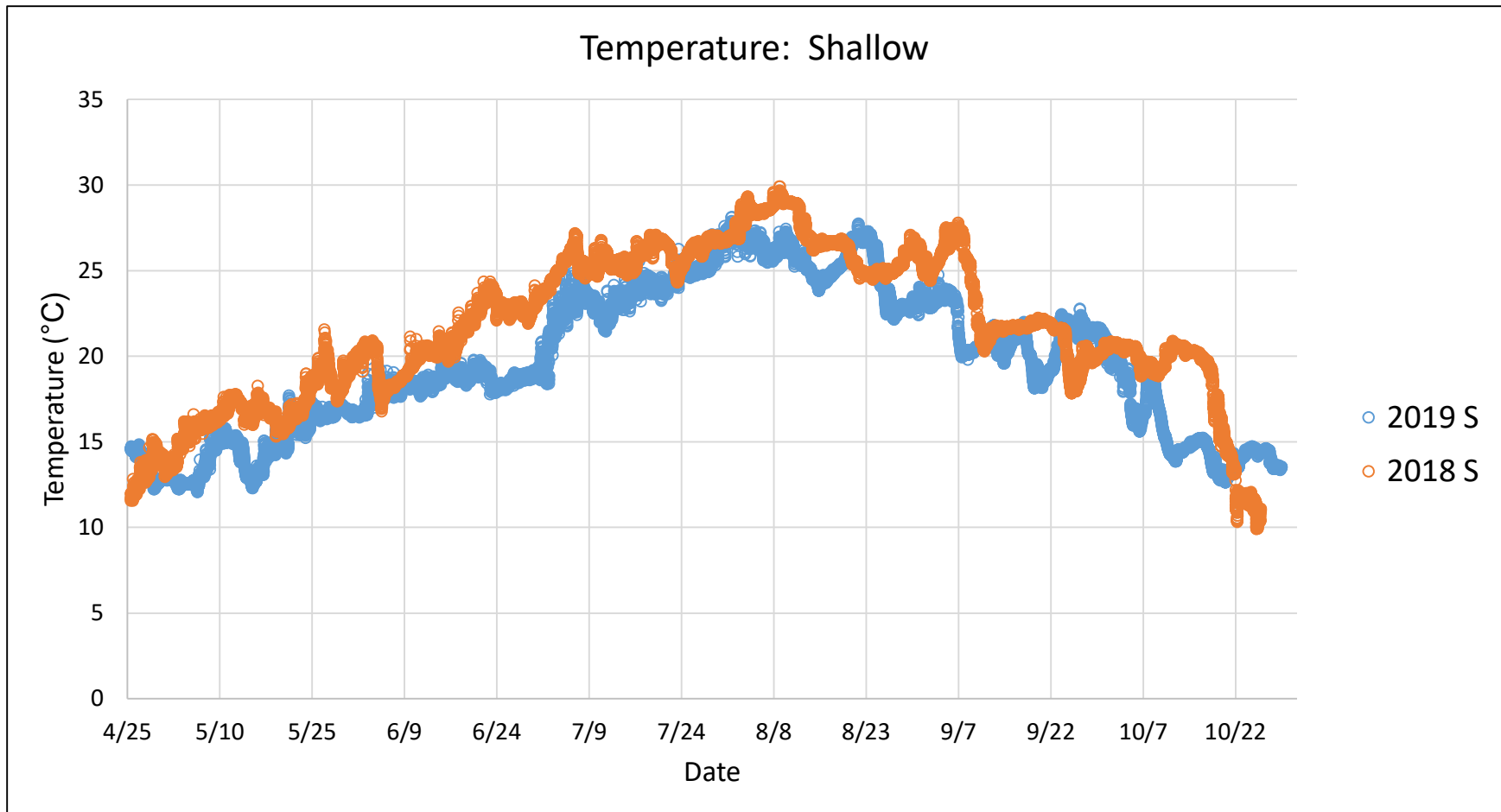


Figure 5. Cedar Pond 2018 and 2019 Continuous Shallow Temperature Readings. The 2019 device was installed from April 25 to October 29, while the 2018 device was installed from November 3, 2017 to October 26, 2018 (only data from April to October is shown). Both devices were located at a depth of approximately 1.2 m. Temperatures followed approximated the same pattern, but the average temperature in 2018 was $\sim 2^{\circ}\text{C}$ higher.

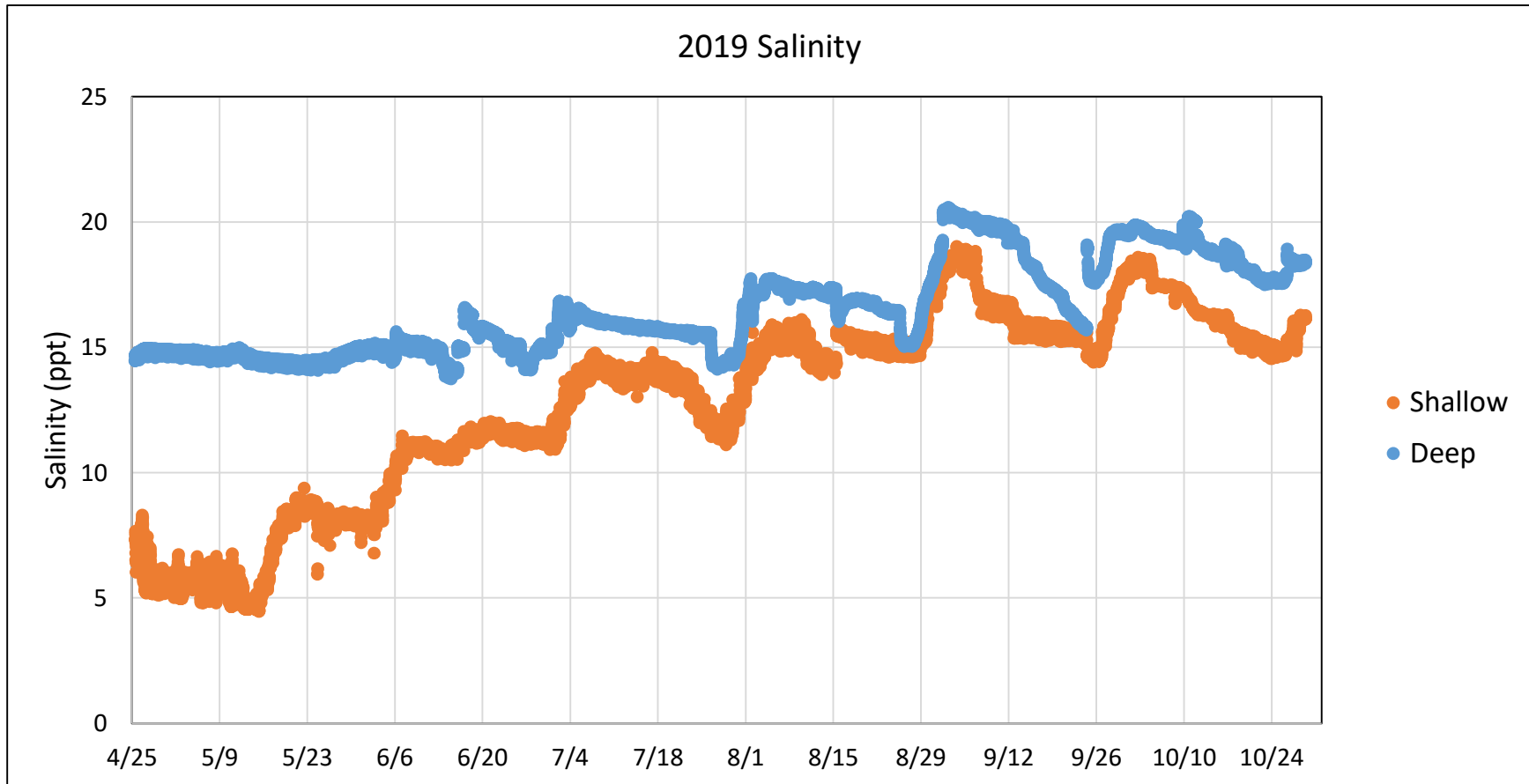


Figure 6. Cedar Pond 2019 Continuous Salinity Readings (April 25 to October 29). Both devices recorded temperature readings every 15 minutes and were located in the main basin at averages depths of 1.2 m and 3.6 m. The shallow salinity concentration at the time of initial deployment was approximately 5 ppt and increased until early September at a rate of 0.086 ppt per day before reaching an equilibrium concentration of 16.2 ppt. Deep salinity began at a concentration of approximately 15 ppt and changed within a much smaller range reflective of incoming tidal water settling to the bottom of the pond: average June to July deep salinity was 15.4 ppt, while average August to September salinity was 17.8 ppt.

