Cedar Pond
Adaptive Management Monitoring Program: Annual Technical Report

January 2022 to December 2022

FINAL REPORT

September 2023

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: Alewife in fyke net in Cedar Pond Creek (April 2022)
(photo 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, Ronni Mak, Dale Goehringer and others at the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth.

The authors also note with sadness the passing of Brian Howes. Brian had a long and illustrious career in coastal and estuarine ecology, was a Chancellor Professor at the University of Massachusetts Dartmouth School for Marine Science and Technology, and founding Director of the Coastal System Program at SMAST. Brian will be remembered with fondness and admiration for the foundational work completed to restore Cedar Pond and most of the surface waters of Cape Cod. But more than all of that, Brian was a friend and mentor. Brian passed in December 2022.

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Executive Summary

Cedar Pond
Adaptive Management Monitoring Program: Annual Technical Report
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Cedar Pond is a 15 acre brackish pond that has been subject to a series of *ad hoc* adjustments that have impaired its water quality, including filling a portion of the pond for Route 6 construction, installing regional power lines over the pond that became a seasonal roosting location for a large cormorant population, and alterations of the creek connection between the pond and Rock Harbor. Water quality assessments prior to 2013 indicated that the pond water quality was impaired and regular fish kills clearly showed that the impairments were significant. Even with its impairments, the pond removed 58% of its watershed nitrogen and protected Rock Harbor from the full nitrogen loading impact of development within its watershed. The Town acknowledged the impairments and asked Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) to conduct detailed monitoring and develop a management plan with three goals: 1) restore water quality, 2) restore the herring run, and 3) protect the Atlantic White Cedar wetland that is adjacent to the pond.

In 2013, CSP/SMAST completed the Town of Orleans Cedar Pond Management Plan.[1] Development of the plan included regular snapshots and continuous monitoring of the pond water column and stream outflow. This monitoring data showed that salinity had increased, water quality conditions in the pond had worsened since a 2007 data review,[2] and the nitrogen attenuation that was measured in 2002/03[3] had disappeared (and in some months was exporting more nitrogen than watershed inputs).

The Management Plan recommended that the Town implement three actions to meet the management goals: a) reinstall boards that historically had been in place at the pond outlet to reduce gradually salinity to brackish conditions (1 to 4 parts per thousand), b) relocate the electrical wires over to the pond to move the roosting cormorant population, and c) address the sediment nutrient regeneration. The Plan further recommended that these steps could be taken sequentially or concurrently and that the implementation of the Plan should be accompanied by regular monitoring and reporting of water quality conditions so that management steps could be adapted/adjusted as the system gradually improved.

The Management Plan was reviewed and approved by the Town Select Board and Conservation Commission in 2015, but a group of citizens appealed the approval and the Town was then required to complete Massachusetts Environmental Policy Act (MEPA) filings of an Expanded

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

[2] Eichner, E. 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.

[3] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, and E.M. Eichner. 2008. 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.

Environmental Notification Form (EENF) and then an Environmental Impact Report (EIR) and a Development of Regional Impact filing with the Cape Cod Commission. All of these additional reviews eventually confirmed the initial Town approvals and the Massachusetts Secretary of Energy and Environmental Affairs and Massachusetts Department of Environmental Protection approved the Management Plan and its implementation in 2017.[4]

Part of the MEPA approval was the inclusion of a Fishway Operations and Maintenance Plan (Fishway Plan) to be developed in coordination with Massachusetts Division of Marine Fisheries (MassDMF). Subsequent discussions with MassDMF led to the initial seasonal adjustment of the elevation of boards to encourage spawning herring to enter the pond between March and July and juvenile herring (spawn of the year) to leave the pond between July and November.

Implementation of the Cedar Pond Management Plan began in 2017 with the start of specified monitoring just prior to the reinstallation of the boards at the outlet. Monitoring included the installation of two continuous monitoring devices in the center of the pond in the deep basin, regular collection of streamflow and water quality samples at the long-term station in Cedar Pond Creek, and water column samples and dissolved oxygen and temperature profiles at the same location as the continuous monitoring devices. The boards were reinstalled at the outlet on January 4, 2018. As required in the Management Plan, the status of monitoring was reviewed in a mid-year technical memo and all monitoring results throughout the year were summarized in an annual report.

Monitoring has continued each subsequent year and results have been regularly reviewed in Annual Reports (2018-2021) with brief semi-annual memos providing updates on monitoring activities. CSP/SMAST, MassDMF, and Town staff typically review monitoring results at the time of an annual report and/or semi-annual memo and decide whether adaptive management adjustments are warranted. Following each of these reviews (except 2020 due to COVID restrictions), the height and/or the configuration of the boards has been adjusted. Also as a result of these meetings, CSP/SMAST added a continuous recorder at the outlet in 2019 to better measure water levels relative to board heights and MassDMF installed fyke nets in the Creek in 2022 to assess whether alewives were entering the pond during the primary spawning period. The Town also began discussions with Eversource to move the power lines over the pond in 2017 and the removal of the key lines was completed in December 2018.

This 2022 Annual Report reviews Cedar Pond data collected in 2018-2022 and includes data previously presented in the 2022 semi-annual Technical Memorandum.[5] All reporting on Cedar Pond, including this annual report, has been delayed due to the sudden passing of Brian Howes, Director of the Coastal Systems Program at SMAST/UMASSD. This report also includes recommendations for adjustments in management strategies to better attain the Management Plan goals. Findings from available collected data include:

[4] 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.

[5] CSP/SMAST Technical Memorandum: Cedar Pond Adaptive Management Monitoring Program: 2022 Semi-Annual Report. January 9, 2022. From: E. Eichner and D. Schlezinger. To: G. Meservey and N. Sears, Town of Orleans. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 10 pp.

- Acceptable DO concentrations were measured in 2022 throughout a greater portion of the water column than in any of the 2018-2021 monitoring years. Water column dissolved oxygen (DO) concentrations in 2022 were incrementally better than 2021, which in turn were incrementally better than in 2020. Just as in 2021, all 2022 DO readings in individual profiles at the surface, 0.5 m, and 1 m were greater than the MassDEP 5 mg/L minimum.[6] DO concentrations at 1.5 m were greater than the MassDEP minimum in 5 of the eight monthly samplings, including July and September, and August was 4.8 mg/L. In 2021, only three of seven 1.5 m DO readings were greater than 5 mg/L. Some DO improvement was also measured at 2 m in 2022. Deep anoxia continued to be sustained in all but one reading at 2.5 m and deeper. Higher shallow DO provides better habitat for spawning herring.
- Salinity stratification is largely responsible for the better shallow water quality conditions. Salinity stratification was present March through October 2022, either at the same depth as temperature stratification when it was present, or at a shallower depth: generally 1-1.5 m in the spring and October, 2-2.5 in July-September. This stratification is largely protecting the shallow waters from the very impaired deep conditions. Deep anoxia throughout the year causes the release of sediment phosphorus and nitrogen. Review of shallow DO concentrations show that the deep anoxia is impacting the entire water column, but the full impact is not measured in shallow waters because of the stratification.
- Shallow nitrogen levels remain high, but phosphorus levels are decreasing. Average 2022 shallow total nitrogen (TN) concentration (1.0 mg/L) was the same as in 2019-2021, but less than 2018 (1.2 mg/L). Average 2022 shallow total phosphorus (TP) concentration (146 µg/L) was the lowest among the four years of monitoring (2018-2022), likely due to higher shallow DO causing precipitation of any deep inorganic P reaching shallower waters.
- Deep TN and TP concentrations continued to show high levels and high variation, likely due to the fluctuations in the depth of stratification. Average 2022 deep TN concentration was 4.1 mg/L, which is slightly lower than 2021 when it was 4.8 mg/L, but higher than 2020 when it was 2.6 mg/L. Average deep TP concentration was 445 µg/L, which is the lowest among the five years of monitoring. Stronger stratification would tend to sustain anoxia in bottom waters; the amount of TP released is usually related to how long anoxia persists and in 2022, not all of the deeper layer was anoxic in the spring. A smaller deep volume created by a larger well-oxygenated shallow layer with the same sediment release would also tend to create higher deep concentrations.
- The annual average TN transfer to Rock Harbor via Cedar Pond Creek is significantly reduced, but still slightly higher than the 2002/2003 MEP baseline. TN transfer in 2022 was 1.5 kg/d, which is slightly higher than the 1.1 kg/d export measured in 2002/2003. The MEP export rate indicated 58% nitrogen attenuation in Cedar Pond. Approximating this level in 2022 means that the pond has largely returned to expected nitrogen attenuation levels after having 2018 TN export level of 8.3 kg/d and monthly readings where Cedar Pond was occasionally transferring all of its watershed TN inputs plus sediment TN additions to Rock Harbor.

[6] 314 CMR 4

- Herring/alewife have returned in a small way to Cedar Pond. Prior to 2022, no fish were observed entering or leaving Cedar Pond during more than four years of Management Plan monitoring and over 80 visits to the pond outlet and Cedar Pond Creek. With the help of MassDMF, fyke nets were installed during March/April 2022 and 30 alewife were trapped and released in Cedar Pond Creek. This is an additional encouraging sign about improved water quality conditions in Cedar Pond and provides some hope that future alewife visits will increase due to fish returning to the stream were they were born.

The 2022 monitoring results continue to confirm the lessons of 2018, 2019, 2020 and 2021, as well as the recommendations in the 2013 Cedar Pond Management Plan:

a) reduced salinity in Cedar Pond improves 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 was important for improvements in water quality.

MassDEP also confirmed the benefits of the Cedar Pond Management Plan implementation in 2022 by issuing the Town a Certificate of Compliance on its 2017 Superseding Order of Conditions that originally approved the Cedar Pond Management Plan. This Certificate of Compliance has one on-going condition: that the Town continue to implement the Cedar Pond Management Plan.[7]

Monitoring from 2018-2022 has documented improvements in Cedar Pond. As of 2022, the shallow, upper portion of the pond water column is consistently attaining MassDEP regulatory standards for dissolved oxygen and these have resulted in lower TP and TN concentrations and lower TN export to Rock Harbor. Deep portions of the pond, however, continue to be significantly impaired with sustained anoxia causing high nutrient levels and impacts throughout the water column. These deep impaired conditions are somewhat constrained by regular salinity stratification where higher salinity waters come into the pond during flood tides and sink to the bottom due to their greater density. This stratification limits the impacts of the deep impairments, something that did not occur when the boards were removed. The primary cause of the deep impairments is the oxygen demand caused by the sediments.

Fluctuations in all these measurements will occur as groundwater levels and precipitation rates change. Higher groundwater elevations and precipitation rates will increase freshwater input to the Pond and decrease salinity levels. Groundwater levels fluctuate from year-to-year and seasonally with lower levels in the summer. During 2022, groundwater levels were close to long-term average elevations, but late summer precipitation (July and August) was the lowest among the five years of monitoring.

Based on the current conditions and review of historical data, project staff recommend the following actions for the continuing management of Cedar Pond:

1. Maintain the same board elevations, configuration and management of board heights as was done in 2022. Regular water elevations over the boards are sufficient for herring to enter and exit. Water quality has gotten incrementally better each year under the current configuration.

[7] MassDEP Certificate of Compliance to Town of Orleans. February 2, 2022. DEP files number: SE 54-2286.

2. Begin to plan strategies to address the sediments and their impact on water quality. Deep water quality was consistently impaired from March through October 2022. The salinity stratification in the pond is facilitating the improvements in the shallow waters, but regular deep anoxia is impacting shallow water quality conditions and future incremental improvements may be limited by the extent of deep impairments.
3. Continue to monitor in order to provide basis for developing management strategies, as well as assessing impacts of management actions.
4. Regular meetings among the Town, CSP/SMAST, and MassDMF should continue as they have provided beneficial recommendations, regular communication, and coordination for effective restoration and management activities

Overall, 2022 readings showed another year of 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 2022 readings were slightly better than 2020 and 2021 and clearly better than 2018 or 2019. Shallow water quality conditions were notably improved with acceptable DO in a greater proportion of the water column along with lower nutrient levels. Challenges remain about creating stable conditions of lower salinity levels and improved water quality, as well as addressing deep water quality impairments, but there are some signs in the available data that ecosystem changes are still occurring and that each year brings the Town closer to attaining the goals for Cedar Pond.

Table of Contents
Cedar Pond
Adaptive Management Monitoring Program
Annual Technical Report
January 2022 to December 2022

List of Figures
Cedar Pond
Adaptive Management Monitoring Program
Annual Technical Report
January 2022 to December 2022

List of Tables
Cedar Pond
Adaptive Management Monitoring Program
Annual Technical Report
January 2021 to December 2021

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**). Since 2018, the Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth (CSP/SMAST) has provided the Town with regular monitoring to support the adaptive management provisions of the Cedar Pond Management Plan.[8] The Management Plan was approved by the Town and the state in 2017[9] and the MEPA approval included regular monitoring and reporting requirements, as well as management of the fishway connection between the pond and Rock Harbor Creek in coordination with Massachusetts Division of Marine Fisheries (MassDMF). Following the state approval, a 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 Management Plan has three goals: 1) restore water quality, 2) restore the herring run, and 3) protect the adjacent Atlantic White Cedar wetland.

The Cedar Pond Management Plan was developed to address identified water quality impairments in the pond and the impact of various management actions implemented over the past 150 years, mostly without comprehensive assessments of potential outcomes. Historical *ad hoc* management actions have included filling a portion of the pond for the construction of Route 6, siting regional power lines over the pond that were subsequently used by a large summer cormorant population for roosting, and changes to the stream channel connecting the pond to Rock Harbor. The significant changes to the stream channel in 2007 were the most recent action and increased tidal saltwater inflows to the pond and gradually increased salinities in the pond. The pond ecosystem was altered from a brackish, slightly salty condition with surface salinity of 6.9 parts per thousand (ppt) to a coastal salt pond with 21.8 ppt surface water salinity. This shift in pond ecology also eliminated the documented watershed nitrogen attenuation the pond provided for Rock Harbor.[10] Monitoring in 2012 in support of the development of the Management Plan showed that the ecological shift to higher salinity caused the pond to export more nitrogen than was added by the watershed and greater anoxia in pond bottom waters.

The Management Plan included a series of steps to begin to attain the identified goals. Initial steps were: 1) return the pond to brackish conditions (*i.e.*, reduce salinity from 21-23 ppt to 1-4 ppt salinity) and 2) limit summer nutrient contributions from the large seasonal flock of double-crested cormorants by removing the regional power lines that are strung over the pond. The reduced salinity would improve water quality conditions, provide better habitat for herring, and protect the Atlantic White Cedar wetland. Moving the regional power lines would reduce a nutrient source and improve water quality. The Management Plan included adaptive management recommendations to monitor and adjust these steps once the impacts were measured. Additional discussions about managing nutrients in the sediments were recommended once initial steps were fully implemented.

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[8] 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.

[9] 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.

[10] 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. SMAST/DEP Massachusetts Estuaries Project, MassDEP. Boston, MA. 132 pp.

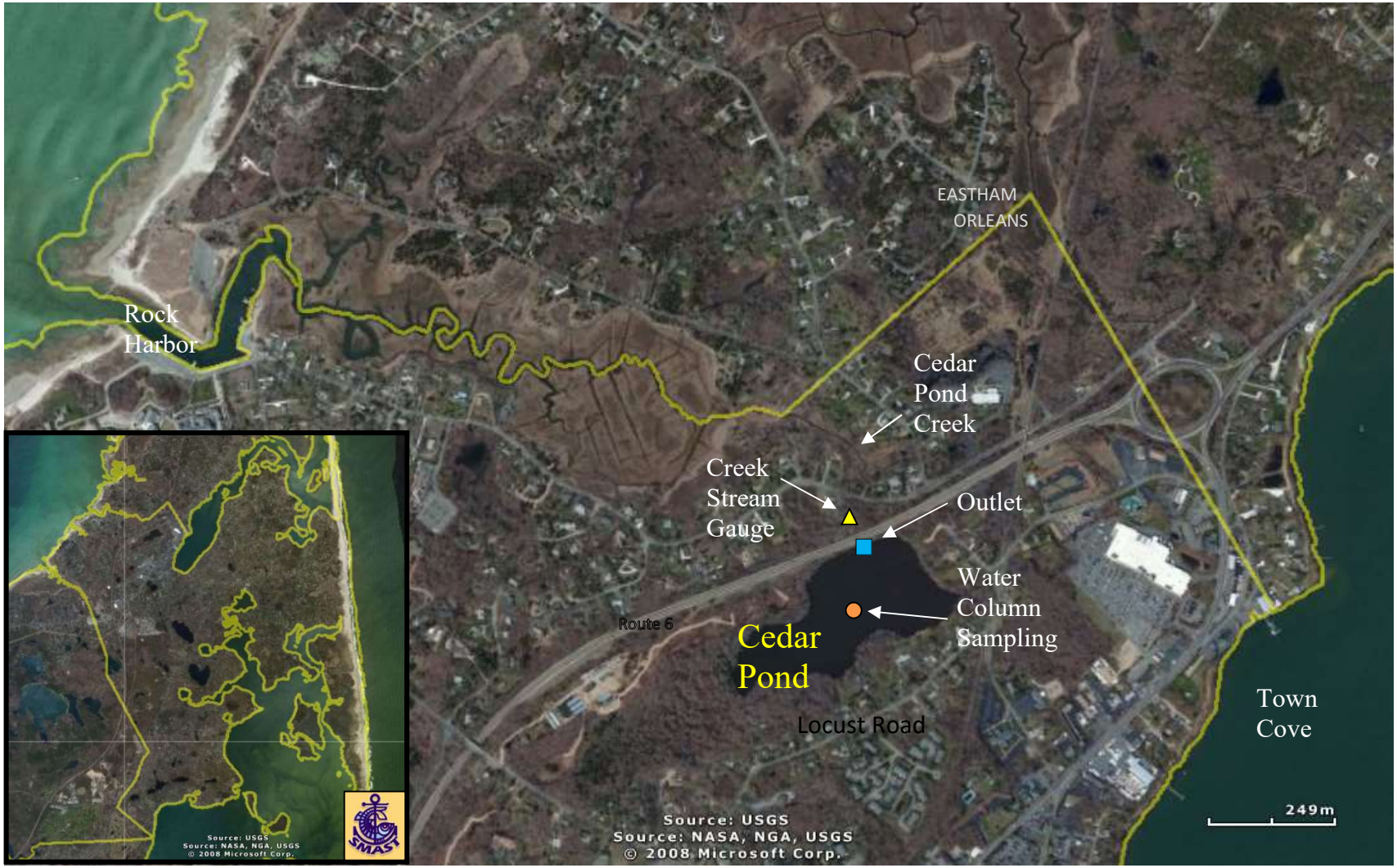

Figure I-1. Cedar Pond Locus and Sampling Stations in the Town of Orleans, MA. Cedar Pond is located in northern Orleans, south of Route 6 and west of Town Cove. The Pond is connected to the Rock Harbor estuary on Cape Cod Bay via Cedar Pond Creek. The creek leaves the pond through a weir at the pond 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).

In order to facilitate the adaptive management provisions, the Management Plan includes regular reporting on monitoring results. This reporting includes an annual report and a semi-annual update. CSP/SMAST to date, has prepared four annual reports: 2018[11], 2019[12], 2020[13], and 2021.[14] During 2022, the Massachusetts Department of Environmental Protection (MassDEP) reviewed the results of the regular monitoring conducted by the Town through CSP/SMAST with regard to their 2017 Superseding Order of Conditions approving the Cedar Pond Management Plan. On February 2, 2022, MassDEP issued a Certificate of Compliance[15] to the Town with one on-going condition: that the Town continue to implement the Cedar Pond Management Plan. This current Annual Report is the fifth Cedar Pond Annual Report and reviews monitoring during 2022, including the data summarized in the 2022 Semi-Annual Report.[16]

II. Insights from Previous Years Management

One of the strategies in the Management Plan adaptive approach has been to improve water quality by gradually returning Cedar Pond to its historically brackish conditions.[17] This management step has been accomplished by reinstalling the tidal boards in the pond outlet and rebalancing the relationship between groundwater and tidal inputs. The initial strategy was that the boards would only allow the highest tides into the pond, while also allowing natural watershed groundwater inputs to gradually lower pond salinities. CSP/SMAST developed the initial board elevation in 2014 based on previously collected data.[18] It was acknowledged at the time that future adjustments would occur as additional monitoring data was collected and reviewed.

Goals in the Fishway Plan led to the initial alterations in planned board heights. In the initial Fishway Plan, board elevations at the outlet were to be adjusted throughout the year to allow spawning fish to enter in the spring and juvenile fish to leave in the summer and fall. The initial recommendation in the Fishway Plan was to have the boards set from March 15 to June 30 at an elevation to allow at least 6 inches (0.15 m) of water depth to flow over the top of the board. This elevation was thought to facilitate entry into the pond by river herring migrating upstream from Cape Cod Bay/Rock Harbor for spawning within the pond. On July 1, the board elevation

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[11] 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.

[12] 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.

[13] 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.

[14] Eichner, E., B. Howes, and D. Schlezinger. 2022. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2021 to December 2021. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 47 pp.

[15] MassDEP Certificate of Compliance to Town of Orleans. February 2, 2022. DEP files number: SE 54-2286.

[16] CSP/SMAST Technical Memorandum. January 9, 2023. Cedar Pond Adaptive Management Monitoring Program: 2022 Semi-Annual Report. From: E. Eichner, and D. Schlezinger. To: G. Meservey and N. Sears, Town of Orleans. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 10 pp.

[17] Brackish = Being or containing water that is somewhat salty but less salty than sea water.

