2021

ECOSYSTEM MONITORING REPORT

CHILMARK POND

GREAT POND FOUNDATION
Julie Pringle, Scientific Program Director

Prepared on behalf of
CHILMARK POND FOUNDATION

Ecosystem Monitoring Report – Chilmark Pond

Executive Summary

Great Pond Foundation (GPF) began monitoring the water quality and ecosystem health of Chilmark Pond (CHP) in May 2021, as part of a three-year monitoring plan to assess ecosystem health with Chilmark Pond Foundation. The sampling methodology consisted of regular monitoring during the spring, summer and fall seasons. Sampling methods included handheld probe measurements, lab-analyzed nutrient analyses, and continuously operated deployed data loggers. Data collection was centered on 8 sampling stations throughout the estuary. At each station parameters such as temperature, salinity, dissolved oxygen, pH, water clarity and turbidity were measured throughout the entire water column. Additionally, concentrations of nutrients such as nitrate, phosphate, and ammonium were analyzed at these stations on select sampling days. These parameters are commonly used indicators for impairment and ecosystem health.

Monitoring data indicate that CHP is a struggling ecosystem, despite meeting management thresholds for temperature and chlorophyll concentrations in 2021. Salinity was relatively consistent across the 7 sampling stations within the main basin of CHP, while station CHPUP, located within Middle Pond, was nearly fresh throughout the monitoring period. Water temperature at all 8 sampling stations remained below the 85°F management target throughout the summer season, with a maximum observed water temperature of 83.8°F on August 14. Visibility into the water column was typically at least 4 feet, yet rarely extended to the bottom. All stations with the exception CHP6 and CHP7 experienced elevated turbidity and reduced water clarity. High turbidity is generally indicative of impaired water quality.

Sufficient dissolved oxygen (DO) concentrations were observed throughout the upper portions of the water column in CHP. This is in contrast to the bottom depths, where lower DO concentrations were consistently observed. Measurements recorded from a continuous DO logger deployed at station CHP2 south of Wades Cove regularly detected periods of hypoxia (DO < 2 mg/L), most often during nighttime hours. Large fluctuations in DO such as this are often an indicator of impairment and decreased habitat quality. Total nitrogen (TN) values in CHP were above the management targets for the majority of the monitoring period, peaking in July and August for most stations. Mean TN values were above the recommended limits established by the 2015 Massachusetts Estuaries Project (MEP) report. Exploratory well-water sampling determined inorganic forms of nitrogen were elevated at 2 of the 4 wells which were investigated, indicating the groundwater upstream of CHP is enriched with nitrogen.

Overall, Chilmark Pond is suffering from multiple water quality issues, including low dissolved oxygen and elevated nitrogen concentrations within the water column. These factors ultimately decreased habitat quality, limiting biodiversity and reducing ecosystem health. Additionally, among all ecosystems monitored for MV CYANO in 2021, CHP was consistently one of the ponds most at risk for a cyanobacteria bloom. While CHP benefited from increased circulation caused by pond cuts, only two cuts occurred in 2021. Opening length varied from 17-24 days and was open for a total of 41 days.

Continued monitoring is recommended to further document the impact of eutrophication on water quality. This can be accomplished via a combination of site visits with handheld sampling equipment and deployed data loggers. Additionally, continued monitoring of nutrient concentrations throughout the pond is recommended. Assessment of nutrient concentrations within the groundwater north of the pond may identify nitrogen hotspots within the watershed and elucidate potential locations for nutrient mitigation efforts.

2021 Ecosystem Monitoring Data

Overview of Ecosystem Monitoring Program

Chilmark Pond (CHP) is a coastal estuary approximately 210 acres in size. CHP is a complex system comprised of a main basin with two coves: Wades Cove and Gilberts Cove. CHP is connected to a secondary basin, called Middle Pond, via a narrow channel named Doctor's Creek. A third and smaller basin, Upper Chilmark Pond or Lucy Vincent Pond, flows into the Middle Pond via Intern's Creek. The approximately 3100-acre watershed is located entirely within the Town of Chilmark. A barrier beach separates CHP from the Atlantic Ocean, which is intentionally breached or "cut" 2-4 times per year to drain the pond and allow it to be flushed with salty ocean water. Water from the Atlantic Ocean is also low in nutrient concentrations compared to CHP, making flushing during openings a nutrient management tool. These pond cuts are temporary and close due to natural forces. The timing of openings is determined by the commissioners of the Chilmark Pond Association, who consider factors such as pond elevation, pond water quality, weather, and the migration patterns of important species such as river herring. After closure of the cut, CHP gradually refills due to groundwater input and surface water flow via tributary creeks (i.e. Fulling Mill Brook), as well as through direct precipitation onto the pond's surface.

The Great Pond Foundation (GPF) Ecosystem Monitoring Program follows the methodology of the Massachusetts Estuaries Project (MEP) and utilizes the management standards established by the MEP report (Howes et al., 2015). This report found that the Chilmark Pond system was moderately to significantly impaired due to the absence of eelgrass habitat and impairment of benthic (bottom) animal habitat. Additional impairment resulted from periodic summer oxygen depletions and phytoplankton blooms caused by excess nitrogen. Results of the MEP report indicated that the CHP estuary is beyond its ability to assimilate nitrogen without further impairment (Howes et al., 2015). The MEP developed threshold nitrogen levels based on modelling the water circulation within CHP and nitrogen loading from within its watershed. These thresholds established the concentration of nitrogen the system can accommodate in order to restore high habitat quality. Regular monitoring of water quality in CHP is required to determine if nitrogen levels in the pond are meeting these thresholds, and to monitor for further degradation or improvement within the ecosystem. GPF began monitoring the water quality and ecosystem health of Chilmark Pond in May 2021, after CHP was added to GPF's Ecosystem Monitoring Program. Sample collection methodology included regular monitoring during the spring, summer and fall seasons. Numerous sampling methods were utilized, including handheld probe measurements, lab-analyzed nutrient analyses, and continuously-operated deployed data loggers.

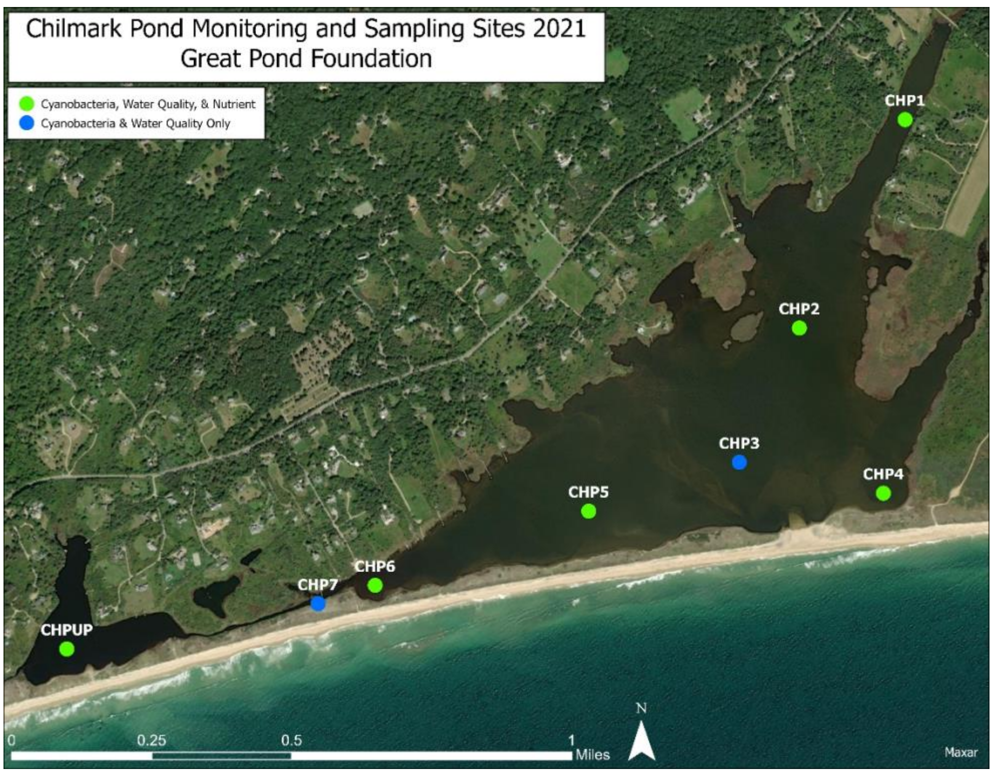

Figure 1. Map of the eight Chilmark Pond (CHP) sampling stations.