These concentrations were ~10 ppt and ~1 ppt lower than respective 2018 concentrations at the same time of the year. The shallow 2019 salinity level increased until early September at a rate of 0.086 ppt per day before reaching an equilibrium concentration of 16.2 ppt. In contrast, shallow 2018 salinity reached a relative equilibrium concentration of 20.4 ppt earlier in the season and lasted between early July and the end of October (Figure 7). Deep 2019 salinities changed within a much smaller range reflective of incoming tidal water settling into deeper waters: average June to July deep salinity was 15.4 ppt, while average August to September salinity was 17.8 ppt. These 2019 concentrations were 6.4 ppt and 4.6 ppt less, respectively, than 2018 concentrations.

The lower 2019 salinities seem to be related to the boards being installed at a higher elevation throughout the 2018/2019 winter with the result that April 2019 salinity was lower than in April 2018. Since the rate of salinity rise in both years was similar, almost the entire reason for the lower salinity at the end of 2019 was due to the lower salinity at the start of the sampling season. The higher boards in the winter reduced the salt inputs from tidal inflows and allowed fresh groundwater inputs to become a larger portion of the fresh and salt water flowing into the pond. Groundwater levels in 2019 were above average, but they were lower than 2018 levels, also reinforcing the role of the higher boards (Figure 8).

As boards were lowered in 2019, the rate of salinity increase between May and July was approximately the same as it increased in 2018 (+2.5 ppt per month). This finding suggests that even though 2019 had a smaller notch opening, the volume of tidal input was approximately same in 2018 and 2019 and reinforces that 2019 had lower levels throughout the sampling season since it began the season at a lower concentration. The 2018 Annual Report, noted that all high tides reached the pond between May 5 and July 8, which is the 2018 period when shallow salinity was increasing at the same rate as measured in 2019.²⁴

Comparison of 2018 and 2019 continuous DO readings was compromised because of the intense biofouling of the shallow sensor after the middle of June 2019, which produced unreliable sensor readings. When the probe was working, shallow readings gradually increased from the initial deployment on April 25, peaked on May 15 (8.16 mg/L), and then decreased to near 0 mg/L in mid-June (Figure 9). Deep concentrations were less than 0.5 mg/L DO throughout the deployment except for some October peaks between 2 and 4 mg/L, which were likely inputs of high oxygen, tidal water that did not mix extensively and rapidly sunk to the sensor depth. In general, continuous DO readings and profile readings had acceptable congruence.

It is unfortunate that the shallow DO probe readings became compromised because the profile readings suggest that DO concentrations increased substantially from mid-August through October compared to what they were in 2018. In 2018, continuous DO concentrations had significant fluctuations due to varying phytoplankton DO inputs and were on average above the MassDEP minimum until June (Figure 10). DO readings fluctuated across a larger range until mid-August when they decreased to near zero and remained there until late October. In contrast, 2019 profile data at the DO probe depth showed increasing DO beginning in mid-June and concentrations in August, September, and October greater than the MassDEP minimum. Although the refined data was not available, this improvement in late summer DO concentrations is likely due to removing cormorant roosting over the pond. Bird guano dropping into the pond would have had high oxygen demand (and high TN and TP inputs) and the peak of the bird roosting when last comprehensively measured (2011 and 2012) was in August, September, and October.²⁵

²⁴ Executive Summary in Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018.

²⁵ see Figure 16, Cormorants on Cedar Pond Power Lines (2011, 2012) in Eichner, E., B. Howes, and D. Schlezinger. 2013.