[18] 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: G. Meservey, Town of Orleans and C. 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.

would be adjusted to allow at least 2 inches (0.05 m) of outflowing water over the top board. This adjustment would last until November 15 and would be designed to allow juvenile herring (spawn of the year) to leave the pond. Boards were to be adjusted by town staff to attain the specified amount of water over the boards throughout the management period. The Town, MassDMF, and CSP/SMAST would also work to note any fish during monitoring or board adjustment visits.

In order to closely monitor the impacts of changes in board elevations, water level and water quality monitoring has been adjusted over the years. CSP/SMAST initially installed shallow and deep sondes with multiple sensors in the center of the pond over the deep basin. These sondes have been collecting continuous readings of water levels, dissolved oxygen (DO), temperature, and salinity since November 2017. In May 2019, CSP/SMAST added another water level recorder at the pond outlet after review of the monitoring results from 2018 (*i.e.*, the first year of monitoring). The continuous data collection at two locations was complemented by: a) approximately monthly water column samples and DO and temperature profiles at the location of the shallow and deep sondes and b) streamflow readings and water quality samples downstream of the pond. The streamflow station is at the same location periodically monitored since 2002 (initially for the Rock Harbor MEP assessment[19]). Town and CSP/SMAST staff had noted no fish entering or leaving the pond at the outlet during over 81 visits to adjust the boards or collect water quality readings between 2018 and 2021.

During the initial 2018 annual review of monitoring results, it was noted that water quality improved, but was not sustained as pond water salinity increased after the boards were lowered to the levels specified in the initial Fishway Plan. Town, DMF, and CSP/SMAST staff discussed options to better attain the Management Plan goal of reduced salinity while also addressing Fishway Plan goals. As a result, it was agreed that the specified board elevations would be maintained in 2019, but the opening in the boards would be limited to a 6 inch notch. The goals of this configuration would continue to allow the prospective fish passage, but would reduce the cross-sectional area exposed to tidal water inputs. It was hoped that this board configuration change would retain the lower salinity that occurred in the winter and early spring.

Review of the 2019 data showed that winter and early-spring salinity in the pond was significantly reduced and the pond began March (the beginning of Fishway Plan board lowering) at a low salinity (~6 ppt) just above the 1 to 4 ppt range targeted in the Management Plan.[20] Because 2019 began at a lower salinity level, salinity levels throughout 2019 were lower than 2018. However, once the boards were lowered through the addition of the notch, 2019 water column salinity levels increased at the same rate as measured in 2018. In the lower salinity setting of 2019, pond water quality improvements were measured for a number of metrics including higher DO levels, lower nitrogen and phosphorus levels, and less nitrogen and phosphorus transferred from the pond to Rock Harbor. Subsequent review of the 2019 outlet water level data showed that board elevation could be raised 4 inches higher while still attaining the water level goals for fish entrance and exit.[21]

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[19] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, E.M. Eichner. 2008. Rock Harbor MEP report.

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

[21] 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.

In 2020, the elevation of the bottom of the notch was raised and water quality incrementally improved again, but salinity rates also increased at the same rate as in 2018 and 2019 after the notch elevation was lowered to address the Fishway Plan goals. Water quality conditions in 2020 showed additional improvements over those in 2019 with a greater proportion of the water column in the pond achieving the MassDEP minimum DO concentration (*i.e.*, 5 mg/L[22]), lower TN and TP water column concentrations, and lower export of TN and TP out of the pond to Rock Harbor. However, the pond, although improved, continued to have impaired conditions.[23]

In 2021, the COVID pandemic disrupted much of Cedar Pond reporting, but monitoring continued without disruption. Water quality conditions were incrementally better in 2021 with:

1) DO profile concentrations from the surface to 1 m were above the MassDEP minimum (5 mg/L[24]) in all readings for the first time,
2) shallow salinity concentrations were generally lower, but increased at same rate as 2018-2020 as boards were lowered for fish passage,
3) shallow TN concentrations were approximately the same as 2020, but shallow TP concentrations were the lowest measured 2018-2021, and
4) deep water column conditions continued to be impaired, but stronger salinity stratification generally kept the impaired conditions from mixing into the shallower waters.

As of the end of 2021, no fish had been observed entering or leaving Cedar Pond during the four years of Management Plan monitoring (>80 visits to the outlet). Following the review of the 2021 Annual Report, CSP/SMAST, Town and MassDMF staff discussed further flexibility in board heights and options to quantify whether fish were entering or leaving the pond and, if so, which species.

III. Cedar Pond Adaptive Management Program 2022 Results

As discussed above, 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 streamflow and water quality into and out of the pond, c) measurement of pond water level fluctuations, d) working with the Town and MassDMF to track factors in the MassDMF Fishway Operations and Maintenance Plan, including outlet board heights, water levels over the boards, fish observations, and e) providing the Town with the regular semi-annual and annual reports required in the approval of the Management Plan. Monitoring during the 2022 calendar year is summarized in this section.

III.A. Board Height, Water Levels, and Fish Movement

One of the strategies in the Management Plan's adaptive approach has been to gradually return Cedar Pond to its historically lower salinity/brackish condition by reinstalling the tidal boards in the pond outlet. The boards should only allow the highest tides into the pond, while also allowing continuous natural watershed groundwater inputs to gradually lower pond salinities. CSP/SMAST developed the initial board elevation in 2014 based on previously collected data.[25]

[22] 314 CMR 4.05

[23] Eichner, E., B. Howes, and D. Schlezinger. 2021. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2020 to December 2020.

[24] 314 Code of Massachusetts Regulations 4.05(4)1.

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

It was acknowledged at the time that future adjustments would occur as additional monitoring data was collected and reviewed.

Goals in the Fishway Plan led to the initial alterations in planned board heights. In the initial Fishway Plan, board elevations at the outlet were to be adjusted throughout the year to allow spawning fish to enter in the spring and juvenile fish to leave in the summer and fall. The initial recommendation in the Fishway Plan was to have the boards set from March 15 to June 30 at an elevation to allow at least 6 inches (0.15 m) of water depth to flow over the top of the board. This elevation was thought to facilitate entry into the pond by river herring migrating upstream from Cape Cod Bay/Rock Harbor for spawning within the pond. On July 1, the board elevation would be adjusted to allow at least 2 inches (0.05 m) of outflowing water over the top board. This adjustment would last until November 15 and would be designed to allow juvenile herring (spawn of the year) to leave the pond. The Town, MassDMF, and CSP/SMAST would also work to identify any fish noted during monitoring or board adjustment visits. Town and CSP/SMAST staff noted no fish entering or leaving the pond during over 81 visits to adjust the boards or collect water quality readings.

Management of the board height is complex because pond water levels are impacted by several variable factors including fluctuating groundwater levels, high tide inputs, and seasonal variations in rainfall and evapotranspiration. Boards had long been in place at the Cedar Pond outlet in historical times,[26] but had been completely removed prior to development of the Management Plan. As part of the initial implementation of the Management Plan, CSP/SMAST determined an initial board height elevation of 1.45 m NAVD88 based on available tidal data (collected between 2001 and 2012).[27]

In order to measure the water elevations over the boards and assess the impacts of management activities in Cedar Pond, CSP/SMAST initially installed shallow and deep sondes with multiple sensors in the center of the pond. These sondes continue to be in place and have been collecting continuous readings since November 2017. CSP/SMAST added another water level recorder at the pond outlet in May 2019 after review of the 2018 monitoring results (*i.e.*, the first year of monitoring). Water levels at the outlet have been recorded every 10 minutes since the initial installation.

During the annual review of the 2018 monitoring results, it was noted that water quality improved, but pond water salinity increased after the boards were lowered. Town, DMF, and CSP/SMAST staff discussed options to better attain the Management Plan goal of reduced salinity while also addressing Fishway Plan goals. As a result, it was agreed that board elevations would be maintained in 2019, but the opening in the boards would be limited to a 6 inch notch (**Figure III-1**). The goals of this configuration would allow fish passage, but reduce the cross-sectional area exposed to tidal water inputs. It was hoped that this board configuration change would retain the lower salinity that occurs in the winter and early spring throughout the summer.

[26] There also was a downstream dike with a flapper valve. Hydrodynamic modeling showed that removal of the dike would increase salinity in Cedar Pond by 0.3 ppt (Applied Coastal Research and Engineering, Inc. Technical Memorandum. January 15, 2010).

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

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 could have a notch in the upper board to facilitate fish passage while also trying to limit the volume of high tides reaching Cedar Pond. Subsequent water level monitoring in 2019 showed that once a notch was added, salinity levels increased at the same rate as in 2018 when the boards were lowered. 2020 monitoring suggested that the elevation of the bottom of the notch could be increased while also attaining similar frequency of water levels meeting the Fishway Plan goals. Notch elevations are adjusted according to Fishway Plan goals for 6 inches of water over the notch bottom in the spring for spawning herring immigration (March 15 to June 30) and 2 inches of water over the notch bottom in mid/late summer to allow young of the year emigration (July 1 to November 15). No herring had been observed during more than 81 visits from 2018 through 2021, but use of fyke nets by Town and MassDMF in March/April 2022 trapped and released 30 alewife. Herring in the Cedar Pond Creek is one indication of improving water quality conditions in Cedar Pond.

Review of the 2019 data showed that winter and early-spring salinity in the pond was significantly reduced and the pond began March (the beginning of Fishway Plan board lowering) at a low salinity (~6 ppt) just above the 1 to 4 ppt range targeted in the Management Plan.[28]

Because 2019 began at a lower salinity level, salinity levels throughout 2019 were lower than during 2018. However, 2019 salinity levels increased at the same rate as in 2018 once the notch in the outlet boards was added. In the 2019 lower salinity setting, pond water quality improvements included higher dissolved oxygen levels, lower nitrogen and phosphorus levels, and less nitrogen and phosphorus transferred from the pond to Rock Harbor. Subsequent review of the 2019 water level data at the inlet showed that boards could be raised 4 inches higher while still attaining the Fishway Plan goals for fish entrance and exit.[29]

In 2020 and 2021, the notch elevation was increased and water quality incrementally improved each year, but salinity rates again increased at the same rate as in 2018 and 2019 after the notch elevation was lowered to address the Fishway Plan goals. Water quality conditions in both 2020 and 2021 showed incremental improvement with a greater proportion of the water column in the pond achieving the MassDEP minimum dissolved oxygen concentrations, lower TN and TP water column concentrations, and lower export of TN and TP out of the pond to Rock Harbor but, overall, the pond continued to have impaired conditions.[30] In 2021, all DO concentration measurements from the surface to 1 m depth were greater than the MassDEP regulatory minimum for the first time.

In 2022, board elevations adjustments were more limited than in the past with the regular addition of the notch on March 15, but removal of the notch in May (**Table III-1**). The goal of this change was to see if lower spring salinity values could be sustained. Unfortunately, the recorder had a partial failure in 2022 with a complete failure in late April. Water elevations during the January through April 2022 period generally had similar average characteristics to past years, but also had a wider range of elevations, suggesting some changes in the Cedar Pond Creek or the Rock Harbor salt marsh (**Figure III-2**). Water levels in 2022, though limited to the first third of the year, had approximately the same average characteristics as 2020 and 2021 (**Table III-2**).

Since the 2022 recorder did not operate correctly after April 21, comparison of water level and Fishway Plan board elevations can only occur form March 15 to April 21, but comparison to similar periods in 2020 and 2021 show conditions were generally similar. In 2022, 9% of the water elevations were above the notch elevation, while in 2020 it was 8% and in 2021 it was 6%. Water elevations were 6 inches above the notch elevation, the Fishway Plan goal, in 2% of the readings in 2022, 3% in 2021, and 4% in 2020. While data was limited in 2022, the available data suggests that general conditions for any spawning herring were similar to readings in 2020 and 2021.

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

[29] CSP/SMAST Technical Memorandum: Cedar Pond Board Adjustment. October 21, 2020.

[30] Eichner, E., B. Howes, and D. Schlezinger. 2021. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2020 to December 2020.

Table III-1. Cedar Pond Board Height Log: 2020-2022. During 2020-2022, Town staff adjusted the board elevations according to the Fishway Operations and Maintenance Plan (source of town adjustments: Nate Sears, Natural Resources Manager, Town of Orleans). CSP/SMAST staff often visit the site with a GNSS/GPS with RTK enabled to record board elevations. These readings were also used to determine 2020 - 2022 board elevations. Water levels over the notch and board elevations will vary depending on timing of visits and water levels at the time of the visits.

	Date	Time	Low Tide	Outflow (water over boards)		Water Level (ft)	Fish noted	Board adjustment	Elevations (m NAVD88)		
				Initial (inches)	Final (inches)				Bottom Notch	Top of Boards	Pond Elevation
Town	4/13/20	10:45	10:36	0	3	2.25	No fish	Notch added	1.42		
Town	4/28/20	9:45	9:45	1	1	2.08	No fish	none			
SMAST	5/26/20	15:22					No fish		1.38	1.50	1.35
SMAST	6/25/20	14:20					No fish		1.37	1.48	1.38
SMAST	7/22/20	14:23					No fish		n/a		
SMAST	9/23/20	15:11					No fish		1.39	1.50	1.49
Town	9/28/20	14:30	16:15	0	1	2.58	No fish	Removed notch			
Town	3/17/21	14:45	8:38	0	0	1.6	No fish	Notch added	1.48		
Town	7/1/21	14:30	11:24	1	5	2.0	No fish	Removed boards	1.34		
Town	11/29/21	10:40	12:33	0	0	1.3	No fish	Boards added; removed notch		1.63	
Town	3/15/22	9:30	15:51	0	0	2.1	No fish	Notch added	1.48		
Town	5/15/22	9:00	5:05	1	0	2	No fish	Removed notch		1.63	

Table III-2. Cedar Pond Outlet Water Level Elevation Summary: 2019-2022. Summary of continuous water level readings collected at the Cedar Pond outlet show similar characteristics in each year. The continuous recorder was first installed on 5/23/19 and has been recording with occasional disruptions due to equipment problems (*e.g.*, battery failure).

	2022	2021	2020	2019
Beginning Date	1/1/22	1/21/21	1/1/20	5/23/19
Ending Date	4/21/22	12/31/21	9/23/20	12/31/19
Average Elevation (m NAVD88)	1.35	1.28	1.28	1.28
N	10,603	33,275	37,533	25,359
Maximum Elevation (m NAVD88)	2.04	1.96	1.98	1.80
Minimum Elevation (m NAVD88)	0.94	1.08	1.17	1.16
25th percentile Elevation (m NAVD88)	1.27	1.22	1.23	1.22
75th percentile Elevation (m NAVD88)	1.43	1.28	1.28	1.29

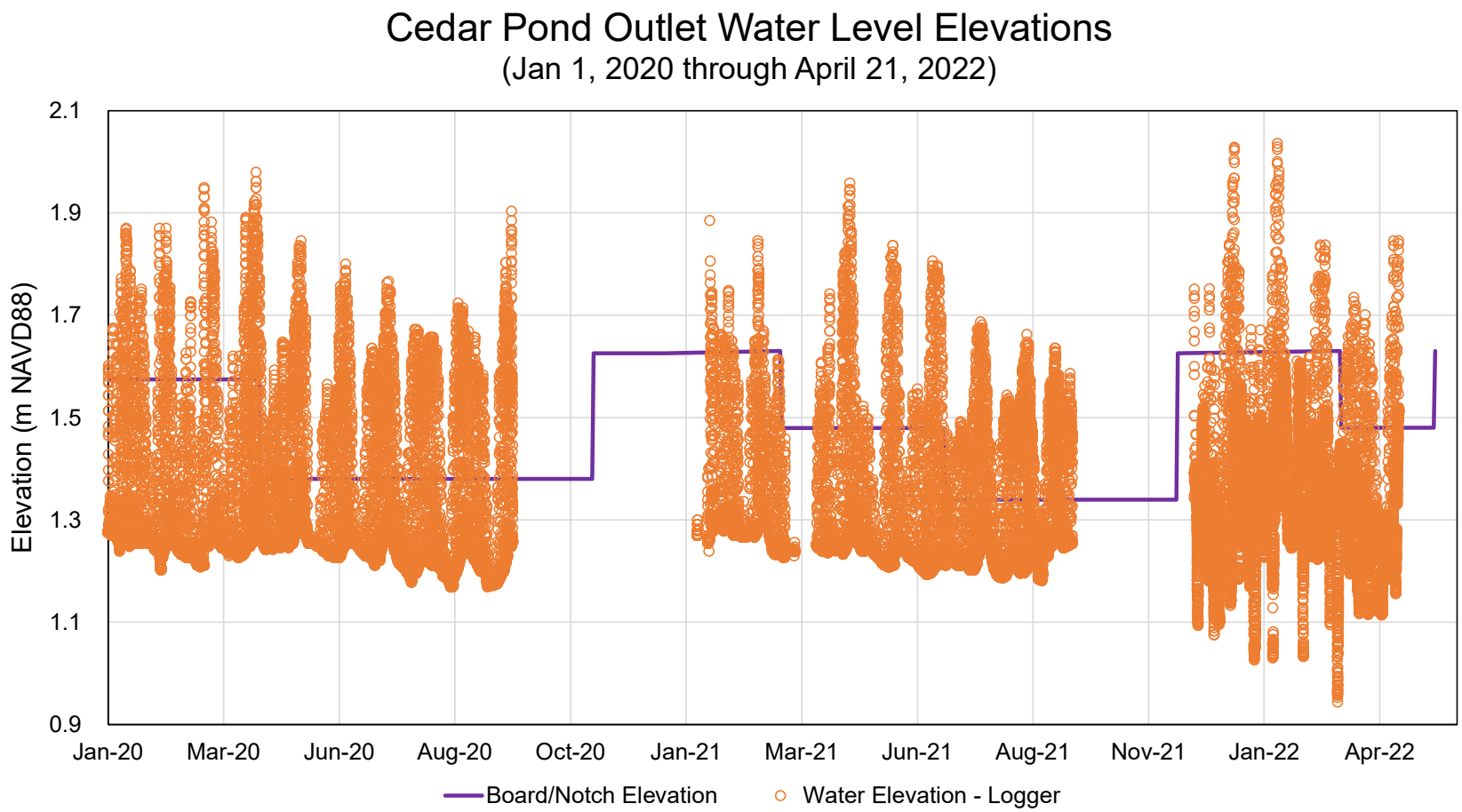


Figure III-2. Cedar Pond 2020-2022 Water Levels and Outlet Board Heights. CSP/SMAST staff installed an autonomous recording device programmed to record water levels every 10-15 minutes at the pond outlet on May 23, 2019 and the device has recorded through April 21, 2022 with occasional record gaps due to various factors. As specified in the Fishway Plan, a notched board was added at the outlet around March 15 with the goal of 6 inches of water above the bottom of the notch. In early 2022, 2% of readings between 3/15 and 4/21 were 6 inches above the bottom of the notch. This is slightly lower than the 2.6% and 4% of readings in the same periods in 2021 and 2020, respectively. Readings in 2022 also show higher and lower elevations than previous years, suggesting that there was some change in Cedar Pond Creek or the Rock Harbor salt marsh.

III.B. Water Quality Monitoring

Water quality monitoring in 2022 included regular collection of water column salinity and water quality samples coupled with detailed dissolved oxygen and temperature profiles, as well as two continuous recording devices at two depths at the deepest basin and regular water quality monitoring in Cedar Pond Creek, just north of the pond outlet. All 2022 monitoring was conducted by CSP/SMAST staff and followed the same procedures used in previous years.

CSP/SMAST staff collected water column samples and profiles monthly between March and October: March 9, April 21, May 17, June 15, July 26, August 23, September 20, and October 19. 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: 0.5 m, 1.5 m, and 3.5 m. 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 2020-2022 (and continue to be deployed in 2023). The 2022 continuous monitoring devices were at shallow (1.5 m) and deep (3.9 m) depths (approximately the same depths during 2018-2021 deployments) and were programmed to record DO, temperature, salinity, and depth every 15 minutes. The shallow device also recorded chlorophyll-*a* concentrations. 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 2022, stream water quality samples and flow readings were collected 20 times with continuous water level recordings collected at the same location. The stream monitoring site is the same site used during the a) the MEP Rock Harbor assessment,[31] b) data collection for development of the Cedar Pond Management Plan,[32] and c) 2018-2021 monitoring for the implementation of the Management Plan.[33] All collected water quality samples were assayed at the Coastal Systems Analytical Laboratory at SMAST/UMASS Dartmouth using the same assay procedures used for Town water quality samples collected from estuaries and freshwater ponds.

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

Monthly 2022 water column salinity and temperature readings were generally similar to those in 2021, but with some notable differences. Water column temperature readings in both 2021 and 2022 showed surface temperatures peaked in July and were warmer for more of the summer than during 2020. Deep water temperatures peaked in September; this is consistent with incoming tidal water since Cape Cod Bay average monthly temperature peaks in August.[34] Temperature stratification began in May and the depth of the warm upper layer gradually deepening from 1.5 m in June to 3 m in August, but was not present in September or October (**Figure III-3**). Salinity stratification was present March through October, either at the same depth as temperature stratification when it was present, or at a shallower depth: generally 1-1.5 m in the spring and October, 2-2.5 in July-September. These interactions between temperature and salinity stratification generally kept the deepest waters isolated from atmospheric interaction. These deep waters had higher salinity reflective of their source as incoming flood tide waters that typically sink toward the bottom once they reach Cedar Pond. Since the average deep salinity was 15.7 ppt rather than the >20 ppt salinity measured in 2018, it suggests that the pond has become a bit more brackish and that the water column must occasionally mix, likely during the

[31] September 2002 to August 2003

[32] June 2012 to September 2012

[33] 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.

