Cedar Pond
Adaptive Management Monitoring Program: Annual Technical Report
January 2020 to December 2020

FINAL REPORT
November 2021

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 Outlet (March 23, 2021)
(courtesy of Nate Sears)

Acknowledgements:

The authors acknowledge the contributions of the many individuals, groups, and town boards who have worked tirelessly for the restoration and protection of Cedar Pond. Without these pond stewards and their efforts, this project and its associated management actions would not have been possible.

The authors also specifically recognize and applaud the generous commitment of time and effort spent by past and present members of the Orleans Marine and Fresh Water Quality Committee (née Task Force). These individuals collected water quality information, shared their observations, and, on occasion, ferried SMAST staff to monitoring locations on Cedar Pond.

In addition to these contributions, technical and project support has been freely and graciously provided by Nate Sears, George Meservey, and other staff at the Town of Orleans, Brad Chase at the Massachusetts Division of Marine Fisheries and Sara Sampieri, Jennifer Benson, Betsy White, Micheline Labrie, Paul Mancuso, Dale Goehringer and others at the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth.

Recommended Citation
Eichner, E., B. Howes, and D. Schlezinger. 2021. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2020 to December 2020. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 44 pp.

Executive Summary

Cedar Pond
Adaptive Management Monitoring Program: Annual Technical Report
January 2020 to December 2020

Continued implementation of adaptive management adjustments in Cedar Pond led to 2020 water quality conditions that were improved over 2019 and 2018. Overall water conditions continue to be impaired, but 2020 measurements showed improved dissolved oxygen levels, lower total nitrogen (TN), and total phosphorus (TP) concentrations, and lower TN and TP exports from the Pond to Rock Harbor. Nutrient exports approached 2002/2003 levels, but additional steps are necessary to achieve the Cedar Pond Management Plan goals to: 1) restore water quality, 2) restore a herring run, and 3) protect the adjacent Atlantic White Cedar wetland.

The Town of Orleans Cedar Pond Management Plan[1] 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 Management Plan had the three goals listed above and recommended an adaptive management approach of monitoring water quality and adjusting management tools based on monitoring results. The Superseding Order of Conditions required regular monitoring of the pond for a minimum of three years with regular reporting of monitoring results in a semi-annual memorandum and an annual report. The approval also required the development of a Fishway Plan in coordination with the Massachusetts Division of Marine Fisheries (MassDMF) to allow herring passage between the pond and Rock Harbor. 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 the Town, and provide the regular reports on progress toward meeting the Management Plan goals.

Initial management steps recommended in the Management Plan 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 internal nutrient additions (*i.e.*, regeneration) from the pond sediments. Reinstalling boards at the pond outlet was recommended as a low cost step to slowly return the pond to brackish conditions and the Town began discussions in 2017 to move the power lines. The boards were re-installed at the outlet on January 4, 2018 and the power lines were moved in December 2018.[2]

Monitoring results have been regularly reviewed in Annual Reports (2018 and 2019) with brief semi-annual memos providing updates on monitoring activities. CSP/SMAST, MassDMF, and

[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] The Town succeeded in obtaining an agreement with Eversource to move the lines in 2017 and the removal of key lines was completed in December 2018.

Town staff typically review monitoring results at the time of an annual report or semi-annual memo and decide whether adaptive management adjustments are warranted. During the past three years, the height of the boards has been adjusted, an opening in the boards has been added, and the height of the opening has been raised as a result of review of data collection at Cedar Pond.

This 2020 Annual Report reviews Cedar Pond data collected in 2018, 2019 and 2020. This Report includes data previously presented in the 2020 semi-annual Technical Memorandum, which was presented to the Town in December 2020.[3] All reporting on Cedar Pond, including this annual report, has been delayed due to COVID pandemic issues. This report also includes recommendations for adjustments in management strategies to better attain the Management Plan goals. Findings from available collected data included:

- More of the pond water column had acceptable dissolved oxygen (DO) concentrations in 2020 than in 2018 or 2019. Average 2020 DO concentrations at 0.5 m, 1 m, and 1.5 m depths exceeded the MassDEP regulatory minimum of 5 mg/L after only achieving this at 0.5 m and 1 m in 2019. In addition, the average DO at 2 m was 3 mg/L greater than in 2019. Waters deeper than 2 m continued to be impaired throughout the summer.
- Deep nutrient concentrations were significantly reduced in 2020. Average deep 2020 TN and TP concentrations were 52% and 19% lower, respectively, than in 2019. Shallow concentrations were approximately the same in both years, while interim depth concentrations were slightly lower in 2020. These water column reductions were likely related to the higher DO concentrations: less of the pond sediment area was exposed to hypoxic/anoxic conditions in 2020 leading to lower sediment nutrient regeneration and reduced water column concentrations.
- Nutrient and streamflow measurement in Cedar Pond Creek showed that the 2020 mass of TN transferred out of the pond toward Rock Harbor was significantly less than in 2018 or 2019 and approached 2002/2003 levels. Rock Harbor was identified as impaired by nitrogen in a 2008 Massachusetts Estuaries Project (MEP) assessment.[4] Average daily TN export during the 2002/2003 monitoring for the MEP was 1.1 kg/d, while the 2020 TN export was 1.4 kg/d (49% less than 2019). MEP monitoring showed a 58% watershed N attenuation/removal by Cedar Pond, so comparable or greater natural removal could reduce the amount of required Rock Harbor watershed nitrogen reductions. Annual 2020 TP export was also 45% less than 2019 export, but comparison of TN and TP concentrations shows that nitrogen is the key nutrient for managing water quality in both Cedar Pond and Rock Harbor.
- The regular lowering of boards to attain Fishway Plan goals is keeping salinity concentrations higher than the Management Plan goals (1 to 4 ppt). Salinity levels

[3] CSP/SMAST Technical Memorandum: Cedar Pond Adaptive Management Monitoring Program: 2020 Semi-Annual Report. December 8, 2020. From: Howes, B., E. Eichner, and D. Schlezinger. To: George Meservey and Nate Sears, Town of Orleans. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 11 pp.

[4] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2008. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA. 132 pp.

regularly decrease during the winter and into spring as the inlet board elevation is set at a higher level than during the summer. Once boards are lowered (2018) or a notch is added (2019 & 2020) in mid-March, water column salinity in the pond begins to rise; the rate of the rise has been similar in all three years. Near surface salinity peaks in late fall in the 17 to 20 ppt range and then begins to decline as fall/winter precipitation increases groundwater levels. In over 30 visits to the pond inlet by Town and CSP/SMAST staff, no herring or other anadromous fish have been noted.

The 2020 monitoring results largely confirmed the lessons of 2018 and 2019 and the recommendations in the 2013 Cedar Pond Management Plan:

a) reduced salinity in Cedar Pond can improve water quality conditions (*i.e.*, higher DO and lower TN and TP concentrations),
b) salinity reductions can be sustained by installation of the boards at the pond outlet, and
c) reduction of cormorant roosting through the relocation of the power lines will improve 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 combination of the increase of the elevation of the notch in 2020 and a second year without cormorants provided some additional water quality improvements over 2019, but the pond continues to be impaired. And the lowering of boards and the impaired water quality conditions are not attracting the fish that the board movement is designed to encourage. 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 and allow sufficient water quality improvements to make Cedar Pond an attractive and sustainable herring habitat.

Overall, 2020 readings showed additional incremental 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 2020 readings were better than 2018 or 2019. Shallow water quality conditions were notably improved with acceptable DO in a greater proportion of the water column and lower nutrient levels. 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 I-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[5] was reviewed and approved by appropriate Town Committees, including the Board of Selectmen and the Conservation Commission, and then the state in 2017.[6] The Management Plan recommended a series of steps to attain the three goals selected by the Town 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 Cedar Pond Management Plan require 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.

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[5] 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.

[6] Certificate of the Secretary of Energy and Environmental Affairs on the Single Environmental Impact Report: Cedar Pond Water Quality Management Plan. May 26, 2017. EEA#: 15474. 34 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 I-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 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 to begin to reduce salinity. Discussions on moving power lines began in 2015 and the Town was eventually successful in 2017 in reaching an agreement with Eversource to move the lines. The key power lines were moved (removing preferred roosting lines for cormorants) and replacement lines have now been installed along Locust Roads, which is located south of the pond.

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 reducing 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.

Based on the 2018 findings and in consultation with MassDMF, the outlet boards were left at a relatively high elevation during the 2018/2019 winter and then were adjusted as required in the Fishway Plan throughout spring and summer 2019. In addition, based on 2018 comparisons of water levels to the board heights, staff from CSP/SMAST, MassDMF and the Town collectively agreed to limit the size of the board opening during the 2019 summer to a 6 inch notch. The adaptive change in board height during the winter led to a much lower salinity to start the 2019 year, which led to lower salinity levels throughout the year. This change, combined with reduced number of cormorants roosting over the pond, produced notable water quality improvements in 2019:

- Shallow salinity in April 2019 had decreased to the 5 to 7 ppt range.[9] These salinities were only slightly higher than the Management Plan goal of 1 to 4 ppt and equivalent to some historic salinity readings collected between 2001 and 2005.
- Shallow dissolved oxygen (DO) concentrations were acceptable in the late summer (mid-August through October 2019). Concentrations were greater than the MassDEP regulatory minimum (5 mg/L) and much improved from the anoxic concentrations at the same depth during the same period in 2018.
- Shallow Total Nitrogen (TN) and Total Phosphorus (TP) concentrations were lower than those in 2018. This change was largely due to stronger stratification from salinity and temperature in 2019 and the accompanying isolation of deeper nutrient-enriched, more impaired waters.
- Improved shallow water column conditions also reduced TN and TP export to Rock Harbor in pond outflows. 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.

[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] Eichner, E., B. Howes, and D. Schlezinger. 2020. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2019 to December 2019. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 38 pp.

Although overall 2019 water quality was improved, deep water quality conditions continued to be impaired and as the summer progressed, impairments throughout the water column increased, just as they had in 2018 to match increasing salinity levels. Salinity levels in 2019 increased at the same rate as 2018 even with the notch restriction, but remained lower than 2018 because of the lower starting concentrations in April. Deep DO concentrations continued to be anoxic and unacceptable throughout the April to November 2019 monitoring period. Overall, water column TN, TP, and chlorophyll a concentrations remained high and indicative of impaired conditions. In addition, no fish were noted immigrating into the pond in the 2019 spring, which was two consecutive springs without any herring or other anadromous fish noted entering the pond.

The 2019 monitoring results largely confirmed the lessons of 2018: a) reduced salinity in Cedar Pond improves 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.

One significant change in monitoring procedures in 2019 was the installation of a continuous recorder at the Pond inlet by CSP/SMAST. This recorder was installed to directly measure water elevation at the inlet boards and provide more refined information to better assess board height elevations and Fishway Plan goals. The water level sensor at the inlet showed that board elevations attained the water levels in the Fishway Plan approximately half of the time during the summer and, as such, suggested that Fishway Plan goals could be attained with even higher board heights. It was thought that higher board heights would lower pond salinity and sustain the better water quality conditions that accompanied lower salinities.

After further review of the water level data at the inlet, Town, CSP/SMAST, and MassDMF discussed further adaptive management options within the goals of both the Management Plan and the Fishway Plan while also sustaining improved water quality conditions in Cedar Pond. Based on the 2019 water level monitoring at the inlet, CSP/SMAST determined that a 4 inch increase in the notch elevation would reduce the percentage of time tides reach the pond from 48% to 12%, but the frequency of water levels exceeding this elevation would be reduced only slightly from 90 times to 83 times. In addition, the average time of each event where water levels exceed the higher elevation would only be reduced from 3.3 hours to 2.6 hours.[10] In October 2020, Town, CSP/SMAST, and MassDMF decided that the July to October notch elevation in the boards could be raised 4 inches and still attain the goals of the fish passage in the Fishway Plan. This change will be implemented in 2021.

This Annual Report includes a comprehensive review of all data collected during 2020, including the data summarized in the 2020 Semi-Annual Tech Memo.[11] This report also includes

[10] CSP/SMAST Technical Memorandum: Cedar Pond Board Adjustment. October 21, 2020. From: E. Eichner, Howes, B., and D. Schlezinger. To: G. Meservey, Director of Planning & Community Development and N. Sears, Natural Resources Manager, Town of Orleans. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 6 pp.

[11] CSP/SMAST Technical Memorandum: Cedar Pond Adaptive Management Monitoring Program: 2020 Semi-Annual Report. December 8, 2020. From: Howes, B., E. Eichner, and D. Schlezinger. To: G. Meservey, Director of Planning & Community Development and N. Sears, Natural Resources Manager, Town of Orleans. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 11 pp.

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 the pond through an outlet under Route 6 during the highest tides and the pond discharges water through the outlet to Cedar Pond Creek and then Rock Harbor when the high tide recedes.

When regular monitoring of the Cedar 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 gradually 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 2018 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 threshold in Massachusetts surface water regulations (314 CMR 4) due to high sediment and water column oxygen demand and frequent large phytoplankton blooms.[12] Extreme oxygen demand events caused a significant fish kill in 2001, which included herring and white perch. Water quality data collected in 2009 and 2012, after recent changes to the downgradient stream channel, documented that DO impairment had continued and had become more extreme under the new, increasingly more saline conditions.[13] Another significant fish kill occurred in 2008. Cedar Pond was first added to the Massachusetts Integrated List as an impaired water body in the 2012 version of the list.[14]

Extensive water quality monitoring conducted for the 2007 Rock Harbor Massachusetts Estuaries Project (MEP) assessment also showed that Cedar Pond had impaired water quality,[15] but streamflow monitoring in Cedar Pond Creek showed that it was removing 58% of its watershed nitrogen inputs and, therefore, was lowering the watershed N load to Rock Harbor.[16] Similar stream monitoring in 2012, after the pond had become more saline, showed that the

[12] Eichner, E. 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.