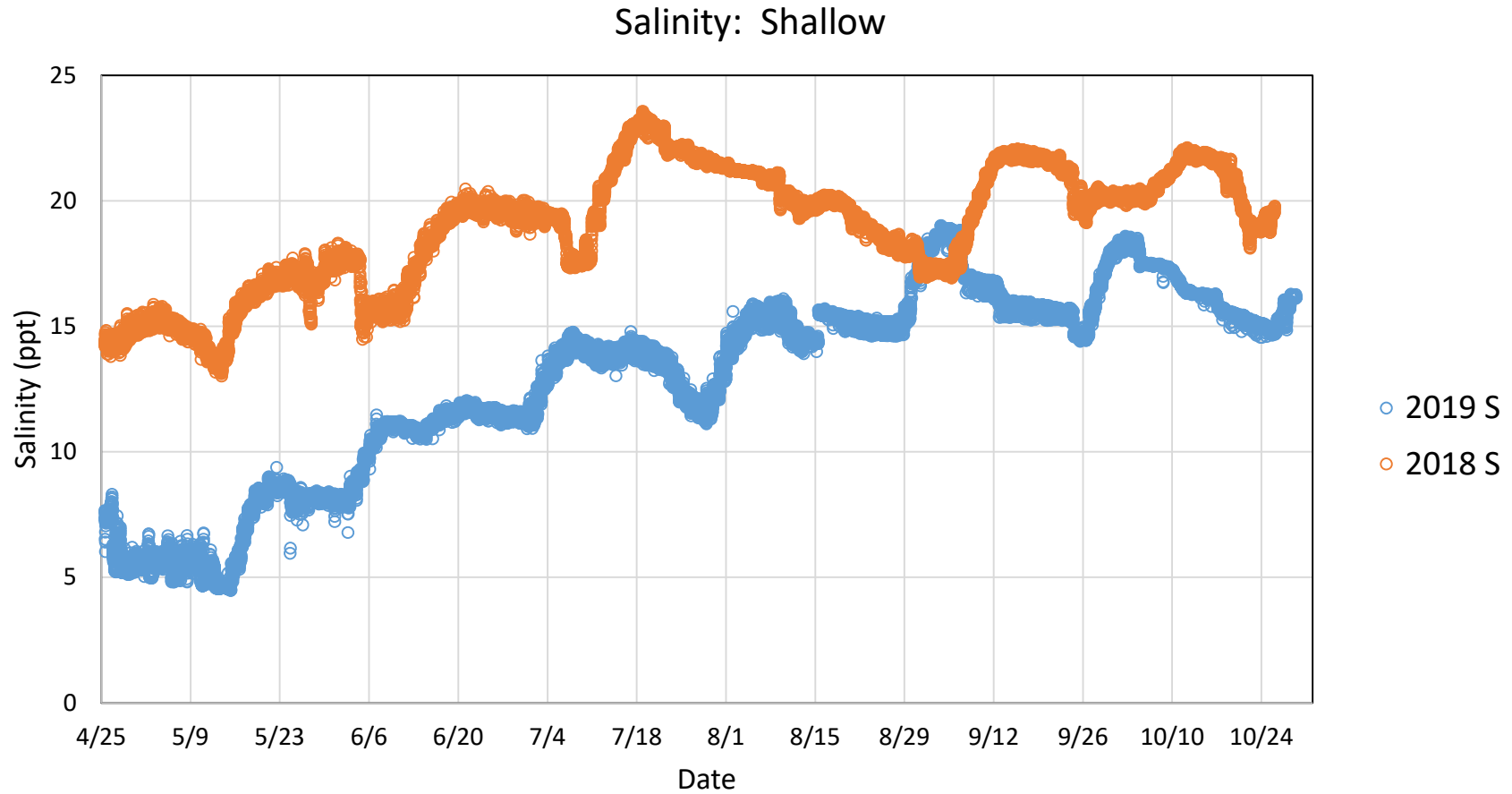


Figure 7. Cedar Pond 2018 and 2019 Continuous Shallow Salinity Readings. The 2019 device was installed from April 25 to October 29, while the 2018 device was installed from November 3, 2017 to October 26, 2018 (only data from April to October is shown). Both devices were located at a depth of approximately 1.2 m. In April 2018, shallow salinity was approximately 15 ppt, while in April 2019 it was approximately 5 ppt. This difference was likely due to higher outlet board elevation during the 2018/2019 winter. Both 2018 and 2019 shallow salinities increased between April and July at the same rate (0.086 ppt per day) suggesting similar tidal inflows, but 2018 concentrations reached an equilibrium concentration in July (20.4 ppt), while the increase continued until early September during 2019 and reached an equilibrium concentration of 16.2 ppt.

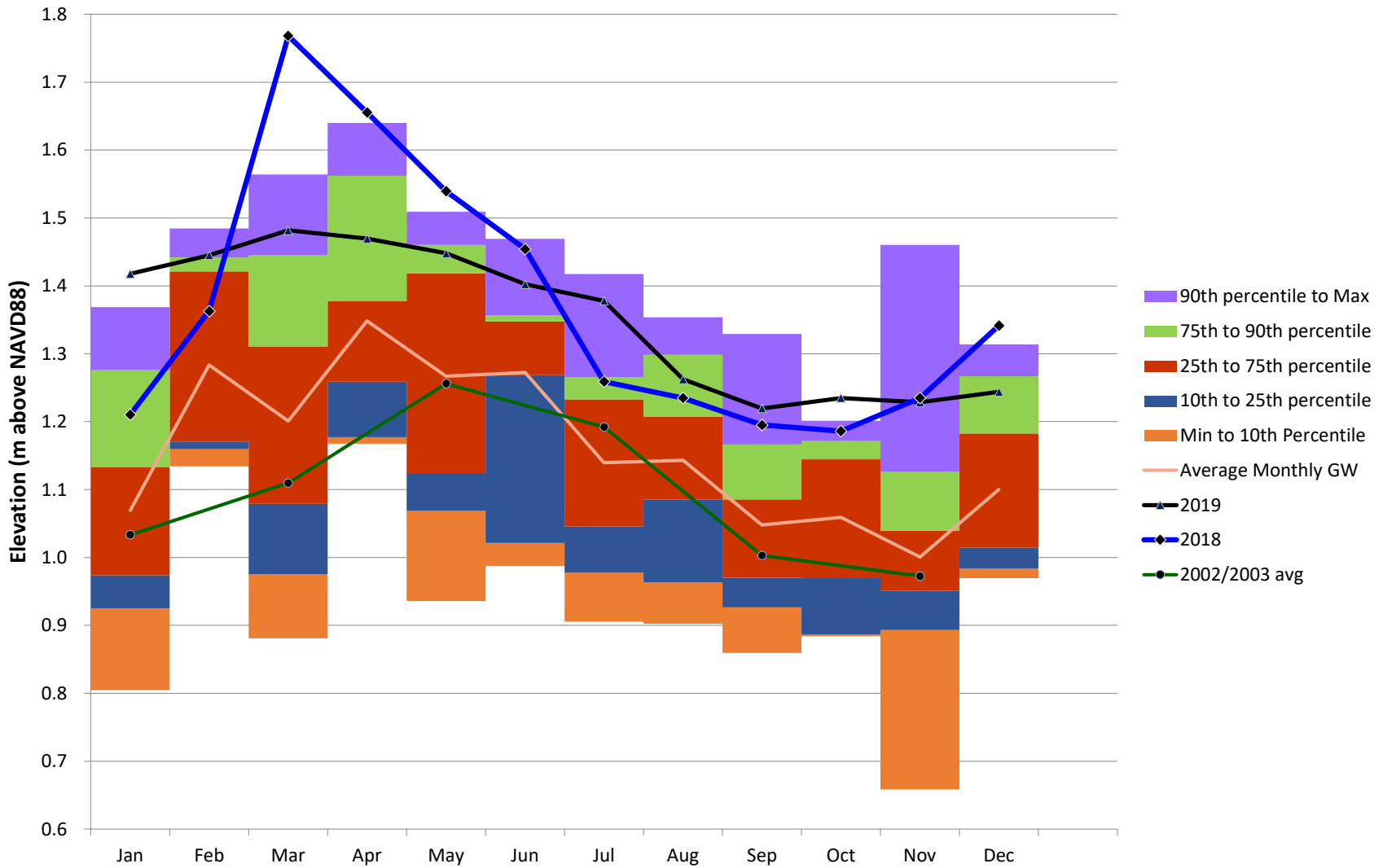


Figure 8. Orleans Groundwater Elevations (OSW-22). Groundwater elevations in Orleans during 2018 were exceptionally high with March, April, May, and December recording new high monthly levels. 2019 levels remained high, but were lower during the winter and about the same as 2018 during the summer, so groundwater inflow differences cannot explain the lower salinities in 2019 vs 2018. Lower levels would reduce groundwater discharge rates into Cedar Pond. Average levels during 2002/2003, when MEP stream outflow readings were recorded, were less than the long-term average groundwater elevations.

