Cedar Pond
Adaptive Management Monitoring Program:
Annual Technical Report
January 2021 to December 2021

FINAL REPORT
April 2022

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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Prepared By

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Cover photo: Cedar Pond Outlet (March 23, 2021)
(courtesy of Nate Sears)

Acknowledgements:

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

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

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

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Executive Summary

Cedar Pond
Adaptive Management Monitoring Program: Annual Technical Report
January 2021 to December 2021

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 based on limited data indicated that the pond water quality was impaired and regular fish kills clearly showed that the impairments were significant. Even with the 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 and continuous monitoring of the pond water column and the stream outflow. This monitoring data showed that salinity had increased, water quality conditions in the pond had worsened since the 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 strive to achieve the three goals for Cedar Pond by a) reinstalling boards that historically had been in place at the pond outlet to reduce salinity to brackish conditions (1 to 4 parts per thousand), b) relocating the electrical wires over to the pond to move the roosting cormorant population, and c) addressing 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 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 Environmental Notification Form (EENF) and then an Environmental Impact Report and a Development of Regional Impact filing with the Cape Cod Commission. All of these additional

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[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. 2007. Linked Watershed-Embayment Model to Determine Critical Nitrogen Loading Thresholds for the Rock Harbor Embayment System, Orleans, MA. SMAST/DEP Massachusetts Estuaries Project, Massachusetts Department of Environmental Protection. Boston, MA. 132 pp.

reviews confirmed the Town approvals and the Massachusetts Secretary of Energy and Environmental Affairs and Massachusetts Department of Environmental Protection approved the Management Plan 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 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, status of monitoring was reviewed in a mid-year technical memo[5] and all monitoring results throughout the year were summarized in an annual report.[6]

Monitoring results have continued each subsequent year and have been regularly reviewed in Annual Reports (2018, 2019, and 2020) 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 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 and in 2019, CSP/SMAST added a continuous recorder at the outlet to better measure water levels at the board. The Town also began discussions with Eversource to move the power lines over the pond in 2017 and the removal the key lines was completed in December 2018.

This 2021 Annual Report reviews Cedar Pond data collected in 2018, 2019, 2020, and 2021. This Report includes data previously presented in the 2021 semi-annual Technical Memorandum, which was presented to the Town in November 2021.[7] All reporting on Cedar Pond, including this annual report, has been delayed due to on-going COVID pandemic and associated supply chain issues. This report also includes recommendations for adjustments in

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[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: 2018 Semi-Annual Report. September 17, 2018. From: Howes, B., E. Eichner, D. Schlezinger, and R. Samimy. To: C. Kennedy and G. Meservey, Town of Orleans. Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 22 pp.

[6] 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.

[7] CSP/SMAST Technical Memorandum: Cedar Pond Adaptive Management Monitoring Program: 2021 Semi-Annual Report. November 12, 2021. From: Howes, B., 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. 13 pp.

management strategies to better attain the Management Plan goals. Findings from available collected data include:

- Water column dissolved oxygen (DO) concentrations in 2021 were incrementally better than 2020. DO concentrations from the surface to 1 m were all above the MassDEP minimum (5 mg/L)[8] for the first time. This follows the DO improvement in 2020, including all shallow continuous August/September DO measurements exceeding 5 mg/L and June/July shallow continuous DO 2 mg/L higher than in 2019. Waters deeper than 2 m continued to be impaired throughout the summer with regular hypoxia/anoxia.
- Salinity stratification/layering of the water column generally began at 1.5 m depth throughout 2021, while temperature stratification occurred at 2.25 m to 2.75 m during summer months. As a result, salinity, rather than temperature, stratification determines the potential depth of anoxia. Average shallow water column salinities in 2021 were lower than 2018-2020. The depth of stratification determines how much of the water column is cut off from the atmosphere and, therefore, the minimum depth where anoxia will occur. The depth where anoxia occurs determines the depth of sediments that can add additional nutrients to the water column. With a deeper surface layer of well oxygenated water column, less nutrients are in the water column, lower phytoplankton levels occur, less nutrients are transported to Rock Harbor, and the habitat is better for herring to spawn.
- Average shallow total nitrogen (TN) concentrations were approximately the same in 2021 as they were in 2020, which were both less than 2018 and 2019. Similarly, shallow 2021 total phosphorus (TP) concentrations were the lowest among the four years of monitoring, likely due to stronger stratification preventing water column mixing and higher shallow DO causing precipitation of any deep inorganic P reaching shallower waters. Average deep TN and TP were higher in 2021 compared to 2020 likely due to the same factors, although average deep TN was less than 2019.
- Average deep TN and TP concentrations were higher than 2020, likely due to the stronger stratification. Average deep TN was higher than 2020, but lower than 2019, while average deep TP was highest among 2018-2021. Stronger stratification would sustain anoxia in bottom waters once it is established; the amount of TP released is usually related to how long anoxia persists. A smaller deep volume created by a larger well-oxygenated shallow layer with the same sediment release would create higher deep concentrations.
- TN transfer to Rock Harbor via Cedar Pond Creek in 2021 was similar to 2020, which was an improvement over transfers in both 2018 and 2019. TN transfer is still greater than during the MEP 2002/03 readings when the pond removed 58% of the watershed nitrogen, but 2021 readings in May, June, and July were similar to the MEP rate.
- No fish have been observed entering or leaving Cedar Pond during the four years of Management Plan monitoring. Town and CSP/SMAST staff have visited the outlet and the creek over 80 times to adjust board heights or measure streamflow or water levels and have noted no fish entering or leaving the pond.

[8] 314 Code of Massachusetts Regulations 4.05(4)1.

- Seasonal lowering of boards to attain Fishway Plan goals is regularly increasing salinity during the summer. June 2021 shallow salinity matched 10 ppt levels measured in 2019 and 2020 (all reduced from ~15 ppt in 2018), but each year had a similar, gradually increasing summer rate that resulted in ~17 ppt salinity in September. This annual reset of higher salinities during summer creates a challenge to achieving the salinity goals in the Management Plan (1 to 4 ppt) and restoration of a herring habitat.

The 2021 monitoring results largely confirmed the lessons of 2018, 2019, and 2020 and the recommendations in the 2013 Cedar Pond Management Plan:

a) reduced salinity in Cedar Pond can improve water quality conditions (*i.e.*, higher DO and lower TN and TP concentrations),
b) salinity reductions can be sustained by installation of the boards at the pond outlet, and
c) reduction of cormorant roosting through the relocation of the power lines was important for improvements in water quality.

The Town, CSP/SMAST and MassDMF have regularly reviewed the pond monitoring data and have used these regular discussions to adjust board heights and configurations to try to lower salinity while achieving the potential herring access to the pond. The combination of the same board notch in 2021 as in 2020, lower groundwater levels, and another year without cormorants provided some additional water quality improvements in 2021 over 2020, but the pond improvements are incremental rather than substantial. And the lowering of boards and the impaired pond water quality conditions are not attracting the herring that the board movement is designed to encourage although it has lessened the threat to the adjacent Atlantic White Cedar Swamp.

As a result of the review of data through 2021, CSP/SMAST is recommending that the Town work with MassDMF to see if further flexibility in board heights can be implemented to achieve lower salinity levels and allow sufficient water quality improvements to make Cedar Pond an attractive and sustainable herring habitat. Specifically, CSP/SMAST is recommending 1) that the outlet boards be kept at a higher elevation throughout the 2022 summer and 2) the Town work with MassDMF to better characterize the fish population moving in and out of the pond (if any). Keeping the boards at a higher level will lower salinity levels and provide a better understanding of potential summer improvements in water quality at lower salinity. More refined monitoring of the fish in Cedar Pond Creek will provide a more quantitative assessment of whether there are fish entering Cedar Pond and, if there are fish, what species they are. It is further recommended that the boards be adjusted to a lower elevation if large numbers of herring are noted or if pond water levels become too high. Regular water quality monitoring should continue. We are also recommending that the Town consider beginning the process to address the nutrient loads from the sediments.

Overall, 2021 readings showed additional incremental progress toward attaining the Management Plan goals. Cedar Pond remains impaired and with poorer water and habitat quality than existed in 2002/2003 and pre-2007, but 2021 readings were slightly better than 2020 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 once shallow improvements are sustained.

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I. Introduction

Cedar Pond is a 6.4 ha (15 acre) surface water body with a 48.4 ha watershed located within the Town of Orleans (**Figure I-1**). 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.[9] The Management Plan was approved by the Town and the state in 2017[10] 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.[11] 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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[9] 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.

[10] 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.

[11] 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, Massachusetts Department of Environmental Protection. Boston, MA. 132 pp.

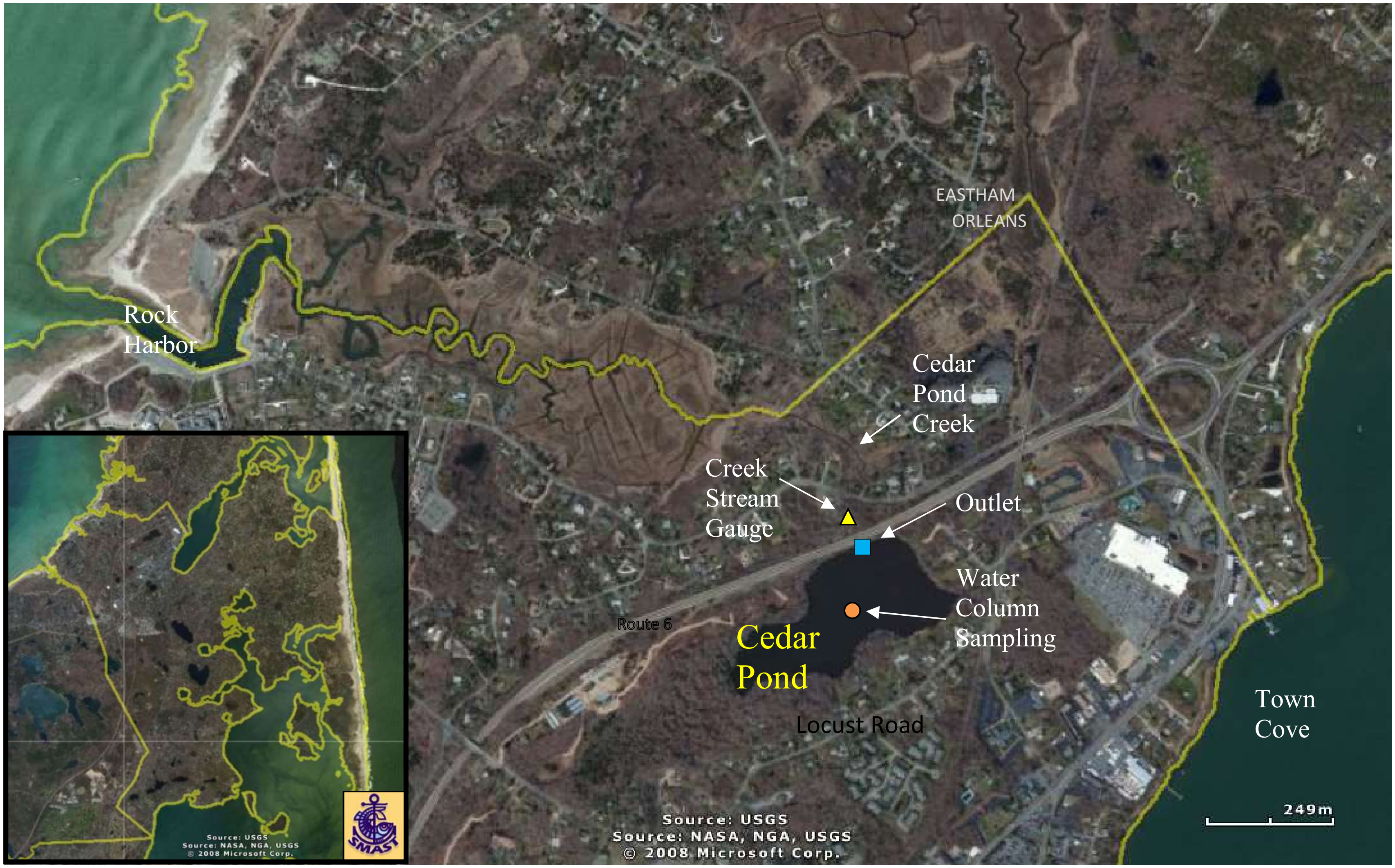

Figure I-1. Cedar Pond Locus and Sampling Stations in the Town of Orleans, MA. Cedar Pond is located in northern Orleans, south of Route 6 and west of Town Cove. The Pond is connected to the Rock Harbor estuary on Cape Cod Bay via Cedar Pond Creek. The creek leaves the pond through a weir at the pond 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 three annual reports: 2018[12], 2019[13], and 2020.[14] This current Annual Report is the fourth Cedar Pond Annual Report and reviews monitoring during 2021, including the data summarized in the 2021 Semi-Annual Report.[15]

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.[16] 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.[17] 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. 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

[12] 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.

[13] 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.

[14] 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.

[15] CSP/SMAST Technical Memorandum. November 12, 2021. Cedar Pond Adaptive Management Monitoring Program: 2021 Semi-Annual Report. From: Howes, B., 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. 13 pp.

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

[17] 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.

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[18]). Town and CSP/SMAST staff have 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.[19] 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.[20]

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[21]), lower

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

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

[20] 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.

[21] 314 CMR 4.05

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.[22]

III. Cedar Pond Adaptive Management Program 2021 Results

Data collection and synthesis was impacted by COVID issues during 2021, but CSP/SMAST staff generally were able to sustain a schedule similar to previous years. 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 2021 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 conditions 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.[23] 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 have 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,[24] but had been completely removed prior to development of the

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

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

[24] 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).

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).[25]

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 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.

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.[26] 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.[27]

In 2020, the notch elevation was increased and water quality incrementally improved, 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 2020 showed another 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.[28]

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

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

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

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

Figure III-1. Notched Board at Cedar Pond Outlet. After reviewing 2018 water levels at the outlet, Town, MassDMF, and CSP/SMAST staff agreed that the boards at the outlet 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 this decreased salinity in the pond, but once it was added, salinity levels increased at the same rate as in 2018. 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 have been observed during more than 81 visits from 2018 through 2021.

Water elevations in 2021 at the pond outlet were similar to those collected in 2020, while water quality showed another incremental improvement from 2020, but with continued impaired conditions (discussed below). Board elevations were adjusted in 2021 according to the Fishway Plan (**Table III-1**). Water elevations at the outlet in 2020 and 2021 had similar ranges and fluctuations (**Figure III-2**). Average water levels at the outlet during approximately the same period in 2020 and 2021 had less than 1 cm (<1%) difference and the range between 25^{th} and 75^{th} percentile readings was also the same (**Table III-2**).