[34] https://www.ncei.noaa.gov/access/coastal-water-temperature-guide/all_table.html (accessed 5/8/23).

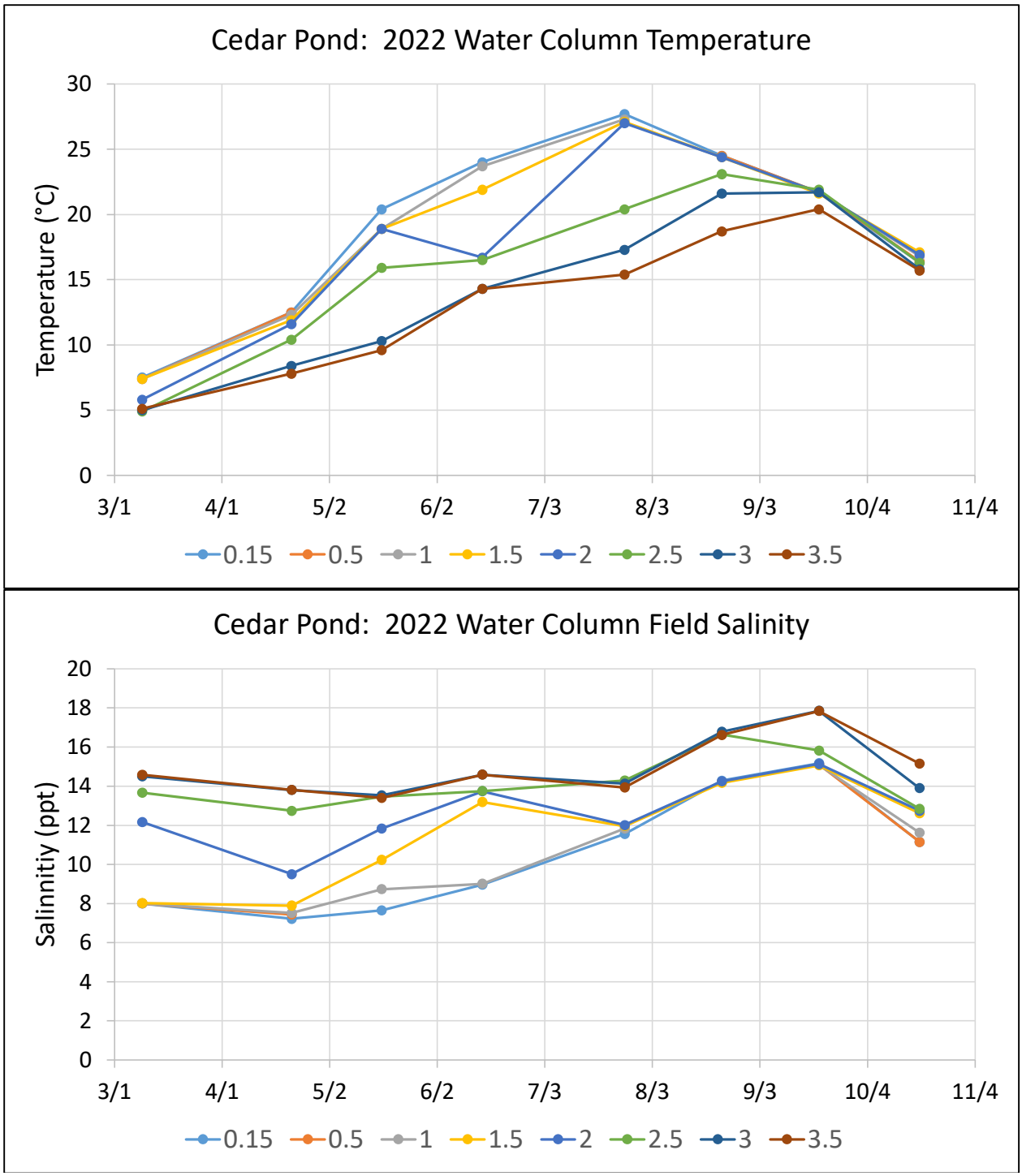


Figure III-3. Cedar Pond 2022 Water Column Temperature and Salinity Readings. Shallow temperatures peaked in July, while deep temperatures peaked in September. Temperature stratification began in May with the depth of the warm upper layer gradually deepening from 1.5 m in June to 3 m in August, but was not present in September or October. Salinity stratification was present in all months, either at the same depth as temperature stratification or at a shallower depth. Shallower waters to 1-1.5 m were generally isohaline in the spring and October and then deepened to 2-2.5 in July-September. None of the 2022 salinity profile readings were within the 1 to 4 ppt Cedar Pond Management Plan target range.

winter, though that was not measured in 2022. Shallow waters generally had lower salinity reading, likely reflective of watershed groundwater discharge occurring along the pond margins. However, none of the 2022 salinity water column readings were within the 1 to 4 ppt Cedar Pond Management Plan target range. The lowest salinity reading was 7.22 ppt on April 21 at 0.15 m and the average 2022 shallow salinity concentration was 10.5 ppt.

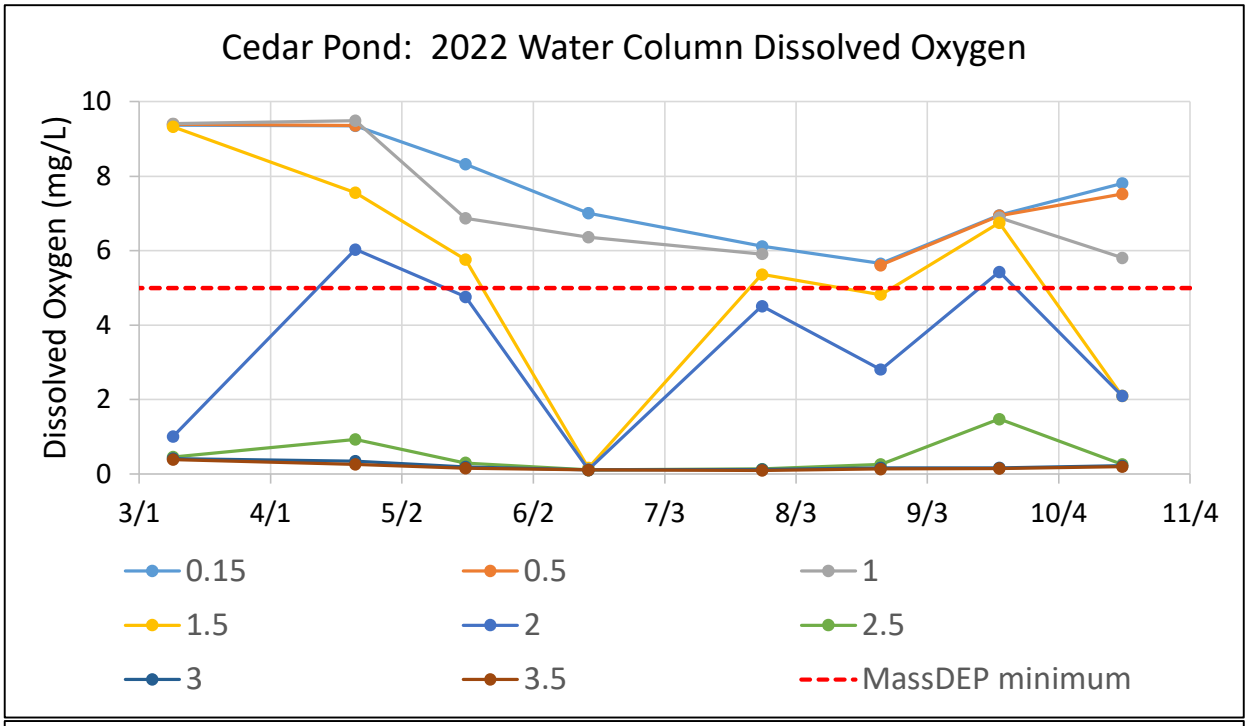
Water column DO concentrations showed some slight improvements over 2021, but also continued to show continued deep water anoxia. Just as in 2021, all 2022 DO readings in individual profiles at the surface, 0.5 m, and 1 m were greater than the MassDEP 5 mg/L minimum (**Figure III-4**). DO concentrations at 1.5 m were greater than the MassDEP minimum in 5 of the eight monthly samplings, including July and September, and August was 4.8 mg/L. The shallow DO patterns are an improvement from 2021, where 3 of the 7 profiles at 1.5 m depth had DO concentrations greater than 5 mg/L. Another sign of improvement was occasional DO concentrations at 2 m greater than 5 mg/L (April and September) and two others greater than 4 mg/L. In 2021, only one DO reading at 2 m was greater than 5 mg/L and that occurred in May.[35] While shallow conditions continued to improve, deep anoxia was sustained in almost all readings at 2.5 m and deeper. However, even this was a bit of an improvement since anoxia was regularly recorded at 2 m and deeper in 2021. This gradual deepening of anoxia continues an annual pattern: DO profiles in 2018 and 2019 had anoxia recorded at 1.5 m and deeper, while 2020 and 2021 had anoxia recorded only at 2 m and deeper. Shallow improvements in DO and increasing depth of acceptable DO continue to be signs of improving trends in Cedar Pond.

The extent of bottom anoxia appears to be related to both salinity stratification and temperature. In March and April 2022, profile data showed no temperature stratification, but salinity stratification was between 1.75 and 2 m in March and 1.5 m and 2 m in April. During both of these months, the deepest waters were anoxic, but water at the top of the deep layer still had DO >1 mg/L. This type of profile was sustained into May, but by June when deep temperatures had increased by 4°C from May, the whole deep layer was anoxic. In subsequent months, the sustained deep anoxia began to create hypoxia within the warmer shallow layer, but DO concentrations in the shallow layer did not include a decrease below 1 mg/L (the minimum was 1.48 mg/L DO in September).

Review of DO saturation levels confirm that deep anoxia was impacting the shallow layer even though DO concentrations were greater than 5 mg/L. Shallow DO % saturation levels were regularly between 60% and 80% during the summer (see **Figure III-4**). Overall, this means the anoxia in the deep layer is seeping into the upper layer, but the regular atmospheric mixing in the upper layer is providing replenishment of oxygen depletion. This decreased DO % saturation throughout the water column is something that has been relatively consistent across all of the Cedar Pond Management monitoring years.

Collectively, the 2022 water column salinity, temperature and DO readings generally continued the pattern of slow improvements seen in 2019-2021. DO readings at the surface, 0.5 m, and 1 m in 2022 were greater than the MassDEP 5 mg/L minimum, just as they were in 2021. Improvements in DO concentrations at 1.5 m and at 2 m were also seen with more frequent DO concentrations >5 mg/L in 2022 than in 2021. Salinity stratification continues to isolate the deeper portions of the water column and these deep portions have sustained anoxia that has impacts throughout the pond water column (*e.g.*, reduced % DO saturation). DO conditions in the deeper water continue to experience anoxia and this anoxia regularly lowers DO concentrations in the upper portions of the water column as well.

[35] See Figure III-3 in 2021 Cedar Pond Annual Report.



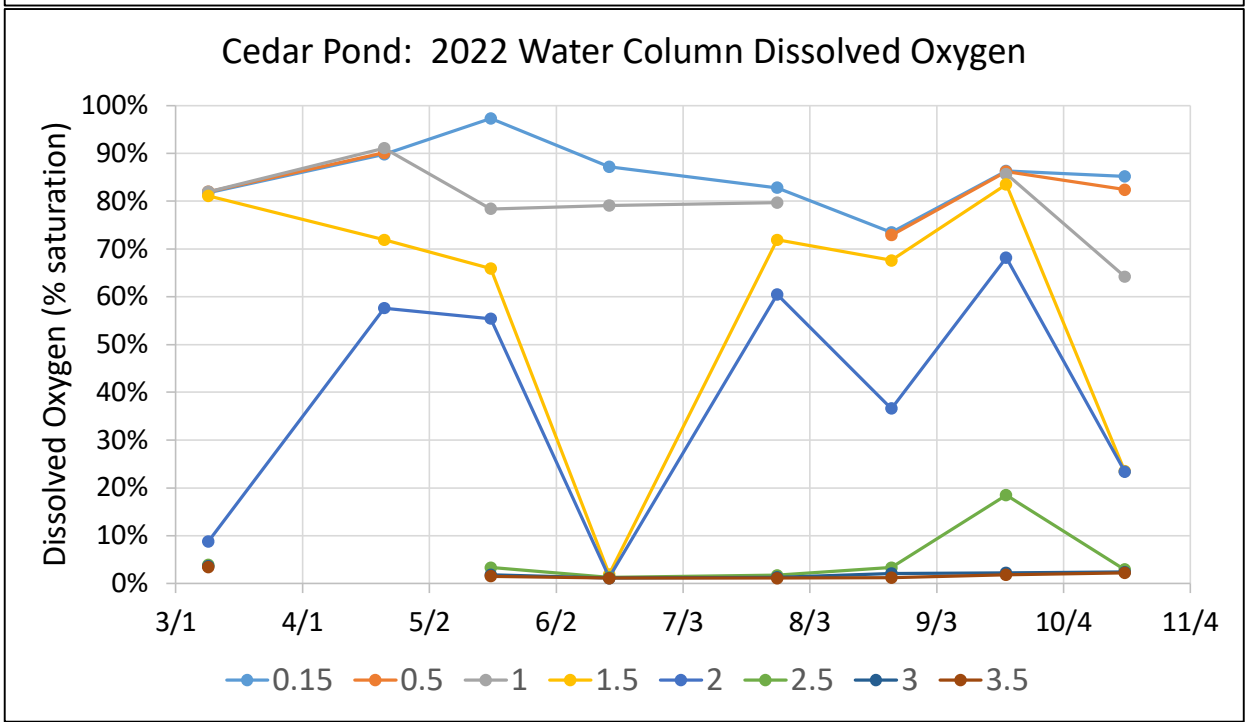


Figure III-4. Cedar Pond 2022 Water Column Dissolved Oxygen Readings. All DO concentrations at the surface, 0.5 m, and 1 m were greater than the MassDEP minimum (5 mg/L), just as they had been in 2021. DO concentrations at 1.5 m were >5 mg/L in 5 of the eight monthly samplings, including July and September and August was 4.8 mg/L at 1.5 m. This frequency at 1.5 m was an improvement from 2021. In addition, DO concentrations at 2 m were >5 mg/L in April and September and two other profiles had 2 m DO concentrations >4 mg/L. All but one 2021 DO readings at 2 m were less than 5 mg/L. DO % saturation levels showed, however, that bottom anoxia is impacting the whole water column, but stratification and atmospheric replenishment maintaining improving levels in the shallow layer.

III.B.2 Cedar Pond Water Column: Continuous Water Quality Recordings

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 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 measures 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 initial 2018 monitoring after the Management Plan approval, as well as in 2009, 2012, and 2015 as part of prior limited pond assessments.[36] In 2022, the shallow and deep continuous devices were in place throughout the year with average continuously measured depths of 1.5 m and 3.9 m, respectively. These are approximately the same sensor depths as in the 2018-2021 deployments.

Continuous 2022 temperature readings at the two sensors showed the warming of the water column during the summer and how temperature stratification was largely sustained through the summer. March readings showed that deep waters were generally warmer than shallow waters (average temperatures of 8.1°C and 6.7°C, respectively) (**Figure III-5**). Comparison of March shallow and deep temperatures showed that, on average, they were not sufficiently different to prevent mixing of water column, but salinity concentrations were sufficiently different to prevent mixing. By early April, the temperature difference was sufficient to prevent mixing; this is earlier than the profile readings, which did not show temperature stratification until the May 17 profile. Detailed review of the continuous data showed that the stratification in April went through periods of weak stratification until strong temperature stratification was consistently sustained in late April. Temperature stratification between the two sensors strengthened during the rest of the summer, peaking in early August. Temperature stratification broke down in mid-September (9/23), when the temperature difference between the two sensors was <2°C. This breakdown of temperature stratification occurred on September 30 in 2021. Salinity differences were still sufficient in mid-September to prevent complete mixing between waters at the sensor depths.

Average shallow summer 2022 temperatures were approximately the same as 2021, but deep temperatures were lower (**Table III-3**). Average shallow and deep temperatures in June/July 2022 were 23.9°C and 13°C, while June/July 2021 temperatures were 23.3°C and 14.5°C, respectively. August/September 2022 followed a similar pattern with average shallow and deep temperatures of 24.2°C and 16.2°C compared to 2021 averages of 25.0°C and 18.7°C, respectively. The cooler deep temperatures suggest that incoming tidal water was cooler in 2022.

Salinity readings were different than they were in the past with similar shallow readings, but lower deep readings. Review of the continuous data showed that shallow readings followed a similar pattern to 2021 with regular monthly peaks associated with the highest monthly tides and a gradual increase that is correlated with the gradual decrease in groundwater levels (**Figure III-6**). Groundwater levels throughout 2022 closely followed long-term (1976-2021) average monthly groundwater levels with a peak in April/May and decreasing levels throughout the summer (**Figure III-7**). Past readings have established that the regular summer increase in salinity in Cedar Pond is due to decreasing groundwater levels and associated decline in groundwater discharge to the pond.

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

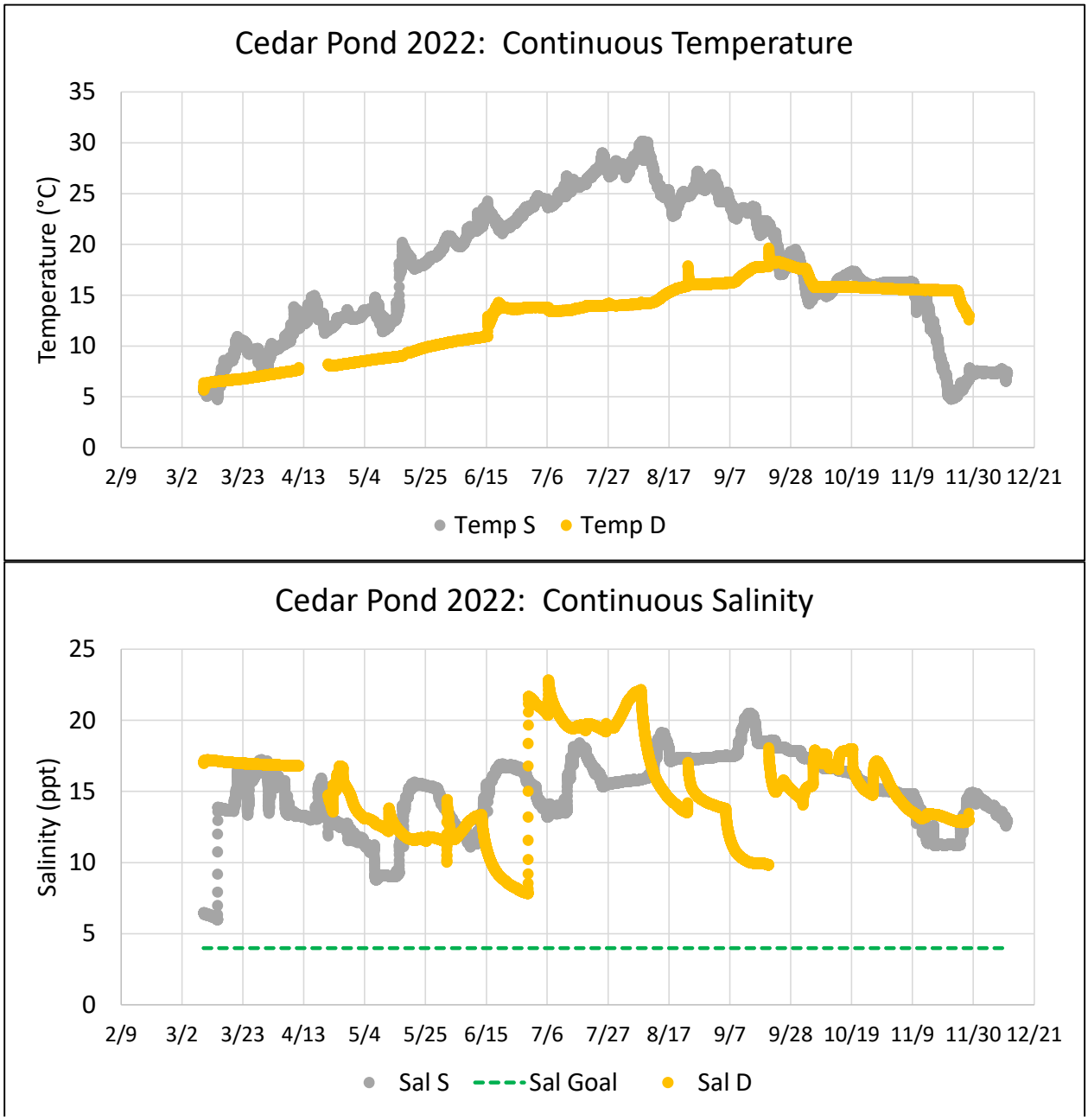


Figure III-5. Cedar Pond 2022 Continuous Temperature and Salinity Readings. Continuous recorders located in the main basin at averages depths of 1.5 m and 3.9 m recorded temperature and salinity readings every 15 minutes. Shallow and deep temperatures were sufficiently different during portions of April, all of May-August, and most of September to prevent mixing of the water column between the two depths. Shallow salinity readings were slightly higher than previous years, but followed a similar increase during the summer due to decreasing groundwater inputs. Shallow readings had regular monthly peaks that correspond to tidal peaks (*i.e.*, spring tides. Deep readings are intermittently consistent with past readings, but rapid decreases and increases (*e.g.*, >10 ppt increase over 3 days) and generally lower concentrations than profiles suggest that the deep sensor was experiencing regular temporary recording failures.