Dissolved Oxygen

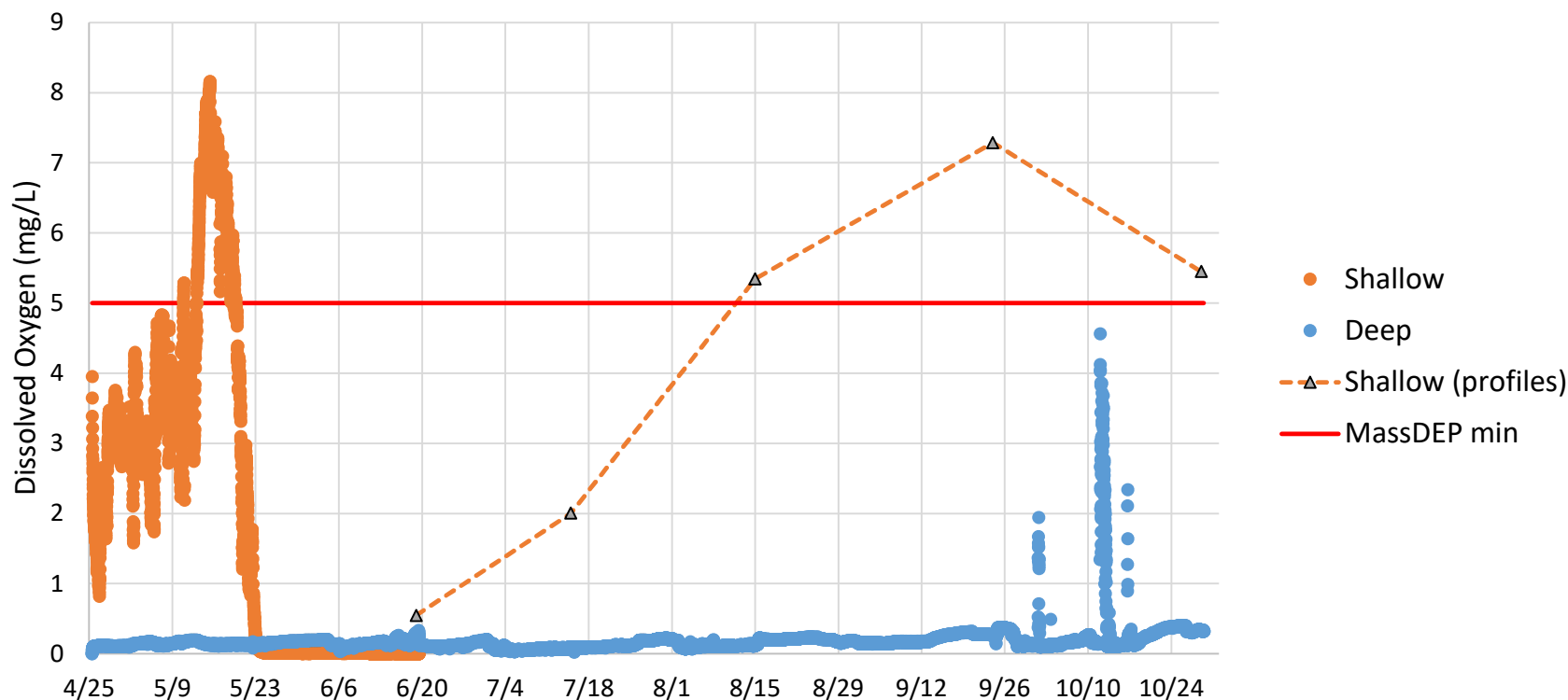


Figure 9. Cedar Pond 2019 Continuous Dissolved Oxygen Readings (April 25 to October 29). In 2019, shallow and deep devices were deployed between April 25 to October 29, programmed to record dissolved oxygen readings every 15 minutes, and were located in the main basin at averages depths of 1.2 m and 3.6 m. The shallow probe recorded acceptable data until mid-June; recording after that point was compromised by biofouling. Prior to the sensor failure, shallow DO concentrations increased from approximately 3 mg/L to 8 mg/L in mid-May before decreasing to near 0 mg/L during the third week of May. Profile DO recordings at the shallow sensor depth showed that sensor concentrations should have increased from mid-June to late September. From mid-August to the last profile in late October, shallow DO concentrations were greater than the MassDEP minimum concentration (5 mg/L). Deep DO readings were near 0 mg/L throughout most of the deployment period except for some short-lived increases in September and October likely due to large tidal inputs.

Dissolved Oxygen: Shallow

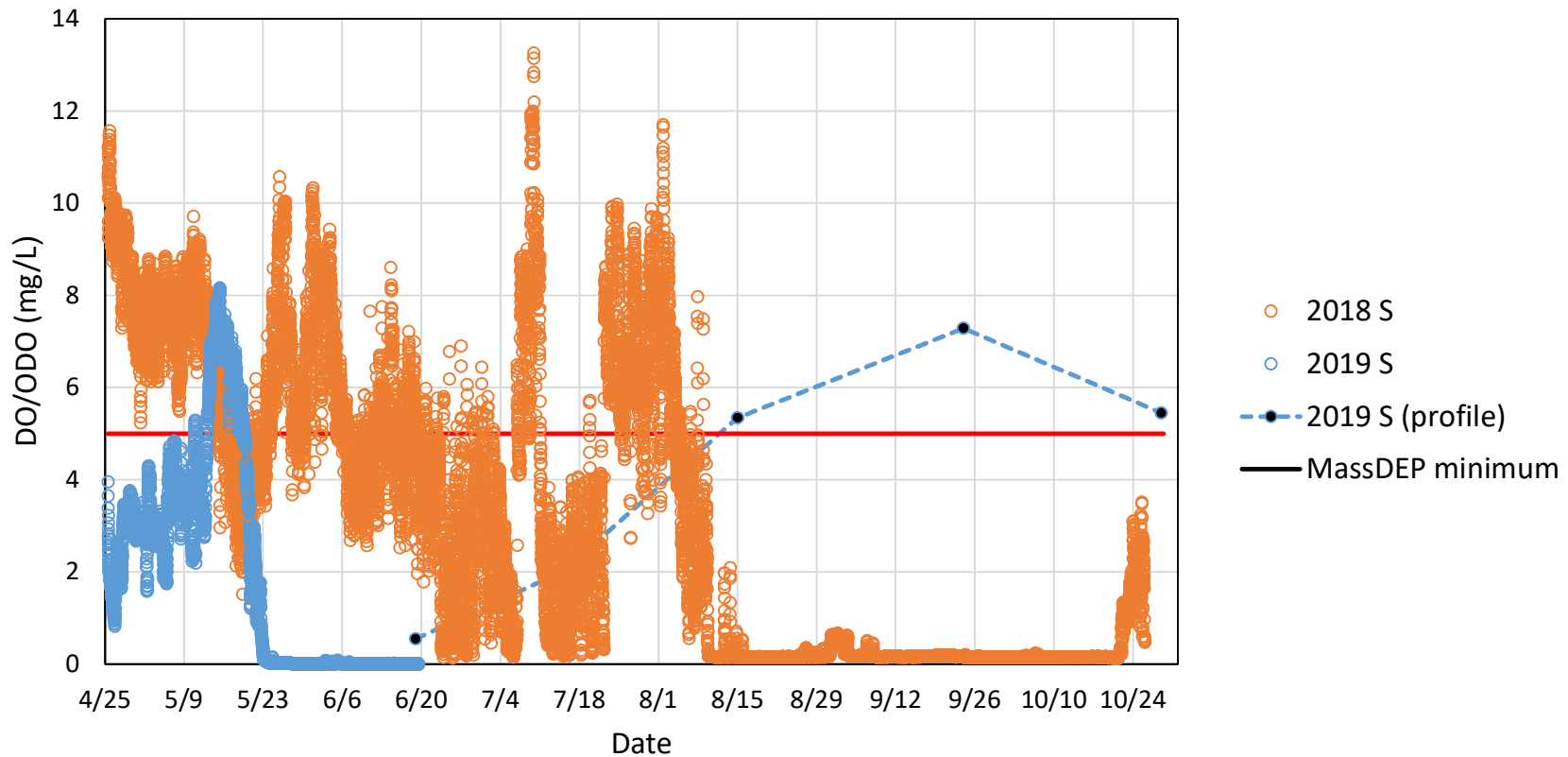


Figure 10. Cedar Pond 2018 and 2019 Continuous Shallow Dissolved Oxygen Readings. Continuous recording devices were installed in Cedar Pond during the same periods and depth during both 2018 and 2019. Both devices were located at a shallow depth of approximately 1.2 m and recorded DO concentrations every 15 minutes. During the 2019 deployment, the device stopped recording in mid-June due to biofouling, so the equivalent profile concentrations are shown. Concentrations in 2018 gradually decreased from April to June, then became extremely variable before decreasing to virtual zero from early August to mid-October. In contrast, 2019 concentration increased from ~1 mg/L in late April to ~8 mg/L in mid-May 2019, then decreased to near 0 mg/L (anoxia), and then began to increase from mid-June to late-September. Profile concentrations at 1.2 m in August, September, and October all were greater than the MassDEP minimum concentration, a notable improvement over 2018. This improvement in shallow DO concentrations was likely due to a decrease in cormorant roosting over the pond caused by the relocation of power lines that used to span the northern half of the pond.