Comparison of water levels to the Fishway Plan goals of water over the board notch during the immigration period (March 15 to June 30) and emigration period (July 1 to November 15) also showed similar readings in 2020 and 2021. Readings during both years were completed during approximately the same period due to sensor failure: 1/1 to 9/23 in 2020 and 1/21 to 10/5 in 2021. In 2021, 3% of the water level readings were 6 inches above the notch during the March 15 to June 30 period when spawning herring should be coming into the pond and 11% of the water level readings were 2 inches above the notch during the July 1 to September 21 period when juvenile herring should be leaving the pond. During 2020, the percentages of water levels above the boards/notch during the immigration and emigration periods were 5% and 7%, respectively. As noted, no fish were observed either entering or leaving the pond during 2021 (three Town staff visits and 24 CSP/SMAST staff visits). No fish have been observed during Town or CSP/SMAST staff visits to the outlet in 2018, 2019, 2020 and 2021.

Table III-1. Cedar Pond Board Height Log: 2020-2021. During 2020 and 2021, 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). During 2020, CSP/SMAST staff visited the site with a GNSS/GPS with RTK enabled to record board elevations. These readings were also used to determine 2021 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; water levels at the outlet varied by 1.23 m in 2021 and 0.81 m in 2020.

	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	Added boards; removed notch		1.63	

Table III-2. Cedar Pond Outlet Water Level Elevation Summary: 2019, 2020, and 2021. Summary of continuous water level readings collected at the Cedar Pond outlet show similar characteristics in each year. Continuous recorder was first installed on 5/23/19 and has had occasional disruptions due to equipment problems (*e.g.*, battery failure).

	2021	2020	2019
Beginning Date	1/21/21	1/1/20	5/23/19
Ending Date	10/5/21	9/23/20	12/31/19
Average Elevation (m NAVD88)	1.27	1.28	1.28
N	32,510	37,533	25,359
Maximum Elevation (m NAVD88)	1.96	1.98	1.80
Minimum Elevation (m NAVD88)	0.73	1.17	1.16
25th percentile Elevation (m NAVD88)	1.22	1.23	1.22
75th percentile Elevation (m NAVD88)	1.28	1.28	1.29

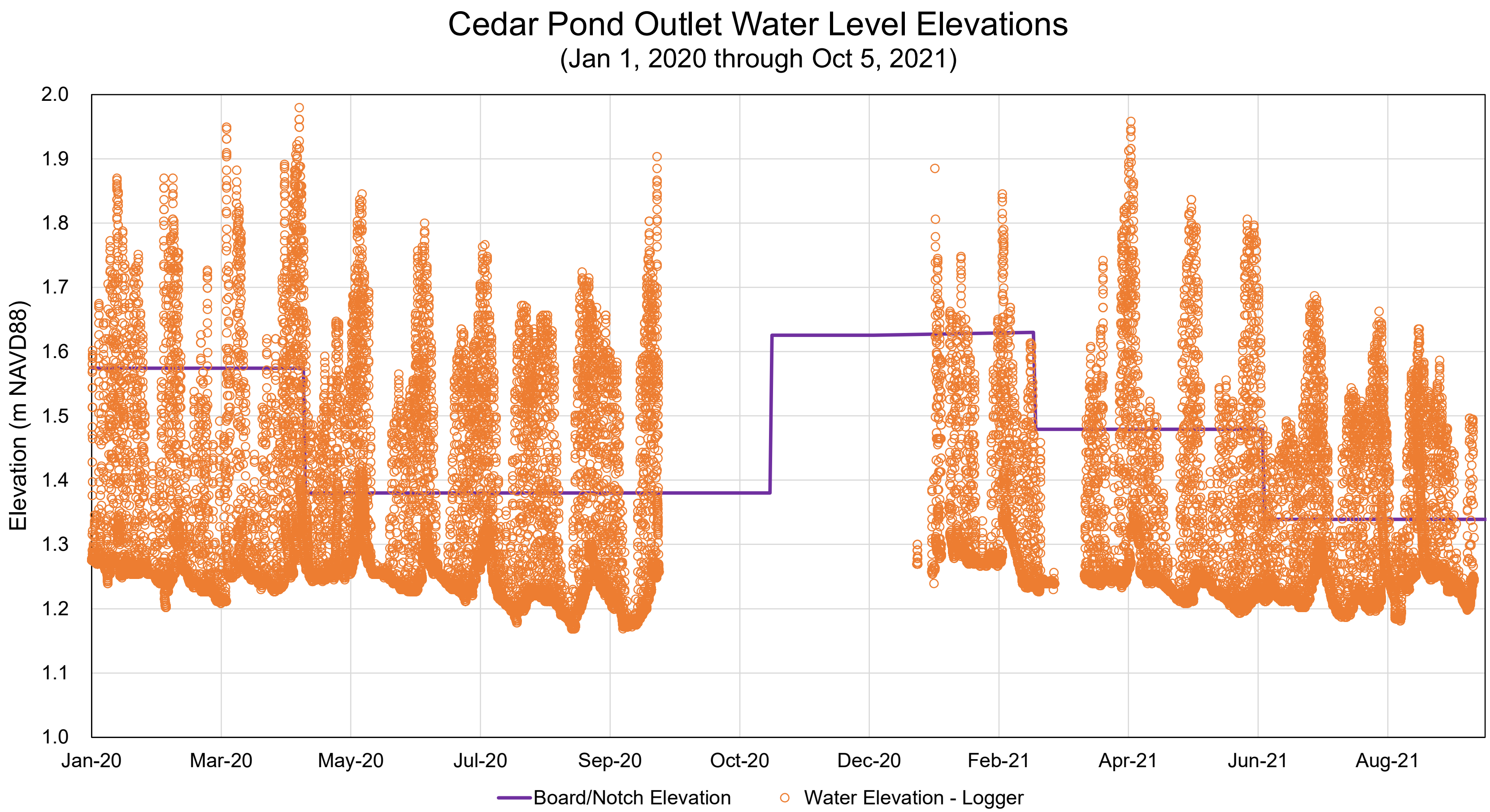


Figure III-2. Cedar Pond 2020-2021 Water Levels and Outlet Board Heights. CSP/SMAST staff installed an autonomous recording device programmed to record water levels every 10-15 minutes at the pond outlet on May 23, 2019 and the device has recorded through October 5, 2021 with occasional record gaps due to battery failures. As specified in the Fishway Plan, a notched board was added at the outlet around March 15 (3/17 in 2021) and maintained until July 1 with the goal of 6 inches of water above the bottom of the notch. On July 1, the notch elevation was adjusted with the goal of 2 inches of water above the bottom of the notch. Review of the water level records showed that in 2021, 3% of readings between 3/17 and 7/1 were 6 inches above the bottom of the notch. This is slightly lower than the 5% of readings in the same period in 2020. Water level readings between 7/1/21 and 10/5/21 were 2 inches above the bottom of the notch in 11% of the readings, which is slightly more frequent than in 2020 when 7% of the readings during this period had 2 inches or more. These two board adjustments are implemented to allow spawning herring to enter the pond and juvenile herring (spawn of the year) to leave the pond, respectively. No fish entering or exiting Cedar Pond have been noted during more than 80 visits to the outlet during 2018, 2019, 2020 and 2021 by CSP/SMAST and Town staff.

III.B. Water Quality Monitoring

Water quality monitoring in 2021 included regular collection of salinity and water quality samples within the water column coupled with detailed dissolved oxygen and temperature profiles, as well as two continuous recording devices at two depths in the deepest basin and regular water quality monitoring in Cedar Pond Creek, just north of the pond outlet. All 2021 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 on seven dates in 2021: April 8, May 26, June 22, July 21, September 21, November 2, and December 9. 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 (and continue to be deployed in 2021). The continuous monitoring devices are at shallow (1.2 m) and deep (3.6 m) depths (same depths during 2018, 2019, and 2020 deployments) and are programmed to record DO, temperature, salinity, and depth every 15 minutes. The shallow device also records 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 2021, stream water quality samples and flow readings were collected 24 times with continuous water level recordings collected at the same location. The stream monitoring site is the same site used during the MEP Rock Harbor assessment,[29] data collection for development of the Cedar Pond Management Plan,[30] and 2018, 2019, and 2020 monitoring for the implementation of the Management Plan.[31] 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. Water Column Profiles: Salinity, Temperature, Dissolved Oxygen

Salinity, temperature, and dissolved oxygen profiles in 2021 were generally similar to those in 2020, but with some notable differences. Temperature profiles showed that 2021 was warmer for more of the summer than 2020. Surface water temperatures in 2021 were slightly higher than 2020 in April through July, but September 2021 temperature was much warmer than September 2020 (approximately 7°C higher). The slightly warmer temperatures in much of 2021 contributed to temperature stratification in the May, June, and July profiles with strong layering at 2.75 m, 2.25 m, and 2.5 m depths, respectively (**Figure III-3**). These temperature stratification depths were deeper than the salinity stratification, so they only played a reinforcing role water quality impacts in the deeper waters, including anoxia. All the other 2021 temperature profiles had insufficient temperature differences to maintain thermal stratification.

Salinity profiles in 2021 were similar to 2020 except salinity levels late in the summer were lower in 2021 and the shallow, well-mixed layer with uniform salinity was consistently to 1.5 m depth in 2021 instead of to the occasional 2 m depth experienced in 2020 (see **Figure III-3**).

[29] September 2002 to August 2003

[30] June 2012 to September 2012

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

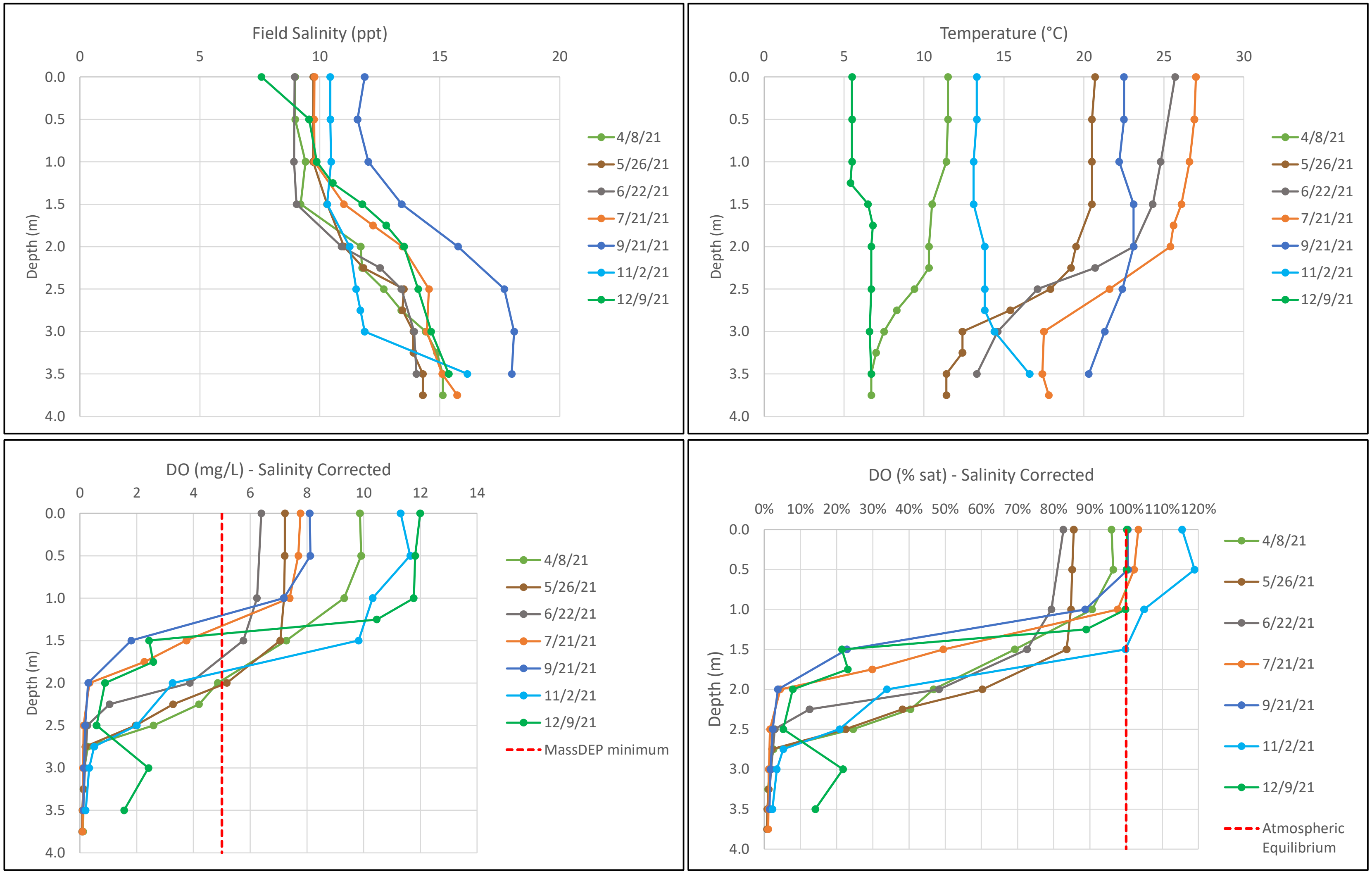


Figure III-3. Cedar Pond 2021 Salinity, Dissolved Oxygen, and Temperature Profiles. 2021 temperature profiles generally showed relatively isothermic conditions throughout the water column except for the May, June, and July profiles, which showed strong stratification deeper than 2 m depth. In contrast, salinity profiles showed isohaline concentrations to 1 m or 1.5 m depth. DO readings were generally consistent with this salinity stratification with similar, acceptable concentrations in the upper, well-mixed, lower salinity layer and hypoxic or anoxic concentrations in the higher salinity, deeper layer. Shallow 2021 DO readings were improved over 2018, 2019, and 2020 levels; none of the readings in the upper 1 m were less than the MassDEP minimum threshold for the first time in the four years of monitoring. Saturation levels showed, however, that sediment oxygen demand was impacting the shallowest waters in May and June and phytoplankton in early November created DO concentrations in excess of atmospheric equilibrium.