Data collection was centered on 7 sampling stations throughout the main basin of the pond and 1 station in Middle Pond, for a total of 8 sampling stations (Figure 1). These water stations cover all geographic features of the CHP ecosystem: near the barrier beach, within and adjacent to the mouth of Doctor's Creek, and stations within Wade's Cove and the Middle Pond. At each of these locations, parameters such as temperature, salinity, dissolved oxygen, pH, water clarity and turbidity were measured throughout the entire water column using a YSI ProDSS handheld water quality meter (see Glossary in Appendix for explanations of parameters). Additionally, concentrations of nutrients such as nitrate, phosphate, and ammonium were analyzed at these stations on select sampling days. Water samples were delivered to the Marine Biological Laboratory in Woods Hole for nutrient analyses. This methodology and suite of parameters are widely used standards for the determination of impairment and the assessment of ecosystem health.

GPF's 2021 field season began on May 14 and the last water sampling collection occurred on October 25. Weekly water samples were collected by the Scientific Program Manager, Watershed Outreach Manager, and interns during this 24-week monitoring period (see Table A1 in Appendix for dates), providing a high-resolution dataset with over 77,500 unique data points. Summer is when the Pond is most biologically active, and frequent sampling allows for rapid detection of biological phenomena, such as algal blooms. Winter prohibits boat-based water sampling, however, the cold weather also limits biological activity making regular sampling less informative. In addition to in-situ data collection during site visits, GPF deployed dissolved oxygen and conductivity/salinity sensors which continuously monitored these parameters. Both data loggers were deployed on June 8 at station CHP2 and collected measurements every 15 minutes (96 measurements per 24 hours) until their removal on October 25. The datasets provided by these instruments are essential to understanding temporal changes and patterns in their recorded parameters and provide greater context and comparison for the accompanying data collected during field sampling.

Pond Elevation and Pond Cuts

- *CHP was opened to the ocean twice in 2021 and was open to the ocean for a total of 41 days.*
- *Opening length varied from 17-24 days, with an average opening duration of 20.5 days.*

The barrier beach was intentionally opened to the ocean 2 times in 2021 (Table 1). During an opening, the Pond will experience an initial drain into the Atlantic Ocean, the magnitude of which is determined by the water elevation in the Pond compared to that of the ocean prior to opening. Following this drain, the remaining fresher, nutrient-rich water from the pond will be steadily replaced by salty ocean water over the course of several tidal cycles. This exchange has the beneficial effects of reducing overall nutrient concentrations, increasing salinity, lowering temperature, and improving water circulation throughout the Pond.

Following a cut, salinity is often used to measure the extent of exchange between the Pond and the ocean and can be used to determine the "success" of an opening. A significant increase in salinity, especially in the coves, indicates a successful flush, where salty ocean water is introduced throughout the entire pond. However, salinity data is not always available, such as during the winter months when sample collection does not occur. The first cut of 2021 was made prior to the beginning of regular water sampling and no salinity data was collected. However, all cuts remained open for at least 17 days, which previous data indicates is sufficient time for complete flushing of the pond to occur. Following the October 6 cut, salinity increased at all sampling stations except CHPUP (in Middle Pond), signaling a full exchange of water with the ocean and indicating a successful cut.

Opening #	Date of Opening	Date of closure	Length of opening
1	4/17/2021	5/4/2021	17 days
2	10/6/2021	10/30/2021	24 days
Mean opening duration			20.5 days

Table 1. Dates of Chilmark Pond openings, when the barrier beach was breached allowing for tidal exchange with the ocean. The average length of the opening was 20.5 days, and CHP was open to the ocean for a total of 41 days. Opening data provided by Martha Cottle.

Overall, CHP was open to the ocean for a total of 41 days in 2021. Opening length varied from 17-24 days, with an average opening duration of 20.5 days (Table 1). Both pond cuts occurred when pond elevation was at least 4 feet above the vertical reference datum NAVD88 (4 feet above NAVD88 = 4.38 feet above local mean sea level) (Figure 2). Pond elevation was measured by a water level logger attached to a dock within Thumb Cove which recorded measurements every 30 minutes. CHP recharge between cuts was approximately 5 months, or 155 days between closure of the first cut and the second pond opening. GPF does not have opening data from previous years, and therefore the 2021 openings cannot be easily compared to other years. However, an analysis of historical water quality data, including opening dates and duration, will be performed in a future GPF report.

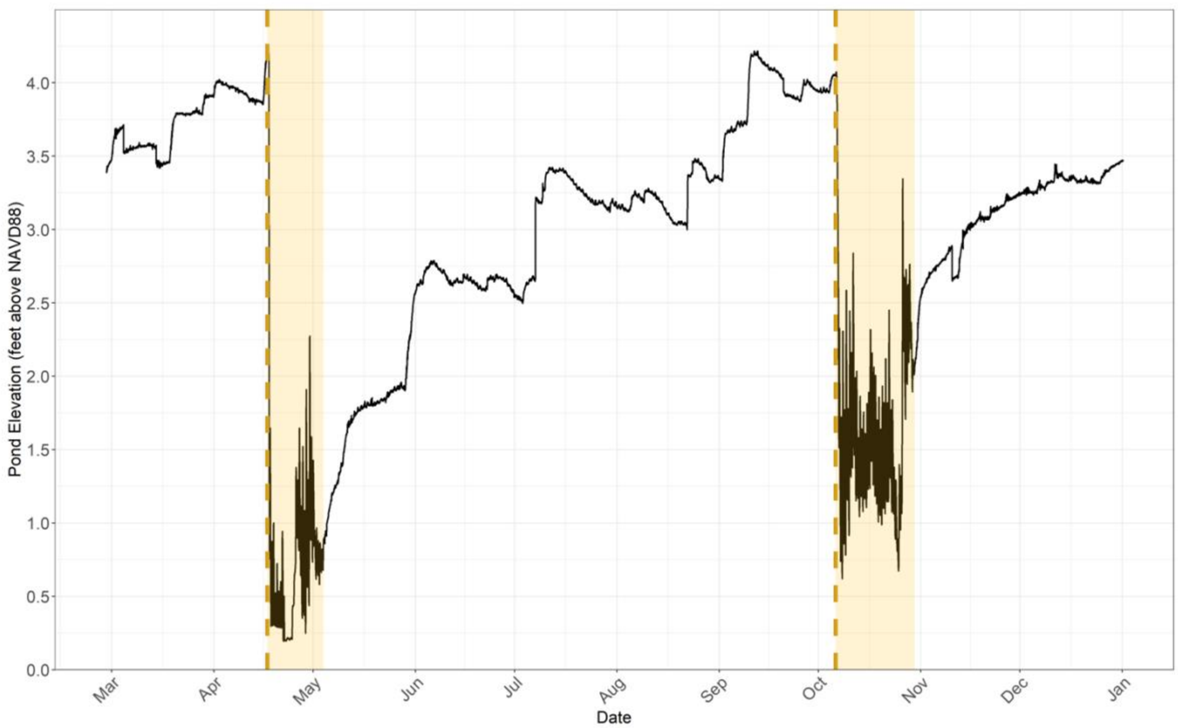

Figure 2. Elevation of CHP in 2021. Data were measured via a water level data logger on the dock in Thumb Cove and are relative to the vertical reference datum NAVD88. The yellow dashed lines represent when ponds cuts occurred, and the shaded yellow areas are when the Pond was open to the ocean.