III.B.3. Cedar Pond Water Column Profiles: Laboratory Assay Results

Water quality samples were collected on the same dates as the temperature and oxygen profiles (see Figure 3). Water samples were generally collected at shallow, middle, and deep depths: averaging 0.15 m, 1.5 m, and 3.5 m, respectively. All collected samples were assayed at the Coastal Systems Analytical Facility at SMAST using the same assays that have been utilized for all Cedar Pond and MEP assessments, including those for the Cedar Pond Management Plan. Sampling procedures and chemical assay methods are presented in the Town's QAPPs for freshwater²⁶ and estuarine²⁷ water quality monitoring. Samples were analyzed at the laboratory for the following constituents: salinity, ortho-phosphorus, total phosphorus, ammonia-nitrogen, nitrate+nitrite-nitrogen, dissolved organic nitrogen, particulate organic nitrogen, particulate organic carbon, chlorophyll-a, and pheophytin-a.

Profile samples generally showed that shallow and middle depths had similar concentrations of various constituents, but these concentrations were usually significantly lower than deep samples. All concentrations showed that Cedar Pond was significantly impaired in 2019, as it was in all previous assessments. Average 2019 total nitrogen (TN) concentrations were: 1.0 mg/L at 0.15 m, 1.4 mg/L at 1.5 m, and 5.6 mg/L at 3.5 m (Figure 11). Average 2019 total phosphorus (TP) concentrations were: 192 µg/L at 0.15 m, 299 µg/L at 1.5 m, and 725 µg/L at 3.5 m. TP and TN both had average concentrations at shallow and middle depths that were not statistically different ($p < 0.05$) from each other, but deep average concentrations were significantly higher due to stronger stratification, anoxic conditions and high rates of sediment regeneration. Breakdown of TP and TN constituents (*i.e.*, ortho-P, NOx-N, ammonia-N) generally followed predictable responses to changes in dissolved oxygen levels.

Average 2019 summer (May to October) TN and TP concentrations at the shallow (0.15 m) depth were notably lower than corresponding 2018 averages, but deep concentrations were significantly (~2X) higher due to the lack of occasional atmospheric oxygen replenishment because of the strength of stratification. Average summer 2019 mid-depth (1.5 m) concentrations were generally similar in both 2018 and 2019.

Some individual 2019 profiles showed relatively consistent TN and TP concentrations at all depths (*e.g.*, October 29), but these were less common in 2019 than in 2018 indicative of less water column mixing. TN concentrations at shallow and mid-depths were generally similar throughout the year, but the deep concentration generally decreased throughout the year. The 2019 average deep TN concentration was approximately 2 mg/L higher than in 2018, largely due to high December 2018 concentrations carrying through the winter into April and May. Review of the TN constituents showed that the deep TN increase in late 2018/early 2019 was largely related to an increase in ammonium-N (NH₄), which suggests that the temperature stratification measured in April/May largely remained consistent throughout the winter and was preventing atmospheric oxygen replenishment. This produced sustained low oxygen conditions and the buildup of NH₄. Comparison of temperature stratification in 2018 and 2019 based on the

²⁶ Town of Orleans Ponds and Lakes Monitoring Program, Quality Assurance Project Plan, 2018-2020. August 2018. Prepared by Town of Orleans Marine and Fresh Water Quality Committee and Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. 48 pp.

²⁷ Town of Orleans Estuary Monitoring Quality Assurance Project Plan: Namskaket, Little Namskaket, Rock Harbor, Nauset, and Upper Pleasant Bay. 2006. Howes, B. and R. Samimy, School for Marine Science and Technology, University of Massachusetts Dartmouth and Town of Orleans. 50 pp.

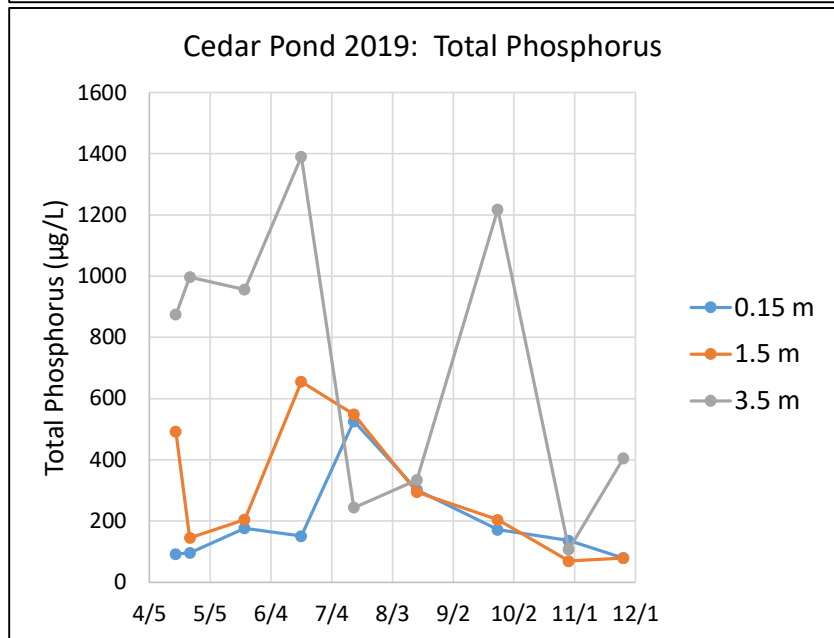
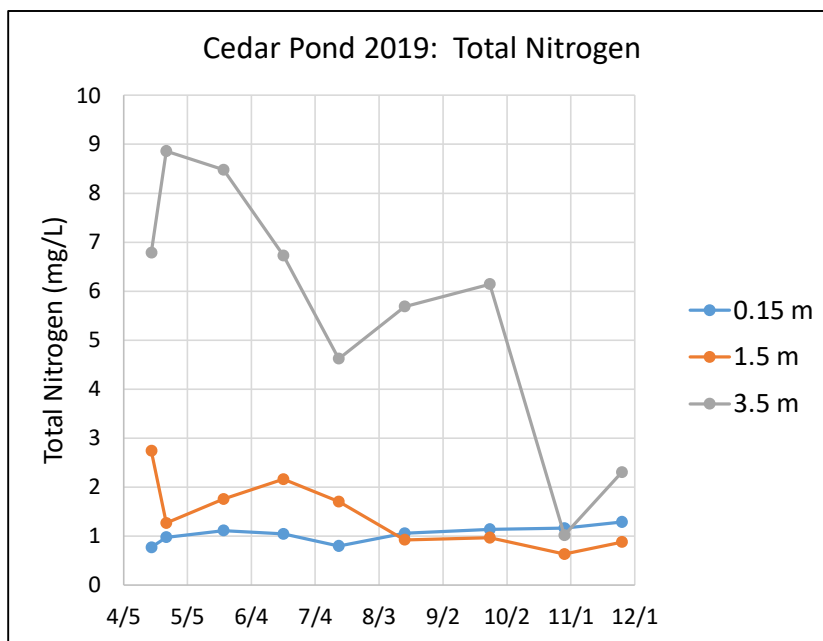
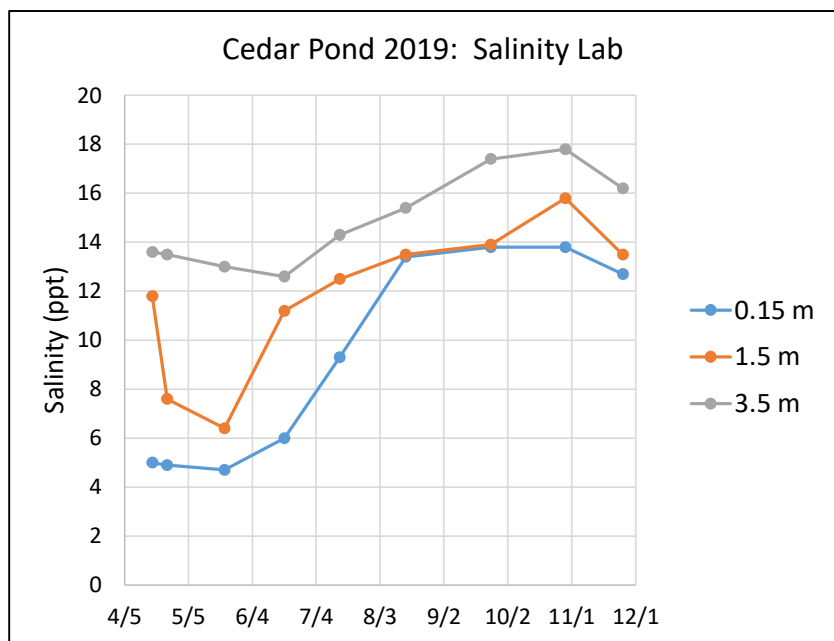