Salinity levels were similar from April through July, but the September 2021 shallow salinity was 11.9 ppt, while the September 2020 salinity was 15.8 ppt. Salinity in the subsequent 2021 profiles remained lower than 2020 (*e.g.*, 0.5 m salinity on December 9 was 9.6 ppt). However, none of the 2021 salinity profile readings were within the 1 to 4 ppt Cedar Pond Management Plan target range.

DO profiles in 2021 showed some marginal improvements over 2020 profiles, but still had summer anoxia in deeper waters. All 2021 DO readings in individual profiles at the surface, 0.5 m, and 1 m were greater than the MassDEP 5 mg/L minimum (see **Figure III-3**). This is an improvement over monitoring from all previous years; all three previous years had at least two profile dates where DO <5 mg/L was recorded at 1 m depth. DO readings at 1.5 m in 3 of the seven 2021 profiles had concentrations <5 mg/L and anoxia (<1 mg/L) regularly occurred at depths of 2 m and deeper. DO readings in the 2021 profiles were an improvement over 2020 profiles and both 2020 and 2021 profiles were improvements over 2018 and 2019 profiles. Individual 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.

Salinity stratification seemed to be the key for the minimum depth of anoxia. Salinity concentrations shallower than 1 or 1.5 m depth (depending on the individual profile) were similar, which indicates well-mixed conditions. Well-mixed conditions mean regular atmospheric contact within this layer to replenish any diminished DO. Waters deeper than 2 m do not mix substantially into the upper layer because of the salinity difference and the sediment oxygen demand and organic matter decay in the water column consumes most of the deep DO creating anoxic conditions. The 2021 salinity pattern was similar to previous years. Although the individual profiles show strong salinity stratification, review of DO % saturation levels in the profiles show that waters in the well mixed shallow layer are often less than 100%, which shows that oxygen uptake in the deep waters was impacting the entire Cedar Pond water column even with the salinity stratification (see **Figure III-3**). This decreased % saturation throughout the water column is something that has been relatively consistent across all four years (**Figure III-4**).

Collectively, the 2021 profiles suggest that water column salinity differences mostly isolated portions of the water column at 1.5 m and deeper and this isolation led to hypoxia and anoxia in these deeper waters. If temperature alone controlled water column layering, low DO would be limited to depths 2.25 to 2.75 m and deeper. Lower salinity conditions in the upper 1 m led to acceptable DO concentrations (*i.e.*, were greater than the MassDEP minimum) in these shallow waters in all 2021 DO profiles for the first time in the four years of monitoring. DO conditions in the deeper water continue to experience anoxia and this anoxia regularly lowers DO concentrations in the upper water column as well.

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

Regular monthly profile samplings of key nutrient related water quality parameters throughout the water column provide valuable insights into habitat quality, but often fail to capture rapid changes and miss transitory, but meaningful, ecological events that can occur between snapshots. The Management Plan monitoring addressed this issue through the use of autonomous recording devices that measure DO, salinity, chlorophyll a and water depth every 15 minutes. Two of these devices (shallow and deep) were installed over the deepest spot in the pond and have been

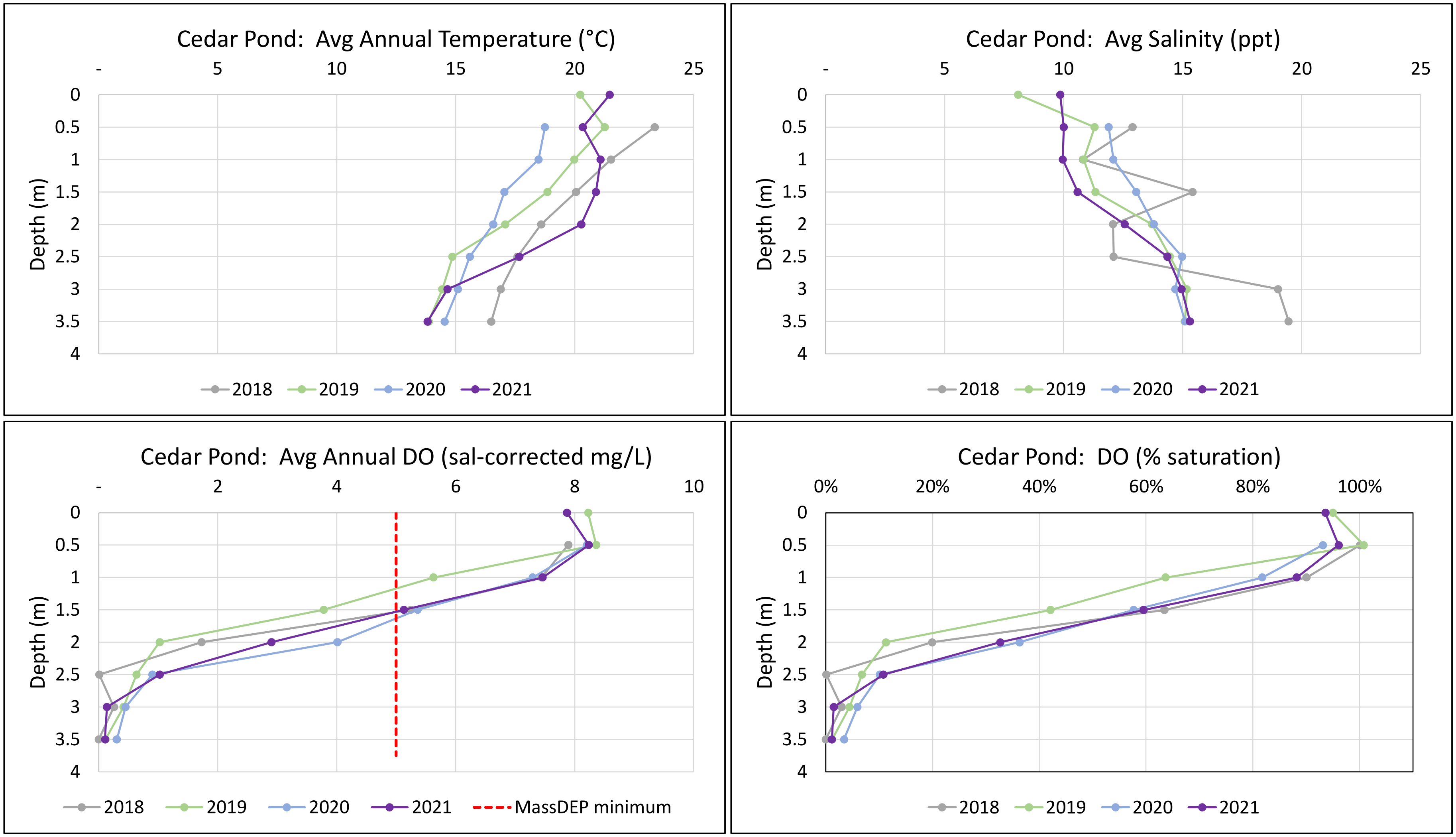


Figure III-4. Average 2018, 2019, 2020, and 2021 Water Column Temperature, Salinity, Dissolved Oxygen, and DO % Saturation (April to October). Comparison of water column profile data showed that 2019, 2020, and 2021 generally had similar conditions in the deep portions of the water column (≥2.5 m) with lower deep temperatures and salinity than 2018. Shallow 2021 waters were warmer than 2020, but generally had lower salinity, and slightly higher DO concentrations. Average 2021 DO concentrations from the surface to 1.5 m were above the MassDEP 5 mg/L minimum and average salinities in these waters were the lowest among the four years. DO % saturation levels generally show that average sediment oxygen demand impacts the whole water column with average saturation at all depths below 100% (*i.e.*, atmospheric equilibrium). Overall, 2021 slightly increased the improved shallow DO concentrations achieved in 2020, but waters deeper than 1.5 m continued to be impaired and higher in salinity.

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.[32] In 2021, the shallow and deep continuous devices were in place throughout the year with average continuously measured depths of 1.2 m and 3.6 m, respectively. These are approximately the same depths for these sensors in the 2018, 2019, and 2020 deployments.

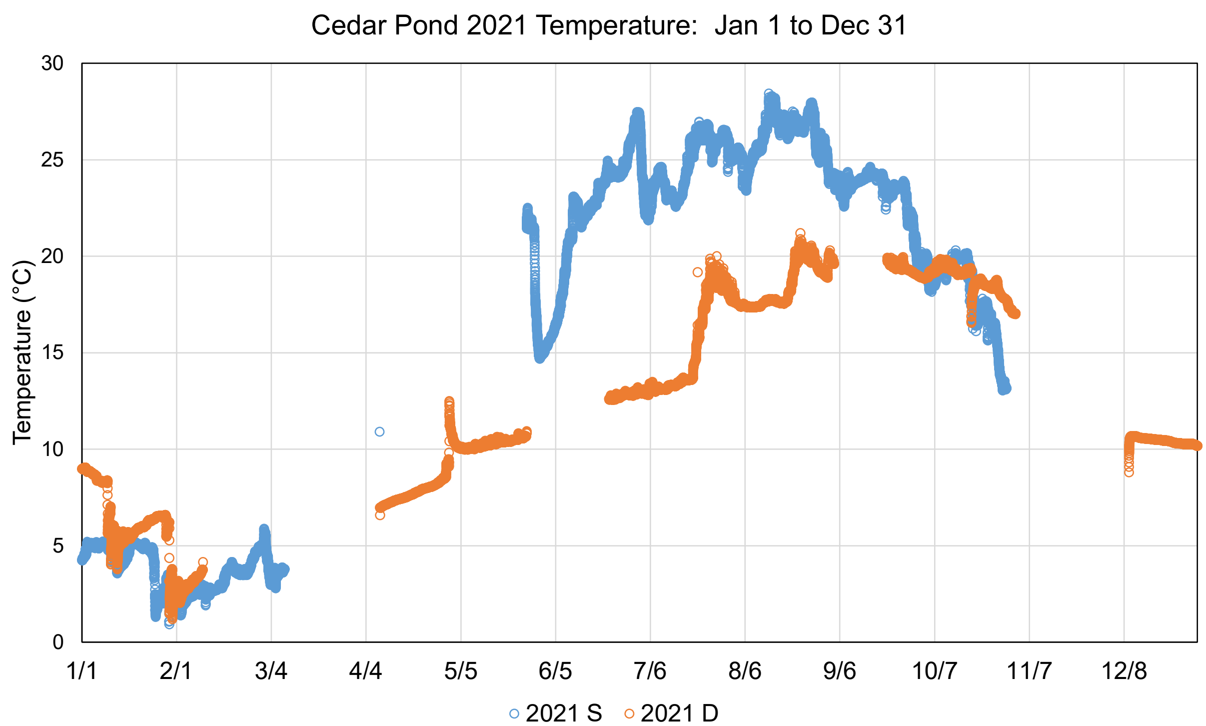
Continuous temperature readings during 2021 showed the warming of the water column during the summer and how temperature stratification varied. Logger failures produced gaps in the recordings, but January readings showed that deep waters were generally warmer than shallow waters (average temperatures of 6.4°C and 4.3°C, respectively) (**Figure III-5**). In limited readings in February and March, averages of available data were similar, but by May the average shallow temperature was 8°C warmer than the deep temperature due faster warming in the pond water compared to Cape Cod Bay inflows. In subsequent months, the difference between average shallow and deep temperatures gradually decreased and was less than 1°C by October, which is the last month when both recorders were operating.

Review of temperature differences at the two depths showed that readings in June, July, August, and most of September were significant enough to prevent mixing between 1.2 m and 3.6 m depths. On September 30, the temperatures at the two depths became similar enough that water column mixing between the two depths could occur if salinity would allow. By October 20, the shallow temperatures had again become colder than the deep temperatures and there was a period of intermittent temporary stratification events until October 25. On October 25, the difference between the shallow and the deep temperatures was sufficient to sustain stratification with warmer deep waters and this was consistent through the end of October, when the shallow sensor record ended. This difference was also reflected in the 11/2 temperature profile, which had a 14.4°C reading at 3 m and a 16.6°C reading at 3.5 m (see **Figure III-3**). In 2020, temperature differences at the two recording depths after early November were not sufficient to sustain thermal stratification.

Average summer 2021 temperatures were lower than 2020 early in the summer, but higher than 2020 in the late summer (**Table III-3**). Average shallow and deep temperatures in June/July 2021 were lower than 2020 (-1°C and -1.7°C, respectively). These 2021 readings were warmer than 2019. In August/September 2021, average shallow temperatures were much higher than 2020 (+1.6°C), but average deep temperatures were similar (18.7°C in 2021 and 18.6°C in 2020). The higher shallow late summer temperatures were comparable to those measured in 2018.

Salinity differences were sufficiently different in all 2021 continuous readings to prevent mixing between the 1.2 m and 3.6 m depths throughout the year. Average summer 2021 salinities were comparable to 2020 with slightly lower surface salinity in June/July 2021, but slightly higher surface salinity in August/September 2021. Average shallow and deep summer salinity levels in 2021 generally approximated those in both 2019 and 2020, while all three years were notably lower than in 2018. Salinity levels are a complex mix of current and previous months tidal and watershed groundwater inputs. Groundwater levels in June, July, and August 2021 were below average and notably less than during 2020 (**Figure III-6**). At the same time, higher tidal elevations occurred more often in July to September 2021 (see **Figure III-2**). Lower groundwater inputs and greater tidal inputs would tend to increase salinity levels, which was notable in late summer averages (see **Table III-2**).