Salinity

- *Salinity was relatively consistent across the 7 sampling stations within the main basin of CHP, which gradually decreased throughout the summer until the 10/6 cut, when it rapidly rose throughout the pond.*
- *Station CHPUP, located within Middle Pond, was nearly fresh throughout the monitoring period. Salinity at this station did not exceed 4 ppt and did not appear to be influenced by pond cuts in CHP.*
- *The station within Doctor's Creek (CHP7) had the largest variability and exhibited more vertical variation of salinity within the water column.*

Salinity is a measure of how much salt is dissolved in water, measured in parts per thousand (ppt) (tap water = 0 ppt, ocean water = 34 ppt). Salinity can be an indicator of the local hydrology within CHP, or of how water enters, circulates, and exits the Pond. Additionally, salinity can be used to assess the success of pond cuts. During a successful opening, the whole Pond is flushed with ocean water, which causes the salinity to increase throughout the main basin and into the coves. The secondary basins of CHP (Middle Pond and Lucy Vincent Pond) are sources of groundwater to the pond, and typically exhibit lower salinity levels than those observed in the main basin.

Overall, most of the stations within the main basin of CHP (CHP1-6) exhibited similar salinity trends. Salinity ranged from 2.05 ppt to 32.96 ppt within the main basin (Figure 3). The lowest salinity was observed in early October, when salinity was below 7 ppt or lower at stations CHP1, CHP5 and CHP6. Maximum salinity measurements occurred on October 21, when the pond was open to the Atlantic Ocean. Stations CHP7 and CHPUP, located within Doctor's Creek and Middle Pond, consistently had lower salinities than the main basin of CHP. The Middle Pond was nearly freshwater for the duration of the monitoring period, with salinity ranging from 0.18-4.02 ppt. While Lucy Vincent pond was not regularly monitored, GPF did a site visit on September 7 to gather baseline data. On this date, salinity within the Lucy Vincent Pond was fresh to very slightly brackish, with salinities ranging from 0.1-0.73 ppt. The Upper and Middle Ponds of the Chilmark Pond system receive freshwater from Mill Brook and Fulling Mill Brook, respectively. Additionally, exchange with the Lower Pond is minimal, as Intern's Creek and Doctor's Creek are narrow and provide enough physical separation to limit saltwater incursion.

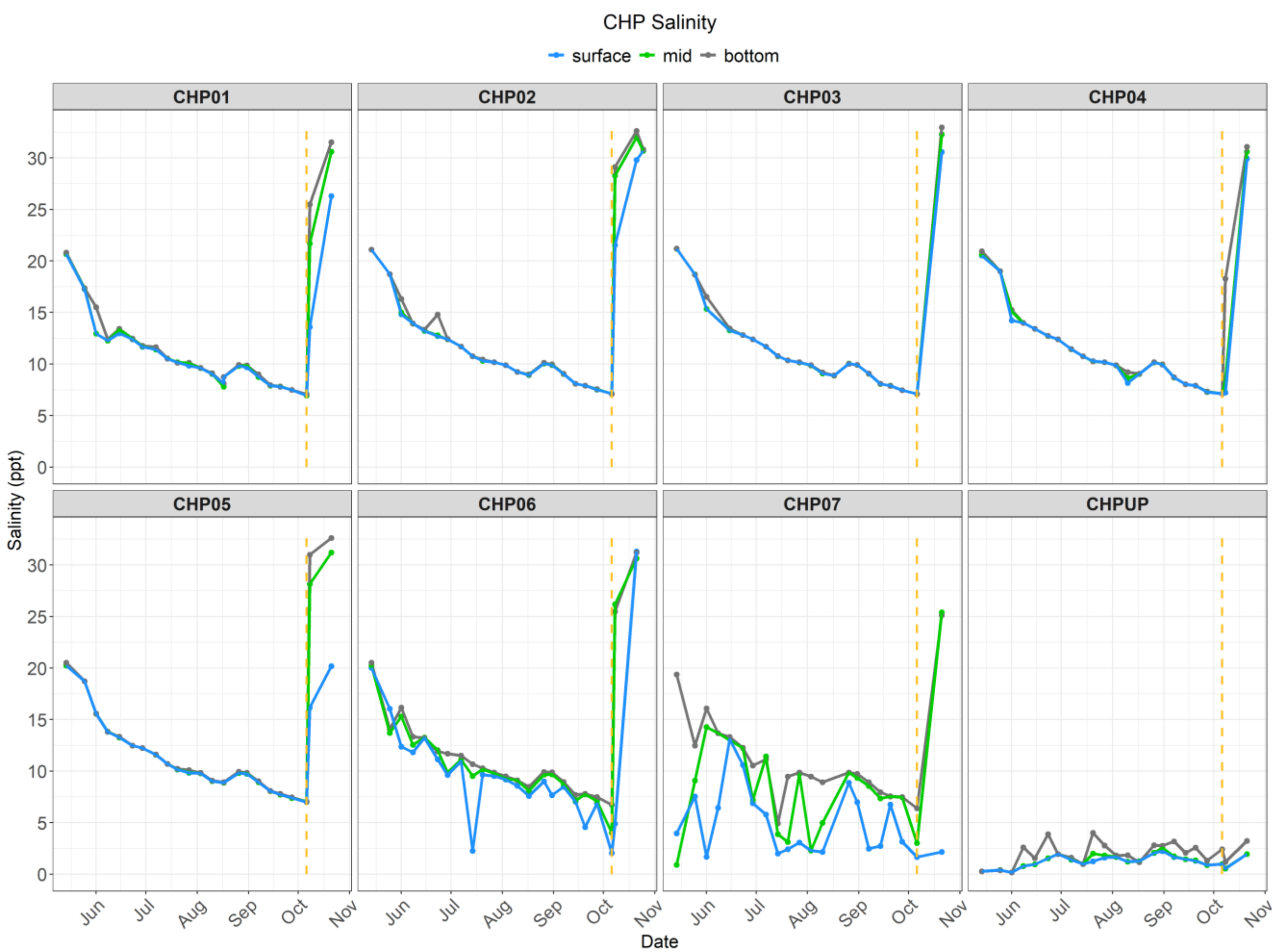

Figure 3. Salinity in parts per thousand (ppt) in Chilmark Pond in 2021. Data were measured with a handheld probe at the surface, mid-depth and bottom water, represented by different colors, at 8 sampling stations (different panels). The dashed yellow line is when CHP was cut to the ocean on 10/6/21.

In fact, data suggest that water predominately flows west to east, from the Middle Pond to the main basin of CHP. This is evident by the stratification of the water column at stations CHP6 and CHP7. Stratification, or the existence of horizontal layers in the water, occurs due to differences in density caused by differences in salinity and temperature. Saltwater is denser than freshwater, which causes it to sink below the more buoyant, fresher water. Station CHP7, located within Doctor's Creek, consistently had salty bottom water similar to the rest of the Pond while measurements from the surface and middle of the water column were much fresher. This indicates that water from both CHP and the Middle Pond mix within the Creek. Yet, the freshwater influence is seen at station CHP6, which is located approximately 500 feet east of CHP7, just beyond where the creek drains into the Pond. The water column at CHP6 was often stratified, indicating that fresher water from the Middle Pond flows into the main basin of CHP.

Salinity rapidly increased following pond cuts at all stations except CHPUP (within Middle Pond). While GPF was not monitoring CHP prior to the April 17 cut, salinity within CHP was typically above 20 ppt at the start of the monitoring period (Figure 2). Salinity gradually decreased throughout the summer to a pond-wide (CHP1-7) bottom water average of 6.94 ppt on 10/6/21, the morning of the cut. After the cut, the pond was flushed with saltwater and the salinity jumped to an average of 31.0 ppt on 10/21, 15 days after the cut. These salinity trends were also captured by the salinity logger deployed at station CHP2 (Figure 4).