Figure 11. Cedar Pond 2019 Water Column Salinity, Total Phosphorus, and Total Nitrogen. Salinity readings increased as boards were lowered, but initial readings in April and May were only slightly higher than the Pond Management Plan target range of 1-4 ppt, largely due to boards installed at a higher elevation during the 2018/2019 winter. TN concentrations at 0.15 m and 1.5 m were generally within the same range during 2019, while deep (3.5 m) concentrations decreased from around 9 mg/L to ~1 mg/L during the year. TP concentrations at 0.15 m and 1.5 m peaked in June and July, respectively, then decreased during the rest of the year. Deep TP concentrations began April around 1 mg/L, but decreased significantly in July and August before increasing again in September.

continuous data showed that 2018 had periods of water column mixing into mid-June, while 2019 readings showed conditions for temperature mixing between the two continuous sensors did not occur from April to early September (see Figure 4). The decrease in deep TN throughout the year suggests that there was a mix of lowered of organic inputs (especially later in the summer due to the decrease in cormorant roosting) and retention of N containing organics (*e.g.*, phytoplankton and bacteria) in the sediments once they were deposited.

TP concentrations in 2019 have a more complex pattern than TN and suggest phytoplankton played a role in increasing TP retention in the upper water column in June and July followed by settling to deeper waters in August and September. Deep 2019 TP concentrations were ~1,000 µg/L in April and May, decreased by ~1200 µg/L from June to July, remained low in August, and increased to ~1200 µg/L (~4X increase) between August and September (see Figure 11). Chlorophyll readings at 1.5 m increased between May and June ~20X, increased again in July by ~25%, and then decreased back to a concentration similar to the 0.15 m concentration (35 µg/L) in August (Figure 12). This pattern suggest phytoplankton having conditions favorable to grow faster at 1.5 m in June 2019, retaining TP (and TN) at that depth while they were growing, and then beginning to die off and the phytoplankton particles slowly settling to lower portions of the water column after the peak in mid-July. The die-off coincides with a significant decrease in DO at 1.5 m between July and August profiles, an increase in clarity, and a decrease in chlorophyll.

Review of 2019 N:P ratios showed that nitrogen availability generally determined phytoplankton growth especially between June and September, but deep in the pond phosphorus and nitrogen were so high that neither would be limiting and growth would be likely more limited by light penetration (see Figure 12). In April 2019, N:P ratios were generally between 15 and 20, which brackets the Redfield ratio of 16. Phytoplankton growth in surface waters with N:P ratios above 16 are generally determined by available phosphorus, while waters less than 16 are generally determined by nitrogen, although ratios close to the Redfield limit are more often N controlled or balanced in their nutrient needs.²⁸ N:P ratios at 0.15 m and 1.5 m decreased from April to June to the 5 to 10 range (more available P than N), were relatively consistently within this range until August, and then began to slowly increase through October. This pattern showed that N controlled phytoplankton growth more than P during the summer. During the early spring and late fall, phytoplankton growth was determined more by an equal balance of N and P. Deep N:P ratios increased notably during the decrease in shallower readings, largely due to more TN being released from the sediments than TP. This peak was also likely related to available TP being retained in phytoplankton in the shallower parts of the water column during the high growth period of June/July. It is also likely that species within the phytoplankton community was quite variable throughout the summer due to changing nutrient availability. Deep TP and TN concentrations were notably higher in 2019 than 2018 due to the stronger stratification, but neither had a big increase experienced in November 2018 likely due to the near removal of TP and TN inputs from the cormorants.

²⁸ Freshwater ponds generally have N:P ratios 2X to 3X the Redfield number, especially on Cape Cod where N is added throughout the aquifers by septic systems.

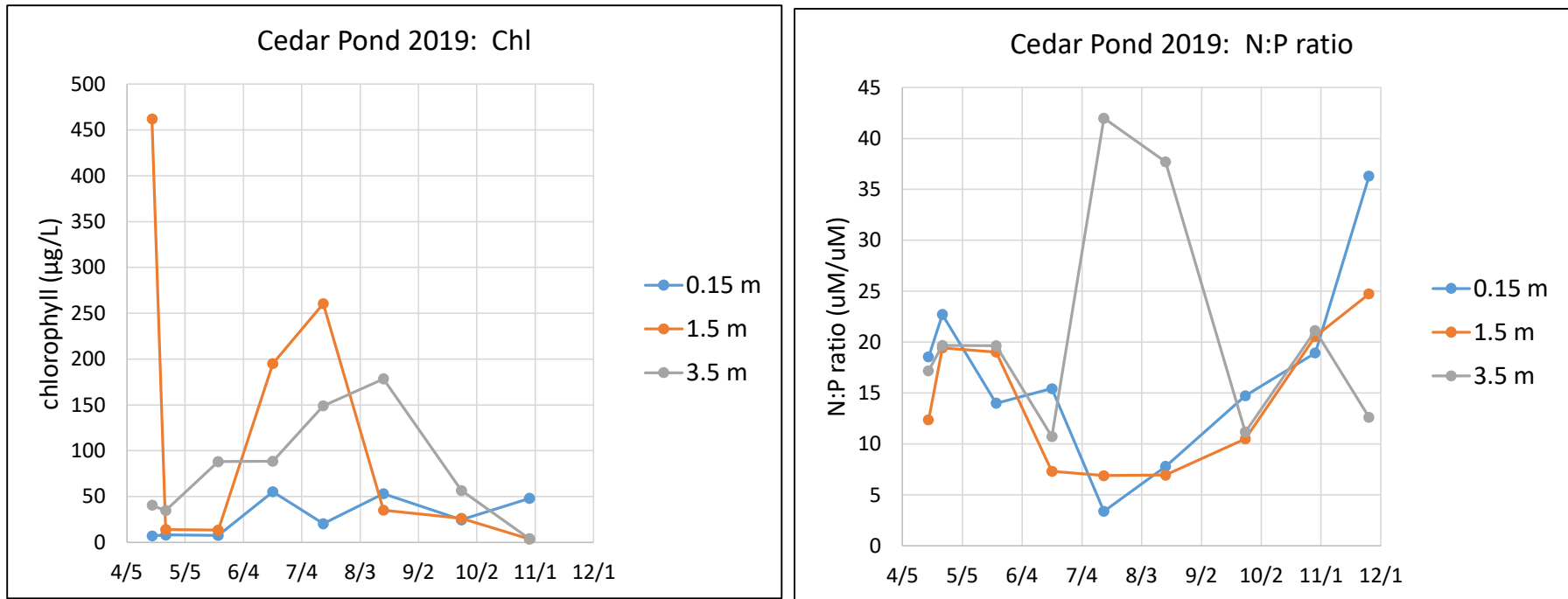


Figure 12. Cedar Pond 2019 Water Column Chlorophyll and N:P ratios. Chlorophyll readings at 0.15 m were high (20 to 50 $\mu\text{g/L}$), but relatively consistent throughout 2019. Readings at 1.5 m increased significantly between May and June, peaked at $\sim 250 \mu\text{g/L}$ in July, then decreased in the remaining samplings as salinity reached peak 2019 levels. Readings at 3.5 m followed a similar pattern to 1.5 m readings, but a 1-month delay, consistent with dead phytoplankton chlorophyll settling within the water column. N:P ratio began April generally in the 15 to 20 range at all three depths, then decreased through July into the 5 to 10 range. During this same period, deep (3.5 m) ratios increased to above 40, while the other two depths continued to decrease. The 0.15 m and 1.5 m ratios increased during September until November at approximately the same rate as they decreased between April and July, while the 3.5 m ratio decreased slightly in August and then generally matched the same range as the 0.15 and 1 m ratios between September and October. The July/August peak in the 3.5 m N:P ratio was due to the greater reduction in TP than TN (both concentrations were decreasing) being released from the sediments or perhaps relatively more TN entering the pond during this period from tidal inputs.