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



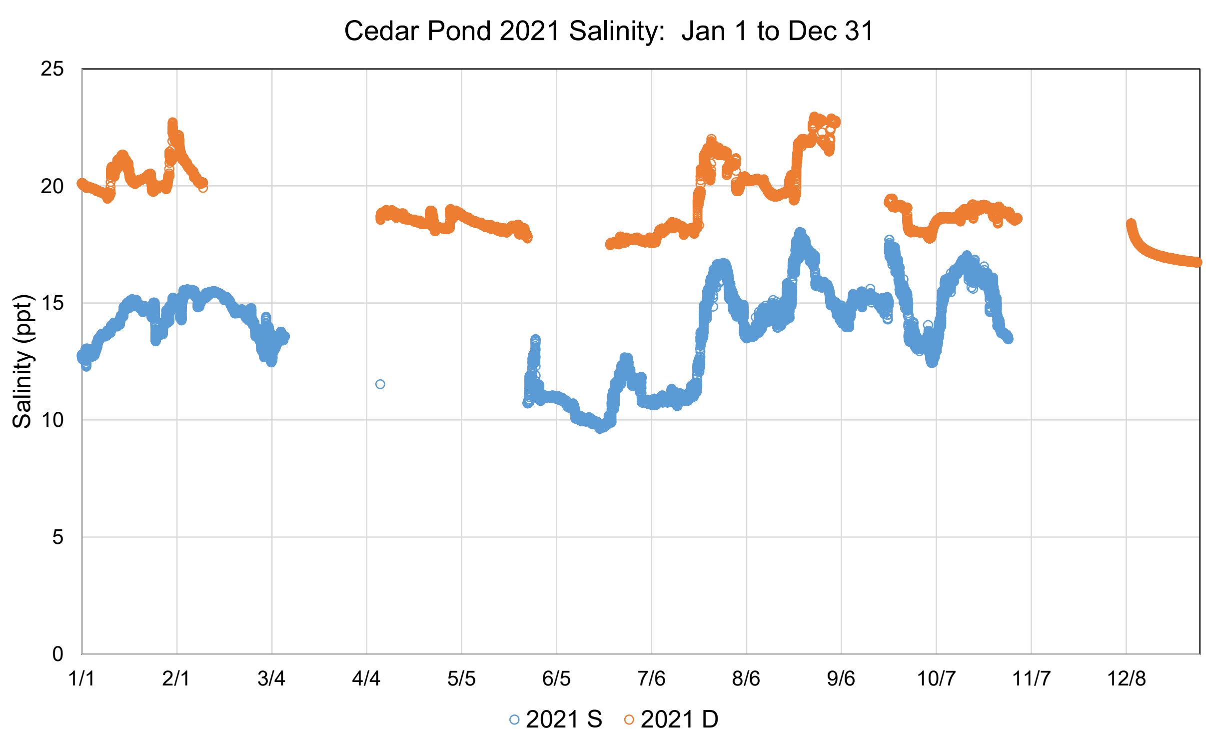


Figure III-5. Cedar Pond 2021 Continuous Temperature and Salinity Readings. Continuous recorders located in the main basin at averages depths of 1.2 m and 3.6 m recorded temperature and salinity readings every 15 minutes. Gaps in the record were caused by recorder failure. Shallow and deep temperatures were sufficiently different during June, July, August and most of September to prevent mixing of the water column between the two depths. Similar differences occurred in January and late October, but deep temperatures were warmer than shallow temperatures during these periods. Salinity differences were sufficiently different in all 2021 readings to prevent mixing between the upper and lower water column.

Table III-3. Summer Continuous Recording Averages in Cedar Pond (2018-2021). 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.*, 1.2 m S and 3.6 m D). 2021 shallow salinity average was lower in June/July, but August/September average was similar to comparable 2019 and 2020 averages. Summer salinity and temperature differences were sufficiently large enough to prevent water column mixing between the depths of the two sensors. This lack of mixing contributed to average deep anoxic conditions. Continuous DO readings at 1.2 m began to become unreliable and inconsistent with 2021 profile measurements in July and this issue persisted throughout the rest of the 2021 deployment.

Notes:

1. Water column profile 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.

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

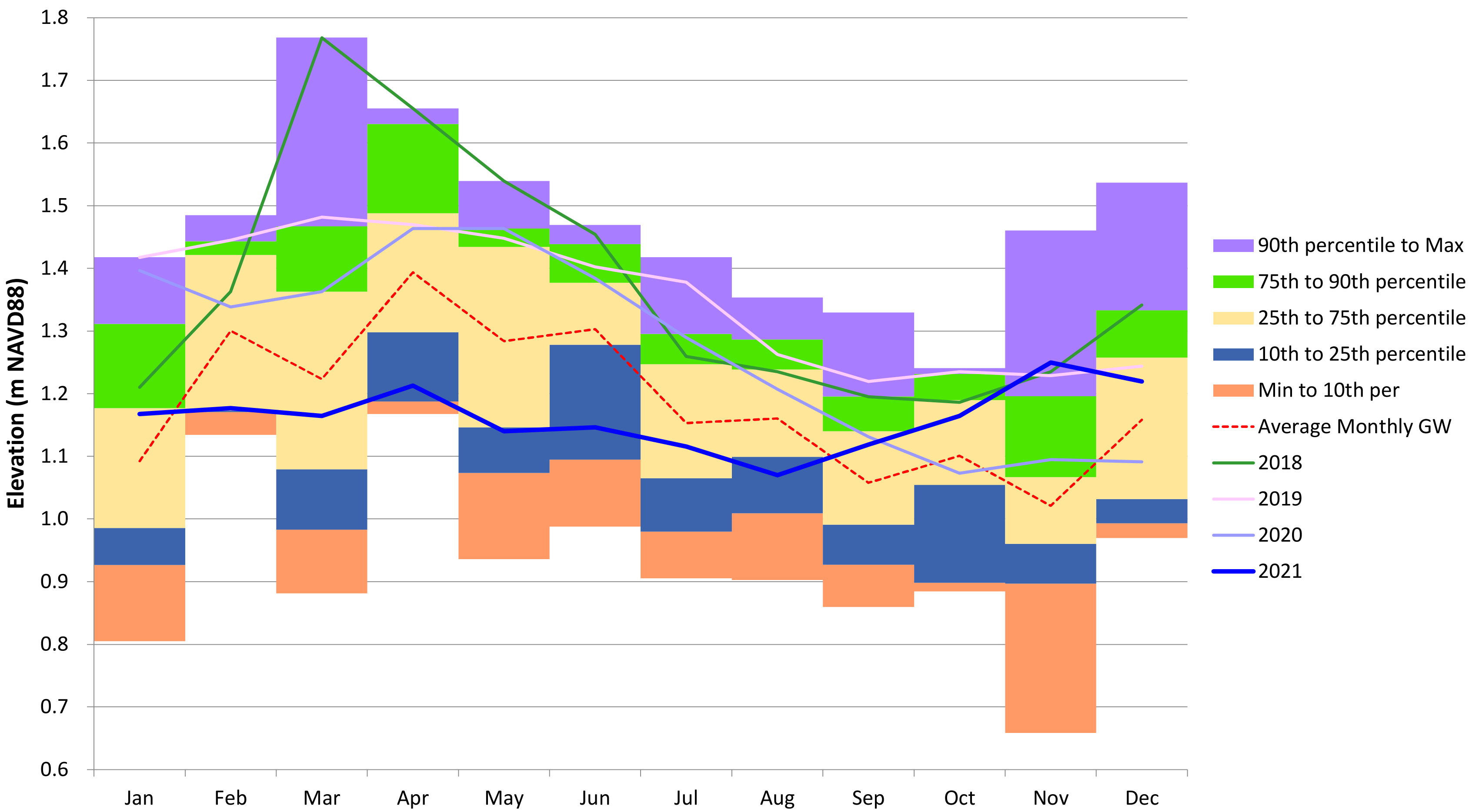


Figure III-6. Orleans Groundwater Elevations (OSW-22). Groundwater levels in Orleans have been above average throughout almost all of the monitoring associated with the Cedar Pond Management Plan implementation (2018-2020), but late in 2020 groundwater elevations in Orleans decreased to average conditions and then were below average until August in 2021. 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. Groundwater levels in 2021 through August tended to be lower than the 25th percentile of historic water levels. Beginning in September 2021, groundwater levels increased above historical average, including rising above the 90th percentile in November. Data source: nwis.waterdata.usgs.gov/nwis/gwlevels?.

Comparison of long-term groundwater and sea elevation levels show that groundwater levels are increasing faster than current sea level rise and this is something that will continue to be monitored for management purposes. Groundwater elevations have been regularly measured at monitoring well OSW-22 since 1975; OSW-22 is located just east of Town Cove. Review of this historical data through February 2022 shows notable scatter, but a statistically significant increasing trend (+6.5 mm/yr; F test, $\rho<4.2E-25$) (**Figure III-7**). This rate would result in a 2.6 inch increase in groundwater levels after 10 years. This rate is also more than double the current regional sea level rise rate (+2.89 mm/yr).[33] Since the sea level rise and regional precipitation are projected to increase with time based on current climate models,[34] monitoring of these changes will be important to check regularly against board elevations, tidal inputs, and salinity levels.

Review of salinity readings in 2018, 2019, 2020, and 2021 show that the lowering of the boards regularly causes both shallow and deep water salinities to increase throughout the summer and review of the rate increases show that they are similar every year (**Figure III-8**). In June to August 2021, shallow salinity levels increased at a statistically significant rate of 0.08 ppt per day. This rate is within the same range of salinity increases measured in 2018 and 2020: 0.06 to 0.09 ppt per day.[35] This increasing rate occurs each year during the period when board elevations are lowered to allow fish passage: March 15 to November 15. The consistency of this annual salinity increase shows that once boards are lowered, higher salinity tidal inputs have a larger impact on water column salinity levels than can be offset by fresh groundwater inputs. Having lower tidal inputs, especially during the summer is the key to achieving the lower salinity goals specified in the Cedar Pond Management Plan for achieving water quality improvements.

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33 Boston sea level measured since 1920s: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8443970 (accessed 3/17/22)

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

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

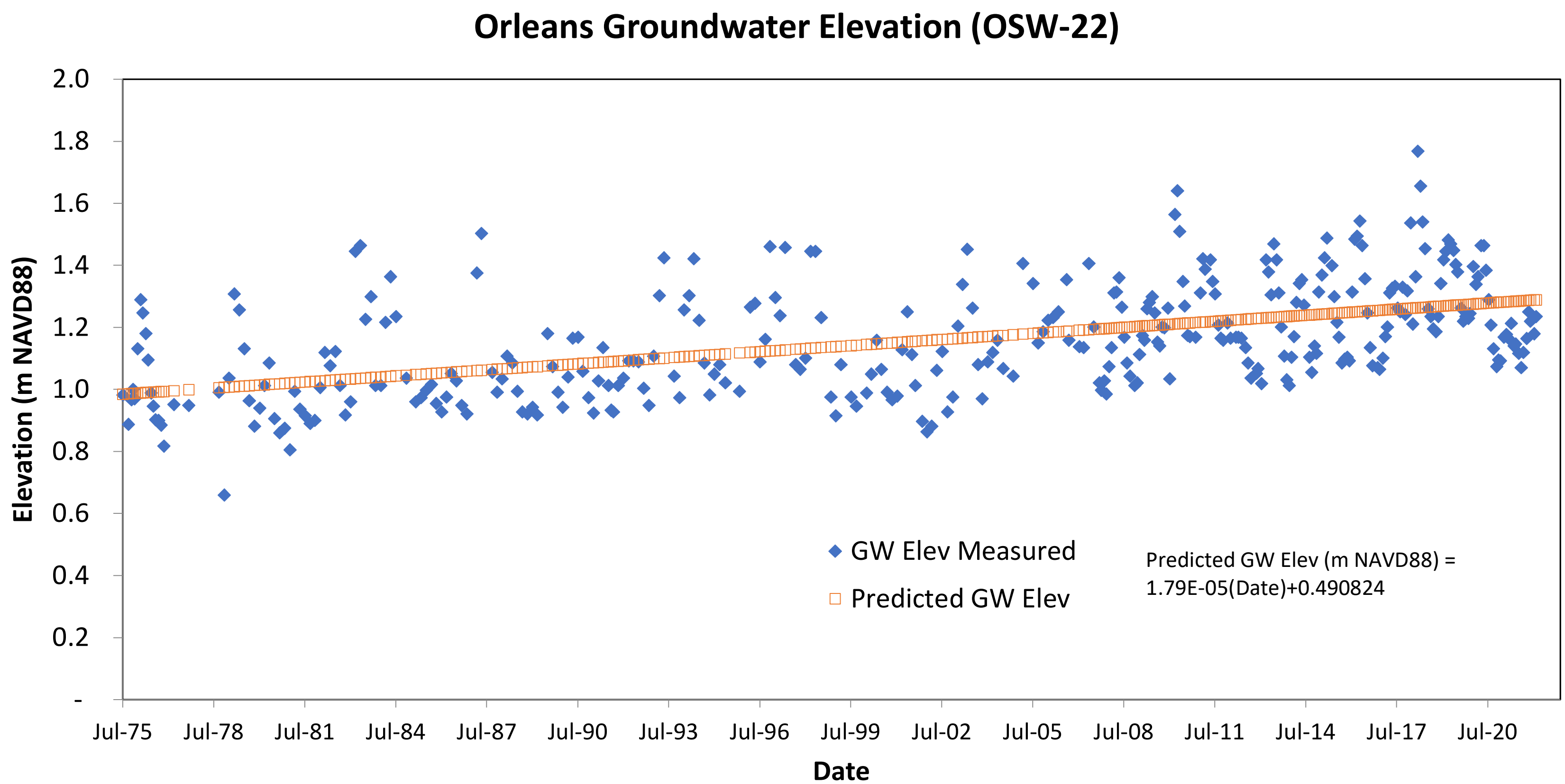
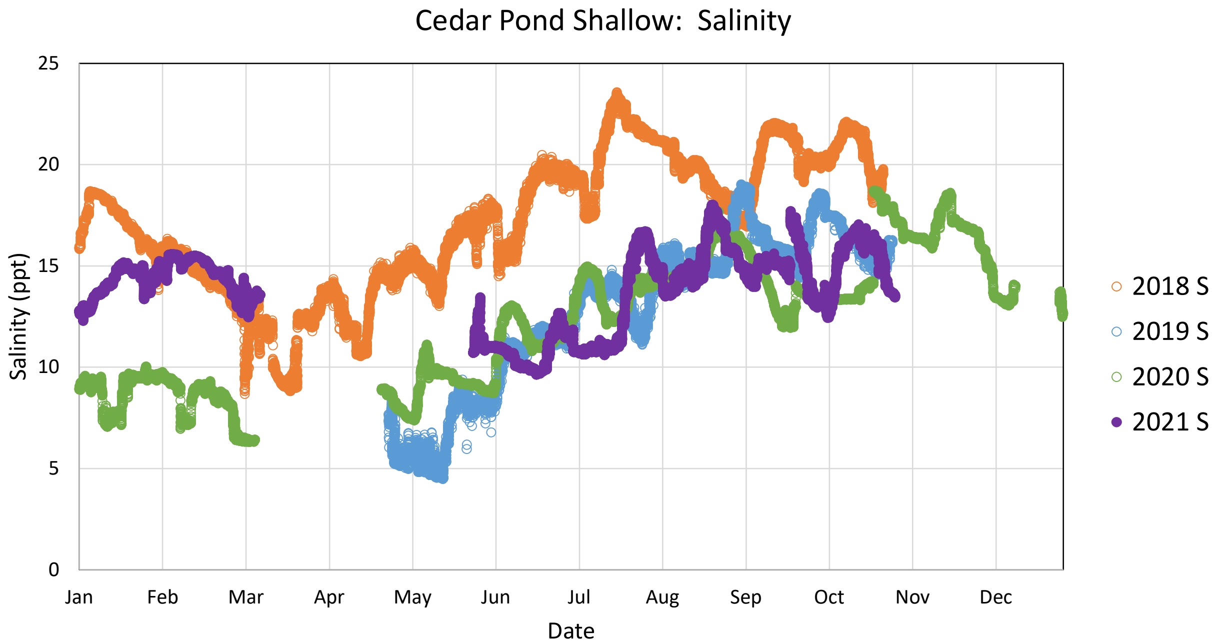


Figure III-7. Long-Term Groundwater Elevations in Orleans (July 1975 to February 2022). Groundwater levels in Orleans have been slowly increasing at a statistically significant rate (+6.5 mm/yr). This rate is greater than regional sea level rise (+2.87 mm/yr), which has been recorded since the 1920s. The combined impact of these increases would result in an additive impact on water levels in Cedar Pond, but should allow the freshwater inputs on average to attain the goal of decreasing salinity in the pond provided the elevation of the boards at the pond outlet is regularly reviewed and set at an appropriate level. As noted in the scatter of the groundwater levels, variations from year-to-year and season-to-season can still have significant, but with shorter term, impacts.
Data source: nwis.waterdata.usgs.gov/nwis/gwlevels?