[13] 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.

[14] Massachusetts Department of Environmental Protection. March 2013. Massachusetts Year 2012 Integrated List of Waters. Final Listing. Massachusetts Division of Watershed Management, Watershed Planning Program. CN: 400.1. Worcester, MA. 313 pp.

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

[16] 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. 132 pp.

nitrogen attenuation in the pond had been eliminated and that during the 2012 summer, the pond was adding nitrogen to the stream outflow and was exporting up to more than 3X the watershed nitrogen inputs.[17] 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).[18] Given the Town's efforts to implement the Cedar Pond Management Plan, an amended CWMP has recommended that the Town review the results of the Cedar Pond management options and then re-assess whether alternative nitrogen reductions solutions should be pursued within the Cedar Pond and Rock Harbor watersheds.[19]

III. Cedar Pond Adaptive Management Program 2020 Results

The 2016 approval of the Cedar Pond Management Plan required three years of monitoring and adjustment of management strategies with regular reporting water quality impacts. 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. In 2019 and 2020, the outlet boards were adjusted each year to adapt the management strategies to reflect the better understanding developed from the monitoring during the previous year (*i.e.*, an adaptive management approach).

The CSP/SMAST portion of the implementation of the Cedar Pond Adaptive Management Plan has focused primarily on 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 2020 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 2013 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 into the pond and allow natural groundwater inputs to gradually return salinity levels to the brackish conditions that had allowed natural nitrogen attenuation[20] and support a restored habitat for a healthy herring run.

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

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

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

[20] Documented in 2002-2003 monitoring for the MEP Rock Harbor assessment

Management of the board height is complex because pond water levels are impacted by several variable 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 prior to development of the Management Plan. As part of the initial implementation of the Management Plan, CSP/SMAST 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/SMAST staff recommended an initial board elevation of 1.45 m NAVD88.[21]

During the discussion of the Fishway Operations and Maintenance Plan that accompanied MassEOEA's approval of the Management 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 reduce saltwater inflow but still allow at least 2 inches (0.05 m) of water depth over the top board to allow juvenile herring to leave the pond.

After one year of board adjustments and the subsequent review of the 2018 YR1 monitoring results, Town, MassDMF, and CSP/SMAST staff discussed refinements to better attain the Cedar Pond 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 (**Figure III-1**). The seasonal Fishway Plan adjustments would be maintained, but the opening in the boards would be limited to the notch. CSP/SMAST also proposed the installation of an autonomous water level recorder at the outlet and this was installed at the weir on May 23, 2019. This recorder has remained in place and has recorded continuously since its initial installation. 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 reviewing data and again meeting in late June 2019, Town, MassDMF, and CSP/SMAST staff agreed to leave the boards in their current configuration. A follow-up discussion in November 2019 led to the Town removing the notched board and adding additional boards. The Town then slightly reduced the board level in December 2019 to manage pond water level.

In 2020 YR3, monitoring efforts became complicated because of the COVID pandemic, but the basic configuration of the boards was maintained and monitoring was maintained as best as possible. In late 2020, CSP/SMAST staff reviewed 2019 tidal data at the inlet with the Town and MassDMF and this led to a consensus that the elevation of the bottom of the notch opening could be raised 4 inches.[22] This review found that the number of tides with water elevations greater than the Fishway Plan goals was approximately the same with the 4 inch height increase, but the duration of tidal inflow during the higher tides would be decreased by an average of 40 minutes, which would reduce salinity inputs. This change will occur during calendar year 2021.

[21] CSP/SMAST Technical Memorandum: Board Height Recommendation for Cedar Pond Outlet. October 10, 2014.
[22] CSP/SMAST Technical Memorandum: Cedar Pond Board Adjustment. October 21, 2020.

Figure III-1. Notched Board at Cedar Pond Outlet. After reviewing 2018 water levels at the outlet, Town, MassDMF, and CSP/SMAST staff agreed that the boards at the outlet should have a notch in the upper board to facilitate fish passage while also limiting the number of high tides reaching Cedar Pond. Subsequent water level monitoring in 2019 showed this decreased salinity in the pond, while 2020 monitoring suggested that the board elevation could be increased without significantly altering the number high tides reaching the pond. Notch elevation is adjusted according to MassDMF goals for high tide elevation over the notch in the spring for spawning herring immigration and a reduced elevation over the notch in mid/late summer to allow young of the year emigration. No herring have been observed at the boards in more than 30 visits between 2018 and 2020.

In order to monitor the water and board elevations, measure streamflow, and note fish counts, Town and CSP/SMAST staff continued to visit the outlet and the stream gauge during 2020. During Town staff visits, water elevations above the boards and any fish were noted and board heights were adjusted as appropriate (**Table III-1**). CSP/SMAST staff visited the outlet for regular maintenance of the autonomous water level device and 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 2020 Town or CSP/SMAST visits; since 2018, no fish have been noted at the inlet during more than 30 visits.[23]

Raising the bottom of the notch by 4 inches in 2020 reduced the number of high tides reaching the pond as planned. In 2019, the autonomous recordings showed the inlet water level was 6 inches (0.15 m) above the bottom of the notch elevation in 44% of the water level readings collected at the outlet during the device deployment. In contrast, during 2020, the percentage of readings 6 inches above the notch was reduced to 4% during the March 15 to June 30 period specified in the Fishway Plan, but these periods occurred on more than half (57%) of the days during the specified period (**Figure III-2**). This finding means that any fish would have optimal Fishway Plan conditions to enter the pond on more than half of the days and would wait no more than one day on average to enter during optimal conditions.

Similarly, 4 inch increase in the notch elevation did not restrict optimal fish exit conditions specified in the Fishway Plan. The Fishway Plan defined optimal conditions for fish exit during July 1 to November 15 as 2 inches above the boards. Review of inlet recordings during this period (truncated to September 23 by instrument failure) found that water levels were 2 inches above the board in 7% of the readings, but optimal conditions were recorded 86 times during the 85 day period. This finding means that any fish would have optimal Fishway Plan conditions to exit the pond every day on average.

Overall, the 2019 and 2020 annual water level readings at the outlet had similar characteristics (**Table III-2**). Average water levels in both years were the same. The overall elevation range in 2020 was slightly higher due to a higher maximum reading. The ranges defined by the difference between the 25th and 75th percentiles was the same in both years.

[23] Eichner, E., B. Howes, and D. Schlezinger. 2020. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2019 to December 2019.

Table III-1. Cedar Pond Board Height Log: 2020. Town and CSP/SMAST staff visited the pond outlet on seven 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 bottom of the notch elevation was 4 inches (0.1 m) higher in 2020 than in 2019.

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	4/13/20	10:45	10:36	0	3	2.25	No fish	6” board replaced with notch board	1.42		
Town	4/28/20	9:45	9:45	1	1	2.08	No fish	none			
SMAST	5/26/20	15:22							1.38	1.50	1.35
SMAST	6/25/20	14:20							1.37	1.48	1.38
SMAST	7/22/20	14:23							n/a		
SMAST	9/23/20	15:11							1.39	1.50	1.49
Town	9/28/20	14:30	16:15	0	1	2.58	No fish	notch board removed			

Table III-2. Cedar Pond Outlet Water Level Elevation Summary: 2019 and 2020. Summary of continuous water level readings collected at the Cedar Pond outlet in 2020 and 2019 show same average elevation and range in each year. Continuous recorder was first installed on 5/23/19. Battery failure ended 2020 recording on 9/23.

	2020	2019
Beginning Date	1/1/20	5/23/19
Ending Date	9/23/20	12/31/19
Average Elevation (m NAVD88)	1.28	1.28
N	37,533	25,359
Maximum Elevation (m NAVD88)	1.98	1.80
Minimum Elevation (m NAVD88)	1.17	1.16
25th percentile Elevation (m NAVD88)	1.23	1.22
75th percentile Elevation (m NAVD88)	1.28	1.29

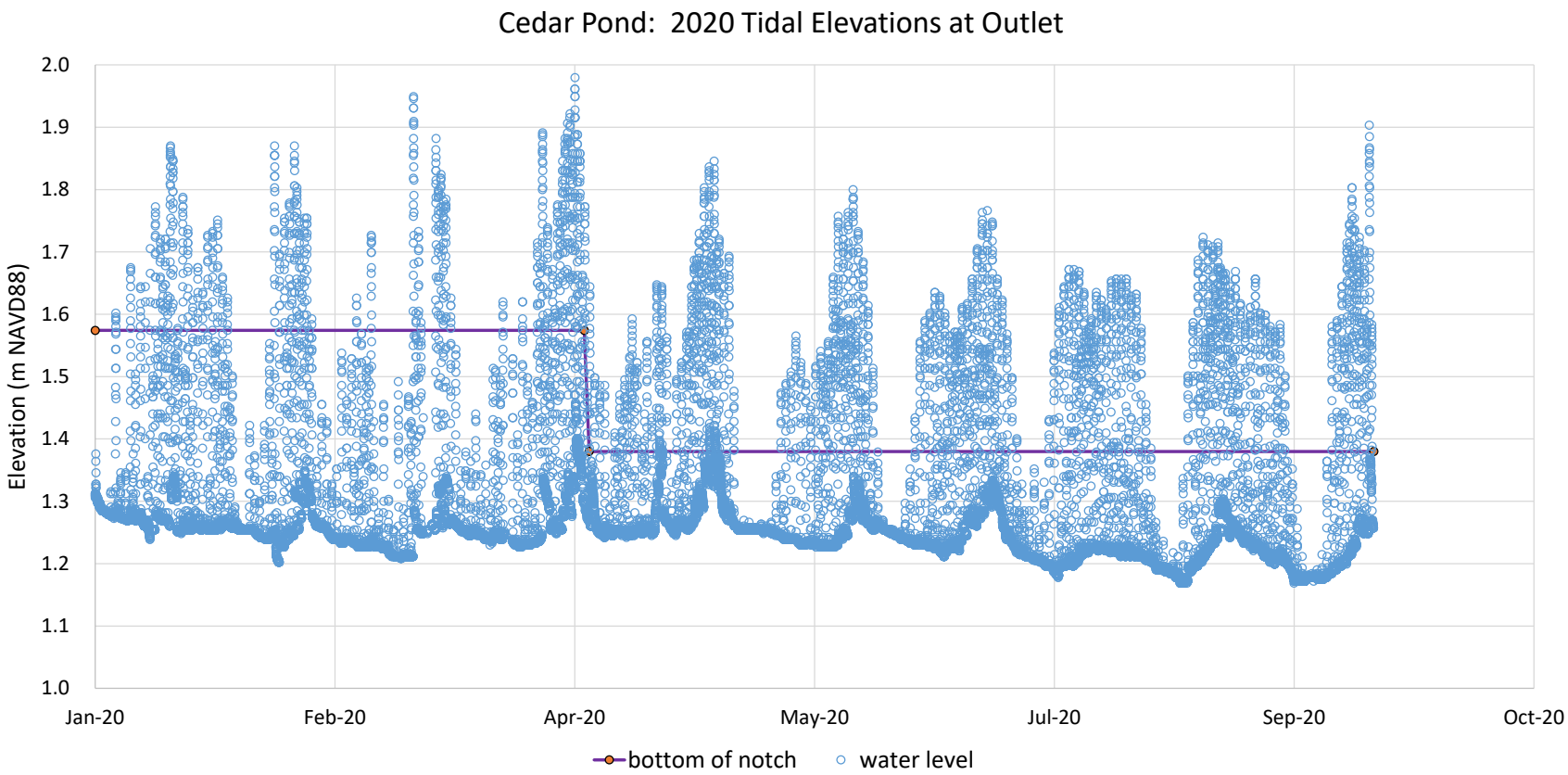


Figure III-2. Cedar Pond 2020 Water Levels and Outlet Board Heights. CSP/SMAST staff installed an autonomous recording device programmed to record water levels every 10 minutes at the pond outlet on May 23, 2019 and the device recorded throughout 2020 until it failed on 9/23/20. Staff also recorded elevations of the boards and the bottom of the notch on numerous occasions in 2020. The board notch was installed on April 12, 2020 and maintained for the rest of the recording period. Review of water elevations showed that the 2020 average water level elevation was less than the notch elevation, but water levels were generally sufficient to meet the goals of the Fishway Plan during both the fish entry period (March 15 to June 30) and the fish exit period (July 1 to November 15). The March 15 to June 30 period attained the water level 6 inches over the boards Fishway Plan goal on more than half of the days, while the July 1 to September 23 period attained the water level 2 inches over the notch Fishway Plan goal every day on average. No fish entering or exiting Cedar Pond have been noted during 35 visits to the outlet during 2018, 2019, and 2020 by CSP/SMAST or Town staff.

III.B. Water Quality Monitoring

Water quality monitoring in 2020 included regular collection of salinity and water quality samples within the water column and dissolved oxygen and temperature profiles, as well as two continuous recording 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 2020 water quality monitoring was conducted by CSP/SMAST staff.

CSP/SMAST staff collected water column samples and profiles on ten dates in 2020: January 6 and 9, April 22, May 26, June 25, July 22, August 27, September 23, October 22, and December 30. 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. Water column samples were collected at the same location as the continuous water column monitoring devices. The continuous water column monitoring devices were in place throughout 2020 (and continue to be installed in 2021). The continuous monitoring devices are at shallow (1.2 m) and deep (3.6 m) depths (same depths during 2018 and 2019 deployments) and are programmed to record DO, temperature, salinity, and depth every 15 minutes. The shallow device also has a chlorophyll a sensor. Stream measurements of volumetric flow and water quality samples were collected approximately every two weeks as part of continuous stream monitoring that began November 3, 2017. During 2020, 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 the MEP Rock Harbor assessment,[24] data collection for development of the Cedar Pond Management Plan,[25] and 2018 and 2019 monitoring for the implementation of the Management Plan.[26] All collected water quality samples were assayed at the Coastal Systems Analytical Laboratory at SMAST/UMASS Dartmouth.