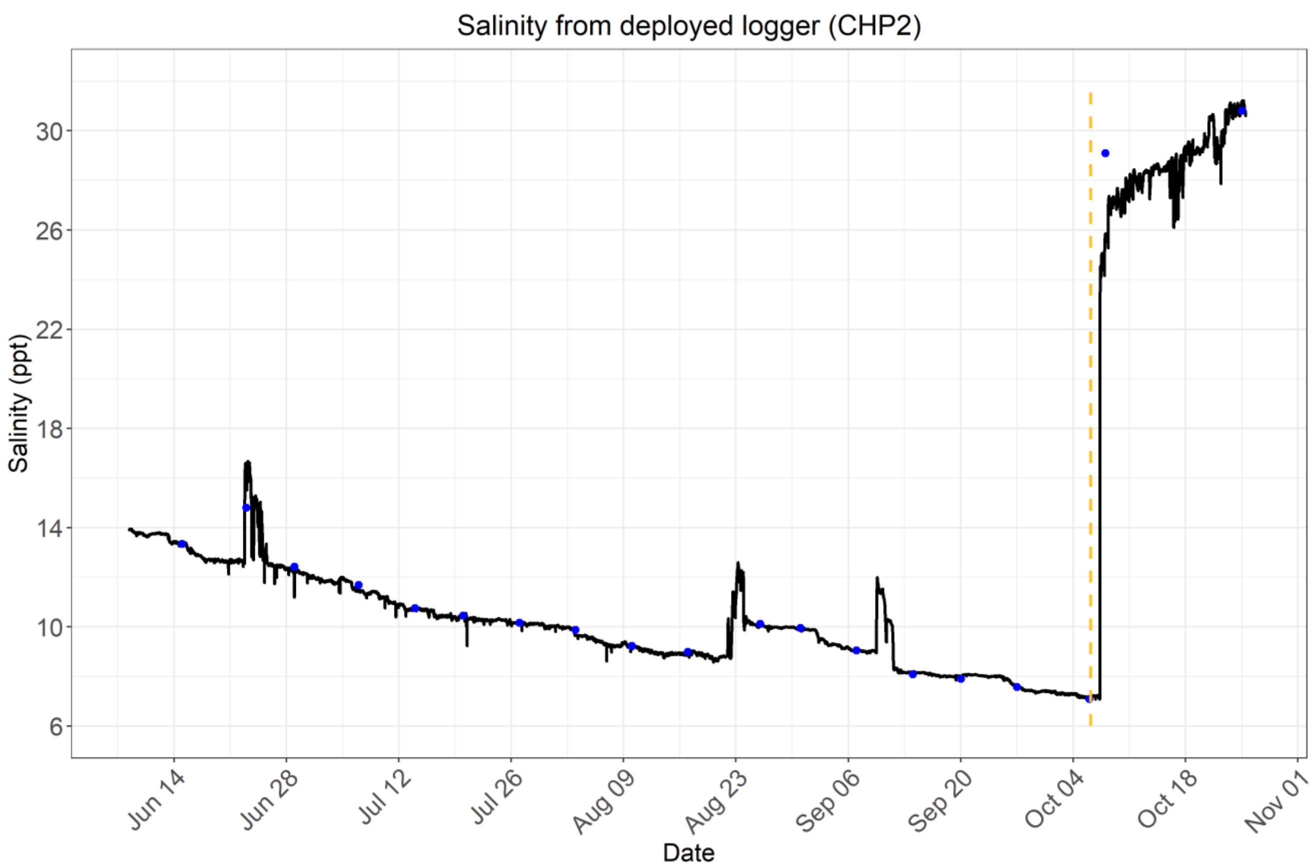

Figure 4. Salinity in parts per thousand (ppt) in 2021. Data were measured with a conductivity/salinity data logger deployed at station CHP2. Blue dots are salinity measured with a handheld probe during site visits. The dashed yellow line is when CHP was cut to the ocean on 10/6/21.

Temperature

- *Water temperature at all 8 sampling stations remained below the 85°F threshold for ecosystem health throughout the summer season.*
- *Maximum water temperature was 83.8°F on 8/14/21, as measured by a sensor deployed at CHP2.*

Temperature is an important factor within aquatic ecosystems, as it drives biological growth rates and chemical reaction speeds. Much like the temperature of our own bodies, elevated water temperature is often associated with problems affecting ecosystem health. The CHP management goal from the MEP report is to maintain water temperatures of less than 85° F during the summer (Howes et al., 2015). However, unlike other parameters that can be influenced by management decisions, there is no way to control temperature. Water temperature may temporarily decrease after the Pond has been cut, as ocean water is often cooler than Pond water during the summer. However, water temperature in the Pond is primarily driven by ambient air temperature.

Water temperature was measured throughout the water column at all stations across the Pond during each site visit. Additionally, bottom water temperature was continuously monitored with a temperature sensor attached to the conductivity/salinity data logger at station CHP2. Maximum water temperature occurred on August 26, where temperatures reached 80.76°F at station CHP1 (Figure 5), while average mid-depth temperature of all stations in the pond was 79.4 °F on the same day. All stations were fairly similar in temperature relative to each other and exhibited the same seasonal trend (Figure 5). Observed temperatures at station CHP7 were consistently highest, as this station is within Doctor's Creek where water depth was limited.

It is noteworthy that observed water temperatures never exceeded the 85°F threshold. This trend was also observed by the continuous data logger deployed at CHP2, which recorded a maximum temperature of 83.8˚F (Figure 6). Coastal ponds such as Chilmark Pond often suffer from elevated temperatures in the summer. GPF's active monitoring timeframe falls between 6-11AM and does not include regular afternoon sampling. It is possible that temperatures may have exceeded the threshold at shallower locations, such as the heads of the coves or within Doctor's Creek, during the hotter times of day. Additional continuous logger(s) in shallower areas of the pond could help to clarify this possibility. Regardless, the health of CHP likely benefited from consistent water temperatures that remained below 85°F.

Figure 5. Temperature in Chilmark Pond in 2021. Colored lines represent data from the different sampling stations, and the black line is the pond-wide average temperature for each site visit.