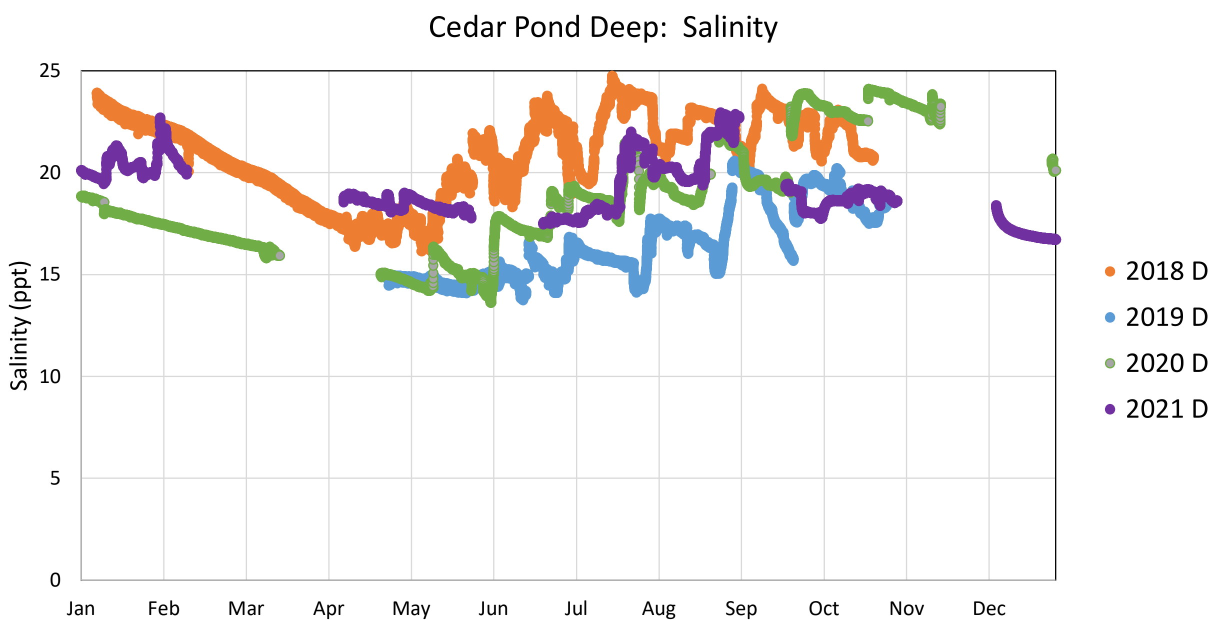


Figure III-8. Continuous Shallow and Deep Salinity at Cedar Pond (2018 – 2021). Salinity readings show that the lowering of the boards during the summer regularly causes both shallow and deep salinity to increase. Shallow salinity levels in all four years increased at approximately the same rate (0.06 to 0.09 ppt per day) between April/May and August once the inlet boards are lowered. Deep salinity readings generally follow a similar pattern, though the rate of change is lower. Since the rate of change is similar in all four years, the early summer starting salinity is a key factor determining salinity throughout the summer and shows that lowering board elevations essentially resets the pond to higher salinity levels every summer. This finding suggests that boards should be kept at a relatively high elevation between November 15 and the installation of the notch in March 15 in order to sustain lower salinity readings throughout the summer. It also suggests 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.

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

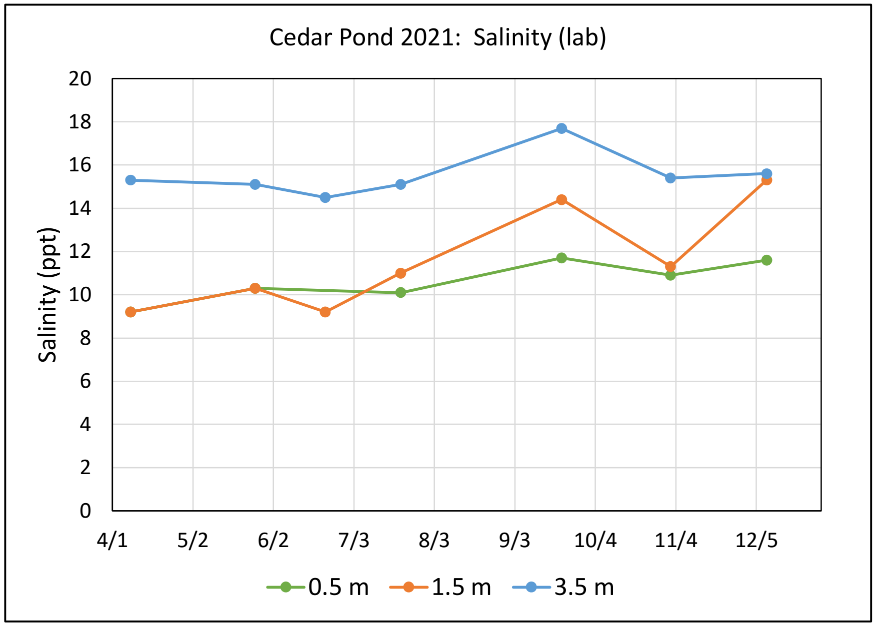
Water quality samples were collected in tandem with the temperature and oxygen profiles (see **Figure III-3**). Water samples were generally collected at shallow, middle, and deep depths: averaging 0.15 m, 1.5 m, and 3.5 m, respectively. The middle and deep depths approximate the sensor depths of the continuous recorders (1.2 m and 3.6 m, respectively). All collected samples were assayed at the Coastal Systems Analytical Facility at SMAST using the same assays that have been utilized for all Cedar Pond and MEP assessments, including those for the Cedar Pond Management Plan and all its subsequent monitoring/reporting. Sampling procedures and chemical assay methods are presented in the Town's QAPPs for freshwater[36] and estuarine[37] water quality monitoring. Samples were analyzed at the laboratory for the following constituents: salinity, ortho-phosphorus, total phosphorus, ammonia-nitrogen, nitrate+nitrite-nitrogen, dissolved organic nitrogen, particulate organic nitrogen, particulate organic carbon, chlorophyll-a, pheophytin-a, and specific conductivity.

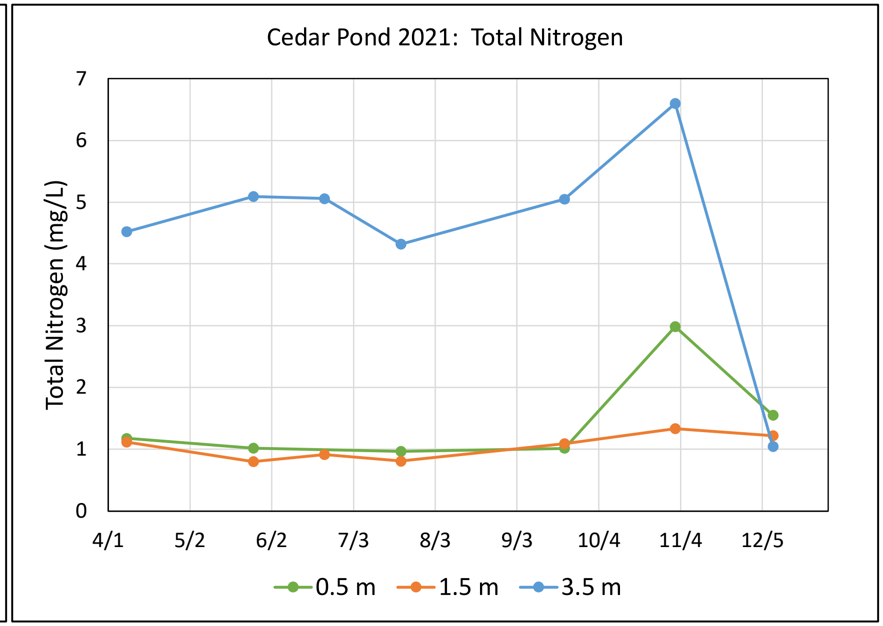
Profile samples in 2021 generally showed that shallow and middle depths had similar concentrations of various constituents and these shallower concentrations were usually significantly lower than deep samples concentrations except for particulate fractions, which tended to be similar throughout the water column (*i.e.*, no statistical difference in averages at the various depths; $\rho>0.05$, T test). Laboratory salinity concentrations followed the same pattern with no significant difference between 0.5 m and 1.5 m averages (10.3 ppt and 10.8 ppt, respectively), but both shallow averages were significantly lower than the 15.5 ppt salinity average in the deep (3.5 m) water. All 2021 TN and TP concentrations showed that Cedar Pond was significantly nutrient-impaired, as it was in all previous annual assessments (2018-2020). Nutrient concentrations at 0.5 m and 1.5 m tended to be similar, while deep concentrations tended to be 2 to 3 times higher than then shallower concentrations (**Figure III-9**).

Notable changes in 2021 compared to previous years were decreases in average TP concentrations at 0.5 m and 1.5 m and large increases in 3.5 m average TP and TN concentrations compared to 2020 (**Figure III-10**). Average 2021 TP concentrations at 0.5 m and 1.5 m were the lowest among the four years of monitoring, but the 3.5 m average was the highest among the four years. In 2020, the April-October 0.5 and 1.5 m TP averages were 235 µg/L and 255 µg/L, while in 2021 they were 160 µg/L and 171 µg/L, respectively. Corresponding 2019 TP averages were 206 µg/L and 326 µg/L, respectively. Deep TP concentrations in 2019, 2020, and 2021 were 764 µg/L, 547 µg/L, and 947 µg/L, respectively. Since deep TP is so strongly tied to DO availability, the high 2021 deep TP concentration was likely due to stronger salinity stratification resulting in more persistent anoxia. Stronger salinity stratification between shallow and deep depths would restrict water column mixing and prevent introduction of atmospheric oxygen to the deep portions of the water column. Adequate DO would tend to bind P into solids that would settle or remain in the sediments, while prolonged anoxia would allow more TP to be solubilized and added to the water column. During August 2020 there was a mixing of the water

[36] 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.

[37] 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.





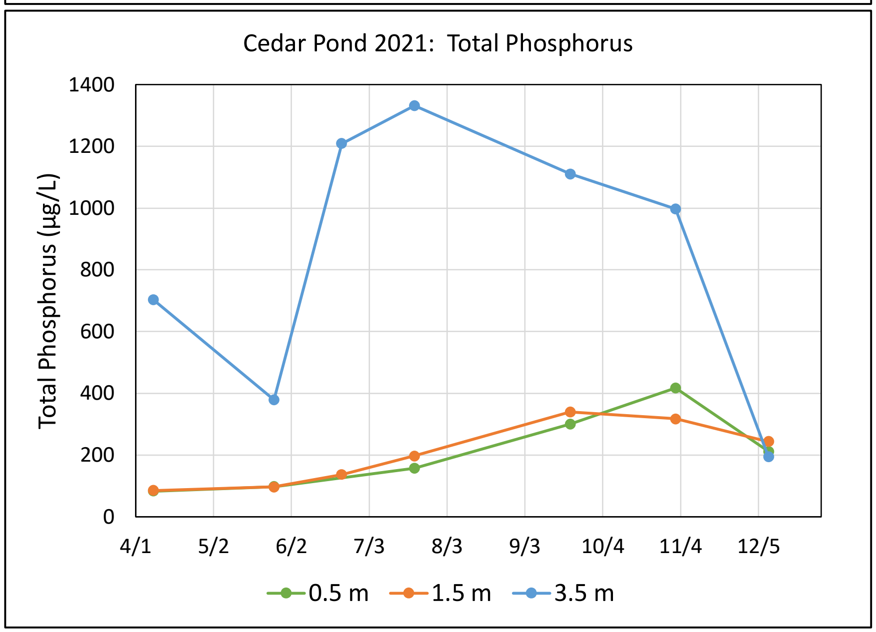


Figure III-9. Cedar Pond 2021 Water Column Salinity, TP, and TN. Shallow and deep 2021 salinity readings did not increase like previous years (to >20 ppt), although continuous readings did show an increase. TN concentrations at 0.5 m and 1.5 m were relatively consistent (~1 mg/L), while 3.5 m was significantly higher with an average of 4.8 mg/L. TP concentrations at 0.5 m and 1.5 m increased through at least September, while 3.5 m TP averaged >5X higher. Significantly higher deep TP and TN concentrations ($\rho<0.05$; T test) were likely due to strong salinity stratification and uninterrupted deep anoxia. N:P ratios were not significantly different at all depths averaging 19, 16, and 14 at 0.5 m, 1.5 m, and 3.5 m, respectively. N:P ratios in individual profiles were phosphorus sensitive in April (*i.e.*, ~30), decreased to co-nitrogen and phosphorus sensitivity in May and June, and were then nitrogen sensitive (<16) throughout the rest of 2021 samples.