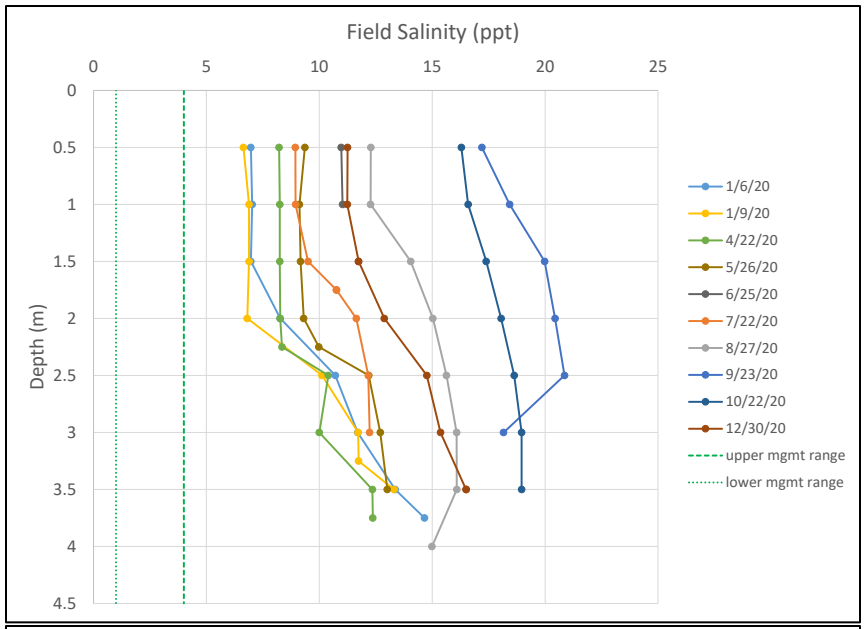
III.B.1. Water Column Profiles: Salinity, Temperature, Dissolved Oxygen

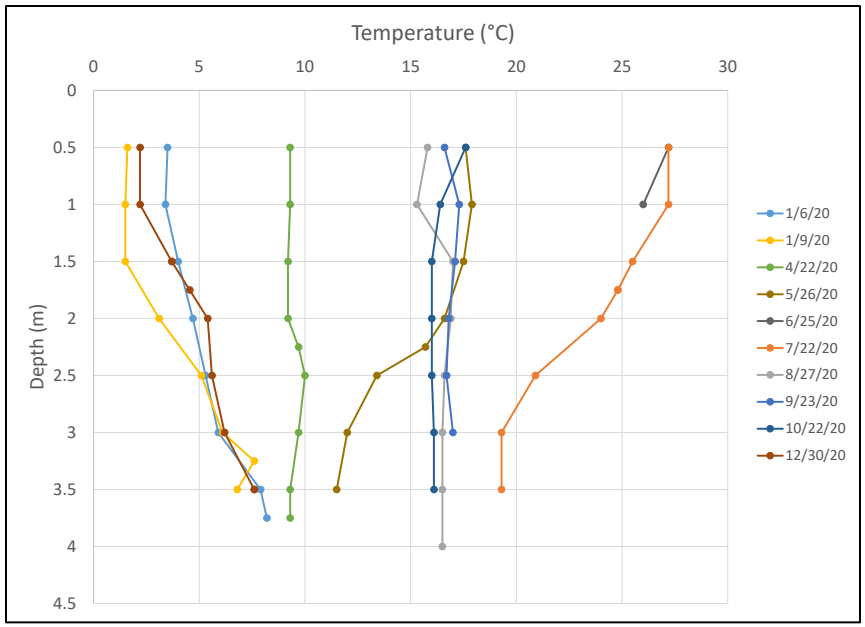
Salinity, temperature, and dissolved oxygen profiles in 2020 were generally similar to those in 2019, but with some notable differences. Temperature profiles suggest that 2020 had a more gradual and intermittent warming of the water column (**Figure III-3**). Profiles on four 2020 dates (4/22, 8/27, 9/23, and 10/22) were isothermic with similar temperatures throughout the water column and, generally, smaller temperature differences between shallow and deep than in 2019. In 2019, only two profiles (both late in the year: 10/29 and 11/25) had isothermic conditions. In the May and July 2020 profiles, there was sufficient temperature differences for thermal stratification (at 2.5 m depth), but cooler temperatures on 8/27 showed no temperature stratification. Review of the continuous temperature recordings suggest that the 8/27 temperature destratification was temporary (see below). Average temperature between April and October in the upper portion of the water column (<2 m deep) was 1 to 2°C cooler in 2020 than 2019, which in turn was cooler than 2018 (**Figure III-4**). Reduced temperature differences in the 2020 water column would mean that salinity differences would tend to be a stronger factor preventing mixing of the whole water column.

[24] September 2002 to August 2003

[25] June 2012 to September 2012

[26] Streamflow in Cedar Pond Creek has been measured continuously since November 3, 2017 following the town and MassDEP approval of the Cedar Pond Management Plan.





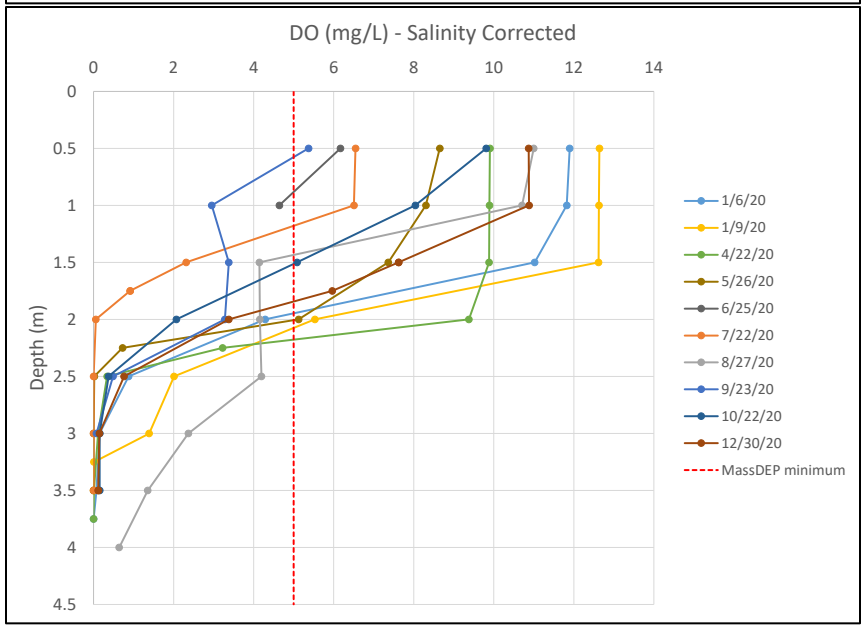


Figure III-3. Cedar Pond 2020 Salinity, Dissolved Oxygen, and Temperature Profiles: January to December. 2020 temperature profiles generally showed relatively isothermic conditions throughout the water column except for the 5/26 and 7/22 profiles, which showed thermal stratification around 2.5 m depth. This finding meant in 2020 salinity differences tended to be the stronger factor maintaining water column stratification. Salinity stratification tended to be at 2 m depth, which created conditions supporting acceptable DO concentrations from the surface to 1.5 m and notably improved DO concentrations at 2 m depth compared to 2019. DO concentrations deeper than 2 m depth were impaired throughout the year and concentrations deeper than 2.5 m were generally anoxic throughout the summer.

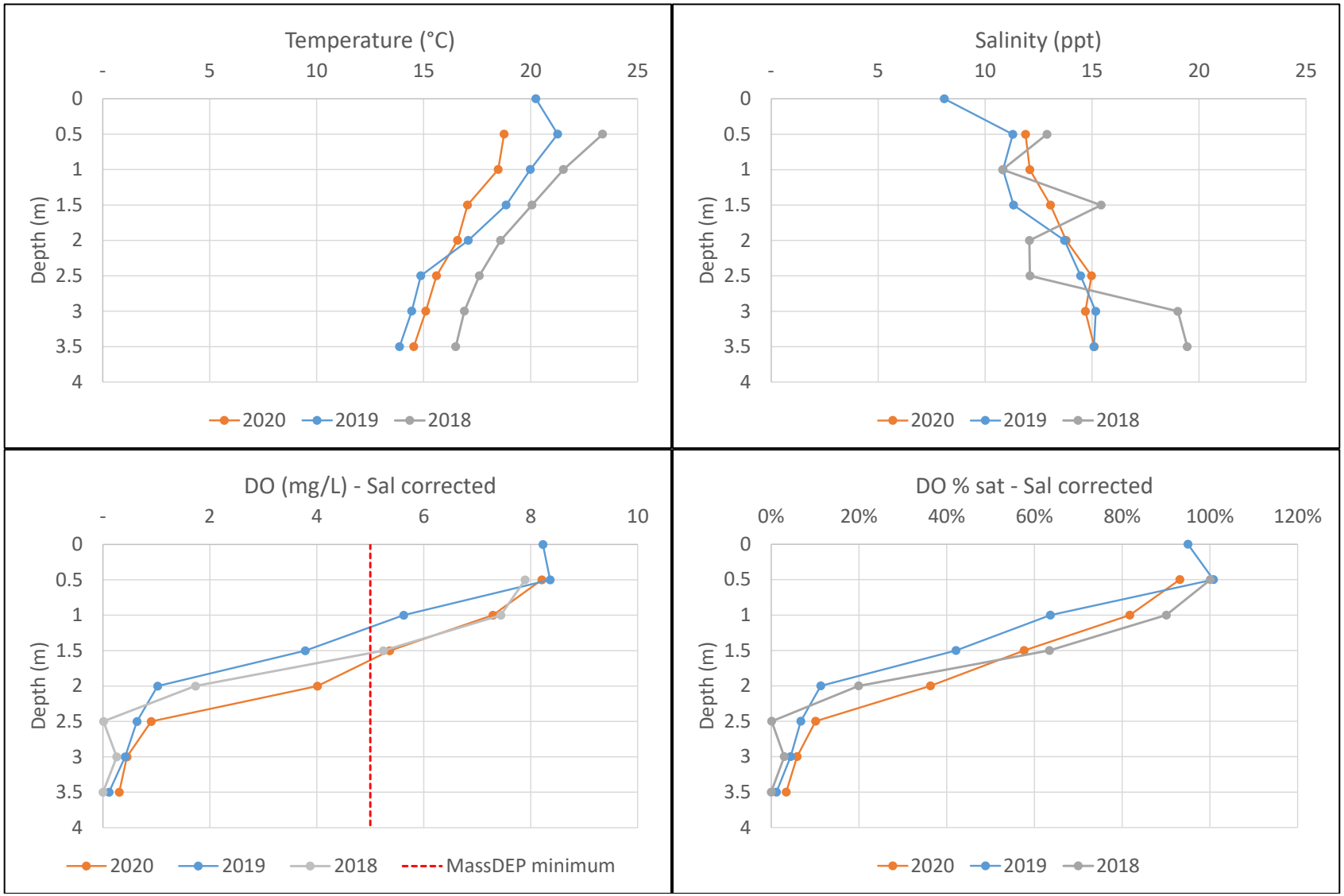


Figure III-4. Comparison of 2018, 2019, and 2020 Cedar Pond average water column temperature, salinity, dissolved oxygen, and DO % saturation (April to October). 2018, 2019 and 2020 generally had similar conditions in the deep portions of the water column (≥2.5 m), although 2019 and 2020 had lower deep temperatures and salinity. Shallow 2020 waters were cooler, generally had higher salinity, and higher DO concentrations than 2019. The most notable DO change was at 2 m depth, where the average concentration was >2X greater than the 2018 and 2019 averages (largely due to a decrease in anoxic measurements; only 1 in 2020). Overall, 2020 had acceptable DO concentrations in a greater portion of the water column than 2019 or 2018.

Salinity differences in the 2020 water column readings are significant enough to maintain stratification between shallow and deep portions of the water column. The initial January 2020 salinity profiles had shallow concentrations of 6.8 ppt and by April 2020, shallow concentrations were 8.2 ppt. The 2020 April reading is higher than April 2019 readings (5.0 ppt). These higher concentrations early in the year generally caused shallow salinity concentrations to be 1 to 3 ppt higher in 2020 than in 2019 (see **Figure III-4**). Deeper salinities, which tend to be determined by the higher salinity in tidal inflows from Rock Harbor, generally were in the same salinity range in 2019 and 2020, but both were much lower than 2018. It is also worth noting that none of the individual 2020 profiles had the extreme salinity differences between shallow and deep readings (>9 ppt) that were noted in the 2019 salinity profiles; 2020 shallow and deep differences tended to be between 4 and 5 ppt. Given the occasional isothermic conditions in 2020, salinity differences would have tended to be the primary cause of water column stratification in 2020. It is also notable that each of the 2020 salinity profiles tended to be similar in differences between shallow and deep readings with higher deep readings, but shifted together during each profile measurement likely due to how the water column mixed and how high salinity tidal waters enter the pond. This movement suggests that the whole water column will shift to brackish, lower salinity conditions once the tidal exchange management is perfected.

Individual DO profiles in 2020 had notable improvements in the shallow portions of the water column, but anoxic conditions continued in the deeper portions of the water column (>2.5 m). In 2019, DO profile concentrations from the surface to 1 m averaged 5.9 mg/L or more between April and October, but average DO at 1.5 m and deeper were less than 5 mg/L. MassDEP regulations specify that surface waters with DO concentrations less than 5 mg/L should be classified as impaired.[27] In 2020, average DO concentrations at 1 m and 1.5 m were greater than the MassDEP threshold and were approximately 1.5 mg/L greater than in 2019. In addition, the average 2020 DO at 2 m was 3 mg/L greater than 2019. These DO improvements appear to be related to water column from the surface to 2 m being well-mixed; salinity and temperature readings (0-2 m) are similar in all profiles. In addition, the cooler temperatures in 2020 allowed the shallow water column to retain more DO. Having a greater portion of the water column regularly mixing would allow the atmospheric replenishment of any DO demand in the shallower portion of the water column. Overall, 2020 had improved DO concentrations compared to 2019 with more of the water column having acceptable DO concentrations; higher DO concentrations were also noted in the deeper waters, but these waters continued to be impaired.