Table III-3. Summer Continuous Recording Averages in Cedar Pond (2018-2022). Temperatures varied by year and portion of the summer; shallow (S) temperatures were higher than deep (D) readings during the summer months shown and were sufficiently different in June-September to prevent mixing of the water column between the two sensor depths (*i.e.*, 1.5 m S and 3.9 m D in 2022). 2022 shallow salinity averages were higher than recent years, but deep salinity was lower and may have included incorrect concentration readings. Past monthly averages showed that D salinity was regularly higher than S salinity, but in 2022 they occasionally switched (June and September monthly average S salinity was greater than average D salinity). Summer temperature readings were sufficiently different to maintain temperature stratification (*i.e.*, isolating anoxic waters) even when salinity differences were not sufficiently different to maintain salinity stratification. Continuous 2022 DO readings continued the pattern of acceptable S DO concentrations in August/September.

Notes:

1. Water column profile 2021 DO readings and shallow samples assayed using Winkler titration had higher concentrations than those recorded by the continuous logger sensor beginning in July and attempts to reconcile/adjust the readings were not sustained throughout the rest of the 2021 dataset. June average at the S sensor was 5.45 mg/L and this is listed in the table.
2. Deep 2020 DO concentrations were limited to August readings because of sensor failure.
3. Deep 2022 salinity readings are thought to include regular, temporary recording failures that caused lower averages than readings associated with profile readings.

		Average Temperature					Average Salinity					Average Dissolved Oxygen				
		2018	2019	2020	2021	2022	2018	2019	2020	2021	2022	2018	2019	2020	2021	2022
	Depth	°C	°C	°C	°C	°C	ppt	ppt	ppt	ppt	ppt	mg/L	mg/L	mg/L	mg/L	mg/L
June to July	S	23.4	21.1	24.3	23.3	23.9	19.5	12.1	12.5	11.6	15.1	4.3	0.4	2.6	5.4[1]	1.5
	D	18.0	13.2	16.2	14.5	13.0	21.8	15.4	18.2	17.9	15.6[3]	0.1	0.1	0.0	0.0	0.0
Aug to Sept	S	24.7	23.3	23.4	25.0	24.2	19.9	15.9	14.6	15.2	17.6	0.8	6.3	5.4	-[1]	5.3
	D	20.1	18.1	18.6	18.7	16.2	22.4	17.8	20.2	20.4	14.7[3]	0.2	0.2	0.0[2]	0.1	0.0

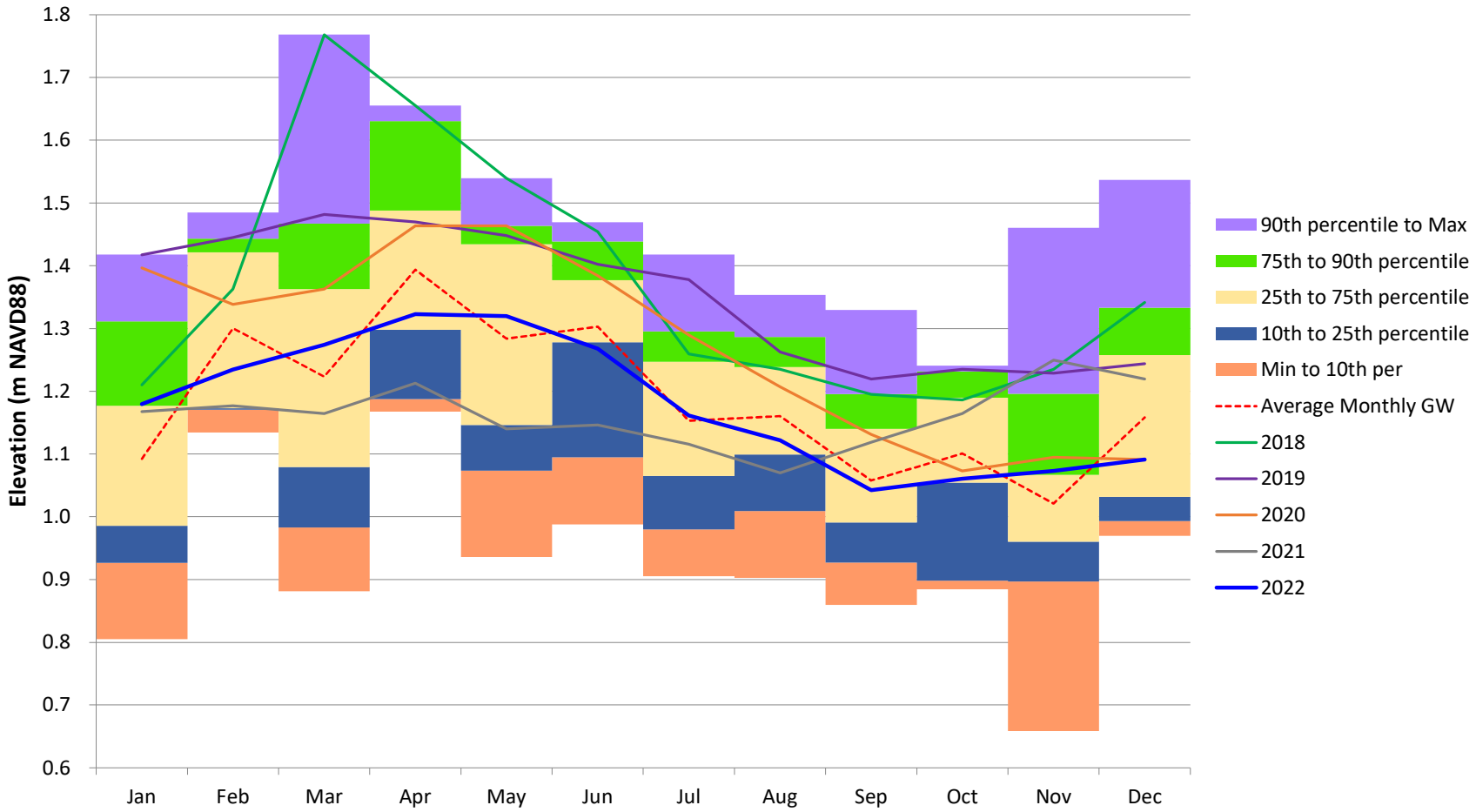


Figure III-6. Orleans Groundwater Elevations (OSW-22). Groundwater levels in Orleans during 2022 were generally within the 25th to 75th percentile range; either slightly above or below monthly averages based on readings from 1976-2021. 2022 groundwater levels were higher than in 2021 levels from January through August, but were much lower than 2021 from September through December. Water levels in 2018, 2019 and most of 2020 were above average and tended to be greater than the 75th percentile of historic water levels. Data source: nwis.waterdata.usgs.gov/nwis/gwlevels?.

Deep 2022 salinity readings were different than past years and close review of the data suggests that the sensor may have been experiencing intermittent problems. Past years generally had deep salinity readings that were higher than shallow readings throughout the year with highest concentrations in late summer (see **Table III-3**). Deep 2022 salinity readings in March and April were generally 2-4 ppt higher than shallow readings, which would be consistent with past readings and the higher shallow salinity readings. But in May, deep salinity concentrations decreased throughout the month and were lower than shallow readings from approximately May 18 through the rest of the month (see **Figure III-5**). Deep salinity continued to decrease through the end of June and then rapidly increased to greater than 20 ppt. This higher concentration was maintained until early August, but then the level began to decrease again. This decreasing level reached approximately 10 ppt on September 20 and then jumped up to approximately 18 ppt on the same day. These decreases and rapid, one day changes in readings are inconsistent with a variety of factors, including tidal changes, staff downloading data, groundwater changes, and individual profile readings and water quality results. This review suggests that the deep salinity sensor was experiencing intermittent recording issues.

Review of shallow salinity readings showed that while 2022 readings increased, just as they had in 2018-2021, the rate of increase was reduced in 2022. Readings in 2018-2021 showed that the lowering of the boards and reduced groundwater inputs regularly caused shallow salinities to increase throughout the summer (**Figure III-7)**. Review of the 2018-2021 rate increases showed that they were similar: 0.06 to 0.09 ppt per day.[37] However, in 2022, the rate of increase was lower (0.04 ppt per day). This decrease appears to be due to higher starting level in May; the late summer maximum largely matched previous maximums during 2018-2021. As noted in Table III-1, the boards were left at a higher elevation after May 15. This change was based on the 2021 review that showed that the higher elevation still allowed adequate water levels for fish passage during the summer. Based on 2022 conditions, the higher board elevation during the summer did reduce the rate of shallow salinity increase, but the conditions in 2022 favored a higher starting point salinity level in the spring, so assessing the impact of the configuration and timing of higher board levels would require addition years of data collection to assess the variability and impact during different starting conditions and groundwater elevations.

Continuous DO readings showed that the shallow (1.5 m) readings varied by month, but deep (3.9 m) readings were consistently anoxic (**Figure III-8**). In March, shallow DO readings were generally greater than the MassDEP minimum (*i.e.*, 6 mg/L) and none of the readings were anoxic (*i.e.*, <1 mg/L), but in each subsequent month, the percentage of shallow readings <6 mg/L increased: 34% in April, 68% in May, and 100% in June. June also saw the peak of shallow anoxic readings; 69% of June shallow readings were anoxic. After June, the percentage of shallow DO readings <6 mg/L improved to approximately 55%, which was similar to the monthly percentages in September, October, and November. It is noteworthy, however, that DO concentrations in September and October were higher due to phytoplankton photosynthesis: 13% and 17% of the respective readings during these months were greater than 110% saturation. Average shallow DO from 26,135 readings between March and December 2022 was 4.5 mg/L, while the deep average was 0.04 mg/L.

[37] Eichner, E., B. Howes, and D. Schlezinger. 2022. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2021 to December 2021.

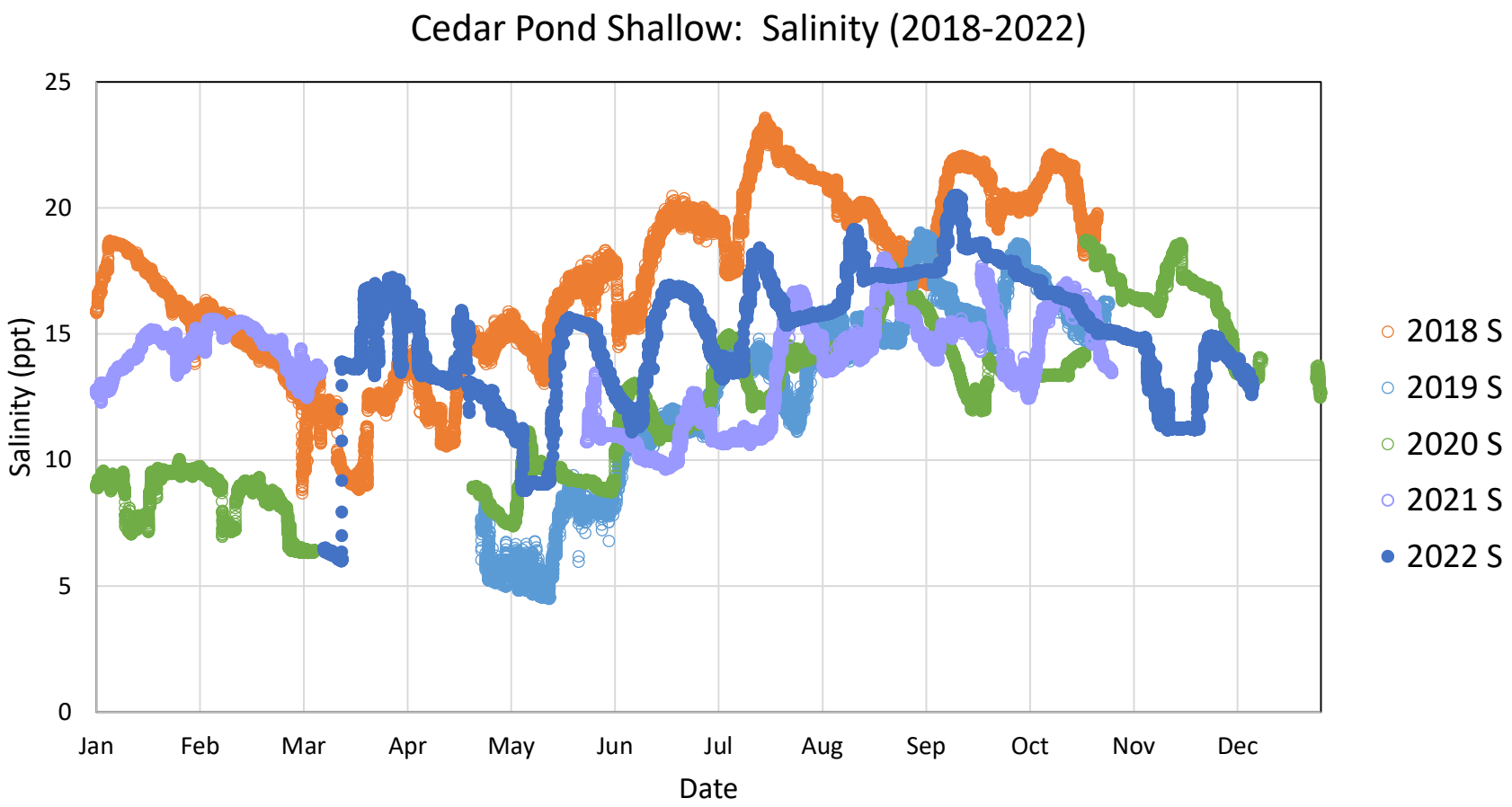


Figure III-7. Continuous Shallow Salinity at Cedar Pond (2018 – 2022). Review of shallow salinity readings showed that while 2022 readings increased, just as they had in 2018-2021, the rate of increase was reduced in 2022. In 2018-2021 lowering of the outlet boards and reduced groundwater inputs regularly caused shallow salinities to increase throughout the summer. Salinity rate increases were in a similar range between May and September during 2018-2021: 0.06 to 0.09 ppt per day. In 2022, however, the rate of increase was lower (0.04 ppt per day) partially due to the higher levels during 2022. Because of the higher levels, the decrease in the rate also did not decrease the late summer shallow salinity maximum, which was approximately the same as the previous years. It also continues to suggest that alternative board configurations should be explored in order to attain the lower salinity levels recommended to improve water quality and establish a herring run.

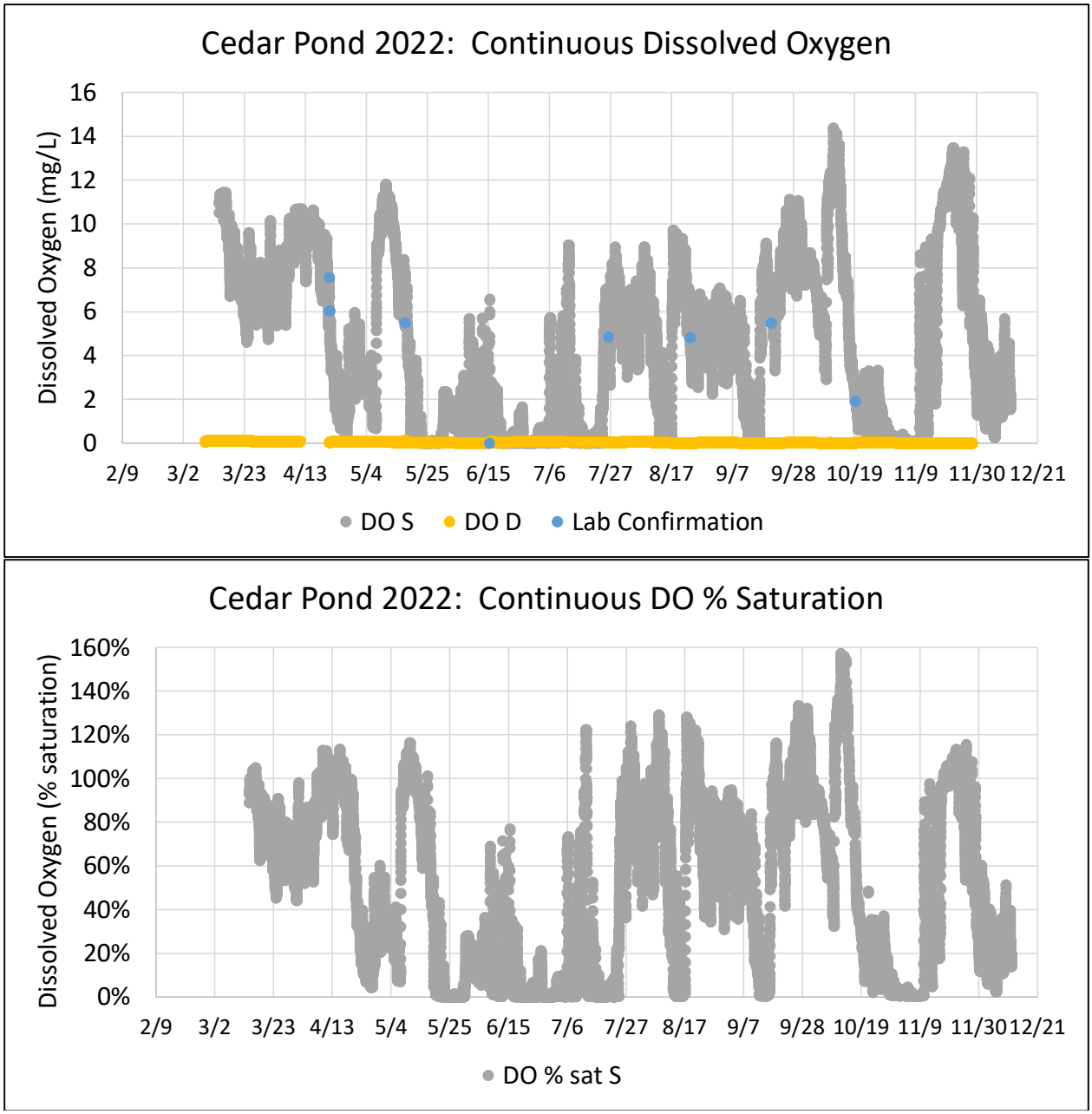


Figure III-8. Cedar Pond 2022 Continuous Dissolved Oxygen and % Saturation Readings. Continuous recorders located in the main basin at averages depths of 1.5 m and 3.9 m recorded dissolved oxygen readings every 15 minutes. Shallow readings varied by month, but deep readings were consistently anoxic (*i.e.*, <1 mg/L; top graph). In March, shallow DO readings were generally greater than the MassDEP regulatory minimum (*i.e.*, 6 mg/L) and none of the readings were anoxic, but in each subsequent month, the percentage of shallow readings <6 mg/L increased: 34% in April, 68% in May, and 100% in June. June also saw the peak of shallow anoxic readings (69%). After June, the percentage of shallow DO readings <6 mg/L improved to approximately 55%, , which was similar to the monthly percentages in September, October, and November. It is noteworthy, however, that DO concentrations in September and October were elevated due to phytoplankton photosynthesis: 13% and 17% of the respective readings during these months were greater than 110% saturation (bottom graph).

Continuous chlorophyll readings showed that there was a phytoplankton bloom that began in April and peaked in May, but nutrient levels were high enough to sustain high chlorophyll concentrations through September with reduced, but still elevated concentrations in October through December (**Figure III-9**). Shallow chlorophyll readings averaged 0.6 µg/L in March, but deep readings averaged 12.1 µg/L suggesting that phytoplankton may have been controlling their buoyance to utilize the higher nutrient levels in the mid-water column. In April, the shallow average increased to 20.2 µg/L, while the deep average remained elevated at 11.2 µg/L. The shallow average monthly reading peaked at 59.1 µg/L in May, decreased slightly to 40.3 µg/L in June, and then averaged 11 µg/L, 15.4 µg/L, and 21.8 µg/L in July, August, and September, respectively. The deep sensor did not record readings in May-July, while average monthly readings in August through November were 0.8 to 1.0 µg/L. The high early season chlorophyll readings suggest that the shallow DO readings may have been supported by extensive photosynthesis. The pattern of readings also suggest that further evaluation of phytoplankton species is warranted to better understand the phytoplankton population, how it changes throughout the summer, and its preferred nutrient sources.

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

Water quality samples were collected in tandem with the 2022 water column profile readings. 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 average depths of the continuous recorders: 1.5 m and 3.9 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 all monitoring/reporting for implementation of the Cedar Pond Management Plan. Sampling procedures and chemical assay methods are presented in the Town's QAPPs for freshwater[38] and estuarine[39] water quality monitoring. Samples were analyzed at the laboratory for the following constituents: salinity, ortho-phosphorus, total phosphorus (TP), ammonia-nitrogen, nitrate+nitrite-nitrogen (NOx), dissolved organic nitrogen (DON), particulate organic nitrogen (PON), particulate organic carbon (POC), chlorophyll-*a*, pheophytin-*a*, and specific conductivity.

Water quality samples in 2022 generally showed that shallow (0.15 m) and middle (1.5 m) depths had similar concentrations of various constituents (*i.e.*, no significant differences in 2022 averages). Both shallow and middle depth averages were significantly lower ($\rho>0.05$, T test) than deep (3.5 m) averages for salinity, specific conductivity, ortho-phosphorus, TP, ammonia-nitrogen, chlorophyll-a, and total nitrogen (TN). No significant differences between average concentrations at various depths were measured of NOx, DON, POC, PON, or pheophytin-a. All 2022 TN and TP concentrations showed that Cedar Pond continues to have excessive nutrients (**Figure III-10**), as it was in all four previous annual assessments (2018-2021).

The controlling nutrients, however, changed throughout 2022. Annual average N:P ratios at all depths showed the pond water quality was controlled by P, but these averages were skewed by exceptionally high early 2022 TN concentrations. In March, N:P ratios at all three depths exceeded 90, which is higher than is generally found in freshwater ponds. By June,

[38] 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.