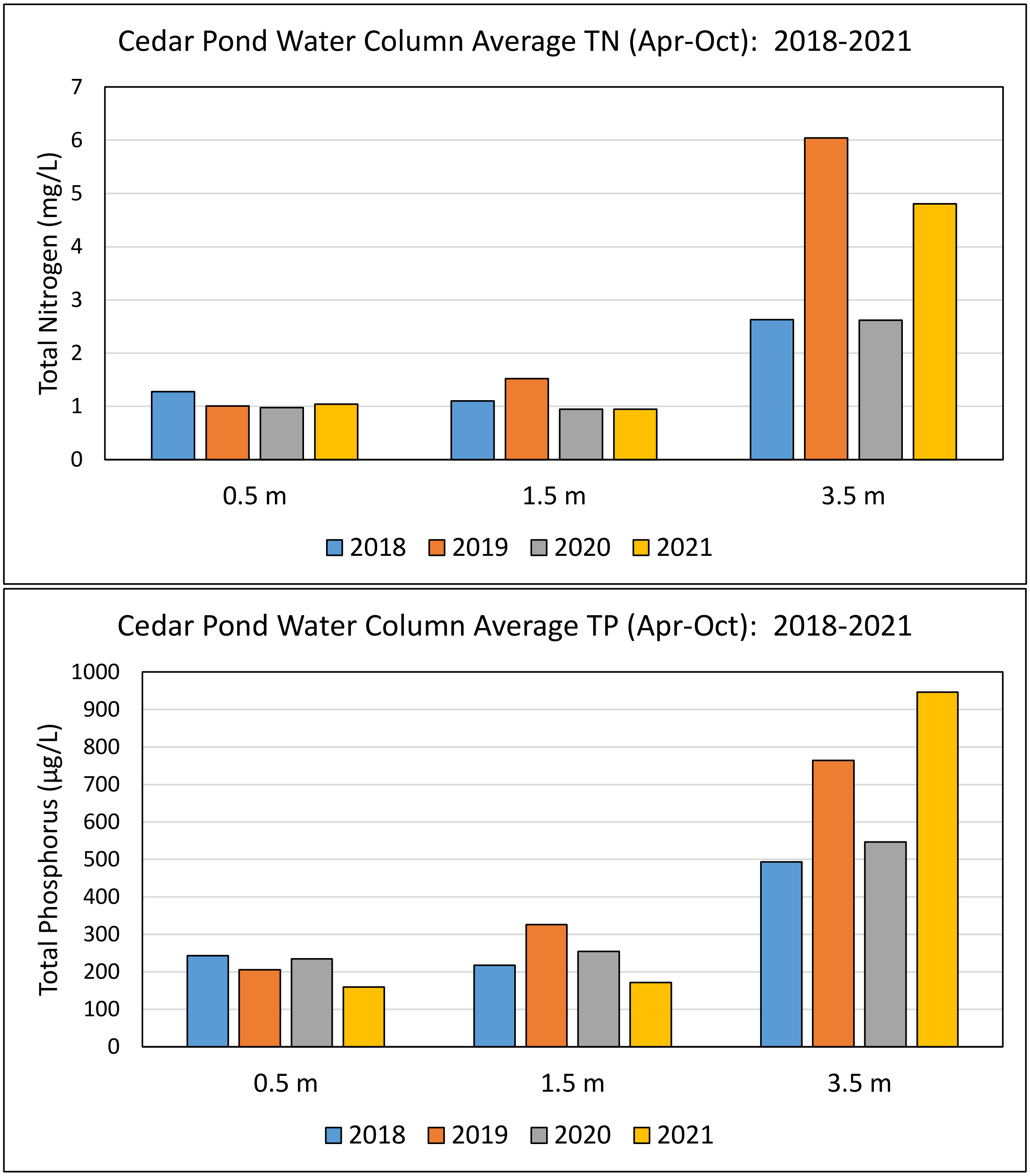


Figure III-10. Cedar Pond Average Water Column TN and TP (April-October): 2018-2021. Average TN concentrations at 0.5 m have been relatively consistent since 2019 (~1 mg/L), while average 1.5 m TN concentrations have been consistent since 2020 (~0.9 mg/L). Average 0.5 m and 1.5 m 2021 TP concentrations decreased significantly compared to 2020 (-32% and -33%, respectively). Deep 3.5 m TN and TP increased notably compared to 2020, likely due to stronger salinity stratification and resulting more consistent anoxia.

column to 3.5 m that would have decreased the sediment TP addition to the water column. During 2021, salinity readings at the two continuous recorders showed no instances where salinity readings at 0.5 m and 3.5 m were similar enough to allow mixing of the water column between the two depths. Stronger stratification would also limit the transfer of the higher deep TP concentrations to the shallower portions of the water column, which would also be consistent with the measured low 2021 shallow TP concentrations.

Average 2021 TN concentrations at 0.5 m and 1.5 m were similar to 2020 (*i.e.*, approximately 1 mg/L), while the 3.5 m average TN concentration was 4.8 mg/L (compared to 2.7 mg/L TN average in 2020). The 2021 0.5 m TN concentration matches the 2019 and 2018 averages (1.0 and 1.1 mg/L, respectively), but the 2021 1.5 m TN of 0.9 mg/L is lower than the 2019 and 2018 TN averages (1.4 and 1.2 mg/L, respectively). Deep 3.5 m average TN concentrations in 2019 and 2018 were 5.6 mg/L and 3.2 mg/L, respectively. This pattern of alternating high and low deep TN averages matches the pattern seen in the TP concentrations and suggest that prolonged anoxia is also causing increased TN release from the sediments.[38] The majority of the TN at 3.5 m (72%) was ammonia-N (consistent with N sediment regeneration), while the majority of TN at 0.5 m and 1.5 m was dissolved organic N (58% and 56%, respectively, and consistent with senescing/degrading phytoplankton). DON levels were slightly lower than at the Rock Harbor creek and marsh sampling stations[39] suggesting that DON is being retained in the pond or precipitating out at the salinity of the creek water. Review of the 2021 N:P ratios showed that there was no significant difference between shallow and deep averages. This suggests that TN and TP were released from the sediments in similar amounts. It also largely confirms that even with changes in component concentrations that TN and TP in the sediments and water column have similar source material.

It is also notable that laboratory salinity readings from the profiles were more stable in 2021, likely due to a combination of the differences in groundwater discharge and the board elevations in 2021. Salinity levels began April 2021 at higher concentrations, but only had the notable increases seen in past years in the 1.5 m samples. Salinity levels at 0.5 m and 3.5 m only varied by 2-2.5 ppt and did not attain >20 ppt measured in past years.

Comparison of TN and TP concentrations showed that the water column, both shallow and deep, tended to be more nitrogen sensitive, especially during the summer. N:P ratios in April at 0.5 m and 1.5 m were 31 and 29, respectively, indicating stronger sensitivity to phosphorus additions, but as the summer progressed these shallow ratios decreased to well below the Redfield ratio (16) indicating that nitrogen was determining water quality conditions (**Figure III-11**). Minimum 2021 N:P ratios at the two shallow depths occurred in September (7.5 at 0.5 m and 7.1 at 1.5 m). Shallow N:P ratios in 2021 were slightly lower early in the season than 2020 indicating relatively greater availability of TP, but were slightly higher during late summer (August and September). Minimum N:P ratios in 2020 occurred in August, but August 2021 samples were not available for comparison. Nutrient sensitivities were similar to those measured

[38] Enhanced TN release from the sediments under anoxia frequently results from the shutdown of nitrification and denitrification, while the stratification contains the release N in the deep waters.

[39] Eichner, E and B. Howes. 2018. Town of Orleans Estuaries: Water Quality Monitoring Database Development and Review. Technical Report, Coastal Systems Program, School for Marine Science and Technology, University of Massachusetts Dartmouth. New Bedford, MA. 95 pp.

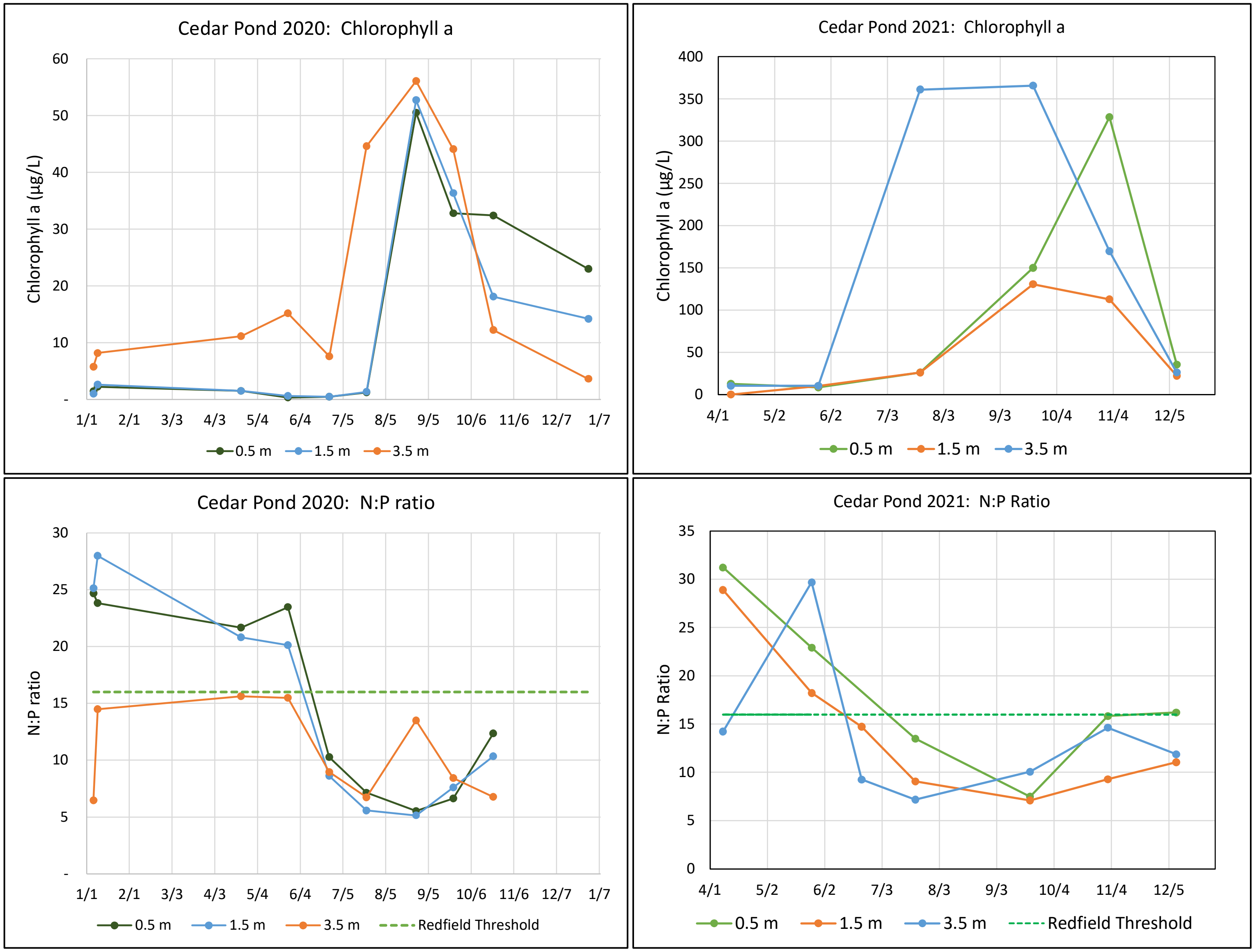


Figure III-11. Cedar Pond 2020 and 2021 Water Column Chlorophyll and N:P ratios. 2021 chlorophyll a concentrations were notably higher throughout the water column than 2020. Increases in chlorophyll a concentrations during the summer in both years corresponded to the increase in salinity (*i.e.*, the lowering of the boards at the outlet) and greater sensitivity to nitrogen. N:P ratio had similar profiles in 2020 and 2021, although 2021 ratios during the summer were slightly higher. N:P ratios during the summer in both years show that nitrogen availability determines water quality and ecosystem conditions.

in 2019, except for deep 2019 conditions were more phosphorus sensitive. As the Town considers further management actions to meet the Management Plan goal to restore water quality and the herring run, these ratios, how they seasonally change, and the role the sediment play will help guide the town to applicable management options. In addition, given the importance of the sediments in generating the high TP levels in the water column and that the removal of the cormorants removed a large P source, it may be time to consider planning a sediment P reduction action.

Average 2021 chlorophyll concentrations were higher than those in 2020, but statistical comparison showed there was no significant difference largely due to the high natural variability in concentrations. Average April-October 2020 chlorophyll concentrations were 17 µg/L, 16 µg/L and 27 µg/L at 0.5 m, 1.5 m, and 3.5 m, respectively. Corresponding 2021 averages were 49 µg/L, 56 µg/L, and 187 µg/L, respectively (see **Figure III-11**). In 2021, chlorophyll a concentrations at all depths increased by >10X between April and September. At 0.5 m and 1.5 m depths, chlorophyll a concentrations in April were ~10 µg/L and increased by >10X by September (130 to 150 µg/L). By November 2, concentrations at 0.5 m more than doubled again (to 328 µg/L) before decreasing by ~90% to 35 µg/L on December 9. In 2020, chlorophyll a concentrations at 0.5 m depth started at a lower concentration (~1.5 µg/L in April) and increased by >30X, but only reached a maximum of 50 µg/L in late August. It is likely that the difference in the peaks is due to the timing of blooms and sampling, as well as higher chlorophyll background levels in 2021. Review of TN and TP concentrations did not seem to differ enough to explain the higher levels in 2021 and the chlorophyll a sensor did not provide continuously reliable data in 2021, so confirmatory sensor data was not available to check the water column results.

Collectively, 2021 water column water quality data continued to show impaired conditions in Cedar Pond which varied with fluctuations mostly in natural conditions. Shallow 2021 measurements showed reduced TP and similar TN concentration to those measured in 2020. Deep 2021 measurements showed increased TP and TN concentrations compared to 2020 likely related to more sustained anoxia in the deep waters caused by stronger salinity stratification. Summer water quality continued to be determined by nitrogen availability, but spring water quality continues to be determined by both nitrogen and phosphorus availability.

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

Streamflow has been measured in Cedar Pond Creek at the same location (just north of Route 6; see **Figure I-1**) continuously since November 2017. This is the same location used during: a) the 2003-2004 streamflow measurements for the MEP assessment of Rock Harbor,[40] b) for 2012 streamflow measurements for the development of the Cedar Pond Management Plan,[41] and c) throughout 2018[42], 2019[43], 2020,[44] and also 2021. Collecting the data continuously, at the same

[40] 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.

[41] 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.

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

location, and using the same measurement methods has allowed data from the various time periods to be directly comparable. In addition to the continuous readings, low tide instantaneous flow readings and water quality samples were collected 24 times during 2021, generally every two weeks.