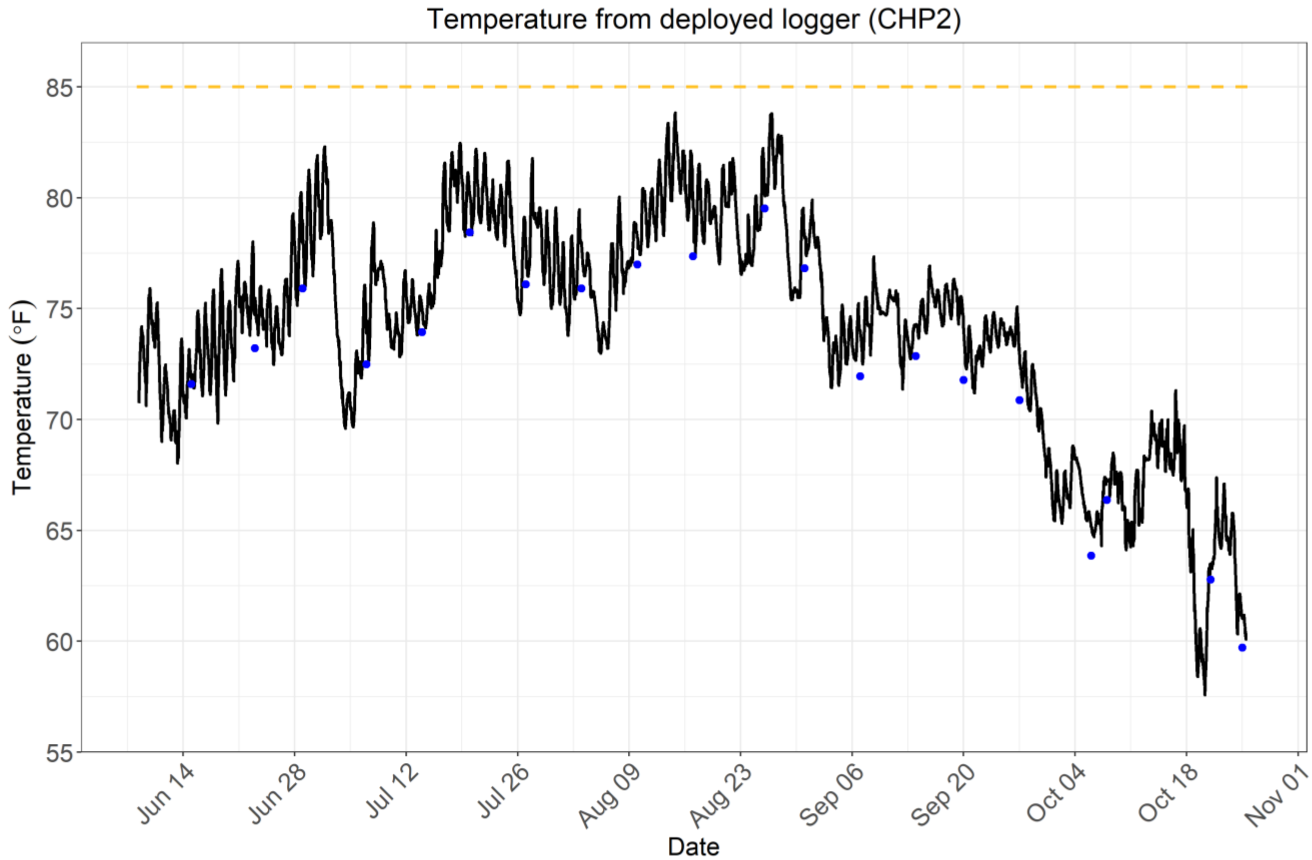

Figure 6. Temperature measured with a data logger deployed at station CHP2. Blue dots are temperature measured with a handheld probe during site visits. The dashed yellow line is the 85°F management threshold.

Dissolved Oxygen

- *Results indicate that the majority of the water column had sufficient oxygen concentrations, however, near-bottom portions consistently exhibited lower dissolved oxygen levels.*
- *The dissolved oxygen data logger detected periods of hypoxia at station CHP2, most often at night, indicating decreased habitat quality in the bottom waters of south of Wades Cove. The large fluctuations in DO that occurred in this area are an indicator of impairment.*

Dissolved oxygen (DO) is the amount of oxygen dissolved in the water, measured in milligrams per liter (mg/L). A battery-operated DO sensor was deployed at station CHP2, which continuously logged the amount of oxygen in the water at 15-minute intervals. Oxygen enters the water through diffusion from the air but is primarily produced by aquatic plants via photosynthesis. Adequate oxygen levels are important as most organisms require oxygen as part of their metabolism.

The MEP DO management target for heathy ponds is 6 mg/L (Howes et al., 2015). When concentrations drop below 4 mg/L, aquatic life begins struggling to breathe. Critically low levels of oxygen (<2 mg/L) are considered hypoxic and can be deadly to most organisms. Normally, the bottom of the water column has lower DO compared to surface waters. This is because oxygen moves from the air into the water at the surface, and most plants, which produce oxygen, are found at or near the surface where there is direct sunlight. Additionally, oxygen is consumed via decomposition of organic matter, which primarily occurs on the bottom and within the sediment. Due to these processes, deeper water often has lower DO concentrations than at the surface. This can be clearly seen when DO from surface, mid-depth, and bottom waters are plotted together on the same graph. A gradient of decreasing oxygen concentration with increasing depth was observed at most monitoring stations, with the exception of the shallower CHP6 site (Figure 7). This gradient was more severe during the summer season, while the Pond experienced the hottest temperatures of the year.

There was a slight seasonal trend, where DO was reduced during the hot summer months. Between July and September, most stations experienced DO concentrations below the 6 mg/L threshold (Figure 7). Often this was limited to measurements taken at bottom depths and only occasionally did mid-depth or surface DO measurements drop below the 6 mg/L threshold. DO fell below the 4 mg/L threshold into the zone of concern, where oxygen deprivation begins to occur, at stations CHP1, CHP7 and CHPUP at least once throughout the summer. While this indicates that bottom water was low in dissolved oxygen, it is typical for coastal estuaries, especially ecosystems with a history of impairment, to experience periodic oxygen depletion. For most stations, the data suggest the water column had adequate oxygen to support aquatic life. DO measurements within bottom waters at CHP7 (withing Doctor's Creek) and CHPUP (within the Middle Pond) were consistently the lowest.

Figure 7. Dissolved oxygen (DO) measured in milligrams per liter (mg/L) in Chilmark Pond in 2021. Data were measured with a handheld probe at the surface, mid-depth and bottom water (represented by different colors) at 8 sampling stations. The dashed yellow line is the 6 mg/L management target, and the red dashed line represents when DO was critically low, below 4 mg/L. The red box indicates when hypoxia was occurring (DO < 2 mg/L).

However, data generated by the deployed DO logger indicate that the main basin of CHP experienced periods of hypoxia at its bottom depths (Figure 8). Hypoxia occurs when DO drops below 2 mg/L, potentially causing harm to plants and animals. The DO data logger was deployed at station CHP2 (south of Wades Cove) on June 8 and collected measurements every 15 minutes until October 25. This logger was deployed at a fixed depth, approximately 3 inches above the pond sediment. This deployment configuration is designed to capture DO concentrations at their minimum to better describe the severity of oxygen depletion, if any. Data from this logger indicate that there were large daily fluctuations in DO, especially during the late summer (Figure 8). Additionally, DO occasionally fell below 2 mg/L to near anoxic conditions, which occur when there is no oxygen present. During these low oxygen events, the data logger recorded DO measurements close to 0 mg/L. These periods of hypoxia most often occurred at night when plants are not photosynthesizing and producing oxygen.

Data recorded using the handheld water quality meter did not capture the same severity of the oxygen depletion that occurred at CHP2. DO naturally undergoes daily fluctuations, as the processes of respiration and decomposition consume oxygen, while aquatic plants produce oxygen only during the day. Typically, the lowest DO measurements occur just before sunrise. The GPF Water Quality Monitoring Program was designed to capture this DO minimum by beginning field sampling days just after sunrise. Yet, even with strict protocols, the GPF sampling team often arrived on station after DO levels began to rise. As such, the data from the handheld sensors did not capture the true DO minimum. This inconsistency illustrates why deployed sensors are useful as a supplement to boat-based sampling efforts. Only one DO logger was deployed in CHP throughout the 2021 monitoring period, and therefore, comparative measurements from other locations within the pond are unavailable. It is reasonable to assume that other areas of CHP experienced low DO concentrations at night, but this hypothesis cannot be confirmed without the deployment of additional sensors.

These results indicate that the majority of the water column retained sufficient oxygen concentrations, while the near-bottom portions were consistently depleted at night. Low DO readings from the continuous data logger are concerning, as this suggests that the bottom of CHP2 suffers from short periods of hypoxia (DO < 2 mg/L). It is common for eutrophic ponds to have anoxic sediment, meaning there is no oxygen present. This is due to large amounts of organic matter decomposing on the bottom of the pond, a process which consumes oxygen. The logger mounts and housing are designed to prevent the instrument from sinking into this sediment layer. Therefore, these low DO readings are representative of the near-bottom portion of the water column and indicate the presence of a hypoxic zone above the sediment layer. Regular oxygen depletions are indicators of impairment and suggest that this is an environment inhospitable to most aquatic life.

Additionally, the continuous DO logger recorded large daily fluctuations in DO at the beginning and end of the summer (Figure 8). DO concentrations within a healthy ecosystem fluctuate on a daily basis, yet still retain adequate levels to buffer against extreme variations which may occur during nighttime hours. The large fluctuations that occurred at CHP2 are an indicator of impairment. Overall, these data indicate that CHP, including the Middle Pond, is a struggling ecosystem. Habitat quality was negatively impacted by oxygen depletions, especially on the bottom of the pond. Organisms that cannot move to areas of higher oxygen, such as shellfish, may have struggled to survive. However, hypoxia was temporary at CHP2, and handheld probe data indicated that oxygen levels recovered to levels which can support aquatic life during the day.