[39] 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.

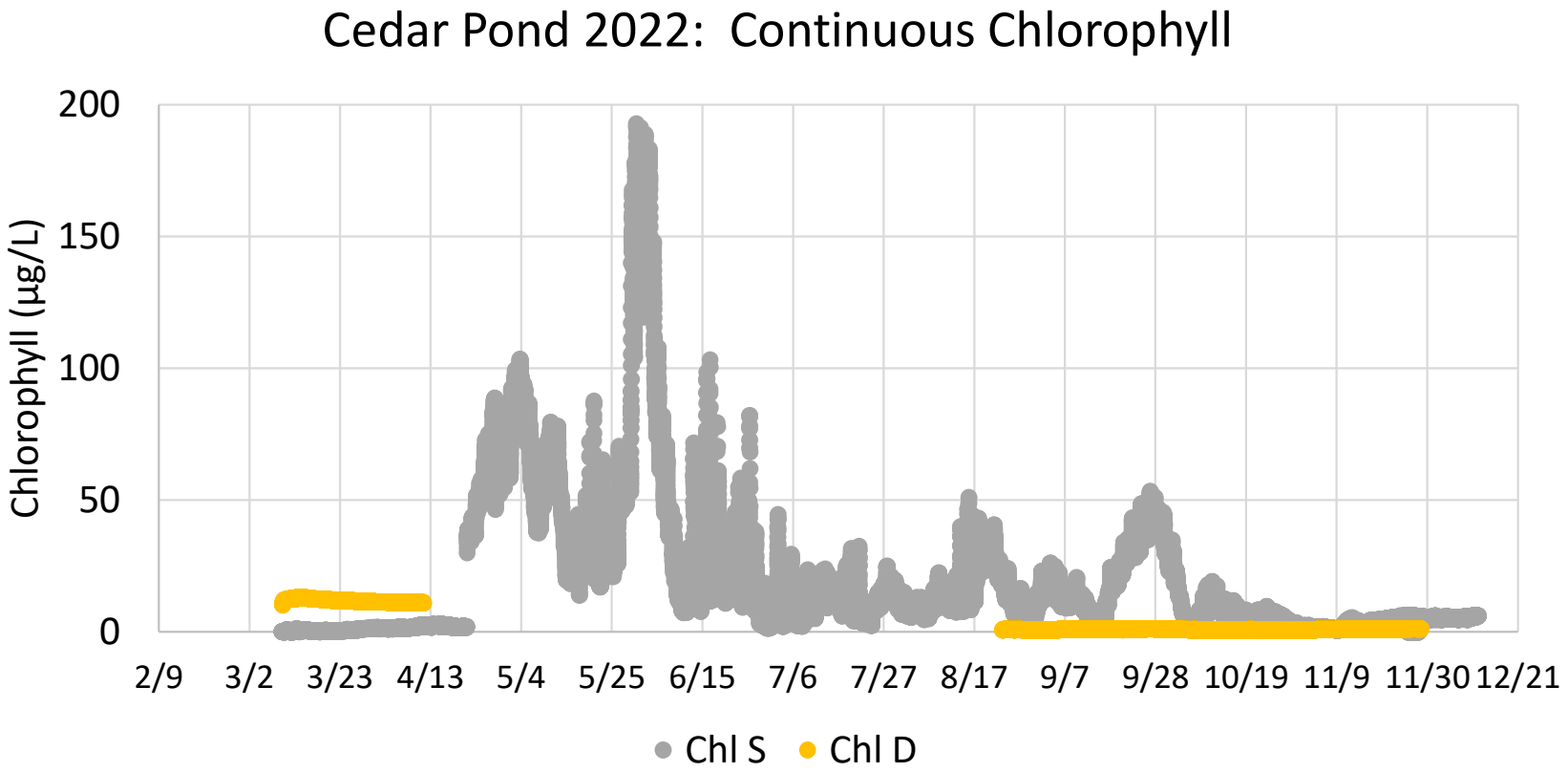


Figure III-9. Cedar Pond 2022 Continuous Chlorophyll Readings. Continuous recorders were located in the main basin at averages depths of 1.5 m and 3.9 m recorded chlorophyll readings every 15 minutes. Shallow readings were elevated from April through December with peak monthly average in May (59.1 µg/L). After the May peak, shallow average monthly reading decreased slightly to 40.3 µg/L in June, and 11 µg/L, 15.4 µg/L, and 21.8 µg/L in July, August, and September, respectively. Average monthly shallow readings were greater than estuarine thresholds associated with healthy ecosystems (*e.g.*, <4 µg/L) in every month except March and November. Deep monthly averages in March and April were greater than a 4 µg/L threshold and suggest that phytoplankton may have been controlling their buoyance to utilize the higher nutrient levels in the mid-water column. The deep sensor did not record readings in May-July, while average monthly readings in August through November were 0.8 to 1.0 µg/L. The high early season chlorophyll readings suggest that the shallow DO readings may have been supported by extensive photosynthesis.

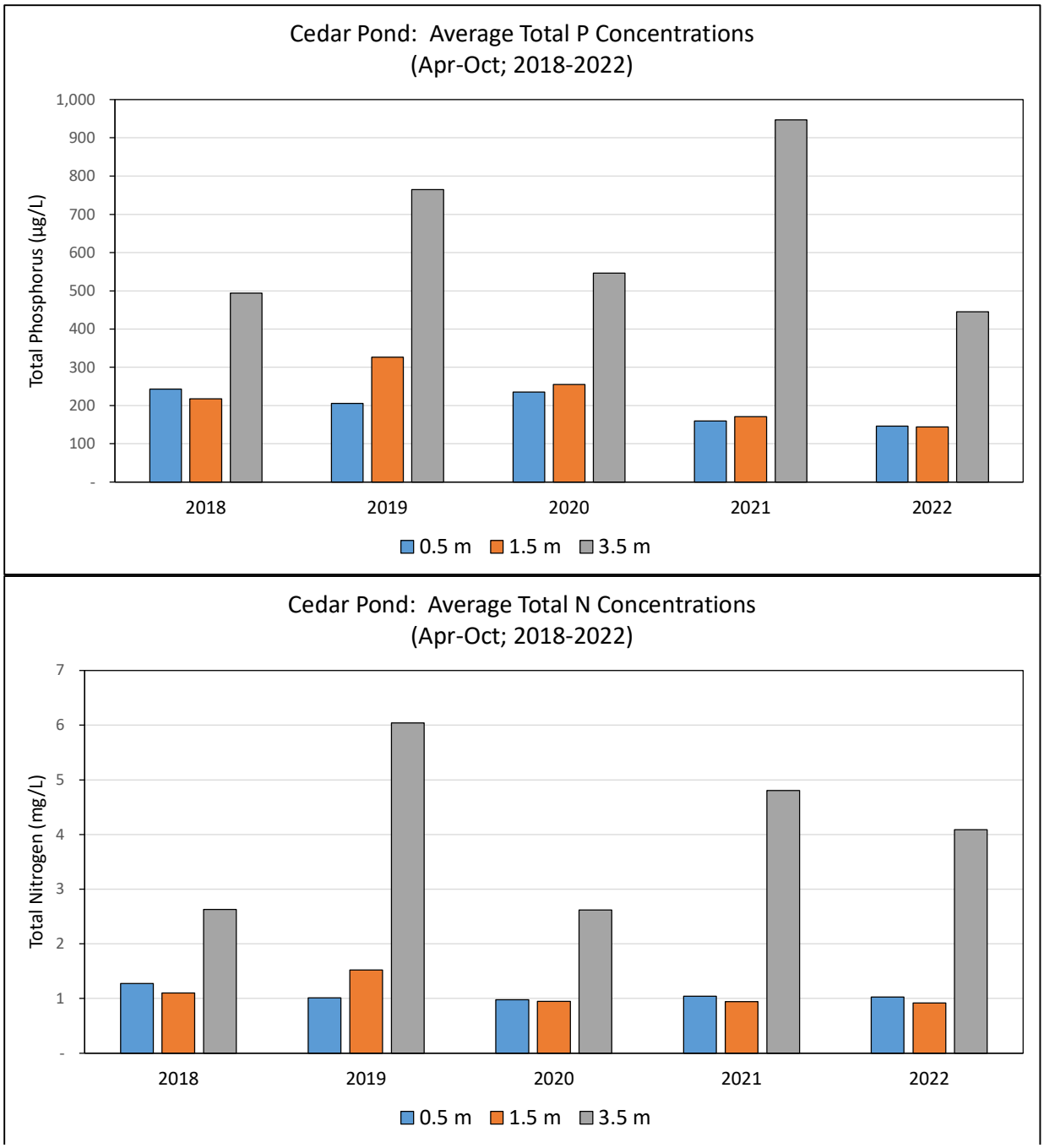


Figure III-10. Comparison of Average Water Column Total Phosphorus and Total Nitrogen in Cedar Pond (2018-2022). Average shallower TN concentrations have largely remained the same throughout the years, while average TP concentrations have decreased. Average shallow (0.15/0.5 m and 1.5 m) TP concentrations ranged between 206 µg/L and 326 µg/L in 2018-2020, were <171 µg/L in 2021 and 2022 TP concentrations at 0.15 m and 1.5 m averaged 146 µg/L and 144 µg/L, respectively. Shallower TN levels, on the other hand have remained relatively stable throughout the years. Average 0.15 m/0.5 m TN concentrations varied between 0.98 mg/L and 1.04 mg/L in 2019-2022 with a slightly higher average in 2018 (1.27 mg/L TN). Average 1.5 m TN concentrations averaged between 0.91 mg/L and 0.95 mg/L in 2020-2022 with slightly higher concentrations in 2018 and 2019. Both deep TN and TP levels have fluctuated significantly over the years.

ratios at 0.15 m and 1.5 m had decreased to approximately 16 (the Redfield ratio and the dividing line between nitrogen and phosphorus control) and decreased further throughout the rest of monitoring period making the pond more gradually more sensitive to nitrogen inputs (**Figure III-11**). It is unclear what sort of impact these relatively rapid changes in nutrient availability might have on the phytoplankton population.

The exceptionally high N:P ratios in March were largely due to exceptionally high DON levels at that time. DON is typically urea and amino acids excreted by zooplankton and various types of benthic infauna. This type of early DON release has not been measured before in Cedar Pond and was also confirmed in the stream outflow readings. It is unclear why this spring DON release occurred, but the water column data suggest it may be due to benthic infauna changes given that phytoplankton levels were low; spring infauna typically have highest densities and populations and perhaps improved water quality conditions have been sustained for long enough in the upper portions of the water column and the sediments they overlay that early season infauna populations dynamics have also shifted to deeper burrowing species that are aerating and altering sediment nutrient dynamics.[40] Sediment and benthic infauna assessments would be required to help clarify what sort of changes are occurring.

Review of the TN and TP concentrations showed the impact of sustained anoxia in the deep sediments, as well as the benefits of the on-going salinity stratification, which kept exceptionally high nutrient levels largely trapped in the deep layer. Shallow (0.15 m and 1.5 m) TN concentrations were extremely high in March, largely driven by the DON levels, but were generally consistently around 1 mg/L throughout the rest of the monitoring period (**Figure III-12**). Deep (3.5 m) TN concentrations were 3-6 mg/L throughout most of 2022 with variations likely reflecting varying depths of sediment exposure to anoxia. Shallow TP concentrations were high throughout 2022 and gradually increased from ~60 µg/L in March and April to 180-190 µg/L in July and this level was sustained throughout the rest of the year. Deep TP concentrations were even higher (~250 µg/L to 450 µg/L), increased to 503 µg/L in September and 607 µg/L in October. These deep TP concentrations had a statistically significant increasing trend ($\rho<0.05$) between March and October. This result suggests an on-going supply of sediment TP released by anaerobic processes given the sustained anoxia in the deep layer (see **Figures III-4 and III-8**).

Comparison of historical TN and TP concentrations show that average shallower TN concentrations have largely remained the same, while average shallow TP concentrations have decreased in recent years. Average shallow (0.15/0.5 m and 1.5 m) TP concentrations, excluding the exceptional March readings, ranged between 206 µg/L and 326 µg/L in 2018-2020, but averages have been less than 171 µg/L in 2021 and 2022 TP concentrations at 0.15 m and 1.5 m averaging 146 µg/L and 144 µg/L, respectively (see **Figure III-9**). These shallow decreases are likely due to less mixing of the entire water column due to stronger stratification and, thus less high TP deep waters mixed into the upper water column. Stronger stratification would tend to keep high TP concentrations in the deeper layer. In addition, the increasingly higher DO levels in the upper layer over the years would cause precipitation of most ortho-P reaching the upper layer and reduce TP levels. Shallower TN levels, on the other hand have remained relatively stable throughout the years. Average 0.15 m/0.5 m TN concentrations varied between 0.98 mg/L and 1.04 mg/L in 2019-2022 with a slightly higher average in 2018 (1.27 mg/L TN). Average

[40] This type of transition has been noted in Lonnie's Pond where the predominant benthic population has shifted from polychaetes to amphipods.

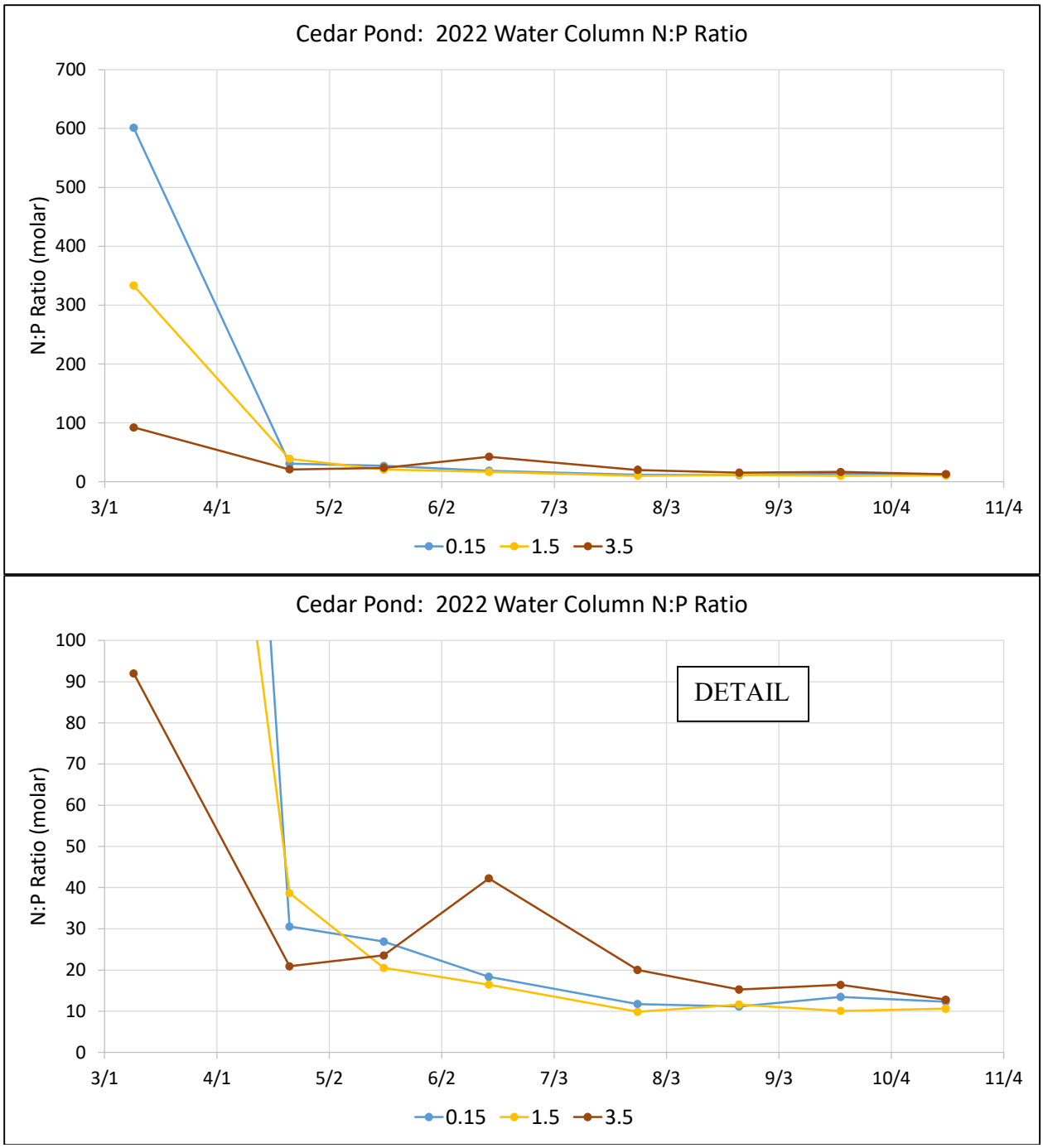


Figure III-11. Cedar Pond 2022 Water Column N to P ratios. In March, N:P ratios at all three depths exceeded 90, which is higher than is generally found in freshwater ponds (upper graph) and indicates pond water quality was controlled by phosphorus. However, by April, N:P ratios had decreased to likely control of water quality by both N and P and decreased further to N control in subsequent months. The March conditions were largely driven by exceptionally high early 2022 DON concentrations. The high DON in the spring, which has not occurred 2018-2021, was likely due to an as yet undetermined change in sediment dynamics, perhaps improvements in the benthic animal population composition. The initial P sensitivity and a gradual return to N sensitivity likely altered the phytoplankton community composition significantly throughout the year.

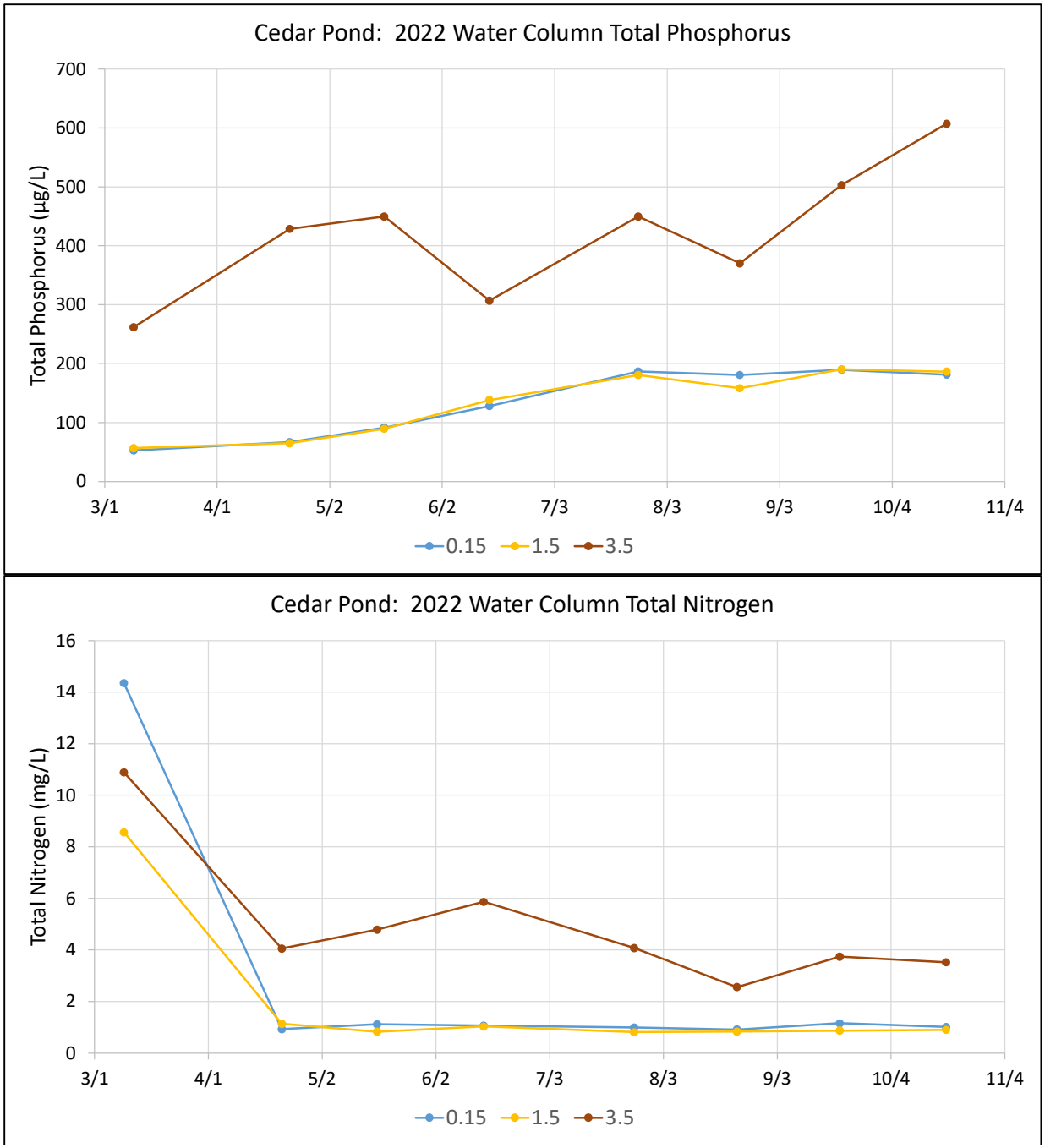


Figure III-12. Cedar Pond 2022 Water Column Total Phosphorus and Total Nitrogen Concentrations. TN concentrations were extremely high in March, largely driven by the DON levels, but were generally consistently around 1 mg/L at 0.15 m and 1.5 m throughout the rest of the 2022 monitoring period. Deep (3.5 m) TN concentrations were 3-6 mg/L reflecting sediment release. Shallow TP concentrations (0.15 m and 1.5 m) were high throughout 2022 and gradually increased from ~60 µg/L in March to 180-190 in July and were level throughout the rest of the year. Deep TP concentrations were even higher (~250 µg/L to 450 µg/L), consistent with the on-going anoxia in the deep layer and increased to 503 µg/L in September and 607 µg/L in October.