During 2021, groundwater levels were lower than average from February through August and returned to above average conditions as existed in most of 2018-2020 for October through December (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 generally were consistent with the stage-flow curve developed from the prior readings. In 2020, as groundwater levels began to decrease, flow and stage measurements became less consistent with the previously established stage-flow relationship likely due to the difference 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 assessment rather than the continuous recordings and stage discharge relationship.[45] 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, project staff continued to utilize the 2020 procedures for determining average and annual flows.

Average monthly outflows in 2020 and 2021 were not significantly different, although there were some months where readings were notably different. In particular, September 2021 had the highest average monthly flow recorded among any month in the four years 2018-2021 of monitoring (**Figure III-12**). This flow was in large part due to the highest amount of precipitation (10.48 inches[46]) among any of the recent 48 months (**Figure III-13**). Average 2021 monthly outflow without September flows was 58,000 m^3/month, which closely matches the 2020 average of 52,000 m^3/month. Average monthly 2021 outflow was also not significantly different from 2019 (67,000 m^3/month), but was significantly less ($\rho<0.05$, T test) than the 2018 average outflow (159,000 m^3/month). All annual average monthly flows were greater than the MEP average flow in 2002/2003 (38,000 m^3/month).[47]

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[43] 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.

[44] 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.

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

[46] Recorded in Orleans; Station MA-BA-12 (south of Town Cove) in the COCORAHS network (https://www.cocorahs.org/ViewData/StationPrecipSummary.aspx; accessed 3/25/22)

[47] Howes and others. 2008. Rock Harbor MEP Report.

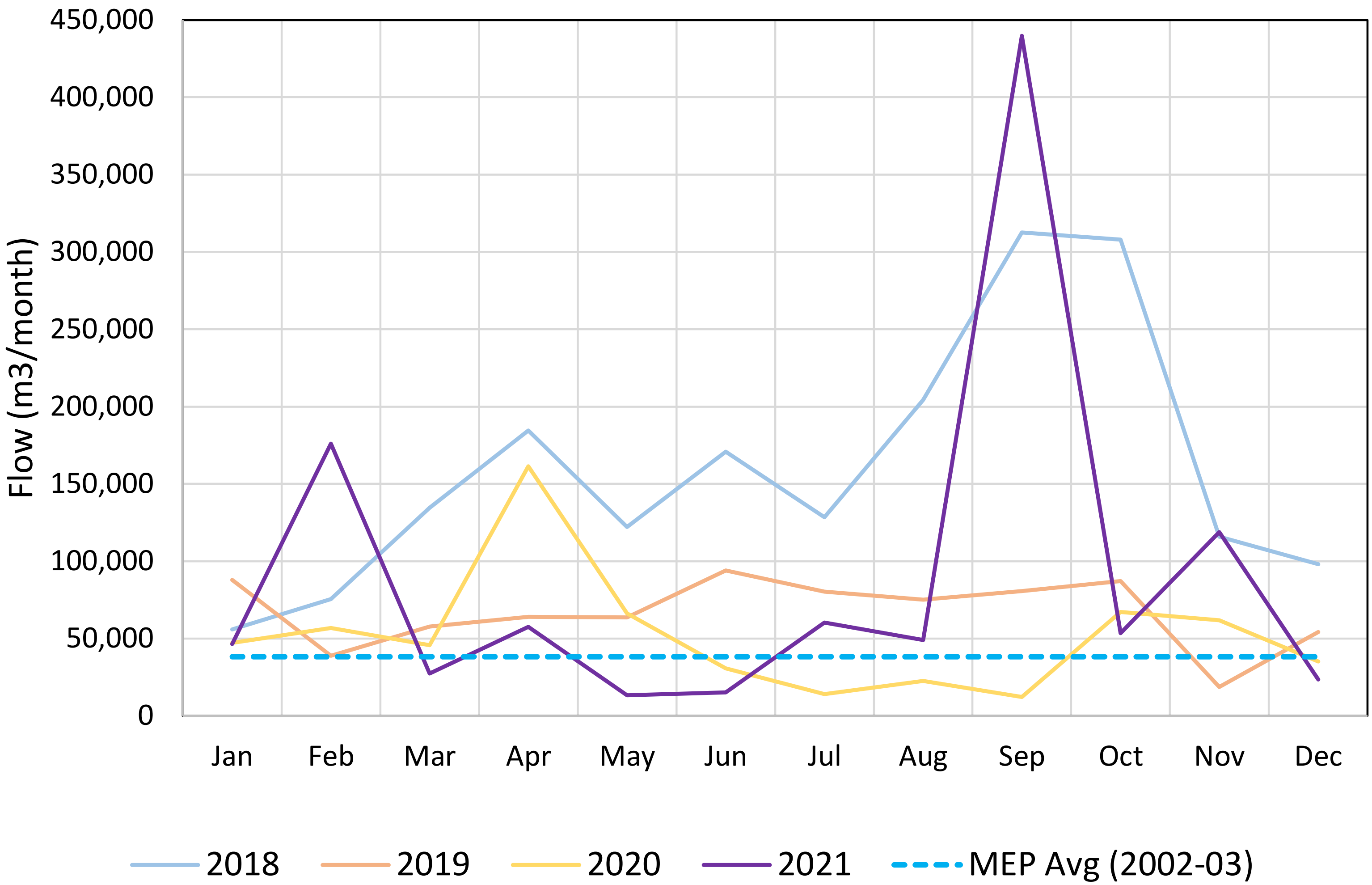


Figure III-12. Average Monthly Outflow through Cedar Pond outlet (2018-2021). Annual average monthly flow in 2021 was not statistically different from average flows in 2019 and 2020, even though September outflow was the highest flow (440,000 m^3/month) among all 48 months measured in 2018-2021. Average annual monthly flow in 2018 was statistically higher than the averages in the other years (2019-2021). Average monthly flow in 2018, 2019, 2020, and 2021 was 159,000 m^3/month, 67,000 m^3/month, 52,000 m^3/month, and 90,000 m^3/month, respectively. Average monthly flow in 2021 without the atypical September flow was 58,000 m^3.

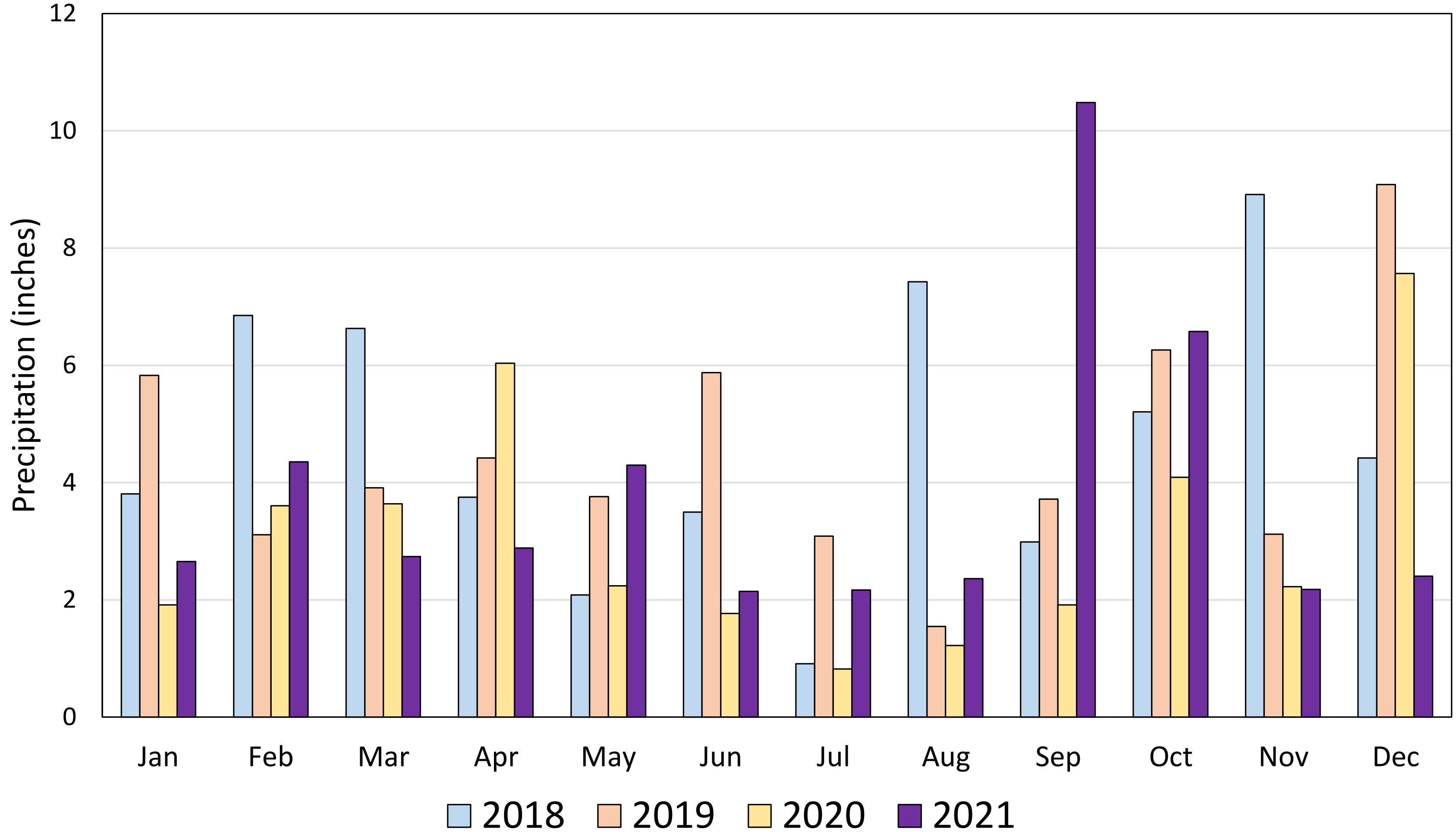
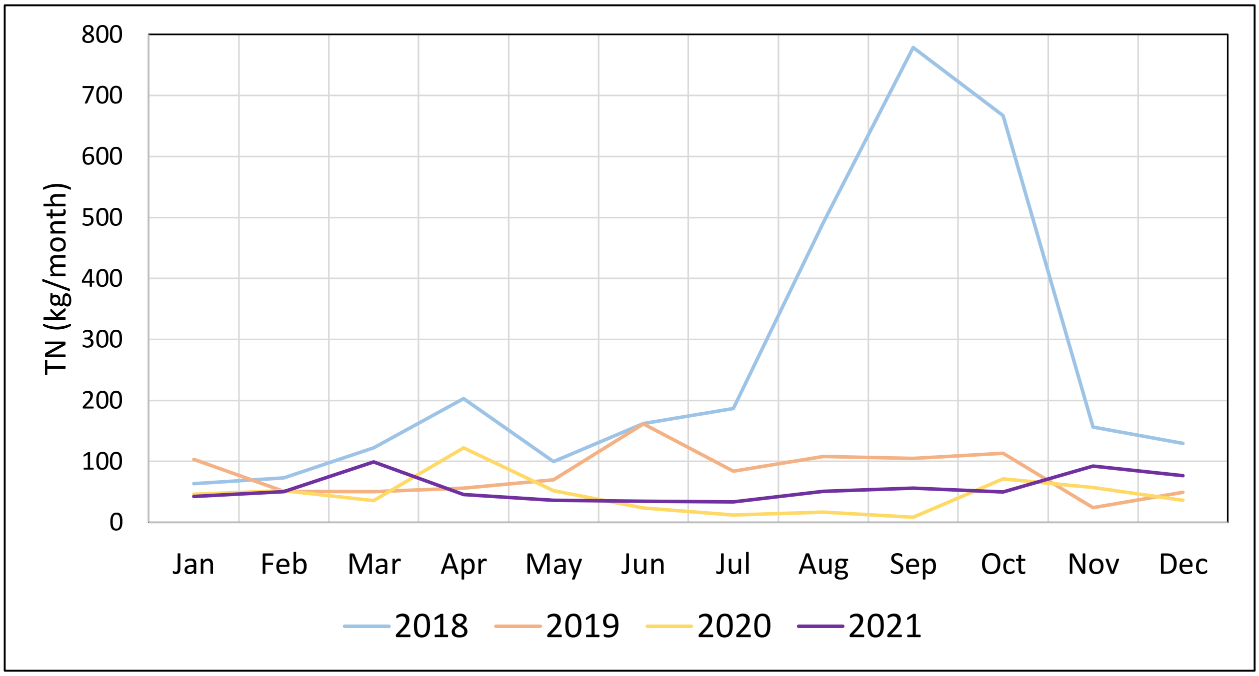


Figure III-13. Orleans Monthly Precipitation (2018-2021). Total annual precipitation in 2021 was 45.22 inches with 23% of the total occurring in September (10.48 inches). September 2021 precipitation was the highest monthly amount in the four years of precipitation recording (2018-2021). Total precipitation in 2018, 2019, and 2020 was 56.47 inches, 53.71 inches, and 37.02 inches, respectively.

Average monthly TN export in 2021 was not significantly different from 2020 even with the exceptionally high stream outflows in September. This is not surprising given that board configurations in 2020 and 2021 were similar. Average monthly 2021 TN export was 56 kg, while the 2020 average was 44 kg. Both of these average loads were lower than 81 kg per month in 2019 and 261 kg in 2018 (**Figure III-14**). TN export in May, June, and July 2021 approximated average TN export measured in MEP 2002/03 monitoring (33 kg). In 2020, TN export in March, June, July, August, and September approximated the MEP export, while this level of export was only attained in one month (November) in 2019. All average monthly TN exports in 2018 were well above the MEP levels. The combined results in 2020 and 2021 show progress toward improving water quality in Cedar Pond and the improvements in the level of TN exports using current board configurations.

Comparison of TN and TP concentrations in pond outflow waters showed that water quality in the pond and, therefore, near surface pond water changes seasonally. N:P ratios in creek waters were typically above the Redfield threshold from January through April before decreasing during the summer and then increasing later in the year (**Figure III-15**). In January to March, N:P ratios in all four years (2018-2021) were above the Redfield threshold, but at a level where both nitrogen and phosphorus would both tend to determine water quality conditions. There were a couple of significant N:P ratio spikes above 50 (March in 2021 and April in 2018) where phosphorus was clearly the controlling nutrient. N:P ratios decreased below the Redfield threshold during all four summers with 2020 having the lowest recorded ratios (*i.e.*, August and September <5). Ratios during July, September, and October 2021 were less than 10 (August TN samples were not collected). In all four years, N:P ratios began to increase again in September or October, but remained less than the Redfield threshold in 2018 and 2021, but increased above the threshold in 2019 and 2020. The 2021 stream N:P ratios were similar to those measured in pond water column samples (see **Figure III-11**) and reinforce that nitrogen availability controls water quality conditions during the summer under current inlet configurations.