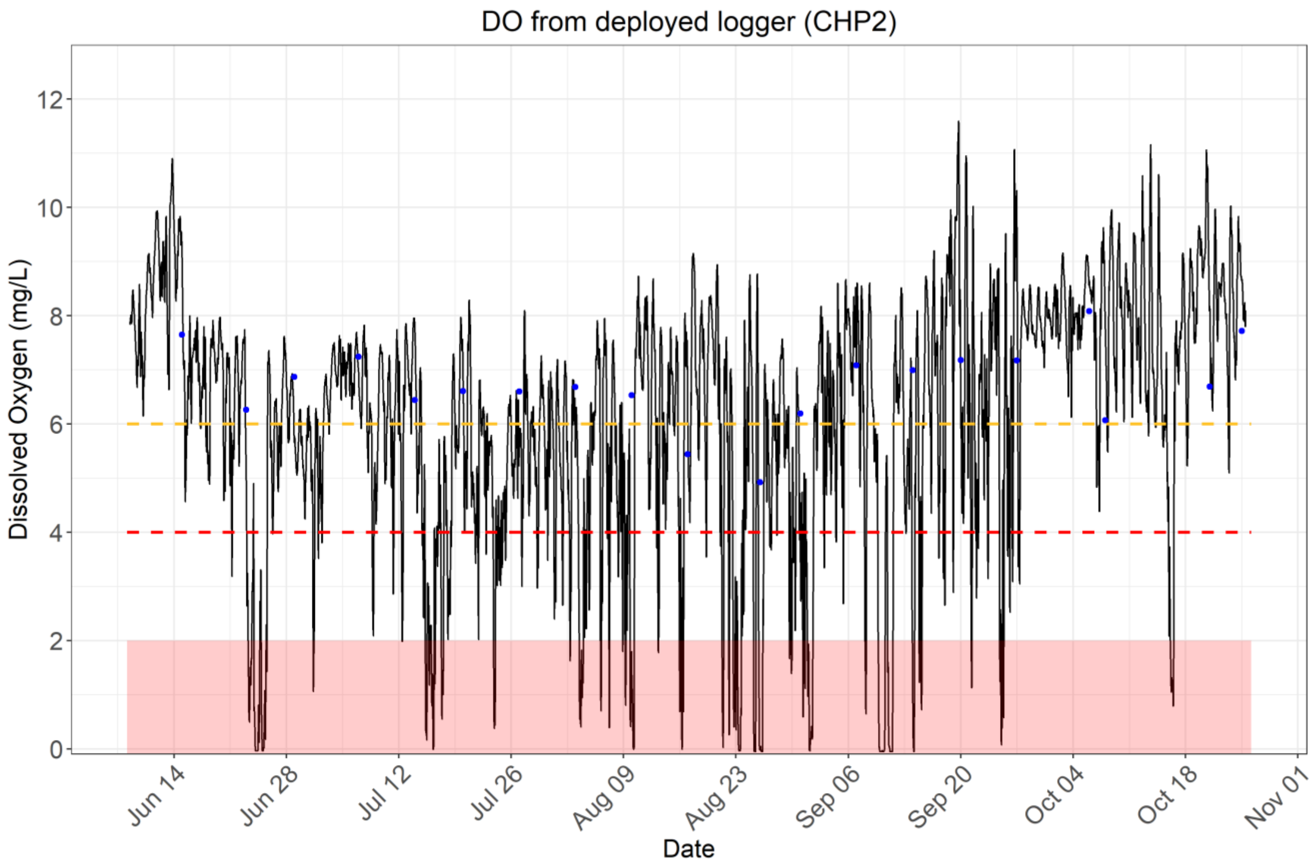

Figure 8. Dissolved oxygen (DO) at station CHP2 in 2021. Data were measured with a data logger deployed approximately 3 inches from the pond bottom. The dashed yellow line is the 6 mg/L management target, and the red dashed line represents when DO was critically low, below 4 mg/L. The red box indicates when hypoxia was occurring (DO < 2 mg/L). Blue dots are DO measured by a handheld probe during site visits. The black line represents a 2-hour moving average of the DO measurements, which were logged every 15 minutes.

Water Clarity

- *Typical visibility was at least 4 feet; however, the water was frequently too murky to see the pond bottom.*
- *All stations except CHP6 and CHP7 experienced elevated turbidity and reduced water clarity. Murky, high turbidity water is generally indicative of impaired water quality.*

Turbidity is a measure of how many particles are dissolved in the water, which affects how much light is transmitted through the water column. Water with low turbidity is clear, with visibility often extending to the bottom, while water with high turbidity appears murky. High turbidity is detrimental to submerged aquatic vegetation, as less sunlight can penetrate the water. Vegetation requires sunlight to photosynthesize, which in turn, provides oxygen to other organisms living in the water. The particles that cause high turbidity can be either living or nonliving. Living particles include microscopic plants called phytoplankton, along with other microscopic organisms which have the ability to reproduce quickly, making the water appear green or brown in color. Elevated concentrations of nutrients and increased temperatures can stimulate growth of these microscopic species. Nonliving particles are usually comprised of sediment that was either resuspended from the bottom of the pond or entered the water from adjacent lands via runoff. Because of this, murky or turbid water is common after rain events.

Turbidity is often used as a benchmark for water quality analyses as it is simple to measure and interpret. Murky water is generally indicative of impaired water quality. One method of measuring turbidity is with a Secchi disk. A Secchi disk is a standardized black and white disk attached to a measuring tape that is lowered through the water column. The depth at which it disappears from view corresponds to the depth at which turbidity is too high for light to penetrate to deeper depths. Thus, light cannot easily reach benthic plants and animals when turbidity is elevated. The MEP management goal for Secchi depth is 3 meters (9.8 feet) or the bottom of the body of water (Howes et al., 2015). All of the CHP sampling stations are less than 3 meters deep, making adequate Secchi depth the bottom of the pond, or "total depth", at the sampling site.