III.B.4. Cedar Pond Stream Flow and Water Quality Monitoring

Streamflows have been measured in Cedar Pond Creek at the same location (just north of Route 6; see Figure 1) continuously since November 2017. This is the same location used during the MEP assessment of Rock Harbor,²⁹ for the development of the Cedar Pond Management Plan,³⁰ and throughout 2018.³¹ Collecting the data continuously, at the same location, and using the same measurement methods has allowed data from the various time periods to be directly comparable. During 2019, low tide instantaneous flow readings and water quality samples were collected 21 times, generally every two weeks. Flow readings were compared to the existing stage-flow relationship and they were consistent with previous flow records.

Average annual, salinity-corrected flow during 2019 was only slightly lower than 2018 (6,419 m³/d vs. 6,886 m³/d) (Figure 13). Aside from the notably higher flows between November 2018 and January 2019, both years tended to have high flows in spring (March/April), lower flows during the summer (May to September), and then a return to higher flows in October. Review of summer flows (May to September) showed there was little difference between average 2018 and 2019 flows (~3% lower in 2019).

While the water outflows from Cedar Pond did not change significantly between 2018 and 2019, the export of nutrients from the pond was notably reduced in 2019. Average annual TN export was reduced 19% from 9.2 kg/d in 2018 to 7.45 kg/d in 2019 (see Figure 13). This reduction was similar during the summer, when the average export was reduced 25% from 7.2 kg/d in 2018 to 5.4 kg/d in 2019. The largest proportion (73%) of the TN reduction was a reduction in particulate organic nitrogen (PON), which is mainly composed of phytoplankton. TP exports also saw a similar pattern of reduction with annual loads and summer loads reduced between 2018 and 2019 at roughly the same rate: average summer TP export in 2018 was 1.4 kg/d and this was reduced 29% to 1.0 kg/d in 2019 (see Figure 13).

These 2019 decreases in TN and TP export were largely due to the improved 2019 DO concentrations and the accompanying 2019 reductions in shallow summer TN and TP concentrations compared to 2018. These reductions were in part also due to the stronger and more consistent water column stratification in 2019. This stratification kept high deep TN and TP concentrations in the deeper water column and prevented the mixing of these high concentrations into the upper water column. Since the upper water column is also the source of streamflow leaving the pond, these lower TN and TP concentrations accompanied the stream outflow and led to the lower 2019 TN and TP export from the pond. It is also worth noting that while 2019 TN and TP exports were lower than 2018 exports, 2019 TN export was still significantly larger than the watershed input, meaning that the pond was not attenuating nitrogen as it was in 2002/2003 and was still adding additional nitrogen to Rock Harbor. However, the improvement measured in 2019 with the initial absence of cormorant inputs provides some hope that TN export will continue to decrease as the accumulated sediment pool is drawn down and reaches a new, lower equilibrium.

²⁹ Recording from June 28, 2002 to May 23, 2004, 23 month deployment, documented in 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.

³⁰ Recording from June 5 and September 20, 2012, 3 month deployment, documented in Eichner, E., B. Howes, and D. Schlezinger. 2013. Cedar Pond Water Quality Management Plan.

³¹ Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018.

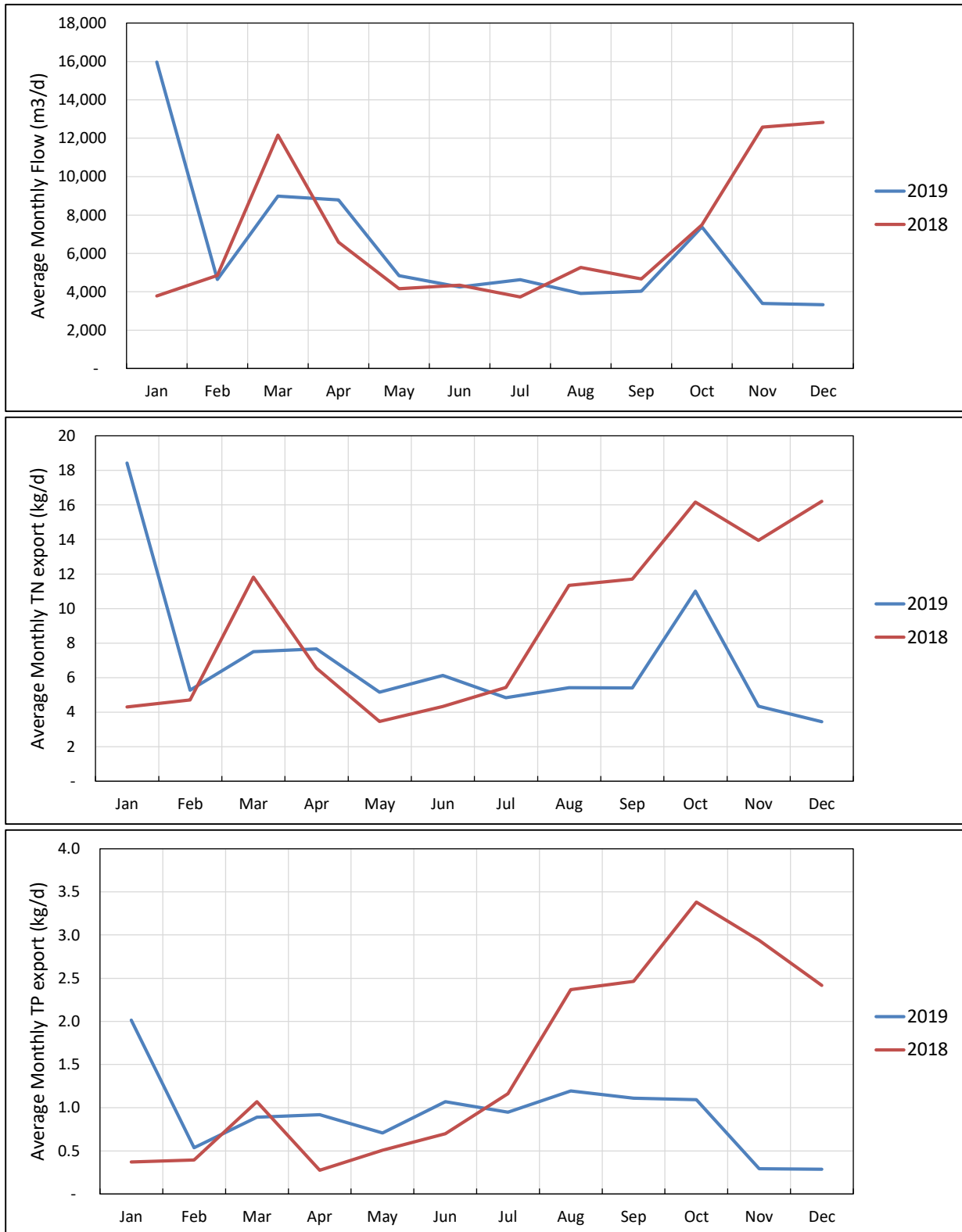


Figure 13. Average Monthly Outflow, TN, and TP through Cedar Pond outlet. Annual average outflow had little variance between 2018 and 2019, while both TN and TP export decreased in 2019 by 19% and 35%, respectively. Summer outflow (May to September) was also similar between the two years with similar decreases (~25%) in TN and TP export. Note significant TP and TN decreases in late summer, which was the peak of cormorant roosting.