Collectively, the Cedar Pond Creek water quality data reflect the improvements in the pond water column and lower nutrient export to Rock Harbor even with high flows seen in September 2021. Consistently attaining previous 2002/03 nitrogen export levels will require further, but incremental, improvements in Cedar Pond water quality conditions. Sustaining acceptable export during all the natural fluctuations (*e.g.*, high vs. low groundwater conditions, high vs. low precipitation years and months) will require additional water quality improvements, but attaining this improvement was one of the main goals listed in the Cedar Pond Management Plan.



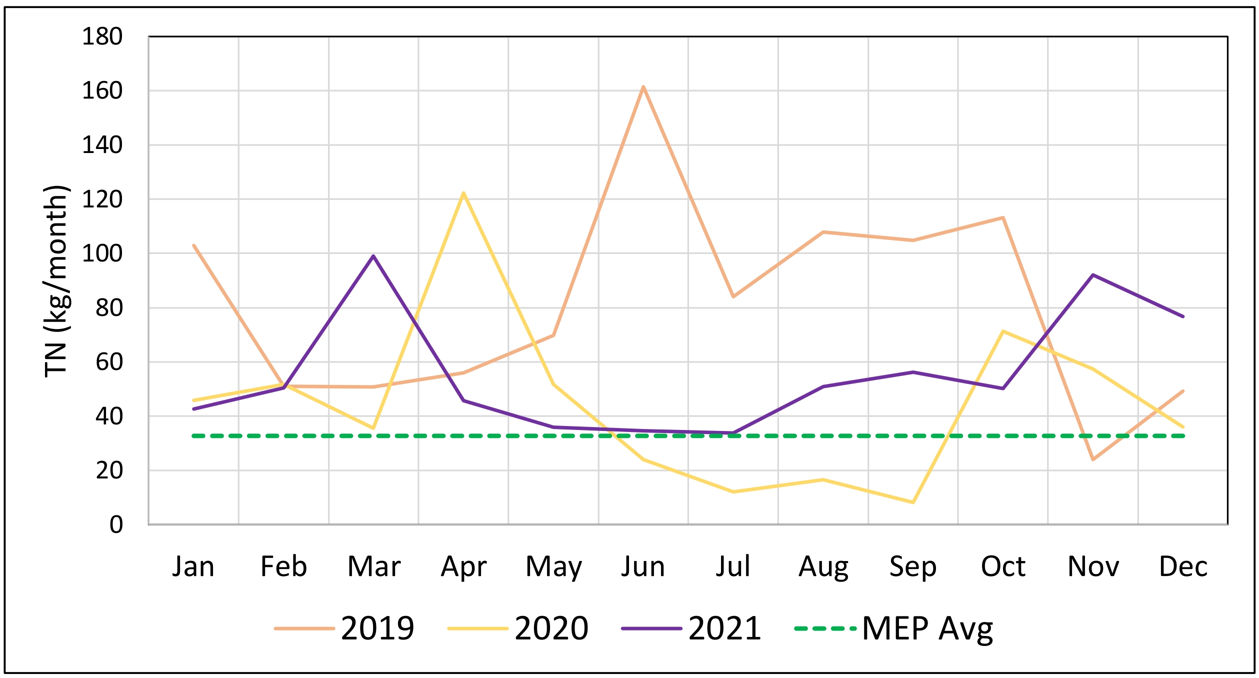


Figure III-14. Average Monthly Total Nitrogen Outflow through Cedar Pond outlet (2018-2021). Average monthly TN outflow in 2021 was not significantly different from 2020, but both years were significantly less ($\rho<0.05$, T test) than 2019, which in turn was significantly less than 2018. The lack of significant difference between 2020 and 2021 even with the exceptionally high September 2021 outflow shows that the on-going water quality improvements in Cedar Pond are robust even with slightly increased outflow. TN export in May, June, and July 2021 approximated export measured in 2002/03 for the MEP assessment of Rock Harbor.

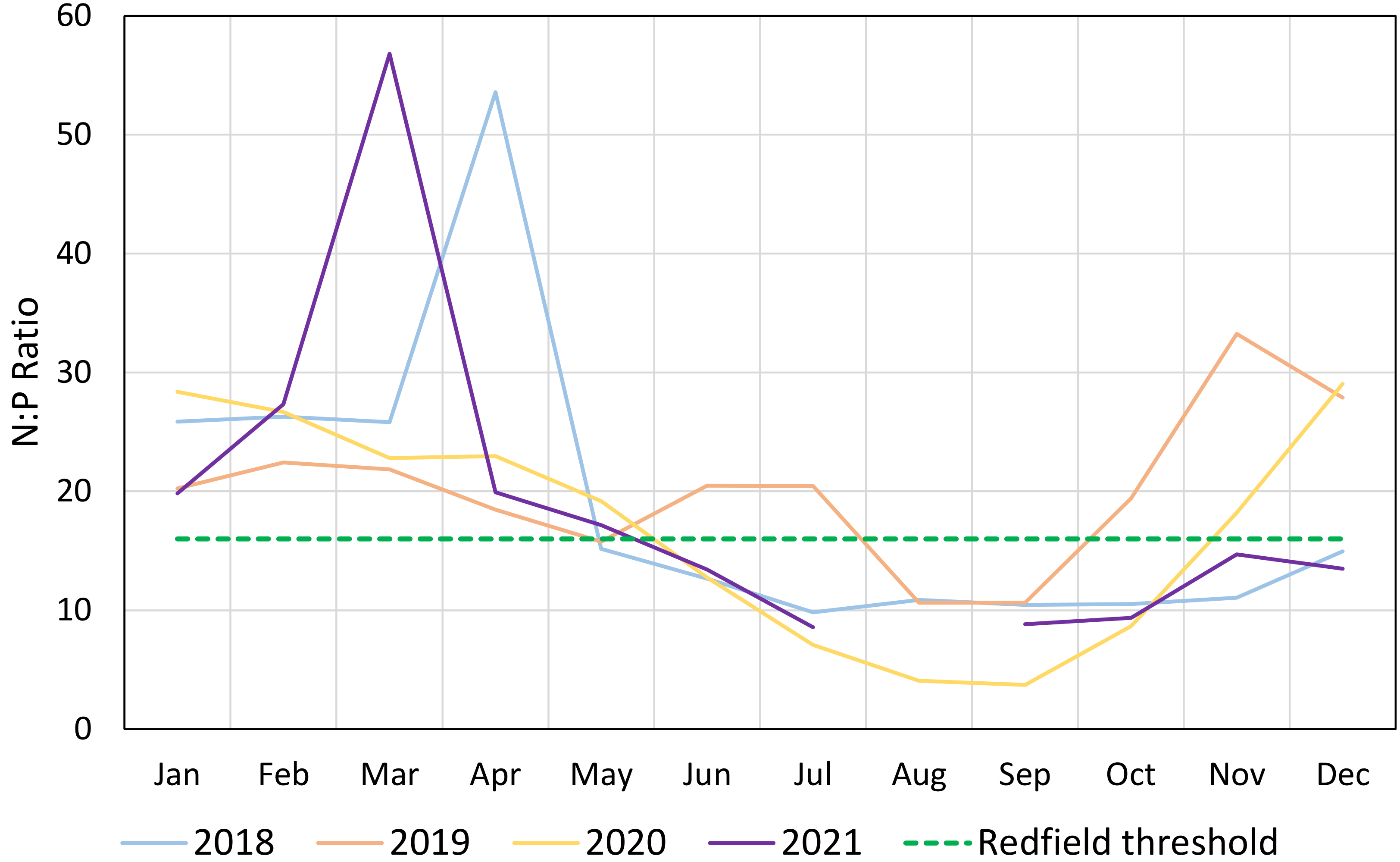


Figure III-15. Average N:P ratios in Cedar Pond Creek (2018-2021). Comparison of TN and TP concentrations showed that the nutrient controlling water quality conditions in near surface pond water and the downstream creek changed throughout the year. N:P ratios typically showed that both N and P determined water quality conditions in January through April (*i.e.*, N:P ratios above 16, but less than 32). Spikes in ratios in March in 2021 and April in 2018 show that occasionally phosphorus was the controlling nutrient, but nitrogen was consistently the key nutrient during summer months.

IV. Conclusions and Proposed Management Changes

The 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 preparation of the 2013 management plan and its approval, Cedar Pond was significantly impaired. Implementation of the adaptive management steps in the plan have improved pond water quality conditions and reduced N exports to Rock Harbor, but the pond continues to be impaired in 2021. As with all adaptive management plans, management steps are planned, implemented, and the response of the system is monitored. If monitoring results show that management steps should be modified to better reach the goals, restoration actions are adjusted and the process continues. Monitoring in 2021 showed additional improvements beyond those measured in 2019 and 2020, but more substantial water quality improvements are limited by Fishway Plan conditions.

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. Other planned steps in the Plan to be completed either concurrently or sequentially included a) addressing nutrient inputs from the large number of cormorants roosting during the late summer (*i.e.*, move the regional electrical lines from over to pond) 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 natural fresh groundwater inputs to have a greater impact. The main powerline over the pond was removed in 2019, which removed the cormorant N and P inputs, so reducing salinity and addressing the sediments are the remaining management actions.

It appears from the monitoring through 2021 that the pond sediments are the primary driver of the high P levels in pond waters, which support blooms. Furthermore, the bottom waters contain very high TP levels during summer stratification and this TP mass is declining very slowly since the release P is redeposited to the sediments. Based upon all of the data collected to date and the fact that the P source from the cormorants has been dealt with, it may be time to begin planning for an action to remove or sequester the P in the pond's surficial sediments.

According to the 2017 MEPA approval of the Management Plan, board elevations had to be adjusted throughout the year according to a Fishway Plan to allow spawning herring to enter and juvenile herring to leave the pond. Monitoring results from 2018, 2019, 2020, and 2021 have shown that installation of the boards has reduced salinity and resulted in incrementally improved water quality conditions in each year. But it has also shown that the required adjustments of the boards specified in the Fishway Plan allows salinity levels to increase during the summer each year. The continued monitoring has provided better understanding of key factors for sustaining acceptable water quality and annual refinements in Fishway Plan management activities in coordination with the Massachusetts Division of Marine Fisheries (MassDMF).

Monitoring in 2018 showed improvements in water quality as a result of reinstallation of weir boards at the pond outlet. Review of this monitoring data led to changes in the pond inlet board configuration in 2019 to try to lower summer salinity and maintain low winter salinity levels. With the 2019 removal of regional electrical wires that spanned the pond, water quality improved substantially and less nutrients were exported from the pond to Rock Harbor, but substantial impairments remained (*e.g.*, high nutrient and chlorophyll levels, low dissolved oxygen (DO) throughout the water column, bottom anoxia, sediment nutrient regeneration). In 2020, water quality continued to improve notable improvements in DO: a) average shallow continuous DO in August/September 2020 exceeding the MassDEP regulatory minimum (5 mg/L) for the first time and b) June/July average DO being 2 mg/L greater than in 2019, but still below 5 mg/L. Significantly less TN was transferred to Rock Harbor as well. In 2021, all water column DO measurements from the surface to 1 m were above the MassDEP minimum for the first time and 2020 improvements were sustained even as water levels changed and exceptionally high September precipitation occurred after a summer with below average groundwater levels.

The collected data show the importance of lowered salinity, but also showed that the board lowering specified in the Fishway Plan resulted in a regular annual summer increase over winter salinity levels. The annual board lowering makes it difficult to attain the salinity goals of the Cedar Pond Management Plan and the overall goals of restoring a sustainable herring spawning habitat, protecting the adjacent Atlantic White Cedar wetland, and achieving restored water quality. The Fishway Plan is also attempting to create conditions for herring to spawn, but the impaired water quality and high salinity do not appear to be acceptable to herring. During more than 80 visits by Town and CSP/SMAST staff to the pond outlet during expected herring movement periods, no fish have been noted.

Near surface salinity in June 2021 matched 10 ppt levels measured in 2019 and 2020 (reduced from ~15 ppt in 2018), but each year had a similar, gradually increasing summer rate that resulted in ~17 ppt salinity in September. Pond water quality has improved and continues to make small improvements each year, but the lowering of boards during the summer as specified by the Fishway Plan, make water quality improvements difficult to sustain or increase in a substantial way.

The Fishway Plan was adopted as a condition of the EOEA approval of the Management Plan and was developed in consultation with MassDMF. The goal of the Fishway Plan was to provide sufficient water flow between Rock Harbor and Cedar Pond to allow herring to spawn in Cedar Pond between March and June and for juvenile herring to leave between July and November. Water level monitoring at the pond outlet in 2019, 2020, and 2021 showed that water levels were sufficient to meet the Fishway Plan goals with the reinstallation of the boards. MassDMF staff has regularly worked with the Town and CSP/SMAST to adjust board configurations and elevations to try to better meet water quality salinity goals, while also meeting the water level goals for herring movement. However, none of the board elevation changes have seemed to encourage sufficient herring to enter or exit Cedar Pond.

Based on the insights provided by both the monitoring data and lack of herring entering or leaving the pond, <u>we recommend that: 1) the boards be kept at a higher elevation throughout the 2022 summer and 2) the Town work with MassDMF to better characterize the fish population moving in and out of the pond (if any)</u>. Keeping the boards at a higher level will lower salinity levels and provide a better understanding of potential summer improvements in water quality at lower salinity. More refined monitoring of the fish in Cedar Pond Creek will provide a more quantitative assessment of whether there are fish entering Cedar Pond and, if there are fish, what species they are. This type of monitoring would also allow the Town to adjust the board heights if large numbers of herring are noted. Regular water quality monitoring should continue. Since no herring have been noted in four years, this change could also create improved water quality conditions that would favor fish spawning in Cedar Pond in 2022/2023.

This proposed change would need to have contingencies to address unexpected increases in pond levels. If pond levels rise to unacceptable levels, contingencies should be in place to lower board elevations. Regular observations will be adjusted to increase attention to this issue with boards at a higher level.

We are making this recommendation recognizing that these proposed changes will need to be reviewed and accepted by MassDMF. Details of the board elevations and potential adjustments in 2022 will be discussed among MassDMF, Town and CSP/SMAST staff.

V. References

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, Director of Planning & Community Development 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.

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.

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