1.5 m TN concentrations averaged between 0.91 mg/L and 0.95 mg/L in 2020-2022 with slightly higher concentrations in 2018 and 2019. These decreases in later years are consistent with increasingly stronger stratification and a deeper stratification depth (>1.5 m). Perhaps the stability of shallow TN concentrations is due to a greater influence of watershed inputs on water column TN levels as the warmer upper layer is more stable; watershed inputs would tend to be very stable given mixing within the aquifer, especially at the pond interface.

Both deep TN and TP levels have fluctuated significantly over the years. These fluctuations are likely due to the regular changes in stratification, both the depth of stratification and its strength, as well as how the sediments may be changing with less carbon deposition as more of the available nutrient pool remains in the sediments and, perhaps, as in 2022, are occasionally exported via the stream. Deep average TN concentrations have ranged from 2.62 mg/L to 6.04 mg/L in 2018-2022.

Overall, chlorophyll-a levels were high throughout 2022 (**Figure III-13**). Chlorophyll and pheophytin concentrations suggest there was a phytoplankton bloom in the spring, but diminished populations in July through October. Shallow and deep chlorophyll-a concentrations were approximately 6-11 µg/L in March. The chlorophyll-a concentration at 1.5 m increased to ~26 µg/L in April, likely driven by phytoplankton utilizing the high TP concentrations in the deep waters. At that time, N:P ratios were >2X the Redfield ratio suggesting that species in the phytoplankton population that grew best on greater phosphorus availability would have been favored. Another sign of P limitations at that time was a peak in NOx concentrations. In May, deep pheophytin concentrations increased significantly suggesting a large phytoplankton die-off perhaps due to the change P availability (**Figure III-14**), although N:P ratios were still in the 21-27 range. Shallower chlorophyll-a concentrations remained relatively high in June, but then decreased significantly to <8 µg/L in July, before increasing to ~10 µg/L in August, and ~15 µg/L in September. Deep chlorophyll-a concentrations increased in June and July suggesting active growth in the upper portions of the water column, but also rapid senescence. Overall, these patterns suggest shifting phytoplankton species and, perhaps, other factors, such as zooplankton, fish or clams altering phytoplankton populations.

Comparison of 2022 chlorophyll-a levels to 2020 and 2021 show a significantly different pattern and generally lower concentrations. In 2020, chlorophyll-a concentrations in the shallower samples (0.5 m and 1.5 m) were <10 µg/L into July, then peaked over 50 µg/L in late August (**Figure III-15**). In 2021, shallow (0.5 m) concentrations peaked in October at >300 µg/L, while 1.5 m concentrations peaked in September at >100 µg/L. These peak concentrations in 2020 and 2021 generally matched up with the lowest N:P ratios (*i.e.*, where N was the primary driver for water quality conditions). As mentioned, in 2022, the highest shallower chlorophyll-a concentrations occurred in April, May, and June at levels <27 µg/L (see Figure III-13) and during periods when N:P ratios were highest and P was the primary driver for water quality conditions. Collectively, this appears to show an improvement in shallow water quality conditions, but the change in the N:P ratios and its potential impact should continue to be monitored.

Salinity concentrations in 2022 generally followed the same patterns seen in 2021. The salinity pattern seems to reflect the impact of the board notch addition and decreasing freshwater inputs

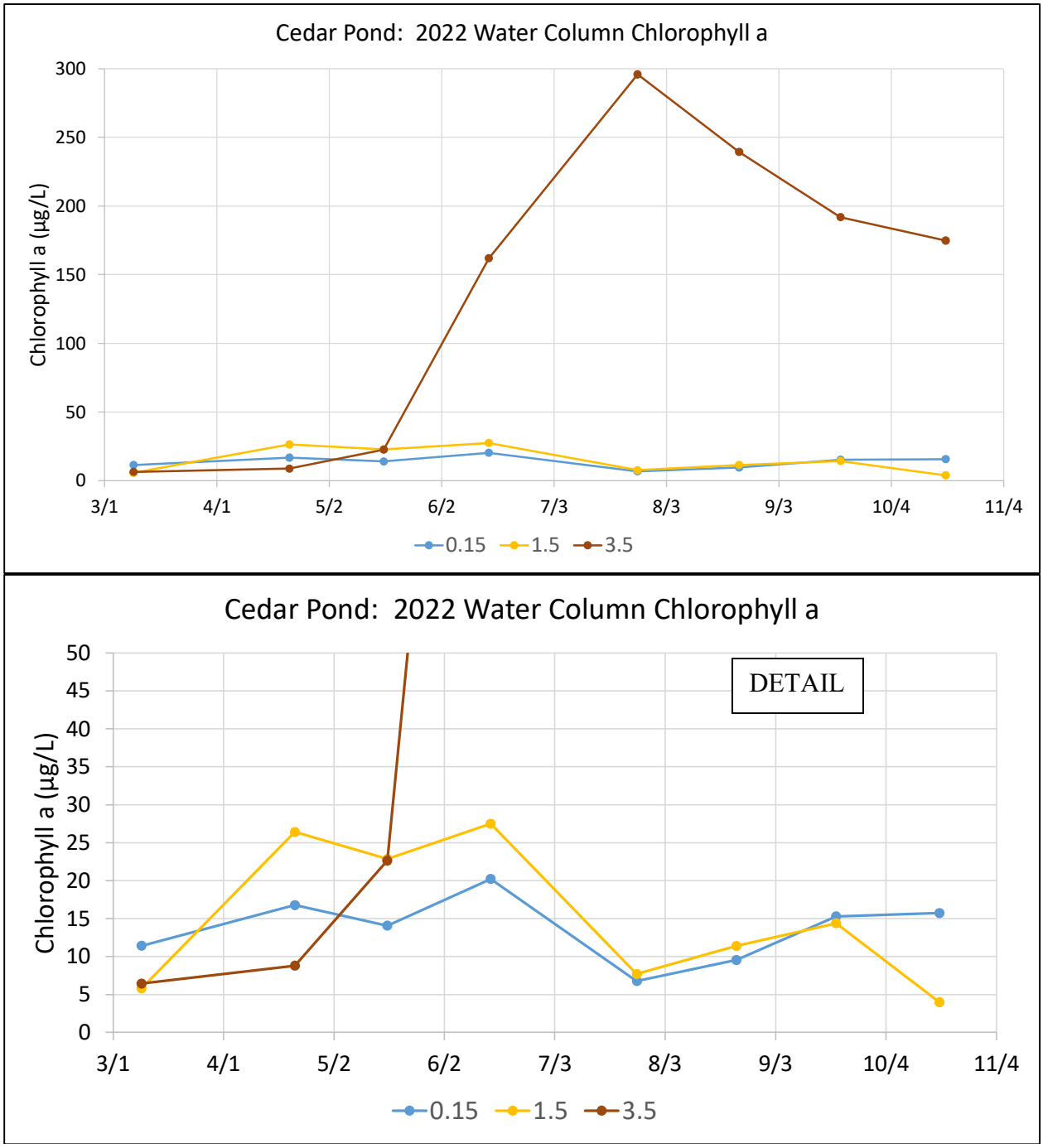


Figure III-13. Cedar Pond 2022 Water Column Chlorophyll-*a* Concentrations. Chlorophyll-a levels were high throughout 2022; shallow and deep chlorophyll-a concentrations were approximately 6-11 µg/L in March and the concentration at 1.5 m increased to ~26 µg/L in April. In May, deep chlorophyll-a (and pheophytin) concentrations increased significantly suggesting a large phytoplankton die-off. Shallower chlorophyll-a concentrations remained relatively high in June, but then decreased significantly to <8 µg/L in July, before increasing to ~10 µg/L in August, and ~15 µg/L in September. Deep chlorophyll-a concentrations increased in June and July suggesting active growth, but also rapid senescence. These patterns combined with shifting N:P ratios suggest shifting phytoplankton species and, perhaps, other factors, such as fish or clams altering phytoplankton populations.

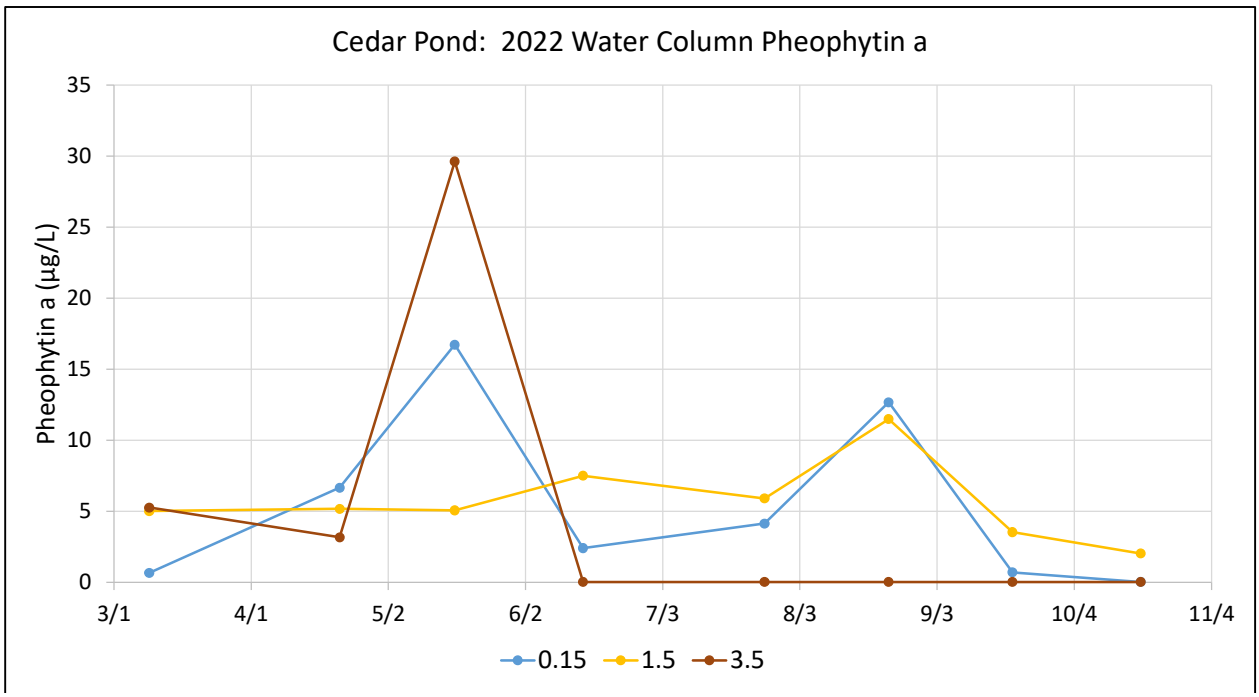
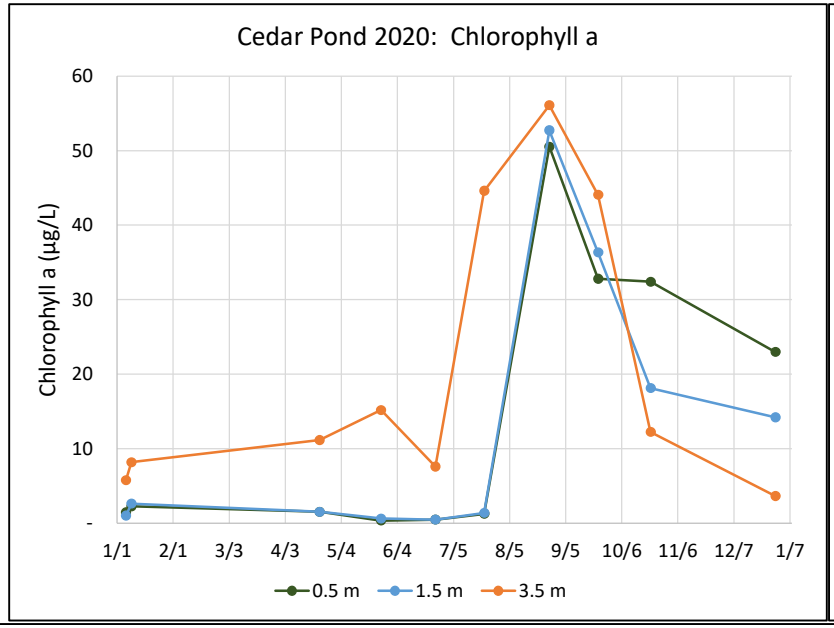
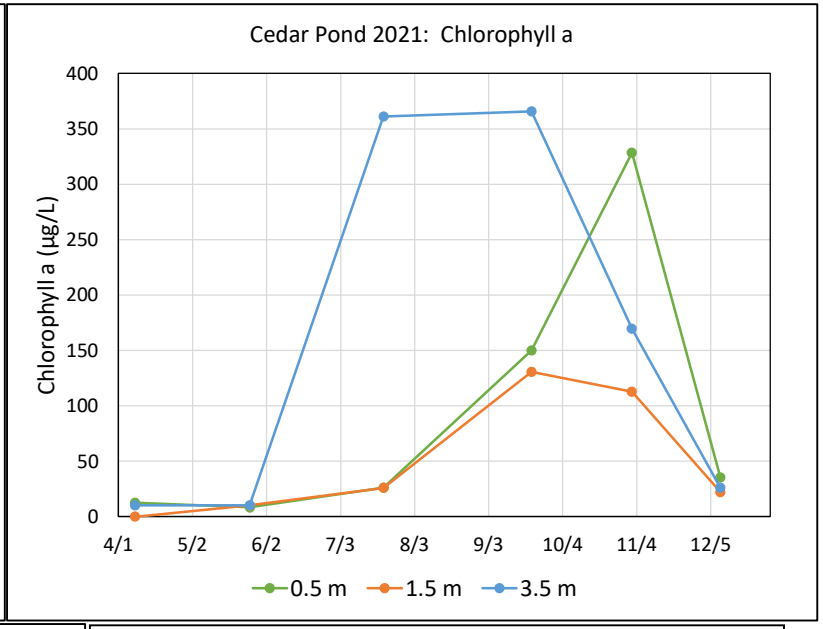


Figure III-14. Cedar Pond 2022 Water Column Pheophytin-*a* Concentrations. Pheophytin concentrations suggest a phytoplankton bloom just prior to May 17 and another just prior to August 23. Extremely low 3.5 m pheophytin-a concentrations in June and subsequent months suggest that the large concentrations of available phytoplankton seen in the deep chlorophyll-a concentrations were not degraded significantly before sediment deposition.





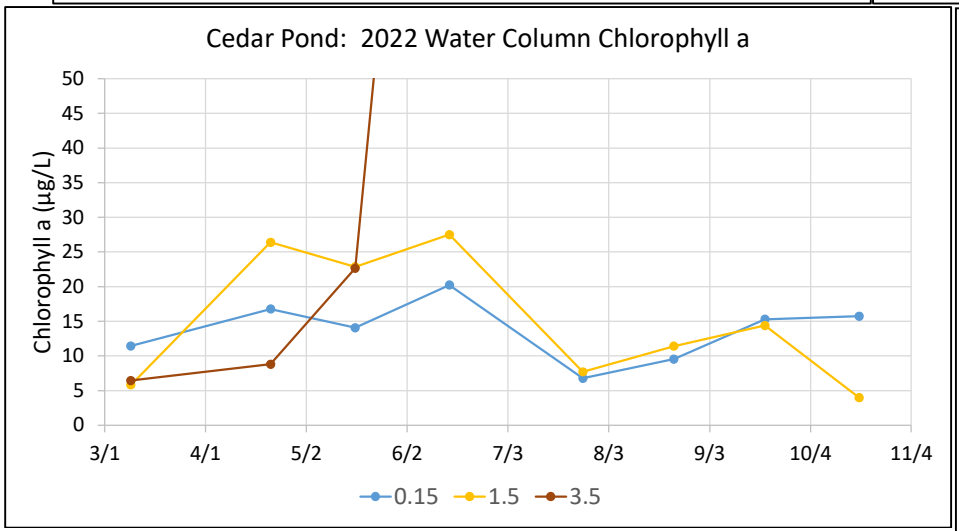


Figure III-15. Cedar Pond 2020, 2021, and 2022 Shallow Water Column Chlorophyll-*a* Concentrations. Shallow 2022 chlorophyll-a concentrations had a lower peak concentration and the peak occurred earlier in the year than in 2020 or 2021. Peaks in 2020 and 2021 tended to occur when N:P ratios were lowest (*i.e.*, N controlling water quality conditions), while the peaks in 2022 occurred when N:P ratios were highest (*i.e.*, P controlling water quality conditions). These changes in 2022 were generally accompanied by additional improvements in shallow water quality conditions compared to previous years, but these changes should continue to be monitored.

as the summer precipitation and groundwater levels decrease (**Figure III-16**). Since the outlet notch was only present from March 15 to May 15 (see **Table III-1**), the measurements suggest that much of the increase in summer salinity is likely due to the seasonal decrease in groundwater discharge. As noted in **Figure III-6**, Orleans 2022 groundwater levels peaked in April/May and then decreased through September. Initial shallow (0.15 m and 1.5 m) water column salinity on March 9 was 8 ppt, 2X the upper end of the management target range. The notch at the boards was added on March 15, but 0.15 m salinity remained at 8 ppt through May 17, suggesting fresher water floating to the top of the water column. Salinity at 1.5 m was the same as 0.15 m in April, but increased to 10.1 ppt on May 17, increased to 11.1 ppt on June 15 and then was approximately the same as the 0.15 m readings through September. Review of the stratification data shows that on May 17 there was temperature stratification starting at 1 m and salinity stratification starting at 1.5 m. These layering data suggest the initial rise in salinity at 1.5 m was also related to the stratification depth and whether water at 1.5 m was mixing with the shallower, lower salinity layer or a deeper, higher salinity layer. The rise in salinity seen in the shallow layer during the rest of 2022 mirrors the decrease in groundwater levels seen through September. Salinity levels even decreased slightly in October when groundwater levels began to increase.

Collectively, these 2022 salinity measurements and the limited changes in the board elevations suggest that salinity in Cedar Pond will naturally vary seasonally mostly based on groundwater changes as long as the current board configuration is maintained. Average groundwater conditions in 2022 produced shallow salinity of 8 ppt in the spring, but salinity concentrations of 15 ppt in the fall (see **Figure III-16)**. In 2019 when spring groundwater levels were between the 75^{th} and 90^{th} percentile, spring shallow salinity readings were 5 to 7 ppt. Deep salinity will continue to be higher as it reflects incoming tidal water that regularly sinks to the bottom of Cedar Pond (hence the higher salinity in the deep samples). Keeping this higher salinity water in the bottom and continuing to support salinity stratification is important for maintaining improved shallow water quality conditions. The salinity data also suggests that the only way to further reduce water column salinity levels is further restrict tidal inflows at the inlet.

Overall, 2022 water column water quality data continued to show impaired conditions in Cedar Pond which varied with fluctuations mostly in natural conditions, but also showed some notable changes, including some suggesting improvements in sediment characteristics. Shallower TN concentrations have remained relatively stable, while TP concentrations have decreased. N:P ratios showed that early 2022 had phosphorus controlling water quality conditions, but this shifted to nitrogen in most of the summer. Phytoplankton populations were likely impacted by these changes. Deep conditions continue to be more impaired than shallow conditions, but salinity stratification is important for sustaining improved shallow conditions by isolating the more impaired deep conditions.

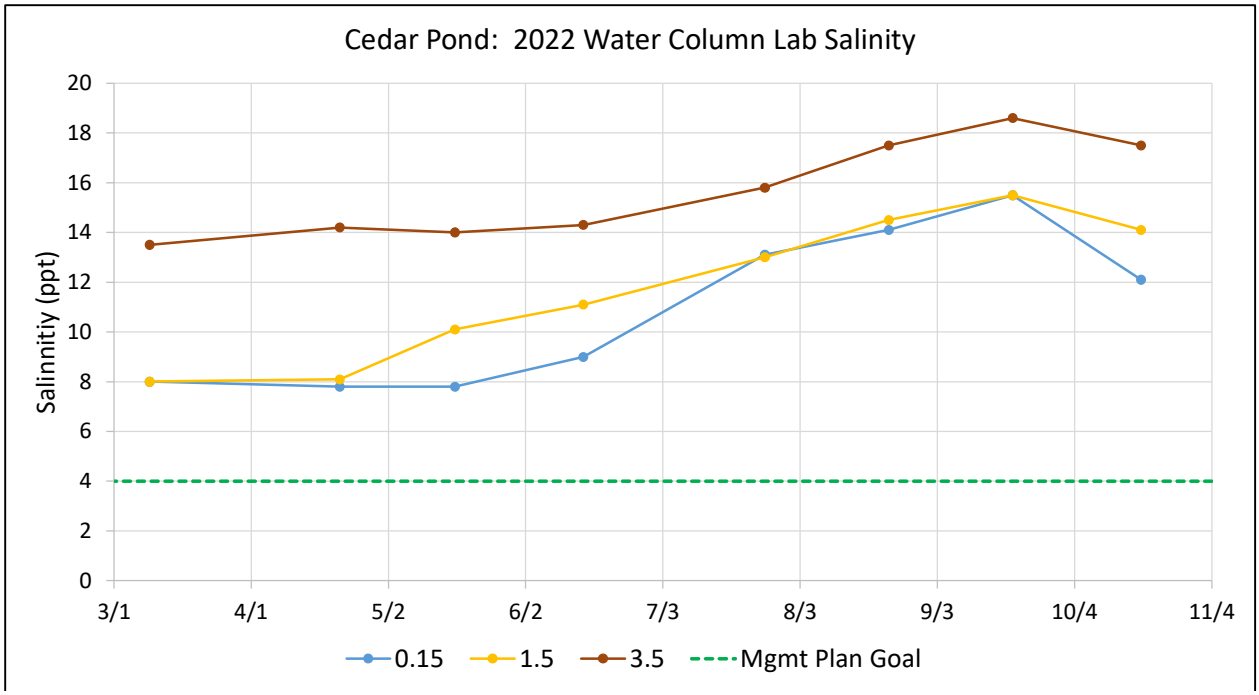


Figure III-16. Cedar Pond 2022 Water Column Lab Salinity Concentrations. Initial 2022 shallow (0.15 m and 1.5 m) water column salinity on March 9 was 8 ppt, 2X the upper end of the management target range. The notch at the boards at the pond outlet was added on March 15, but 0.15 m salinity remained at 8 ppt through May 17. Salinity at 1.5 m was the same as 0.15 m in April, but increased to 10.1 ppt on May 17, increased to 11.1 ppt on June 15 and then was approximately the same as the 0.15 m readings through September. Review of the timing of changes in salinity concentrations suggest that these readings mostly reflect changes in groundwater levels and water column stratification. The rise in salinity seen in the shallower readings after May generally mirrors decreases in groundwater levels seen through September. Salinity levels even decreased slightly in October when groundwater levels began to increase.