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 changes and miss transitory, but meaningful ecological events that can occur between snapshots. The Management Plan monitoring addressed this issue through the use of autonomous recording devices that measure DO, salinity, chlorophyll a and water depth every 15 minutes. Two of these devices (shallow and deep) were installed over the deepest spot in the pond and have been used in Cedar Pond since the 2018 initial monitoring after the Management Plan approval, as well as in 2009, 2012, and 2015 as part of partial prior pond assessments.[28] In 2020, the shallow

[27] 314 CMR 4: Massachusetts Surface Water Regulations

[28] CSP/SMAST Technical Memorandum: Cedar Pond Continuous Monitoring. January 14, 2016.

and deep continuous devices were in place throughout the year with average depths of 1.2 m and 3.6 m, respectively. These are approximately the same depths for the 2018 and 2019 deployments.

Continuous temperature readings during 2020 showed the warming of the water column during the summer and how temperature stratification varied. In January and most of February, deep waters were typically warmer than shallow waters, largely due to warmer, but saltier, tidal inputs sinking to the bottom (**Figure III-5**). Review of temperature differences during this period were not significant enough to prevent mixing of the whole water column, but salinity differences were significant enough to maintain water column stratification. However, in early May, shallow waters began to warm faster than deep waters and by May 14, the temperature difference was consistent enough to sustain temperature stratification. This stratification was sustained until September 16 (124 days) with the strongest stratification on August 12. Salinity differences throughout the summer were usually sufficient to also sustain salinity stratification, but there were a few periods during the strong temperature stratification where salinity differences between shallow and deep readings were ~1 ppt. Review shows that the temperature stratification varied, even during the strongest periods, and re-established for short periods (hours or days[29]) both before and after the main summer period. After November 9, temperature differences were not sufficient to sustain thermal stratification in the water column.

Average summer 2020 temperatures were generally higher than 2019, but varied compared to 2018 averages (**Table III-3**). Shallow average temperature in June/July 2020 were higher than both 2018 (+0.9°C) and 2019 (+3.1°C), but deep averages were lower than 2018, but higher than 2019. Salinity averages followed a similar pattern, suggesting that either less groundwater or more tidal water was entering the pond. The above review of the water levels at the pond outlet showed that less tidal water entered the pond in 2020 compared to 2019, so lower groundwater inputs were the likely source of higher 2020 salinities. Review of 2020 groundwater elevations showed that although elevations were above average in 2018, 2019, and 2020, 2020 elevations tended to be less than both 2018 and 2019 (**Figure III-6**).

Table III-3. Summer Continuous Recording Averages in Cedar Pond (2018-2020). Temperatures varied by year and portion of the summer; shallow (S) temperatures were higher than deep (D) readings. 2020 salinity averages tended to be higher in deep waters than in 2019, but were lower than 2018. Average 2020 shallow and deep DO readings continued to be impaired except in shallow August/September readings, which continued to average above the MassDEP minimum. Average June/July shallow DO improved significantly from 2019, but remained impaired. *Deep 2020 DO was limited to August readings because of sensor failure.

		2018	2019	2020	2018	2019	2020	2018	2019	2020
		Temp	Temp	Temp	Sal	Sal	Sal	DO	DO	DO
AVERAGES	Depth	°C	°C	°C	ppt	ppt	Ppt	mg/L	mg/L	mg/L
June to July	S	23.44	21.13	24.31	19.50	12.06	12.54	4.34	0.38	2.61
	D	18.03	13.22	16.15	21.82	15.39	18.23	0.07	0.13	0.00
Aug to Sept	S	24.67	23.33	23.41	19.92	15.86	14.55	0.79	6.31	5.37
	D	20.14	18.08	18.64	22.38	17.80	20.20	0.16	0.19	0.00*

[29] Maximum short-term temperature stratification outside of the main sustained period was 12 days (Oct 28 to Nov 9).

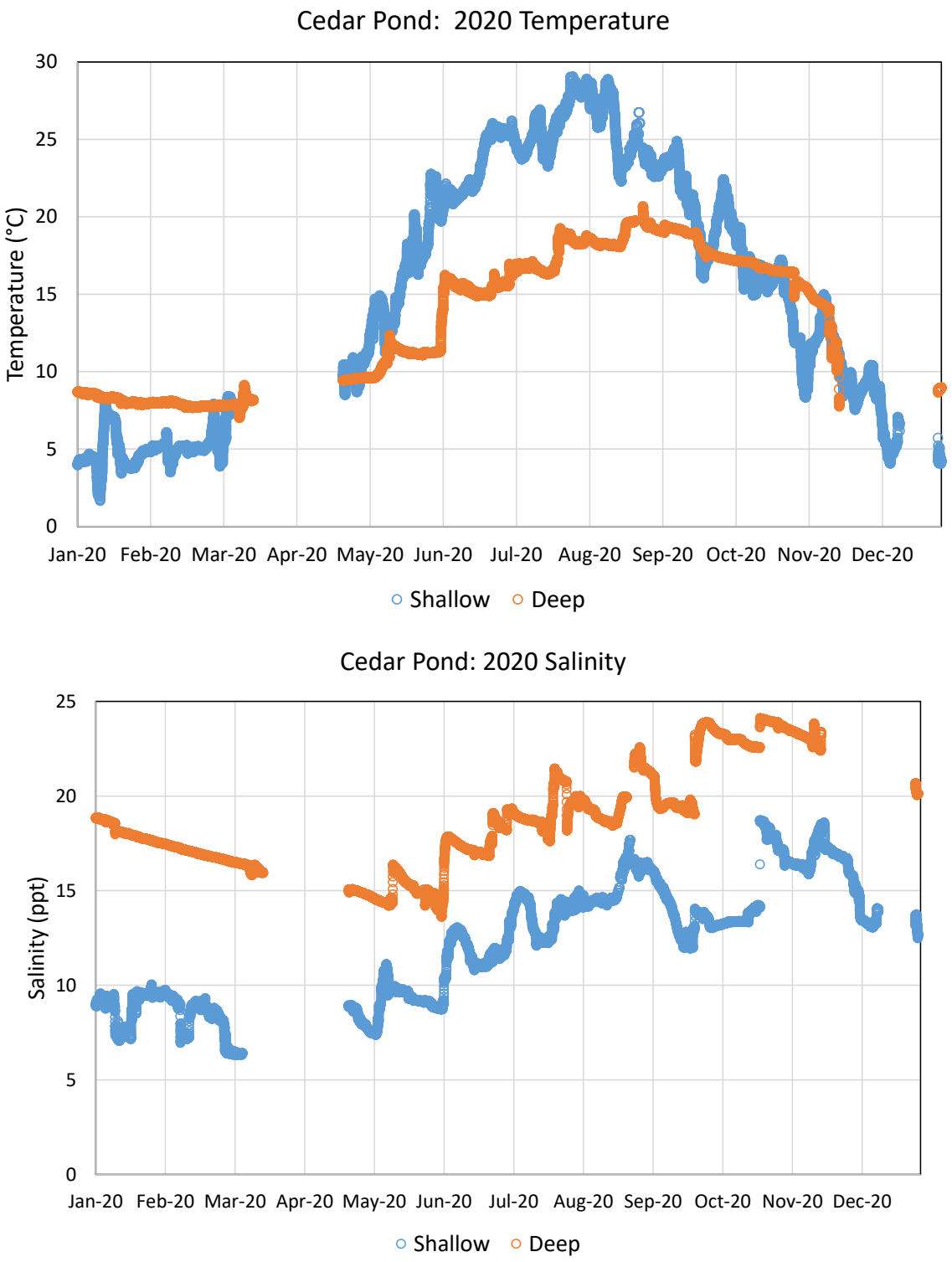


Figure III-5. Cedar Pond 2020 Continuous Temperature and Salinity Readings. Both devices recorded temperature and salinity readings every 15 minutes and were located in the main basin at averages depths of 1.2 m and 3.6 m. Gaps in the record were caused by battery failure. Shallow and deep temperatures were sufficiently different from May 14 to September 16 to sustain temperature stratification and prevent the water column from mixing. Shallow and deep salinity readings were generally sufficiently different throughout the year to prevent water column mixing.

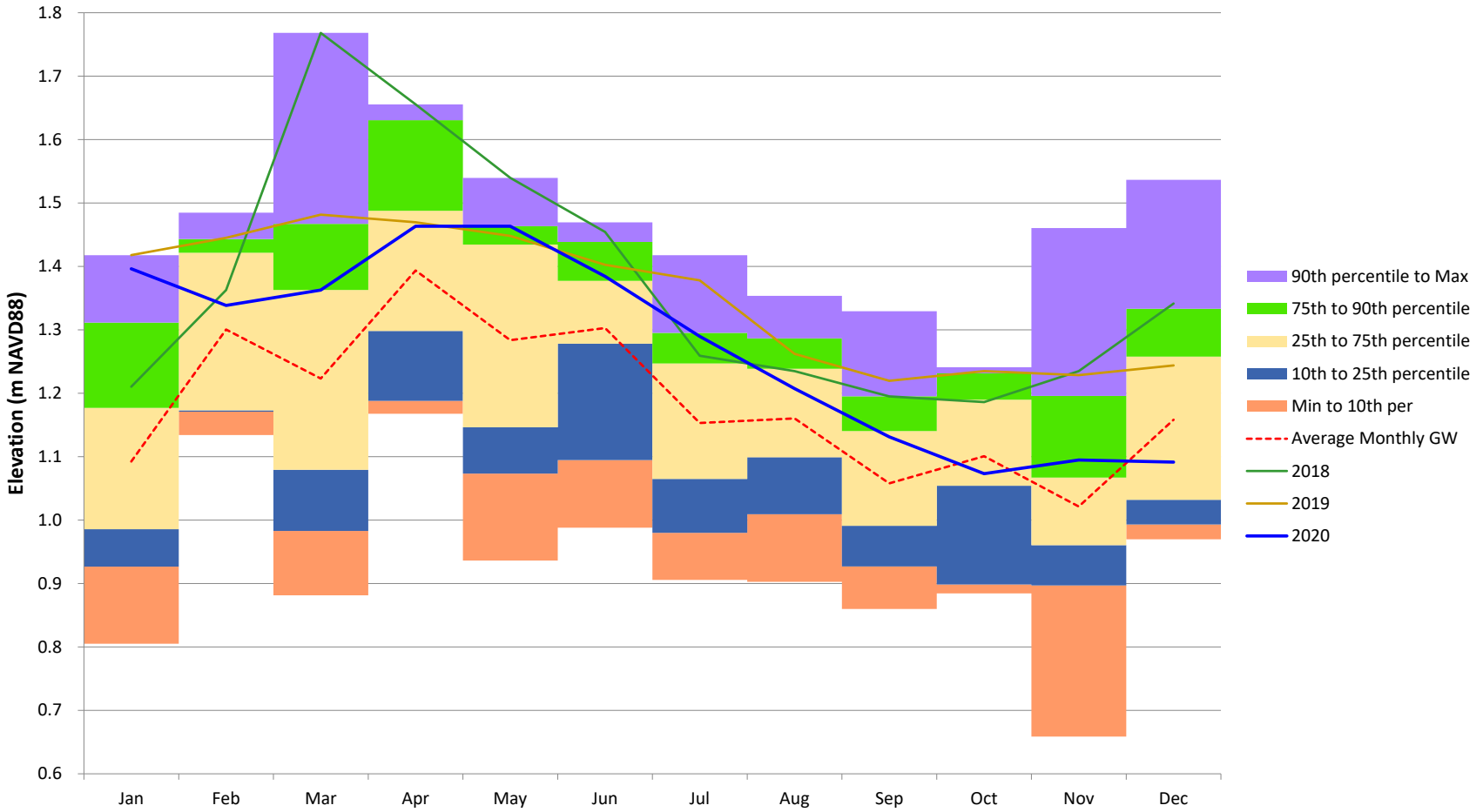


Figure III-6. Orleans Groundwater Elevations (OSW-22). Groundwater levels have been above average throughout almost all of the monitoring (2018-2020), but 2020 groundwater elevations in Orleans tended to be lower than 2018 or 2019 elevations. Lower elevations would result in less groundwater discharge into Cedar Pond, lower streamflow out of the pond, and tend to result in higher salinity levels. Groundwater elevations in Orleans during 2018 were exceptionally high with March, April, and May recording new high monthly levels. 2019 levels remained high with January recording a new maximum and five other months with levels above the 90th percentile. 2020 levels remained above average during most of the year until October, but were generally lower than 2018 and 2019 readings throughout the year. Data source: nwis.waterdata.usgs.gov/nwis/gwlevels?.

Long-term review of groundwater levels suggests that groundwater inputs to Cedar Pond will generally continue to increase though they will also need to be compared to sea level rise. Groundwater elevations have been regularly measured at monitoring well OSW-22 (just east of Town Cove) since 1975. Review of this data shows notable scatter, but a statistically significant increasing trend (+6.9 mm/yr) (**Figure III-7**). This rate of increase is more than double the current regional sea level rise rate (+2.87 mm/yr)[30] and would result in a 2.7 inch increase in groundwater levels after 10 years. Since the sea level rise and regional precipitation are projected to increase with time,[31] monitoring of these changes will be important to check regularly against board elevations, tidal inputs, and salinity levels.