IV. Conclusions and Proposed Management Changes

During 2018 and 2019, the Town implemented management changes that improved water quality in Cedar Pond. Between 2015 and 2018, the Town worked with various partners to relocate the power lines that were strung over the pond and utilized by high numbers of roosting cormorants. The transfer of these lines to Locust Road, just south of the pond, was completed in 2018 and the initial water quality impacts were measured in 2019; it is anticipated that additional improvements will be seen as the cormorant-impacted sediments continue to deplete. The Town also allowed the boards at the stream outlet to remain at a relatively high elevation throughout the 2018/2019 winter, which reduced the number of tides entering the pond. This change resulted in lower initial salinity levels in the pond in 2019; concentrations just slightly higher than the 1 to 4 ppt range recommended in the Cedar Pond Management Plan. The implementation of these management activities resulted in improved, but still impaired, 2019 water quality in Cedar Pond and reductions in the export of TN and TP to Rock Harbor.

The higher board elevations during the 2018/2019 winter (approximating those recommended in 2014) resulted in shallow pond salinity concentrations around 5 ppt. This concentration was just above the 1 to 4 ppt range recommended in the Management Plan. However, once the boards were lowered to address the required fish passage goals in the Fishway Plan, shallow salinity levels increased at the same rate as they did in 2018. The concentrations leveled off at a concentration that was 3 to 4 ppt lower than 2018 due to the lower starting salinity in April 2019. Deep water salinity was also lower than 2019, but it was only approximately 1 ppt lower. These results indicate the rapidity at which the salinity of pond waters respond to manipulation of the boards (*e.g.* the magnitude of tidal inflows) and the growing predictability of this system.

The larger surface salinity reduction compared to the bottom waters strengthened the salinity stratification in the 2019 water column. This stratification combined with strong temperature stratification from mid-May to mid-September effectively isolated the deeper waters and their high nutrient concentrations from mixing into the upper layers of the pond. In 2018, the water column had more frequent mixing which allowed the highly impaired deep waters with no DO and very high nutrient concentrations to impair the entire pond water column. In 2019, the stronger stratification improved the water quality conditions in the shallow (<1.2 m) portion of the water column, including sustained unimpaired/acceptable DO concentrations in August/September.

In order to better understand tidal inflows, CSP/SMASST staff installed an autonomous recording sensor at the inlet in 2019. These recordings showed that all high tides from Rock Harbor reached the pond once boards were reduced to the 1.24 m NAVD88 elevation recommended in the Fishway Plan. These readings also showed that 44% of the water level elevations between May and September were greater than the Fishway Plan goal of 6 inches of water above the board level to allow fish passage into and out of the pond. The lowering of the board elevation to 1.24 m NAVD88 allowed shallow salinity levels to increase at the same rate as in 2018.

Based on these findings, it is thought that increasing the board elevation could occur while still allowing adequate fish passage. A higher board elevation would allow lower salinity levels measured in spring 2019 to be sustained. It appears that a board level less than 1.48 m but greater than 1.24 m NAVD88 will be most appropriate. It is recommended that the Town,

CSP/SMAST, and MassDMF discuss potential options to attain both fishway and water quality goals.

Although the pond water quality remains impaired, moving the power lines did have a notable impact on reducing the nitrogen and phosphorus exported to Rock Harbor. Annual TN and TP export decreased in 2019 by 19% and 35%, respectively, compared to 2018. Although export was still much higher than 2002/2003 (MEP monitoring) or pre-2007, review of collected water quality showed that the 2019 decreases compared to 2018 were mostly composed on particulate organic nitrogen, which would be phytoplankton and components of cormorant guano. It is likely that with the continued absence of cormorant inputs, that the pond will continue to export N and P for a few years at a lesser and lesser extent until it again comes into balance with its external loading and as the accumulated sediment pool is drawn down.

Overall, water quality monitoring in 2019 showed improvements related to the implemented management actions. Cedar Pond remains impaired, but regular monitoring has shown that improvements can be attained as the system is better understood. Monitoring has also shown that it is likely that MassDMF and Town Management Plan goals can be attained at the same time, provided that further refinements based on the monitoring results are implemented.

The Cedar Pond Management Plan was adopted as an adaptive plan based upon regular monitoring and adjustments of management strategies as additional insights were gained about the progress toward the Plan goals: 1) restore water quality, 2) restore a herring run, and 3) protect the adjacent Atlantic White Cedar wetland. The 2018 and 2019 monitoring documented and discussed in this current report confirms that reducing the salinity in the pond through the installation of boards at the pond outlet is effective and that it improves water quality. The monitoring also confirms that removing the boards effectively removes the benefits and worsens water quality. Monitoring at the inlet during 2019 has confirmed that further refinements in the board management are necessary to reach water quality goals and that the monitoring has now effectively constrained the “best” board height. Observations suggest that there is no functional herring run at this point, likely ruined by the high salinity in the pond and the impaired water quality. The high salinity also represents an on-going threat to the adjacent Atlantic White Cedars.

It is anticipated that continued monitoring during the next year will provide additional insights into the net responses of the system to natural changes (*e.g.*, decreased water levels) and support more refined board adjustments for longer-term benefits. It is also anticipated that these impacts will include both shallow and deep-water quality changes, especially as another year of deposition to sediments without cormorant inputs will continue to see a lowering of TN and TP within the pond and exported to Rock Harbor.

V. References

CSP/SMAST Technical Memorandum: Cedar Pond Autonomous Mooring Results, Summer 2009. October 29, 2009. From: Schlezinger, D. and B. Howes. School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 6 pp.

CSP/SMAST Technical Memorandum: Board Height Recommendation for Cedar Pond Outlet. October 10, 2014. From: Howes, B., E. Eichner, R. Samimy, J. Ramsey, and S. Kelley. To: George Meservey, Town of Orleans, Director of Planning & Community Development and Carolyn Kennedy, Chair, Marine and Fresh Water Quality Task Force. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 13 pp.

CSP/SMAST Technical Memorandum: Cedar Pond Continuous Monitoring. January 14, 2016. From: Howes, B., E. Eichner, and D. Schlezinger. To: George Meservey, Town of Orleans, Director of Planning & Community and F Development and Carolyn Kennedy, Chair, Marine and Fresh Water Quality Task Force. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 6 pp.

CSP/SMAST Technical Memorandum: Cedar Pond Adaptive Management Monitoring Program: 2019 Semi-Annual Report. September 9, 2019. From: Howes, B., E. Eichner, and D. Schlezinger. To: Carolyn Kennedy, Chair, Marine and Fresh Water Quality Committee and George Meservey, Town of Orleans, Director of Planning & Community Development. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 17 pp.

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.

Eichner, E., B. Howes, and D. Schlezinger. 2013. Cedar Pond Water Quality Management Plan. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 54 pp.

Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 42 pp.

Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, and 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. 132 pp.

Town of Orleans Estuary Monitoring Quality Assurance Project Plan: Namskaket, Little Namskaket, Rock Harbor, Nauset, and Upper Pleasant Bay. 2006. Howes, B. and R. Samimy, School for Marine Science and Technology, University of Massachusetts Dartmouth and Town of Orleans. 50 pp.

Town of Orleans Ponds and Lakes Monitoring Program, Quality Assurance Project Plan, 2018-2020. August 2018. Prepared by Town of Orleans Marine and Fresh Water Quality Committee and Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. 48 pp.

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