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

Streamflow has been measured in Cedar Pond Creek at the same location continuously since November 2017 (*i.e.*, just north of Route 6; see **Figure I-1**). This is the same location used during: a) the 2003-2004 streamflow measurements for the MEP assessment of Rock Harbor,[41] b) for 2012 streamflow measurements for the development of the Cedar Pond Management Plan,[42] and c) throughout 2018,[43] 2019,[44] 2020,[45] 2021,[46] and also 2022. In addition to the continuous readings, low tide instantaneous flow readings and water quality samples were collected 20 times during 2022, generally every two weeks. Collecting the data both continuously and at regular intervals, at the same location, and using the same measurement methods has allowed data from the various time periods to be directly comparable and provide a good basis for measuring any changes that are occurring in Cedar Pond.

Water outflow from the Cedar Pond was low throughout 2022 and comparison to 2018-2021 data showed that many 2022 months the lowest recorded (**Figure III-17**). These lower flows were likely the result of groundwater levels around the long-term average each month, as well as low groundwater levels in 2021 (see **Figure III-6**). During the 2020 review of outflow readings from the pond, it was noted that the previously established stage-flow relationship developed from past data began to become less reliable when groundwater levels decreased to more average conditions. Previous flow and stage readings (*i.e.*, 2002-2003 MEP and 2012 Management Plan monitoring) were collected during average to low groundwater periods and during a period without changes in inlet board elevations. Stage-flow relationships based on this data were consistent and data collected for the adaptive management in 2017 through 2019, during high groundwater periods, were generally consistent with the stage-flow curve developed from the prior readings. However, in 2020, as groundwater levels began to decrease, flow and stage measurements became less consistent with the previously established stage-flow relationship likely due to the regular changes in the board elevations; MEP readings were collected when boards were present, but decaying. With all of this in mind, project staff decided to utilize the measured instantaneous readings for the 2020 Cedar Pond annual assessment rather than the continuous recordings and stage discharge relationship.[47] Project staff then reviewed historic readings with this same approach 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. In 2021 and 2022, project staff continued to utilize the 2020 procedures for determining average and annual flows.

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[41] 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.

[42] 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.

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

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

[45] Eichner, E., B. Howes, and D. Schlezinger. 2021. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2020 to December 2020.

[46] Eichner, E., B. Howes, and D. Schlezinger. 2022. Cedar Pond Adaptive Management Monitoring Program: Annual Technical Report, January 2021 to December 2021.

[47] Note that the accuracy of the stage records is effected by the flow or groundwater levels.

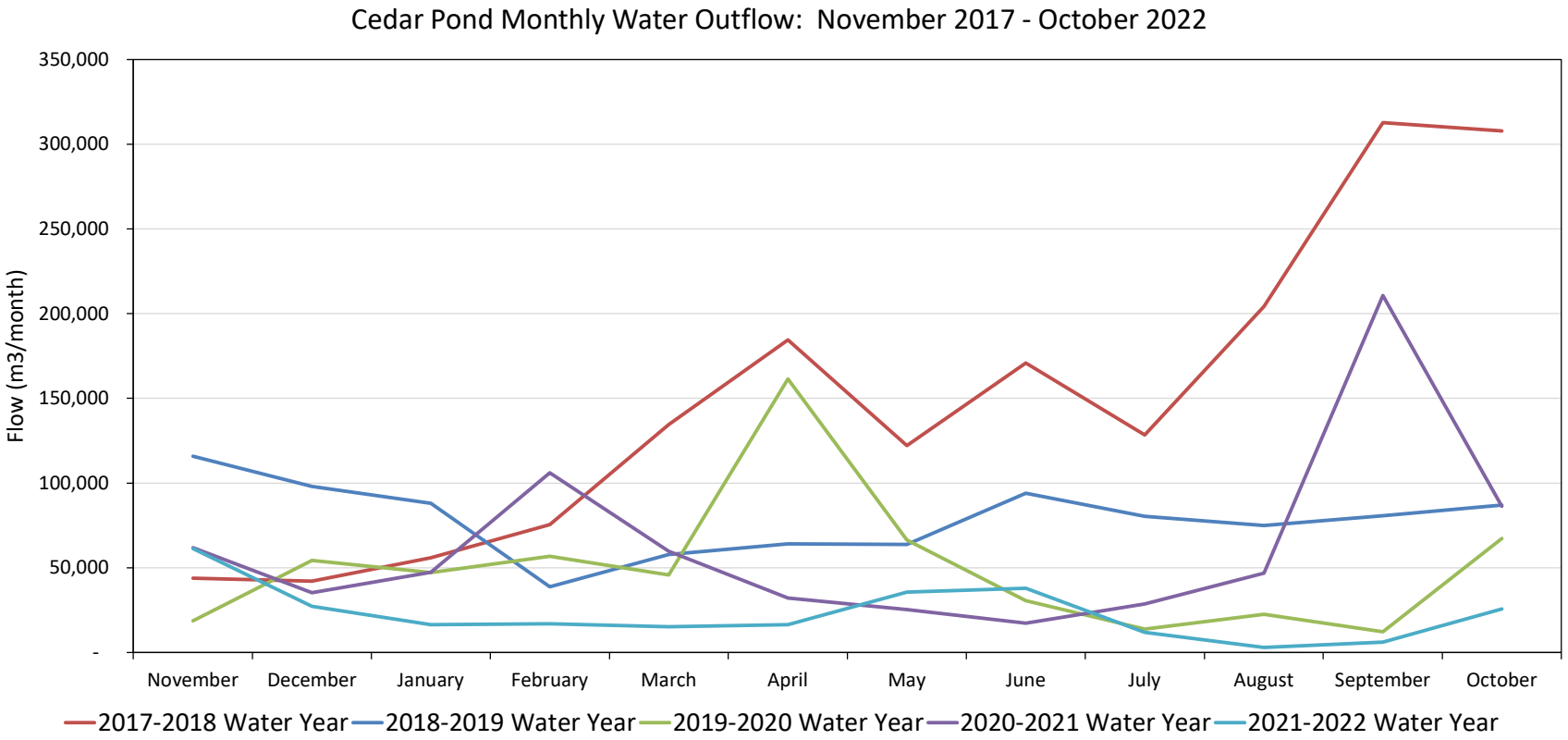

Figure III-17. Stream Outflow from Cedar Pond: 2017-2022. Stream outflow from Cedar Pond was generally low throughout 2022 with 8 of the 12 average monthly readings among the lowest recorded since 2017. These low outflows were likely due to average groundwater conditions during 2022 and lower than average 2021 conditions, as well as exceptionally low precipitation in July and August. Stream outflow from Cedar Pond has been measured approximately every two weeks at the same location since 2017.

Average monthly outflows in 2022 were significantly lower than those in 2018, 2019, 2020, and 2021. Review of the 2022 month by month summer flows shows that among the key summer months, April, July, August, and September flows were the lowest monthly flows among the five most recent years of monitoring. The lowest May and June readings were recorded in 2021. August 2022 outflow (3,045 m^3/month) was the lowest monthly reading in the entire 2018-2022 monthly monitoring dataset.

The low 2022 readings were due to both lower groundwater elevations than past years and significantly lower summer precipitation. Precipitation in 2022 was 43.04 inches, which is slightly less than in 2021 (45.22 inches total) (**Figure III-18**), but July and August 2022 monthly precipitation had the lowest recorded monthly totals for each of those months in the 2018-2022 dataset. July 2022 precipitation was 0.75 inches, while August 2022 precipitation totaled 1.16 inches. Precipitation recovered somewhat in October 2022, which had the second highest monthly amount (9.16 inches) in the entire 2018-2022 dataset; September 2021 precipitation was the highest monthly amount in the dataset (10.48 inches). Total precipitation in 2018, 2019, and 2020 was 56.47 inches, 53.71 inches, and 37.02 inches, respectively. If these significant swings between exceptionally low and high monthly precipitation amounts continue, they will likely have an on-going impact on streamflows and nutrient export from Cedar Pond.

Annual nitrogen and phosphorus export from Cedar Pond in 2022 decreased from 2021, but monthly averages were not statistically different from 2021. Average monthly TP export in 2022 was 4.4 kg, while average 2022 monthly TN export was 45 kg (**Figure III-19**). Corresponding 2021 average monthly exports were 10.9 kg TP and 68 kg TN. These 2021 averages were not significantly different (ttest, $\rho>0.05$) from the 2022 averages largely due to the high month-to-month variability. Review of the monthly exports showed that 2022 had exceptionally low exports especially during the summer. Minimum monthly exports over the entire five year dataset were measured in 2022 during April, July, August, and September for NOx, TN, TDN, DIN, DON, ortho-P and TP. Most of the minima in May and June were recorded in 2021. The quarterly July-September 2022 TN export was 19.5 kg, which was only 4% of the annual total.

The annual 2022 TN export was approximately the same as 2020 export, but lower than the 2021 export. Annual 2022 TN export was 1.5 kg/d, which is slightly greater than the 2002/03 TN export measured for the MEP Rock Harbor assessment (1.1 kg/d).[48] The MEP estimated a 58% nitrogen attenuation of the Cedar Pond watershed nitrogen loading based on the 2002/03 measurements. During 2021, the annual export was 2.2 kg/d, while it was 3.2 kg/d in 2019 and 8.3 kg/d in 2018. The return in recent years to levels that approach the MEP measurements of natural nitrogen removal in Cedar Pond is something for the Town to consider in Comprehensive Wastewater Management Plan (CWMP) implementation, as well as in TMDL compliance issues for Rock Harbor.[49] Based on preliminary results, the return to relatively high nitrogen removal in Cedar Pond also means that the MEP linked models could be used to evaluate Rock Harbor management options with relatively minor changes, especially if a nitrogen TMDL is issued by MassDEP in the future and if these 2022 conditions can be sustained or improved.

[48] Howes B.L., S.W. Kelley, J. S. Ramsey, R.I. Samimy, D.R. Schlezinger, and E.M. Eichner. 2007. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA.

[49] The Rock Harbor MEP report was completed in 2008. MassDEP has not issued a TMDL for Rock Harbor as of the writing of this report.

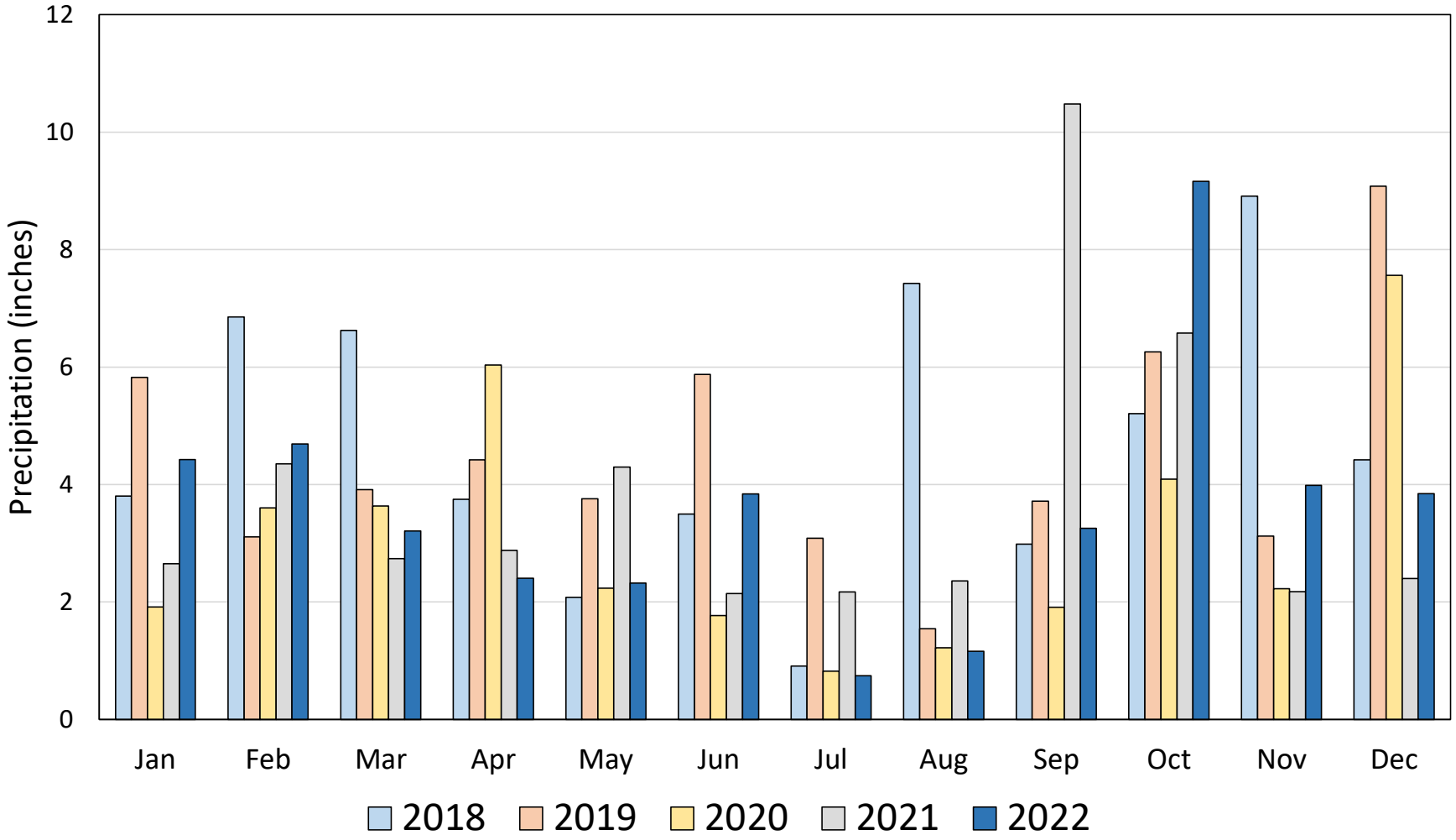

Figure III-18. Orleans Monthly Precipitation (2018-2022). Total annual precipitation in 2022 was 43.04 inches, which is only slightly lower than 2021 total (45.22 inches), but July and August 2022 precipitation were the lowest amounts for those months among all 2018-2022 readings. October 2022 was the second highest monthly amount (9.16 inches) among all months in 2018-2022; September 2021 precipitation was the highest monthly amount among all months in 2018-2022 (10.48 inches). Total precipitation in 2018, 2019, and 2020 was 56.47 inches, 53.71 inches, and 37.02 inches, respectively.

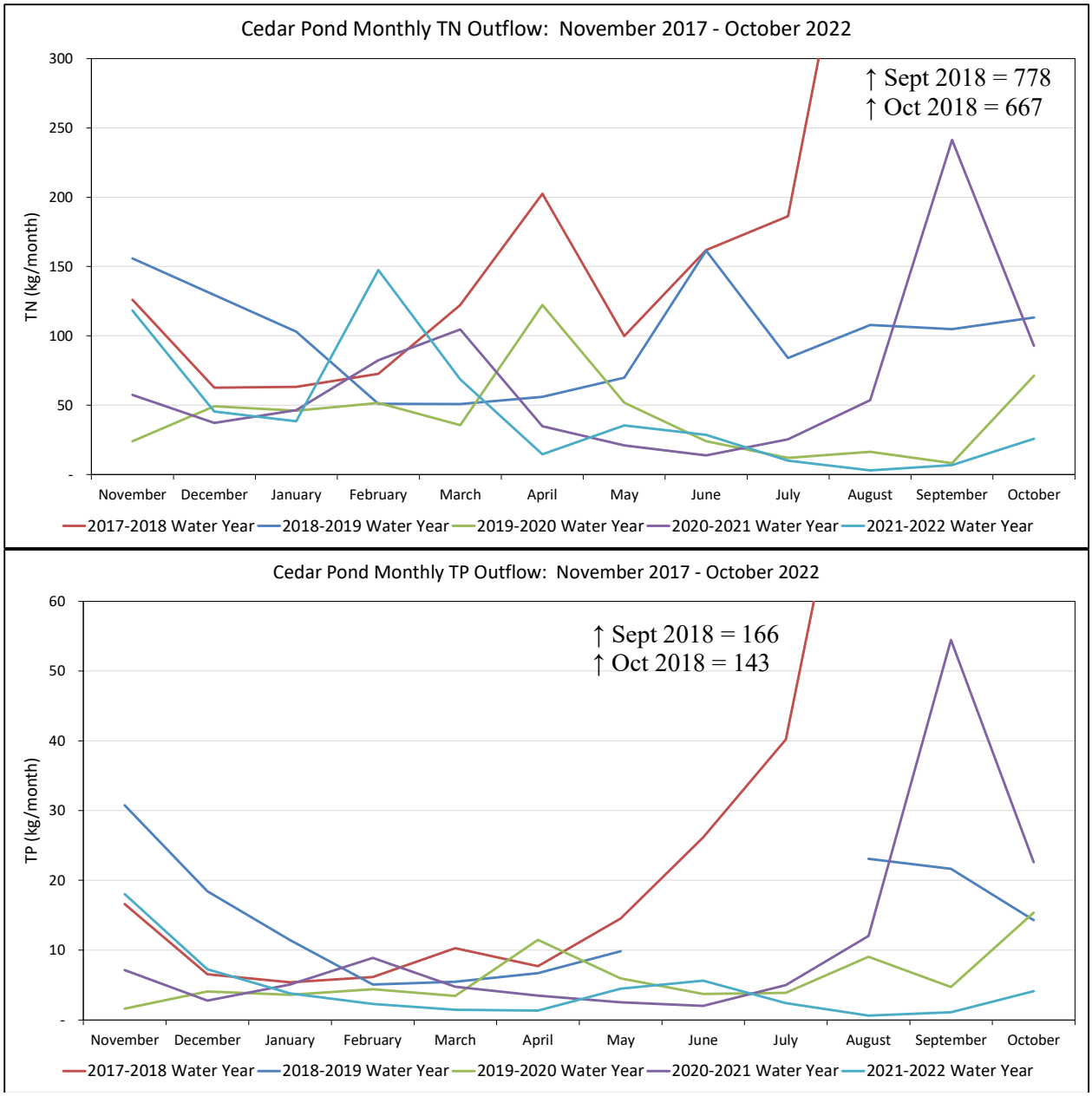

Figure III-19. Cedar Pond Creek Monthly TN and TP mass outflow (2018-2022 water years). Nitrogen and phosphorus mass export from Cedar Pond in 2022 decreased from 2021, but annual monthly averages were not statistically different from 2021. Average annual monthly TP export in 2022 was 4.4 kg, while average annual 2022 monthly TN export was 45 kg. Corresponding 2021 average exports were 68 kg TN and 10.9 kg TP. These averages were not significantly different from the 2022 averages (ttest, $\rho<0.05$). Monthly exports of TN and TP, as well as TN constituents, were exceptionally low during the 2022 summer. Minimum monthly exports over the entire five year dataset were measured in April, July, August, and September 2022 for NOx, TN, TDN, DIN, DON, ortho-P and TP. Most of the minima in May and June were recorded in 2021. Total TN and TP exports in 2022 were 543 kg and 53 kg, respectively, compared to 2021 levels of 811 kg and 131 kg, respectively.

Comparison of TN and TP concentrations in pond outflow waters showed that Creek concentrations generally matched shallow water column concentrations. Statistical comparison of annual average concentrations of TN, TP, and N:P ratios in the water column (0.15 m and 1.5 m depths) and in the Creek showed no significant difference. TP concentrations in the Creek and shallow water column increased in tandem from March through July and then were fairly stable for the rest of the year (**Figure III-20**). TN concentrations in the Creek and the shallow water column were exceptionally high in February and March (mostly due to DON, as noted above), but then decreased to an approximate range of 0.8 to 1.0 mg/L for the rest of the year. The high TN concentrations in February and March made phosphorus the key determinant of water quality in the shallow water column and Creek outflow (**Figure III-21**). High N:P ratios in Creek waters in the early portions of the year were also measured in 2018 and 2021, but the ratios maxima in those years were 50-60, not the 180-600 measured in 2022. As noted above, the high TN concentrations early in 2022 were notably different than previous measurements and may reflect a significant change in shallower sediment conditions.