Review of salinity readings in 2018, 2019, and 2020 show that the lowering of the boards during the summer regularly causes both shallow and deep water salinities to increase (**Figure III-8)**. January to March salinity levels in 2018 and 2020 show salinity levels decreasing likely due to relatively larger groundwater inputs (see **Figure III-6**), but shallow April/May and August salinity levels increase at approximately the same rate (0.06 to 0.09 ppt per day) as a result of lowering board elevations for the Fishway Plan. Review of deep salinity readings show they follow a similar pattern, though the rate of change is lower. Since the rate of change is similar among all three years, the spring salinity is a key factor determining the summer salinities; if the starting salinity in April/May is low, salinity levels throughout the summer will be lower provided groundwater elevations do not decrease significantly. This finding suggests that if the current board height management strategies are maintained, boards should be kept at a relatively high elevation between November when the winter board elevation is set and the installation of the notch/lowering of boards in March to meet the Fishway Plan goals. This approach should ensure lower salinity each summer.

Review of the dissolved oxygen readings show sustained acceptable concentrations late in the summer and improved, but still impaired, concentrations early in the summer (**Figure III-9**). Average shallow August/September 2020 DO was 5.4 mg/L, which meets the MassDEP minimum, is consistent with the 2019 readings, and is much improved from the 2018 average (0.8 mg/L DO). Average shallow June/July 2020 DO was 2.6 mg/L, which is less than the MassDEP minimum, but is much improved from 0.4 mg/L DO in 2019. Deep 2020 DO readings continue to average less than 0.5 mg/L (just as they did in 2018 and 2019). Deep readings in all three years also have occasional (approximately once per month) short periods of higher DO (<4 mg/L) when a sufficiently high tide brings in high salinity/high DO water and it sinks to the bottom of the pond. Review of the 2020 shallow recordings also show that they are very unstable; both August and September had minimum readings <1 mg/L and maximum readings >10 mg/L. This pattern suggests that the combined impact of bottom sediment oxygen demand (SOD) and water column oxygen uptake (*i.e.*, respiration) remain impactful throughout the water column with infrequent periods of water column quiescence where atmospheric aeration cannot keep up with combined oxygen uptake and windy, more turbulent periods where atmospheric

[30] Boston station measured since 1920s: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8443970

[31] IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

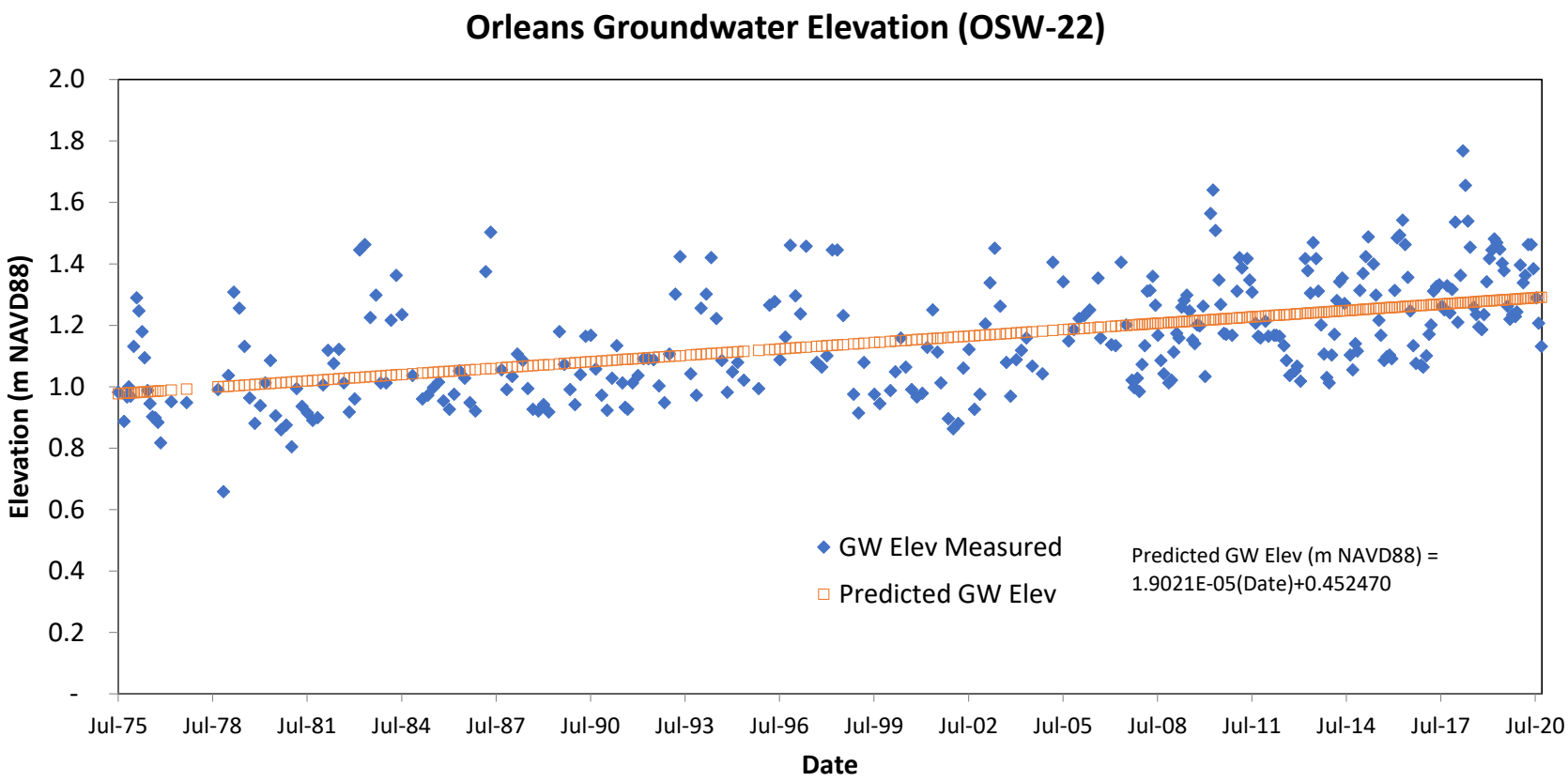


Figure III-7. Long-Term Groundwater Elevations in Orleans (July 1975 to March 2021). Groundwater levels in Orleans have been slowly increasing at a statistically significant rate (+6.9 mm/yr). This rate is greater than regional sea level rise (+2.87 mm/yr), which has been recorded since the 1920s. The combined impact of these increases would result in an additive impact on water levels in Cedar Pond, but should allow the freshwater inputs on average to attain the goal of decreasing salinity in the pond provided the elevation of the boards at the pond outlet is regularly reviewed. As noted in the scatter of the groundwater levels, variations from year-to-year and season-to-season can still have significant, but shorter term, impacts.
Data source: nwis.waterdata.usgs.gov/nwis/gwlevels?

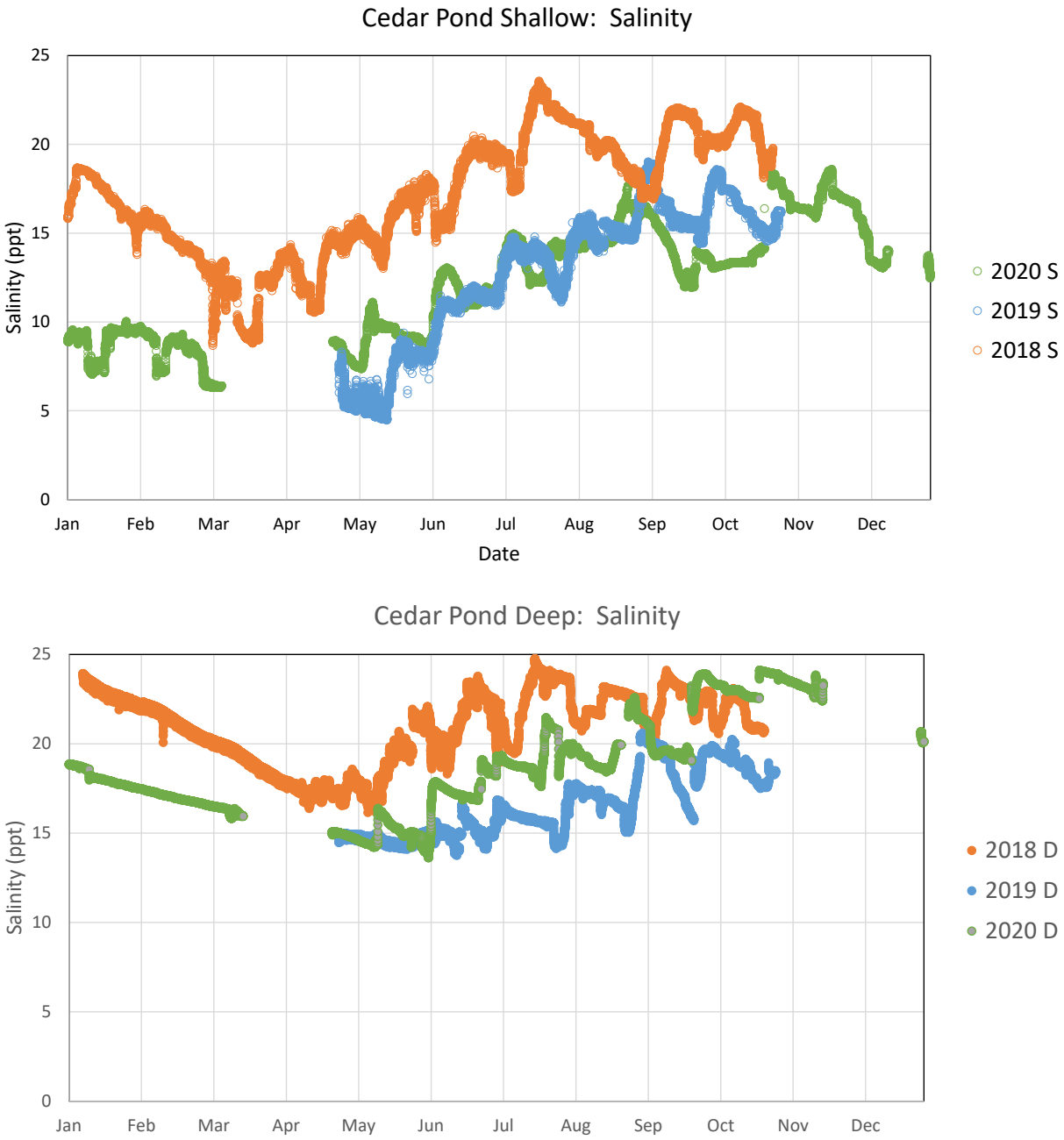


Figure III-8. Continuous Shallow and Deep Salinity at Cedar Pond (2018 – 2020). Salinity readings show that the lowering of the boards during the summer regularly causes both shallow and deep salinity to increase. 2018 and 2020 January to March shallow salinity levels decreased due to relatively larger seasonal groundwater inputs, but shallow salinity levels in all three years increased at approximately the same rate (0.06 to 0.09 ppt per day) between April/May and August once the inlet boards are lowered. Deep salinity readings follow a similar pattern, though the rate of change is lower. Since the rate of change is similar among all three years, the early summer starting salinity is a key factor for determining salinity throughout the summer. This finding suggests that boards should be kept at a relatively high elevation between November 15 and the installation of the notch in March 15 in order to have lower salinity readings throughout the summer.

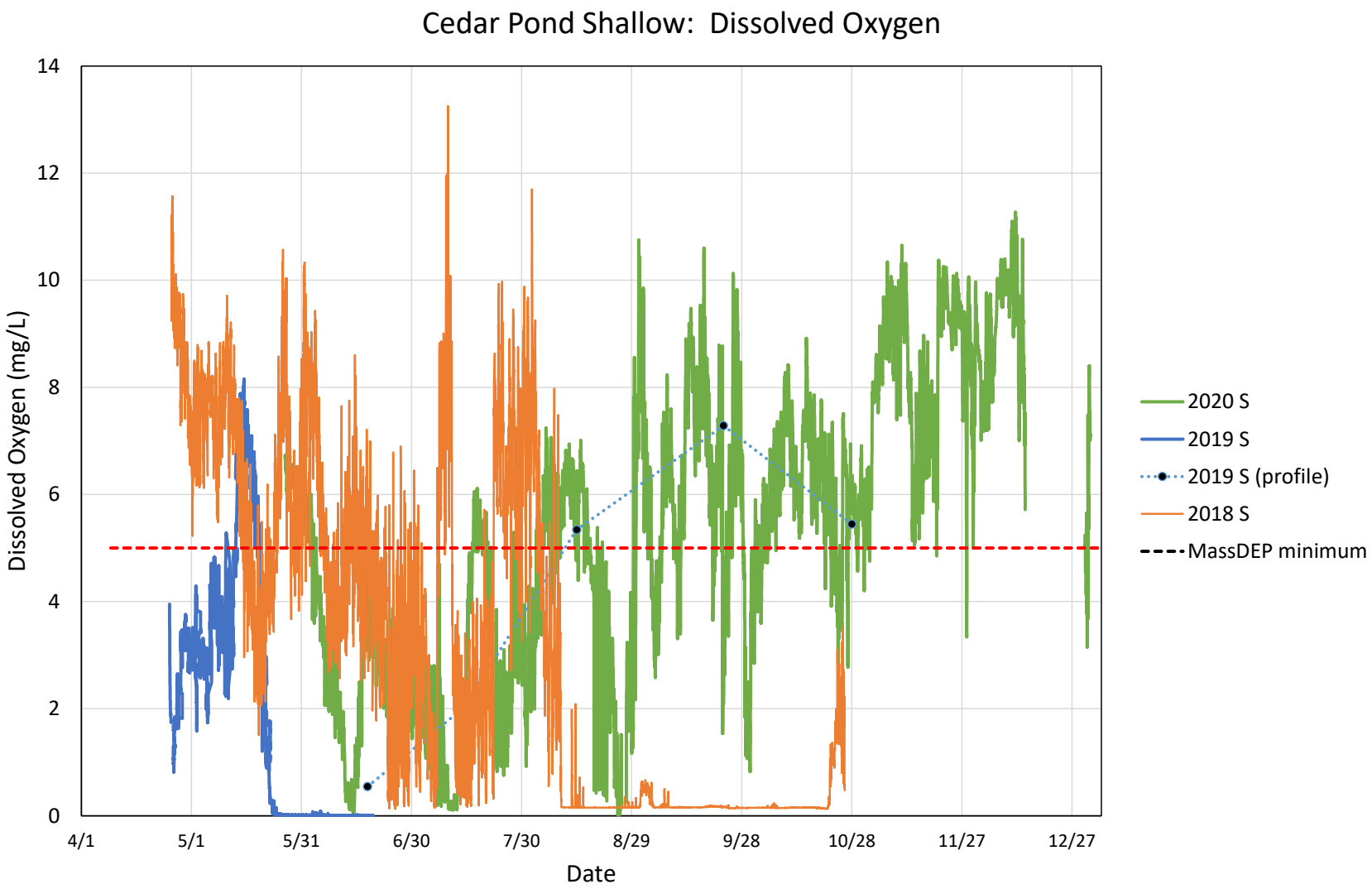


Figure III-9. Continuous Shallow Dissolved Oxygen at Cedar Pond (2018 – 2020). Late summer (Aug/Sep) 2020 DO concentrations averaged greater than the MassDEP minimum and early summer (Jun/Jul) 2020 concentrations averaged less the minimum, but improved over 2019. Shallow DO readings continue to show high variability, which suggests that sediment oxygen demand remains a strong determinant of water column DO concentrations.