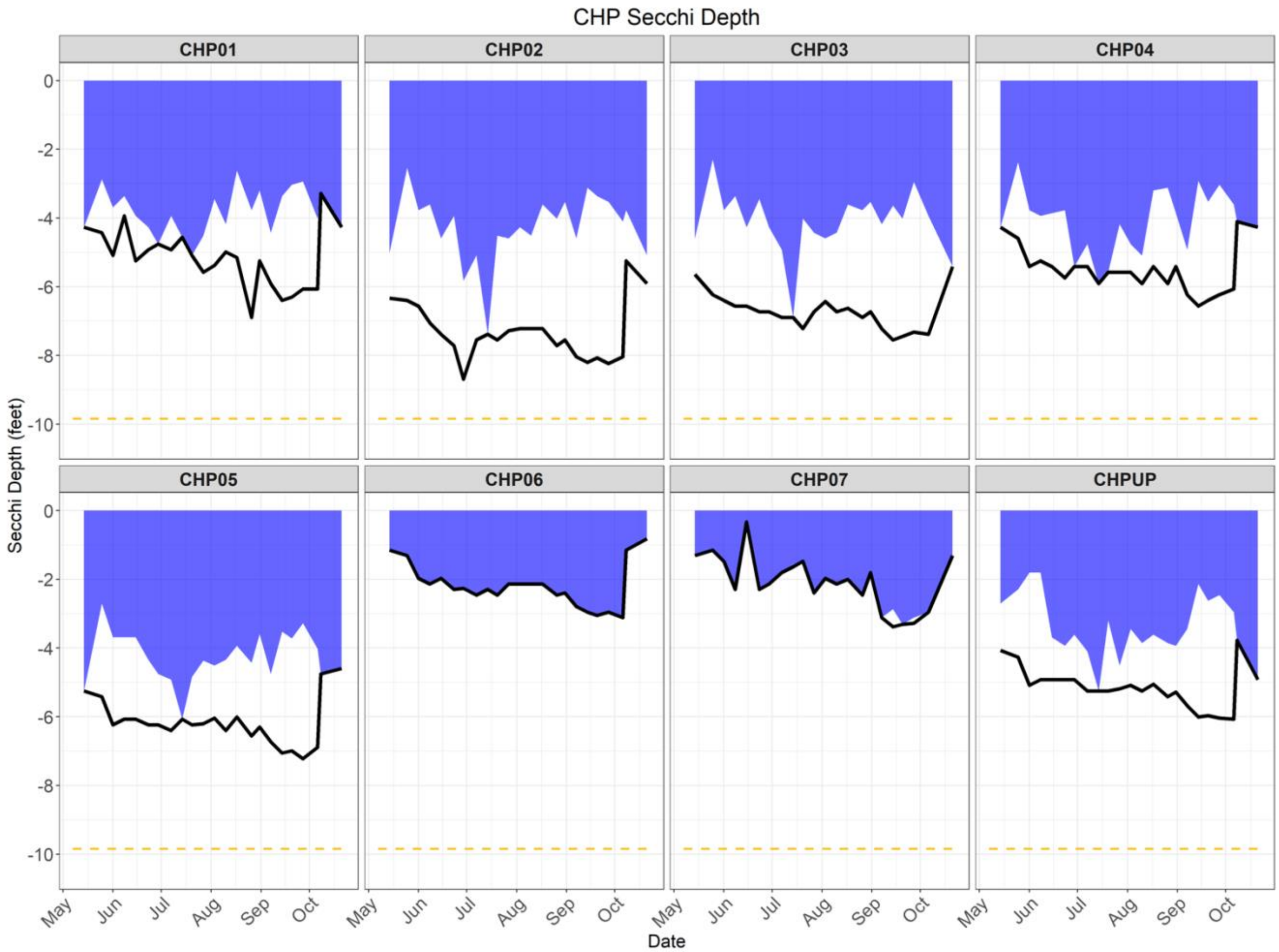

Figure 9. Secchi depth and total depth in feet at each sampling station in Chilmark Pond in 2021. Secchi depth is the depth at which a standardized disk disappears, which often corresponds to total depth. Total depth in the figure is the thick black line, and Secchi depth is the blue shaded area above the black line. The management target for Secchi depth to equal total depth, or be at least 9.8 feet, shown by the yellow dashed line.

Water clarity in CHP varied depending on the location within the Pond. Visibility was typically at least 4 feet, as measured by a Secchi disk (Figure 9). However, at most stations the water was frequently too murky for the Secchi disk to be seen on the pond bottom. Moreover, all stations except CHP6 and CHP7 had Secchi depths less than the management goal of visibility to the bottom of the Pond. Stations CHP6 and CHP7 were exceptionally shallow, and the bottom of the Pond was consistently visible. All other sampling stations experienced reduced water clarity, with Secchi depths occasionally measuring half of the total depth. These stations experienced elevated turbidity and reduced water clarity throughout the entire summer. Stations CHP2 and CHP3 had the greatest depth profiles and exhibited the most reduced water clarity. Elevated turbidity can likely be attributed to higher average temperatures during the summer that fuel algal growth coupled with increased nutrient inputs from surrounding properties via surface water runoff (e.g. from fertilizer application).

Nutrient Concentrations

- *Total nitrogen (TN) values in CHP were above the management targets for the majority of the monitoring period, peaking in July and August for most stations. Mean TN values were above the recommended limits established by the MEP report.*
- *TN measurements at station CHPUP were consistently lower compared to other stations and were below the 0.5 mg/L threshold for all sampling dates except for the October collection.*
- *Exploratory well-water sampling determined inorganic forms of nitrogen were elevated at 2 of the 4 wells which were investigated.*

GPF collected samples to measure the concentrations of phosphate, nitrate, ammonium, as well as chlorophyll pigments in Chilmark Pond. Abundant concentrations of nutrients in coastal waters can lead to eutrophic conditions and an overall deterioration in water quality. Nutrient pollution in marine and brackish ecosystems is often the result of excessive nutrient loading from adjacent land areas, which stems from human development. Measuring the concentration of nutrients in the water can indicate if eutrophication is occurring. Brackish coastal ecosystems often exhibit an excess of inorganic nitrogen, such as nitrate and ammonium, as well as excess organic nitrogen. Nutrient analyses were performed at the Marine Biological Laboratory in Woods Hole. Nutrient sample collection was limited to once per month due to the high cost of analysis and labor involved. Stations CHP3 and CHP7 were excluded from nutrient analyses.

Overall, nutrient concentrations in CHP were elevated, particularly with regards to nitrogen concentrations. Total nitrogen (TN) measures both inorganic and organic forms of nitrogen and is the metric typically used to assess whether eutrophication is occurring in coastal ecosystems. The 2015 MEP study for CHP determined the nitrogen loading threshold for habitat restoration. This study observed that nitrogen concentrations were relatively uniform throughout the estuary and recommended a "sentinel station" for monitoring TN over time. Stations CHP1-CHP5 represent the sentinel station for CHP, however CHP3 has since been removed from the Martha's Vineyard Commission's Unified Island-wide Monitoring Program. The MEP report states that the average TN concentration should remain below 0.5 milligrams per liter (mg/L) at the sentinel station (average of stations CHP1, CHP2, CHP4 and CHP5), across a 120-day period from May through September (Howes et al., 2015). This is a common nitrogen management target for saltwater estuaries, including other Martha's Vineyard coastal ponds. Stations CHP6 and CHPUP are not included in the sentinel station and cannot be used for comparisons to results reported in the 2015 MEP report. However, Middle Pond and Doctor's Creek are important components of the CHP estuary, and these stations are included in both the GPF and MVC monitoring programs to gain a more nuanced understanding of the nitrogen concentrations throughout the entire estuary.

TN values in CHP varied throughout the monitoring period but were mostly above the 0.5 mg/L threshold value. Every monitoring station exhibited at least one measurement above the TN management target (Figure 10). For all stations except CHPUP, TN values peaked in July and August. The maximum TN concentration recorded was 0.76 mg/L at CHPUP on October 8. This measurement was an anomaly, as all other stations experienced a decrease in TN levels during the October sample collection, and all prior measurements of TN at CHPUP were 0.37 mg/L or lower. This elevated TN measurement was driven by increases in dissolved and particulate organic nitrogen (Figures A1 & A2 in Appendix). Outside of CHPUP, maximum TN measurements were 0.73 mg/L at CHP1 on August 10, and two 0.69 mg/L measurements at CHP6 in July and August. TN measurements at station CHPUP were consistently lower compared to other stations and were below the 0.5 mg/L threshold for all sampling dates except for the October collection.