Collectively, the Cedar Pond Creek water quality data reflect the on-going improvements in the pond water column and lower nutrient export to Rock Harbor that has been measured in the last few years. Consistently attaining lower TN nitrogen export levels will be subject to the regular natural fluctuations in the system, both year-to-year and seasonally, due to precipitation and groundwater fluctuations and require further, but incremental, improvements in Cedar Pond water quality conditions to attain levels measured by the MEP (2002/2003). The measurement of 543 kg TN export in 2022 occurred during average groundwater level conditions, but also exceptionally low late summer precipitation. Overall, monitoring has shown that the installation of the pond outlet boards as a result of the implementation of the Cedar Pond Management Plan has approached, but not attained, the goal of returning the TN export from Cedar Pond to Rock Harbor to historical levels. Additional monitoring is recommended to assess whether these conditions can be consistently attained and resolve the factors having the largest influence on the fluctuations seen in 2018-2022.

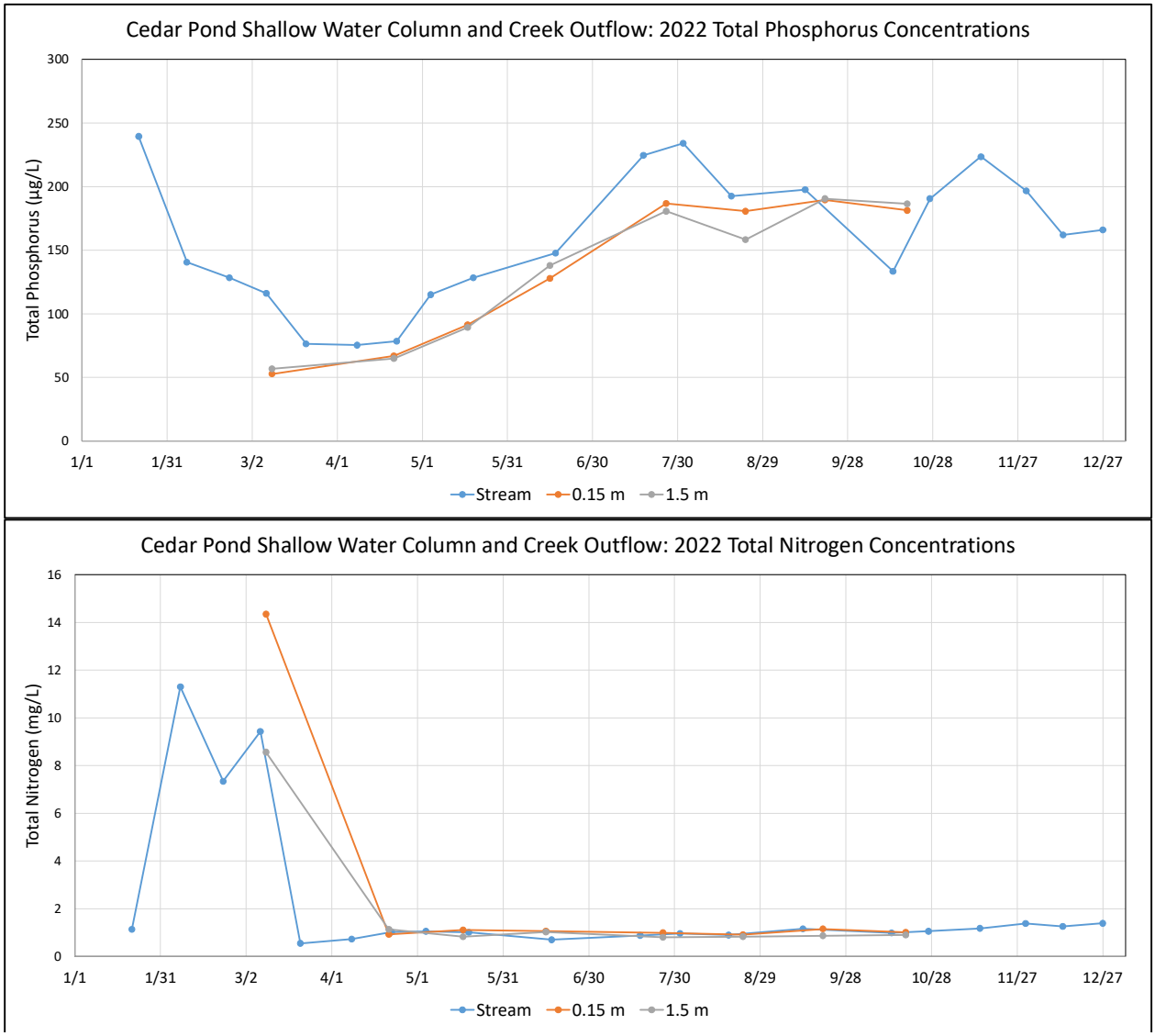

Figure III-20. Cedar Pond Creek and Shallow Pond 2022 TN and TP concentrations. Shallow water column and stream outflow TN and TP concentrations were similar throughout 2022 largely confirming that the shallow portions of pond water column are the source water for the stream outflow. Statistical comparison of annual average TN and TP concentrations in the water column (0.15 m and 1.5 m depths) and in the Creek showed no significant difference. TP concentrations in the Creek and shallow water column increased in tandem from March through July and then were fairly stable for the rest of the year. TN concentrations in the Creek and the shallow water column were exceptionally high in February and March (mostly due to high DON concentrations), but then both decreased to an approximate range of 0.8 to 1.0 mg/L for the rest of the year.

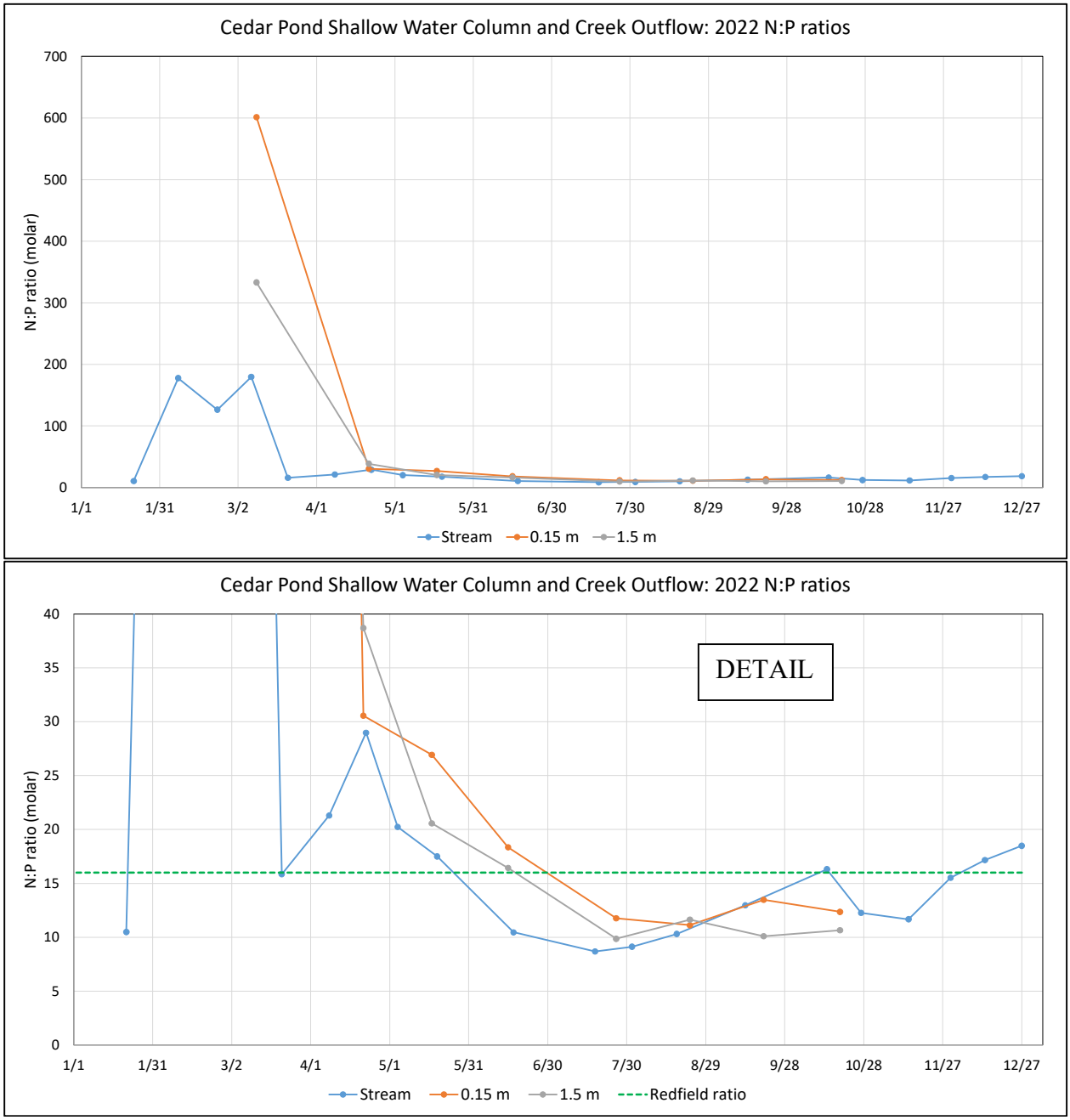

Figure III-21. Cedar Pond Creek and Shallow Pond 2022 N:P Ratios. Average 2022 N:P ratios in the shallow water column (0.15 m and 1.5 m depths) and in the Creek showed no significant difference. Ratios were exceptionally high in January, February, and March both in the Creek and in the Pond largely due to high DON concentrations. This period of greater sensitivity to phosphorus rather than nitrogen was sustained into May/June when ratios decreased below the Redfield ratio (16) and the shallow Pond and Creek water quality conditions became nitrogen-sensitive. High N:P ratios in Creek waters in the early portions of the year were also measured in 2018 and 2021, but the ratios maxima in those years were 50-60, not the 180-600 measured in 2022.

IV. Conclusions and Proposed Management Changes

Water quality in Cedar Pond improved incrementally in 2022, building on improvements that were seen in prior years since the reinstallation of the outlet boards in 2017. The 2013 Town of Orleans Cedar Pond Management Plan focused on effective stewardship of the pond resources through three key goals: 1) restore water quality, 2) restore the historic herring run, and 3) protect the adjacent Atlantic White Cedar wetland. At the time of the management plan preparation, Cedar Pond water quality was significantly impaired, including bottom anoxia, high shallow TN and TP concentrations, increasing chlorophyll-*a* concentrations, and significant sediment nutrient release under both aerobic and anaerobic conditions. In addition, the pond was exporting significantly more nitrogen to Rock Harbor than measured in 2002/2003 during the Rock Harbor MEP assessment. Monitoring initiated in 2017 and continuing through 2022 has demonstrated continuing, incremental improvements in Cedar Pond water quality.

The first step toward meeting the three goals in the Cedar Pond Management Plan was to return the pond to brackish salinity conditions that had previously existed in the pond; a brackish salinity range of 1 to 4 parts per thousand (ppt) was set as a goal. Previous historical readings had shown lower salinity conditions had better, but still impaired, water quality conditions, including a thin layer of acceptable dissolved oxygen within the shallow portions of the pond water column and attenuation of watershed nitrogen prior to its discharge to Rock Harbor. Other planned steps in the Management Plan included a) addressing nutrient inputs from the large number of cormorants roosting during the late summer (*i.e.*, moving the regional electrical lines from over to pond, which was completed in 2019) and b) reducing regenerated loads from the sediments within the pond. Boards were reinstalled at the pond outlet in 2017 as a low cost way begin to gradually reduce salinity by allowing naturally fresh, watershed groundwater inputs to have a greater impact within the pond water column; shallow salinity levels were regularly over 20 ppt during the summer at the time.

Monitoring associated with Management Plan implementation began just prior to reinstalling the outlet boards and has continued to this day. This regular monitoring has provided better insights into the natural variabilities in the system, documented the improvements in the ecosystem and why they are occurring, and provided a basis for adjustment in how and when the boards were installed and configured. The Management Plan included an adaptive management provision to regularly review and adjust the monitoring; monitoring data has been reviewed at least annually and a number of adaptive management and monitoring adjustments have occurred as a result. This regular review of annual findings has been coordinated among the Town, CSP/SMAST, and MassDMF. Adjustments have included changes to outlet board heights and installation of a notch in the top board following review of tidal water levels at the outlet. Monitoring in the pond and the creek connecting the pond to Rock Harbor has shown significant initial improvements and then continuing incremental improvements each subsequent year. Monitoring in 2022 showed additional incremental improvements beyond those measured in 2019, 2020, and 2021.

Water quality improvements in the shallow portions of Cedar Pond have been among the most significant since the implementation of the Management Plan. Dissolved oxygen (DO) levels in the upper 1.5 m portion of the water column exceeded the MassDEP regulatory minimum in most readings collected in 2021 and 2022 after having more than half of the shallowest readings

below the minimum in 2018 and having anoxia within 0.5 m of the surface in 2019. Having sufficient shallow DO concentrations has numerous benefits, including creating better habitat for any spawning herring coming into Cedar Pond and creating conditions to keep deep sediment nutrients from being released into the water column. In addition, since shallow waters are the primary source of water flowing out of the Cedar Pond, the better water quality conditions have also reduced the annual nitrogen export to Rock Harbor.

Salinity monitoring in 2022 showed that spring conditions generally had the lowest salinity concentrations. This is consistent with previous monitoring, although the increase measured in the rest of the 2022 monitoring period was generally lower. Shallow salinity in March and April 2022 was approximately 8 ppt. This is comparable to what was measured in early 2021 when the board configuration was similar. In April 2019, when groundwater levels established new monthly maxima in the preceding months, shallow salinity levels were ~5 ppt. Shallow salinity levels increased to a maximum of 15.1 ppt in 2022, which is comparable to what was measured in 2019, 2020 and 2021. Comparison of 2021 and 2022 data, which had similar board configurations and timing of changes, but different groundwater level settings and seasonal precipitation, suggest that the seasonal increase in salinity that has been measured 2018-2022 in the current board regime is primarily due to seasonally decreasing groundwater levels and associated freshwater discharge to the pond. Higher groundwater conditions increase freshwater discharge to the pond and, provided board configurations and timing of placement remain the same, can decrease salinity concentrations to near the Management Plan goal. As groundwater levels fluctuate and increase over the long term, data collected to date suggests that salinity levels will continue to reflect interactions between the board configuration, the groundwater levels, and precipitation (*e.g.*, July and August 2022 precipitation were the lowest monthly amounts over the whole 2018-2022 monitoring period). Higher deep salinity concentrations, on the other hand, generally reflect the impact of incoming flood tides from Rock Harbor/Cape Cod Bay. Tidal water, because of its higher density and salinity, sinks to the bottom of Cedar Pond. Fresh groundwater discharged into the pond around its margin tends to remain above the deep higher salinity water.

This difference between shallow lower salinity levels and deep higher salinity levels sets up stratification or layering within the water column, which is frequently matched by temperature stratification. The deep high salinity waters are effectively isolated from regular atmospheric interaction and sediment oxygen demand in this deeper layer eventually consumes all the DO in the deep layer without replenishment from the atmosphere. Review of temperature stratification shows that during past years temperature stratification was at a shallower depth during certain times of the year, but salinity stratification was always present. Once all the deep DO is consumed, the anoxic conditions favor the release of sediment phosphorus and nitrogen that would otherwise be retained in the sediments into the overlying water column. Total phosphorus (TP) and total nitrogen (TN) concentrations in the deep layer have fluctuated each year of monitoring, but are generally 2-5X shallow concentrations.

Throughout 2022, salinity stratification was controlling stratification and was present from March through October between 1.5 to 2.5 m depth range. Temperature readings show temperature stratification was also present from May through most of September. The average shallow TP concentration in 2022 (134 µg/L) was the lowest recorded 2018-2022, while average

shallow TN concentrations were similar to past years (~1 mg/L TN after accounting for exceptionally high readings in March). Average deep 2022 TP and TN were 422 µg/L and 4.1 mg/L, respectively.

Review of 2022 DO and nutrient concentrations show that the high nutrients and persistent anoxia in the deep layer continue to impact shallow conditions. The stratification restrains the impacts and allows some improvements in shallow conditions, but the impacts seep through the stratification interface. DO saturation levels, which should be near 100% in shallow waters with regular contact with atmospheric mixing, were frequently between 80% and 90% saturation. Continuous 2022 DO recordings at 1.5 m had monthly saturation averages between 9% (June) and 73% (March). Average 2022 DO saturation at 0.15 m and 1.5 m in DO profiles were 85% and 58%, respectively. This finding reinforces the need to address the sediments and their impacts on the water column.

A notable change in 2022 water quality data was extremely high TN concentrations in February/March that were measured throughout the water column and in stream outflow. These TN concentrations were >7 mg/L. Past monitoring had shown high TN concentrations in the spring in deep waters, but not shallow waters. Review of the TN components showed that these high concentrations were due to exceptionally high Dissolved Organic Nitrogen (DON), which is a component of TN concentrations. Water column DON is typically urea and amino acids excreted by zooplankton and various types of benthic infauna. This type of early DON release has not been measured before in Cedar Pond. It is unclear why this spring DON release occurred, but the type of nitrogen and its typical sources suggest it may be due to benthic infauna changes. Spring infauna typically have the peak annual densities and populations and perhaps improved water quality conditions have been sustained for long enough in the upper portions of the water column that infauna populations dynamics have shifted to deeper burrowing species that are aerating and altering sediment nutrient dynamics (something that has also been seen in Lonnie's Pond after four years of aquaculture).[50] Sediment and benthic infauna assessments would be required to help clarify what sort of changes are occurring.

Monitoring in 2021 and 2022 shows that the pond sediments are the primary driver of impaired deep conditions and high nutrient levels and impacted DO concentrations throughout the water column. These sediments have high oxygen demand and anoxic conditions were sustained in deep waters from March through December 2022. Based upon all of the data collected to date and the fact that the nutrient source from the cormorants has been dealt with, it is recommended that the Town begin planning an action to remove or sequester nutrients in the pond's sediments.

Another sign of improving conditions in Cedar Pond was documented 2022 alewife sightings in Cedar Pond Creek. According to the 2017 MEPA approval of the Management Plan and accompanying Fishway Plan, outlet board elevations were adjusted each year to allow spawning herring to enter and juvenile herring to leave the pond. Prior to 2022, no fish had been noted in over 80 visits to the pond outlet by Town, CSP/SMAST, and MassDMF staff. During review of 2021 data by Town, CSP/SMAST, and MassDMF staff, MassDMF staff offered to assist the

[50] Labrie, M.S., J. Benson, D. Schlezinger, and E. Eichner. 2023. 2022 Lonnie's Pond Annual Report: Aquaculture N Removal/TMDL Goal. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 52 pp.

Town with the installation of fyke nets in Cedar Pond Creek during March/April 2022 with the goal of continuously monitoring fish passage. These nets were in place between March 30 and April 25 (during the primary alewife spawning period) and 30 alewife were trapped and released. The presence of these fish is another sign of improving conditions in Cedar Pond and is a hopeful sign that additional alewife will be seen in the Creek and Pond in the future due to natal homing (*i.e.*, returning to the stream where they originated to spawn).

Massachusetts Department of Environmental Protection (MassDEP) acknowledged the Cedar Pond improvements in 2022. MassDEP reviewed the results of the regular monitoring conducted by the Town through CSP/SMAST with regard to their 2017 Superseding Order of Conditions approving the Cedar Pond Management Plan. In an acknowledgement of the improving conditions, MassDEP issued a Certificate of Compliance[51] to the Town with one on-going condition: that the Town continue to implement the Cedar Pond Management Plan.

Improving conditions in Cedar Pond are also benefiting Rock Harbor. During the initial 2017/2018 Cedar Pond Creek monitoring, Cedar Pond was exporting 8.3 kg/d TN, which was nearly 8X the export measured during the 2002/2003 MEP assessment of Rock Harbor (*i.e.*, 1.1 kg/d). These initial 2017/2018 measurements also showed that some months had N export rates greater than the MEP watershed N load. This increase indicated that the Pond was not only transferring all the Cedar Pond watershed N downstream to Rock Harbor, but the Pond was also internally adding additional N to the downstream outflow. Improved water quality in the pond in subsequent years reduced this N transfer to Rock Harbor by approximately a third in 2019 and in 2020-2022, the TN export rate has fluctuated between 1.4 and 2.2 kg/d. The average 2022 TN export (1.5 kg/d) to Rock Harbor was slightly higher than the MEP rate, but a significant improvement over exports during the initial, high salinity conditions. This reduced TN export, even with continuing impairments in Cedar Pond, is something for the Town to consider in Comprehensive Wastewater Management Plan (CWMP) implementation, as well as in TMDL compliance issues for Rock Harbor if a nitrogen TMDL is issued by MassDEP in the future.

Based on the current conditions, project staff recommend the following actions for the continuing management of Cedar Pond:

1. Maintain the same board elevations, configuration and management of board heights as was done in 2022. Water quality has gotten incrementally better each year.
2. Begin to plan strategies to address the sediments and their impact on water quality. Deep water quality was consistently impaired from March through December 2022. The salinity and temperature stratification in the pond is facilitating the improvements in the shallow waters, but regular deep anoxia is impacting shallow water quality conditions and future incremental improvements may be limited by the extent of deep impairments.
3. Continue to monitor to provide basis for developing management strategies, as well as assessing impacts of management actions.
4. Regular meetings among the Town, CSP/SMAST, and MassDMF should continue as they have provided beneficial recommendations, regular communication, and coordination for effective restoration and management activities.

[51] MassDEP Certificate of Compliance to Town of Orleans. February 2, 2022. DEP files number: SE 54-2286.

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