mixing sufficiently addresses most of the oxygen uptake and allows DO concentrations to recover. It also suggests that long-term management of Cedar Pond will require activities to address the water column organic matter and respiration and the SOD. Options to address this would include techniques to increase water column mixing (*e.g.*, circulators) and/or reduce SOD (*e.g.*, dredging, reduced algal inputs, aeration, etc.).

Continuous chlorophyll readings in 2020 showed that chlorophyll concentrations were relatively low until mid-July, rose to a maximum in early September, and then decreased to a lower, but still elevated level in early October through the December removal of the recorder (**Figure III-10**). Average monthly readings were 3.3 µg/L in May, more than doubled to 7.6 µg/L in June, and increased to 12.0 µg/L in July before increasing by more than 5X in August. August average chlorophyll concentration was 63.8 µg/L with a peak of 174.8 µg/L, while September was even higher with an average chlorophyll concentration of 79.3 µg/L with a peak of 183.1 µg/L. In October, the average concentration decreased to 17.8 µg/L, while November average was 27.4 µg/L and the December average was 14.2 µg/L. The beginning of the increase leading to the August/September peak occurs in mid-July when DO profiles show that portions of the water column shallower than 1.5 m were first exposed to hypoxic conditions. This period also has an increase in TP concentrations and a reduction in N:P ratios. This reduction in N:P ratios likely facilitated phytoplankton that grow best in high N and high P conditions. These results suggest that sediment P release is going to be an on-going water quality management concern for Cedar Pond and might be mitigated by maintaining acceptable DO concentrations from the surface to at least 2 m depth during the summer.

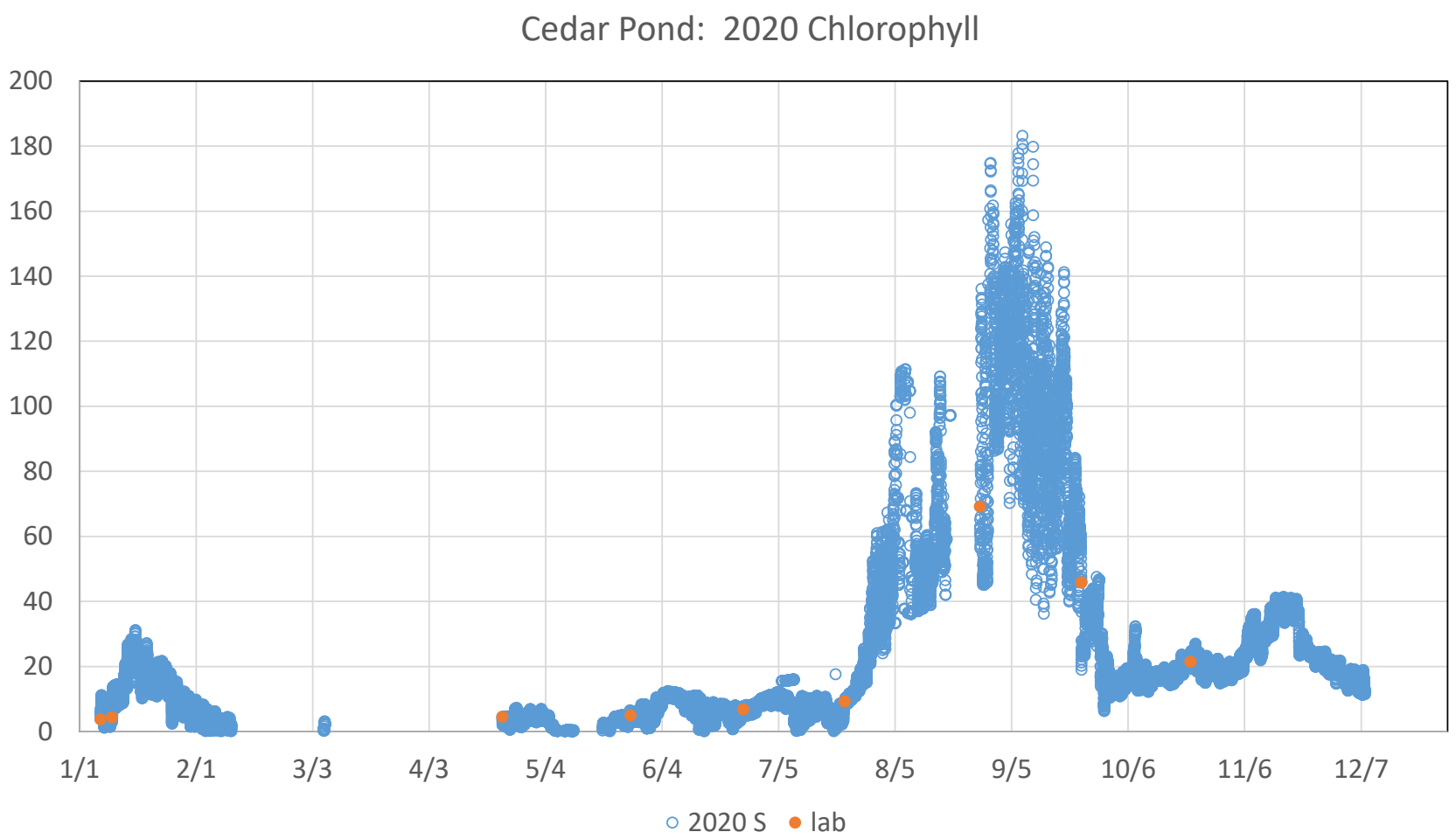


Figure III-10. Cedar Pond 2020 Shallow Continuous Chlorophyll Readings. The continuous shallow (1.2 m) sensor recorded chlorophyll a readings every 15 minutes during 2020. These readings were relatively low until mid-July and peaked near 180 µg/L in late August/early September before decreasing to the 15 to 30 µg/L range in October through December. The mid-July increase corresponded to exposure of more of the pond bottom (>1.5 m depth) to hypoxic conditions and a relative increase in TP concentrations that made the water column more sensitive to available nitrogen.

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

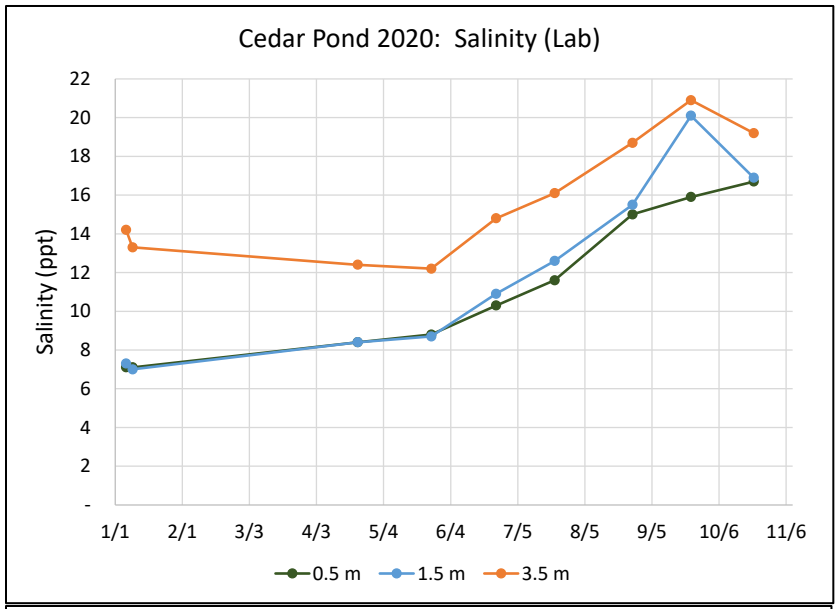
Water quality samples were collected on the same dates as the temperature and oxygen profiles (see **Figure III-3**). Water samples were generally collected at shallow, middle, and deep depths: averaging 0.15 m, 1.5 m, and 3.5 m, respectively. The middle and deep depths approximate the probe depths of the continuous recordings (1.2 m and 3.6 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 and all its subsequent reporting. Sampling procedures and chemical assay methods are presented in the Town's QAPPs for freshwater[32] and estuarine[33] 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.

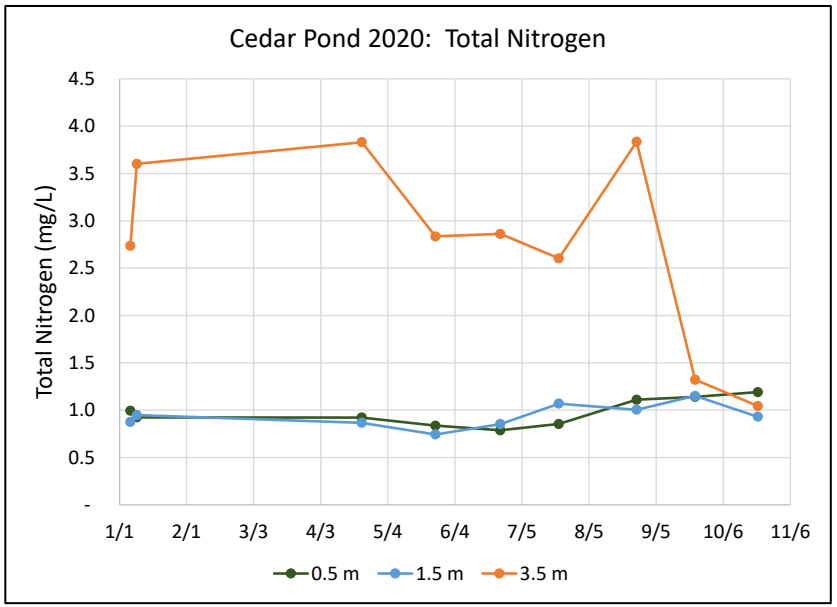
Profile samples generally showed that shallow and middle depths had similar concentrations of various constituents and these concentrations were usually significantly lower than deep samples except for particulate fractions, which tended to be similar throughout the water column. All concentrations showed that Cedar Pond was significantly nutrient impaired in 2020, as it was in all previous assessments, but there was a notable reduction in deep nutrient concentrations and a smaller reduction in mid-depth (1.5 m) concentrations. Average 2020 total nitrogen (TN) concentrations were: 1.0 mg/L at 0.15 m, 0.9 mg/L at 1.5 m, and 2.7 mg/L at 3.5 m (**Figure III-11**); corresponding 2019 TN averages were 1.0 mg/L, 1.4 mg/L, and 5.6 mg/L. Average 2020 total phosphorus (TP) concentrations were: 190 µg/L at 0.15 m, 215 µg/L at 1.5 m, and 590 µg/L at 3.5 m, while corresponding 2019 TP averages were 192 µg/L, 299 µg/L, and 725 µg/L. In both 2019 and 2020, TP and TN both had average concentrations at shallow and middle depths that were not statistically different ($\rho<0.05$) from each other, but deep average concentrations in both years were significantly higher than shallow concentrations due to stronger water column stratification and high rates of sediment regeneration due to anoxic conditions. Breakdown of DO-sensitive TP and TN constituents (*i.e.*, ortho-P, NOx-N, ammonia-N) generally followed predictable responses to changes in dissolved oxygen levels.

Summer (April to October) average TN and TP concentrations mirrored the year-round average pattern: shallow concentrations were similar to those in 2019, 1.5 m depth concentrations decreased slightly, and deep concentrations decreased significantly. Average deep 2020 TN decreased by 57% compared to 2019 (6.0 mg/L in 2019 to 2.6 mg/L in 2020), while deep TP decreased by 29% (765 µg/L in 2019 to 547 µg/L in 2020). The relative stability of the shallow TN and TP concentrations between 2020 and 2019 followed a significant decrease that occurred between 2018 and 2019. The 2020 decrease in the deep concentrations brought them to levels generally measured in 2018. These results suggest that the managed tidal exchange may be supporting a lower mass of TN and TP within the pond.

[32] 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.

[33] 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.





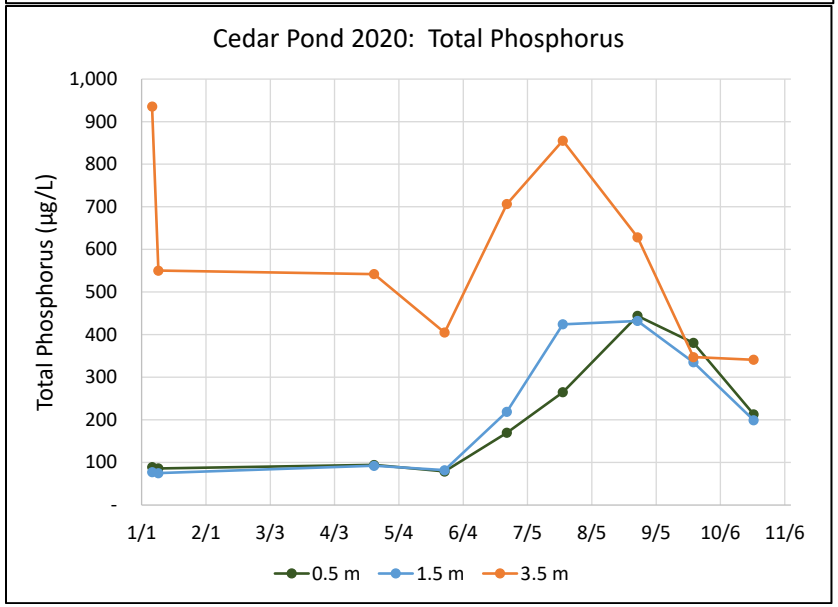


Figure III-11. Cedar Pond 2020 Water Column Salinity, TP, and TN Profiles. Shallow salinity readings began the summer at ~8 ppt (2X the upper bound of the Management Plan target range) and increased to ~16 ppt by the end of October. Deep salinity increased at a similar rate, but began the summer at ~12 ppt. TN concentrations at 0.5 m and 1.5 m were generally the same with a slight increase during the summer; average TN at 0.5 m was the same as 2019, while average TN at 1.5 m was 0.5 mg/L less. Deep TN concentrations were higher than shallow readings, but the 2020 deep average was ~50% less than in 2019. TP concentrations at 0.5 m and 1.5 m were also similar and increased from late May to late August. Deep TP had higher concentrations, but followed a similar pattern and peaked in late July, when the highest proportion of the water column was anoxic. Average TP concentrations at 1.5 m and 3.5 m were notably less than in 2019. N:P ratios generally showed that nitrogen was controlling water quality conditions, although early spring conditions were controlled by both N and P.

Individual 2020 profiles showed relatively consistent TN and TP concentrations at 0.5 m and 1.5 m reflective of the well-mixed water column noted in temperature profiles, but deep readings seemed to change on a separate basis. TN concentrations at 0.5 m and 1.5 m increased from approximately 0.8 mg/L in late June to approximately 1.1 mg/L in late September (a 38% increase). TP concentrations at the same depths increased from approximately 80 µg/L in late May to approximately 435 µg/L in late August (a 444% increase) before decreasing in subsequent profiles. The relatively higher increase in TP is due to how sediments first release phosphorus before they release nitrogen under anaerobic conditions. It is also notable that the deep (3.5 m) TP concentrations peaked in the 7/22 profile, which was also when anoxic concentrations were at the shallowest (2 m) in the water column in 2020; as more of the pond bottom is exposed to anoxic conditions more TP will be released into the water column. As would be expected, samples results showed that most of the TP released was ortho-P. TN was relatively more consistent, but had high concentrations at 3.5 m until the 9/23 sampling when it decreased by 65% from the 8/27 concentration. As would be expected in the anoxic deep waters, sample results showed that most of the TN was ammonium-N (NH4).

Comparison of N and P concentrations showed that the water column, both shallow and deep, tended to be more nitrogen sensitive, especially during the summer. N:P ratios in the June through October samplings at all depths (*e.g.*, 0.5 m, 1.5 m, and 3.5 m) were all less than Redfield balance point (16:1) meaning that water quality conditions were determined more by nitrogen inputs than phosphorus inputs (**Figure III-12**). The January, April, and May samplings, however, all had ratios in 0.5 m and 1.5 m samples that were only slightly above the Redfield line, indicating similar sensitivity to both nitrogen and phosphorus.[34] Nutrient sensitivities were similar to those measured in 2019, except for deep 2019 conditions which were more phosphorus sensitive. As the Town considers further management actions to meet the Management Plan goal to restore water quality and the herring run, these ratios, how they seasonally change, and the role the sediment play will help guide the town to applicable management options.

Lower N and P concentrations matched lower 2020 chlorophyll a concentrations compared to 2019. The maximum chlorophyll a concentration at any depth in the 2020 profiles was 56 µg/L (late August; see **Figure III-12**). This is a high concentration, but 2019 had eight chlorophyll a concentrations (or a third of available readings) that were greater than 56 µg/L and the high profile concentrations were consistent with the continuous sensor readings, which captured even higher peaks (>150 µg/L) (see **Figure III-10**). Shallow 2020 concentrations at 0.5 m and 1.5 m were generally less than 2 µg/L until the late August peak; 2 µg/L or less would generally be representative of acceptable water quality. The late August peak also corresponded to the maximum combined amounts of N and P in the water column, as well as maximum combined photosynthesis pigments (chlorophyll a + pheophytin). Review of combined pigments in the August 27 sampling showed that the highest concentrations were in the 0.5 m sample, as opposed to the highest chlorophyll a concentration on that date, which was in the 3.5 m sample. This comparison of chlorophyll and total pigment concentrations suggests that the August 27 sample was collected shortly after a bloom and portions of the bloom, represented by the pheophytin concentration, had only recently began to settle within the water column.

[34] 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.

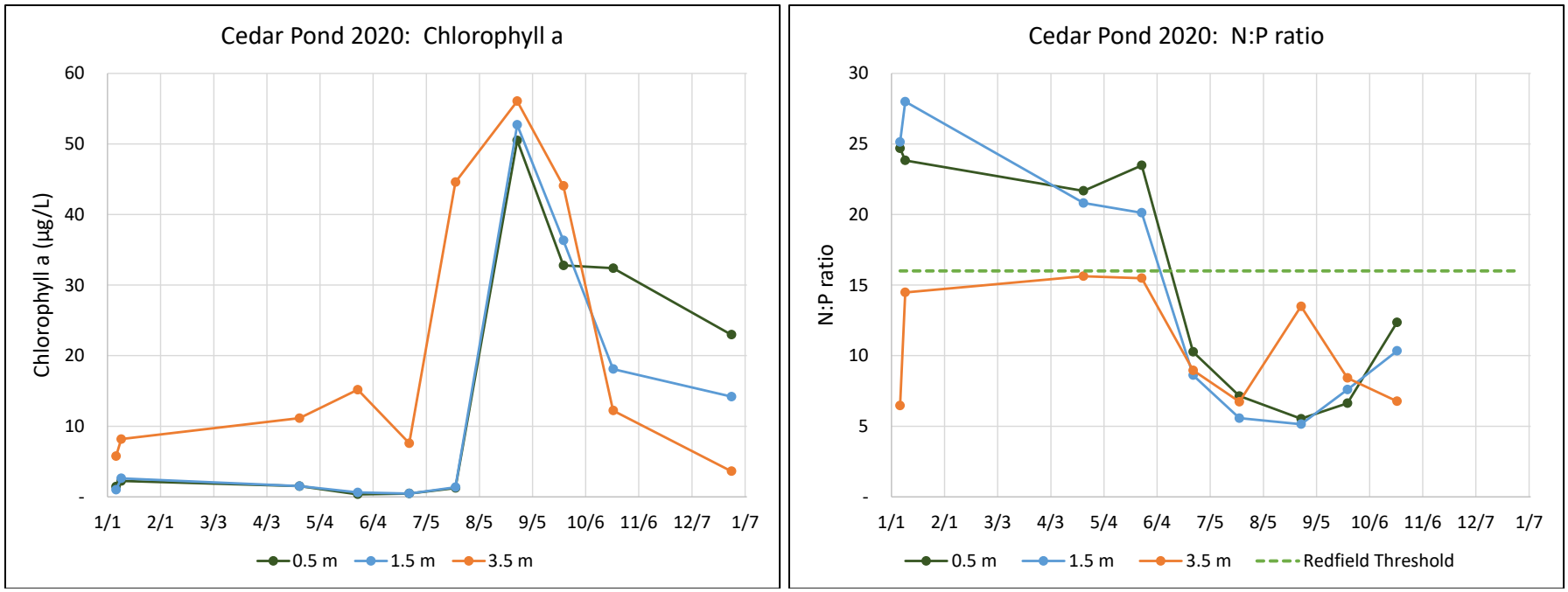


Figure III-12. Cedar Pond 2020 Water Column Chlorophyll and N:P ratios. Chlorophyll a concentrations were notably lower throughout the water column than in 2019; the peak in the 8/27 samples was approximately a third of the maximum August 2019 profile concentration (although the continuous readings did record a peak concentration similar to the 2019 peak). The August peak corresponded to the maximum combined water column TP and TN concentrations in 2020. Chlorophyll a concentrations at 0.5 m and 1.5 m depths from January through July samples were generally reflective of acceptable water quality. N:P ratios generally showed that nitrogen availability was determining water quality conditions, especially during the primary water quality management period (June through October). From June to October, N:P ratios at all three sampled depths were less than the Redfield ratio (16:1), which is indicative of nitrogen limitation and nitrogen controlling water quality conditions. Prior to June, samples at 0.5 m and 1.5 m had N:P ratios sufficiently above the Redfield threshold to indicate sensitivity to both nitrogen and phosphorus. Shallow 2020 N:P ratios (0.5 m and 1.5 m) are similar to ratios in 2019, but the 3.5 m ratio is notably reduced and are consistent with a greater reduction in deep TP concentrations than TN concentrations between the two years.

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

Streamflow has been measured in Cedar Pond Creek at the same location (just north of Route 6; see **Figure I-1**) continuously since November 2017. This is the same location used during: a) the MEP assessment of Rock Harbor,[35] b) for the development of the Cedar Pond Management Plan,[36] and c) throughout 2018[37] and 2019.[38] 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. In addition to the continuous readings, low tide instantaneous flow readings and water quality samples were collected 21 times during 2020, generally every two weeks.

Review of the 2020 flow readings showed that the previously established stage-flow relationship developed from past data began to become less predictable as groundwater levels decreased to more average conditions. During 2017, 2018, and 2019, groundwater levels and flow were high (see **Figure III-6**) and the flow and stage readings were filling in a portion of the stage-flow curve that was not captured during the 2002-2003 MEP readings or the 2012 Management Plan monitoring, which were collected during average to low groundwater periods and during a period without changes in inlet board elevations. Even with the inlet board changes in 2017 through 2019, flow readings were generally consistent with the stage-flow curve developed from the prior readings. In 2020, as groundwater levels began to decrease, flow and stage measurements became less consistent with the previously established stage-flow relationship. With this in mind, project staff decided to utilize the 21 measured instantaneous readings for the 2020 Cedar Pond assessment. Project staff also reviewed this approach to review historic readings and found that the results were generally consistent with previous reviews, although missing the richness of information provided by continuous monitoring, including extreme highs and lows.

Measured 2020 flows were lower than 2019 flows and much lower than 2018 flows. With the revised review, annual, salinity-corrected average daily freshwater outflow during 2020 was 28% lower than 2019 (1,583 m^3/d vs. 2,192 m^3/d) (**Figure III-13**). Annual average outflow in 2020 was 70% less than flow in 2018. Flows were also notably reduced in summer (June through September): 2020 summer average flow was 660 m^3/d, which was 76% less than 2019 and 90% less than 2018.

Each time flow readings were collected in Cedar Pond Creek, water quality samples were also collected and assayed for nutrients. These concentration data generally showed significant nitrogen reductions in outflowing pond water each year from 2018 to 2020, consistent with the reductions/improvements measured in the pond water column. Average 2020 annual TN concentration in Creek water (0.8 mg/L) was 34% less than the 2019 average (1.2 mg/L) and 43% less than the 2018 average (1.4 mg/L)(**Figure III-14**). Review of TN components showed

[35] 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. 2008. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA. 132 pp.

[36] 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.

[37] Eichner, E., B. Howes, and D. Schlezinger. 2019. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2018 to December 2018. 42 pp.

[38] Eichner, E., B. Howes, and D. Schlezinger. 2020. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2019 to December 2019. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 38 pp.

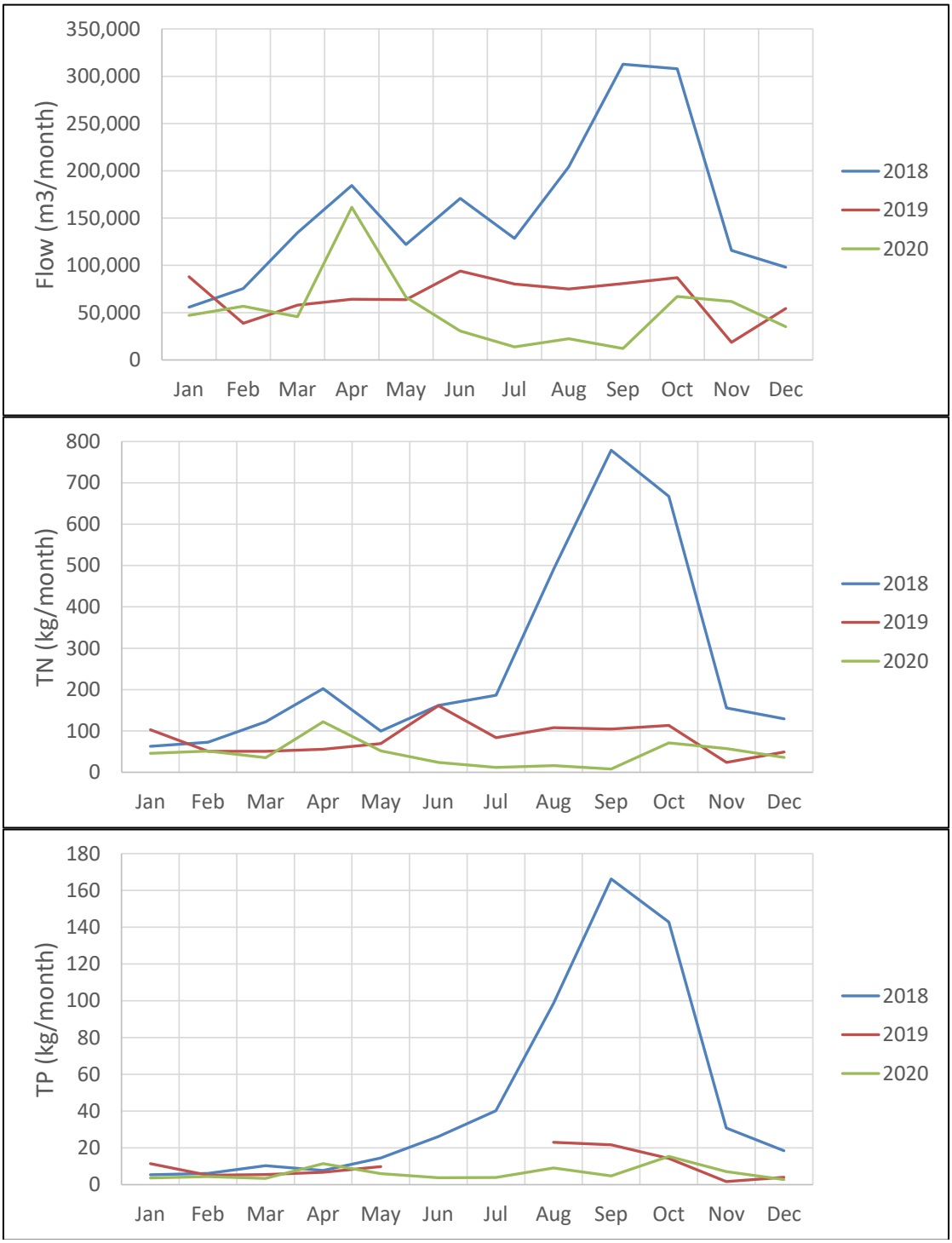


Figure III-13. Average Monthly Outflow, TN, and TP through Cedar Pond outlet (2018-2020). Annual average monthly outflow decreased each year between 2018 and 2020 with annual 2020 flow 28% less than 2019. Summer 2020 flows were comparatively even lower (76% less than 2019). Reduced Pond TN and TP concentrations combined with lower flows resulted in reductions in nutrient exports to Rock Harbor approaching those measured during the MEP (2002/2003) and the Cedar Pond Management Plan measurements (2012). Summer nutrient exports were generally reduced 90% or more compared to 2018 levels.

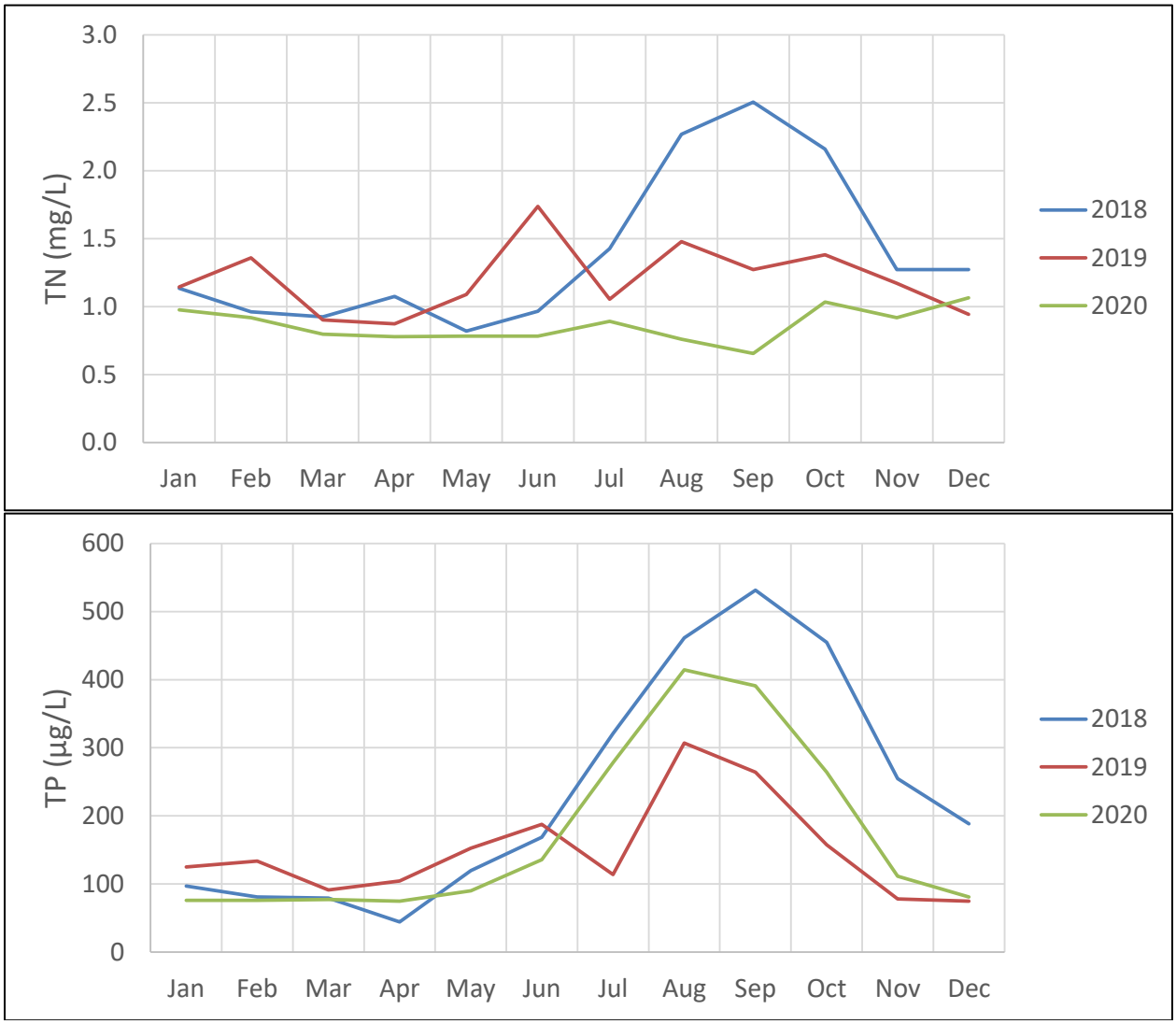


Figure III-14. Average Monthly TN and TP concentrations in Cedar Pond Creek (2018-2020). Creek TN and TP concentrations generally reflected improvements in the Cedar Pond water column. Average annual 2020 Creek TN concentration (0.8 mg/L) was 34% less than the 2019 level (1.2 mg/L) and 43% less than 2018 level (1.4 mg/L). Summer (June to September) TN concentration reductions were slightly larger with the 2020 average 44% less than 2019 and 57% less than 2018. Annual average TP concentrations in the Creek decreased by 36% between 2018 and 2019, but were relatively stable between 2019 and 2020. Average summer TP concentrations decreased between 2018 and 2019, but increased between 2019 and 2020. The increase in 2020 TP concentrations corresponds to increases in the Pond water column caused by a July increase in the area of the pond bottom exposed to hypoxia. N:P ratios decreased from an annual average of 22 in 2018 to 18 in 2019 and 16 in 2020. Summer N:P ratios were even lower: 11 in 2018, 8 in 2019, and 7 in 2020. Summer N:P ratios confirm that water quality conditions in Cedar Pond during this primary management period are controlled by nitrogen inputs.

that 80 to 90% of the Creek TN is composed of organic nitrogen (mostly phytoplankton or decaying components) in 2018, 2019, and 2020. The largest portion of the reduction in TN between 2018 and 2020 is related to a decrease in particulate organic nitrogen (-50% between 2018 and 2020). Average Creek TP concentrations decreased between 2018 and 2019, but was stable in 2019 and 2020. Comparison of N:P ratios show that summer and year-round conditions are becoming increasingly nitrogen sensitive with much more nitrogen sensitive conditions during the summer than during the rest of the year. These results mirror those seen in the Pond water column results and summer conditions likely reflect the increase in TP available during the summer caused by sediment regeneration of TP due to bottom water anoxia.

Combining stream water quality concentrations with flow readings showed that the Cedar Pond TN and TP mass export to Rock Harbor has decreased each year between 2018 and 2020 and, in addition, 2020 TN export approached levels measured in 2002/2003 (MEP). Average daily TN mass export in 2020 was 1.4 kg/d or 84% less than it was in 2018 (8.6 kg/d) and close to the 1.1 kg/d measured by the MEP assessment in 2002/2003. At the time of the MEP, the TN export level represented a 58% watershed nitrogen removal by Cedar Pond.[39] Annual 2020 TP export via the creek decreased 45% from 2019 and 88% from 2018. The decrease in TP export was even greater during the summer: 2020 summer TP export averaged 0.18 kg/d or 93% less than 2018 and 61% less than 0.46 kg/d measured in 2012 as part of the Management Plan monitoring. Summer 2020 TN and nitrogen-components average daily exports were generally >90% less than 2018 levels.

Collectively, the Cedar Pond Creek monitoring data reflect the improvements in the Pond water column and combined with decreasing flows show less nutrient export to Rock Harbor. If the current trajectory of Pond water quality improvements continues, the Pond will attain the levels of nitrogen attenuation and TN export to Rock Harbor that were measured in 2002/2003. Sustaining this level of export during high groundwater conditions will require additional water quality improvements, but attaining this improvement was one of the goals listed in the Cedar Pond Management Plan.

[39] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner (2007).

IV. Conclusions and Proposed Management Changes

During 2018, 2019, and 2020 the Town, in coordination with MassDMF and CSP/SMAST, implemented management changes that have gradually improved water quality in Cedar Pond. On-going collection of water quality data in the pond, at its outlet, and in the stream connecting it to Rock Harbor have helped to document the water quality improvements and provided additional insights into adaptive changes in management strategies to adjust the management of the boards at the pond outlet and better achieve the ecosystem goals established in the Cedar Pond Management Plan.

Management changes implemented between 2018 and 2020 have included: 1) reinstalling the boards at the outlet in late 2017, 2) moving the power lines that were strung over the pond in 2018 (these were utilized by high numbers of roosting cormorants), 3) reducing the size of the summer board opening in 2019, and 4) raising the elevation of the board opening in 2020. Each year saw improvements in water quality in the pond with reductions in nutrient concentrations, improvements in dissolved oxygen, and reductions in salinity.

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 three years of monitoring 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 allowing more salinity inputs by reducing the board elevations during the summer effectively removes the benefits and worsens water quality.

Overall, water quality monitoring in 2020 showed improvements over both 2019 and 2018 related to the implemented management actions. More of the water column had acceptable dissolved oxygen concentrations with shallow concentrations greater than the MassDEP minimum. Average shallow DO in continuous recordings in August/September 2020 exceeded the MassDEP minimum and the June/July average was 2 mg/L greater than in 2019. Total nitrogen and total phosphorus concentrations decreased throughout the water column and, as a result, less TN and TP was exported to Rock Harbor. TN export nearly achieved the same level as measured in 2002/2003. Water column TN, TP, and chlorophyll a concentrations decreased notably in 2020 compared to 2019, especially in the deepest waters.

Collection of the data also indicated that the system is still impaired, but reinforced insights into how management could be further adjusted to attain the Cedar Pond ecosystem goals. Deep DO concentrations are generally still anoxic due to sediment oxygen demand and the portion of the water column below 2 m depth regularly fails to attain the MassDEP regulatory DO minimum concentration. As less of the pond bottom is exposed to anoxic/hypoxic conditions, less phosphorus and nitrogen are released into the water column to support phytoplankton growth and less is exported to Rock Harbor. Windy conditions can replenish DO consumed by the sediments and within the water column, but occasional quiescent periods can exacerbate the low DO conditions. Low DO conditions are typically worst during the late summer. Lowering of boards under the Fishway Plan causes an annual increase in salinity levels to 15 to 20 ppt. This increase makes attainment of the 1 to 4 ppt salinity level goal for restoring the herring run and

protecting the Atlantic White Cedar wetland impossible to attain and lowers the capacity of the water to retain DO.

During 2020, board elevations were raised based on 2019 monitoring. Results from 2019 and 2020 suggest that board elevation management continues to be a challenge as water levels in the pond and the tidal inputs vary from year to year. Groundwater elevations in Orleans are slowly increasing at a rate higher than sea level rise. The combined impact of this rise suggests that board elevations will need to be increased to match this rise, but it is also clear that seasonal variations (*e.g.*, lower pond levels during the summer) will also play a role. Monitoring in 2019 showed that leaving the outlet boards at a higher level throughout the winter until the initial Fishery Plan-specified board lowering (*i.e.*, March 15) allowed salinity levels to decrease and provided a lower starting point for the summer increase that has been documented in all three monitoring years.

Additional adaptive management discussions should also consider further raising the outlet boards or reducing the opening during the summer. The outlet boards are lowered during the summer to facilitate the potential migration of herring. However, during more than 30 visits between 2018 and 2020 by Town and CSP/SMAST staff, no fish have been noted at the outlet. Perhaps management of the desired fishery should wait until the pond water quality is adequate to support a healthy fishery. Observations suggest that there is no functional herring run at this time, likely ruined by the high salinity in the pond and its 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 groundwater levels) and support more refined board adjustments for longer-term benefits. It is also anticipated that these impacts will show continuing shallow and deep-water quality improvements, especially as the benefits of removing the cormorant nutrient inputs have another year of effect.

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