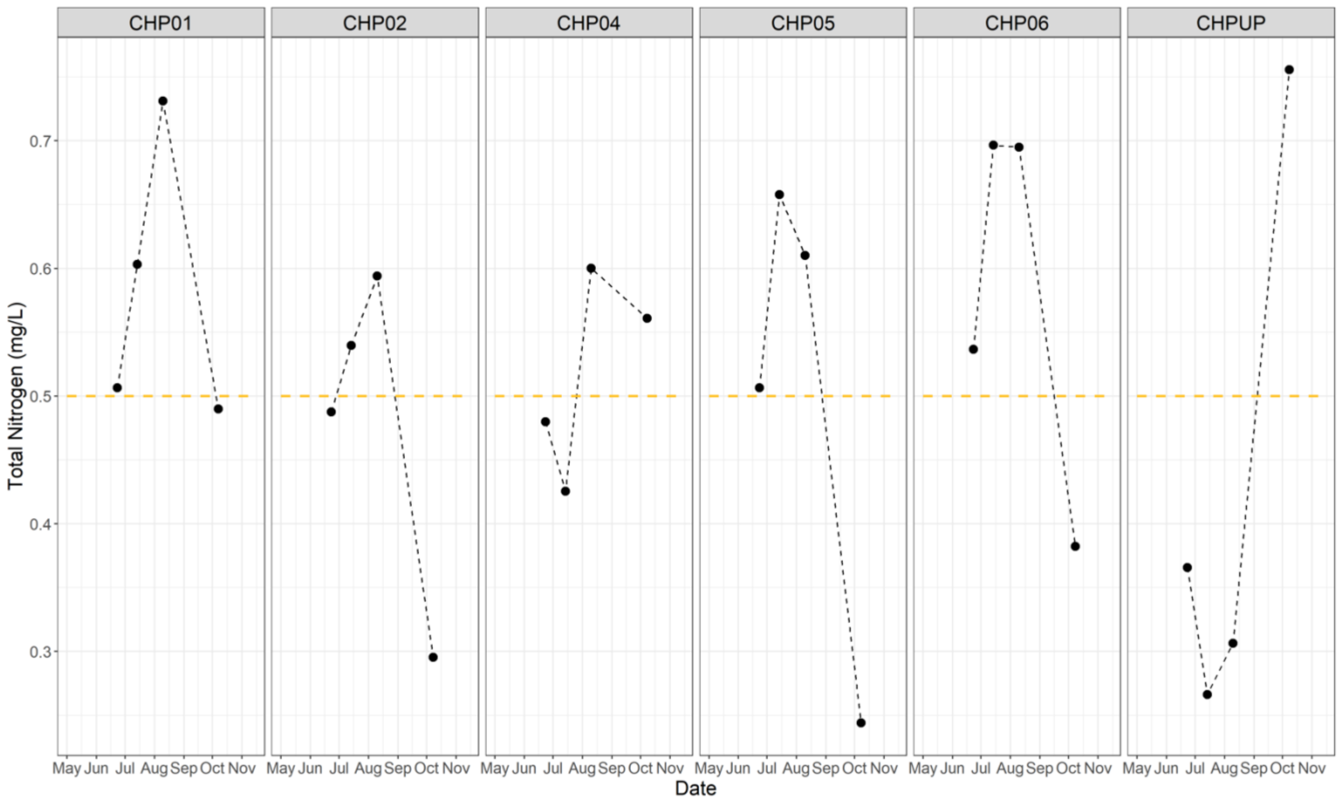

Figure 10. Total nitrogen in milligrams per liter (mg/L) in 2021. Data are from 6 CHP sampling stations (different panels). The dashed yellow line represents the 0.5 mg/L TN management target for the sentinel station (mean of CHP1, CHP2, CHP4, & CHP6) established by the MEP report.

Dissolved nitrogen was a more significant nitrogen source than particulate nitrogen at all stations except CHPUP. Both dissolved and particulate nitrogen contributed roughly equally to TN at CHPUP (Figure A1 in Appendix). At all stations, organic nitrogen was substantially higher than inorganic nitrogen (Figure A2 in Appendix). Organic nitrogen is nitrogen that is already incorporated into the living tissues of plants and animals, whereas inorganic nitrogen is the form that is available to plants and animals for consumption as part of their metabolism. Inorganic nitrogen is comprised of nitrate, nitrite, and ammonium, which can be measured as dissolved or particulate inorganic nitrogen. Other inorganic nutrients include phosphate and silicate. Excess inorganic nutrients can fuel plant growth and lead to eutrophication. Increased growth caused by elevated inorganic nutrients can lead to high organic nitrogen as the nutrients are utilized by plants and animals.

Phosphate measurements exhibited a different trend than TN. Phosphate measurements at all stations were lower in the summer and sharply increased during the October sample collection (Figure 11). This is likely because CHP is an ecosystem driven by nitrogen, which fuels plant and algal growth. This growth also requires phosphate, which is consumed during the summer when growth rates are highest. In the fall, plant growth subsides and the demand for phosphate declines, leading to more dissolved phosphate in the water. Most coastal estuaries are impacted by elevated nitrogen concentrations rather than phosphorus, and the 2015 MEP report did not include a management target for phosphate concentrations. The US Environmental Protection Agency (EPA) has published ambient water quality criteria recommendations to avoid eutrophication in freshwater ponds. The criteria for Massachusetts indicate that total phosphorus should remain below 0.02 mg/L. This is an imperfect comparison, since CHP is a brackish coastal pond, and phosphate concentrations were measured instead of total phosphorus.

Regardless, phosphate measurements were below the freshwater total phosphorus limit except in the October samples, when all stations except CHP4 exceed 0.02 mg/L (Figure 10).

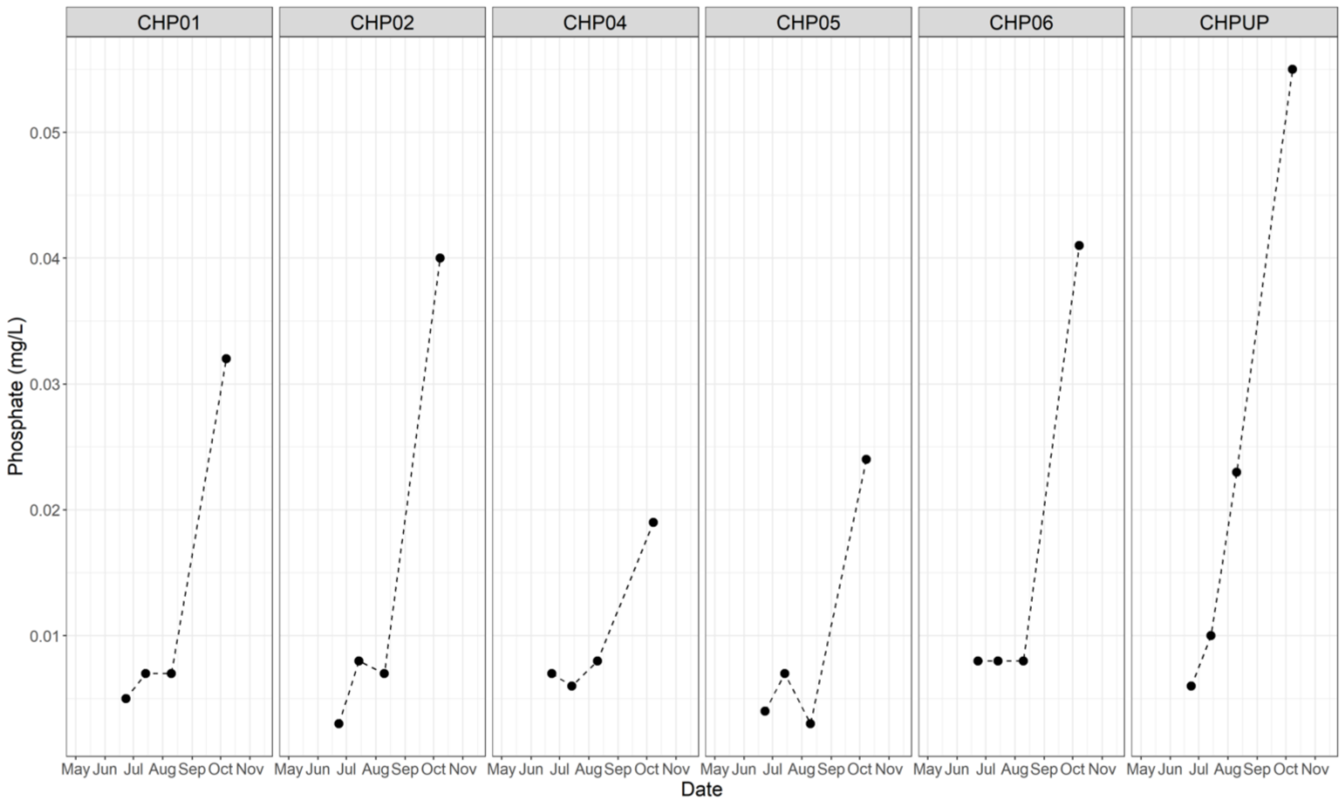

Figure 11. Phosphate concentrations in milligrams per liter (mg/L) in Chilmark Pond in 2021. Data are from 6 CHP sampling stations (different panels).

Overall, average nitrogen values in CHP were above the threshold values for habitat impairment. While analyzing the trend for each individual station is useful, the 2015 MEP report indicates that the mean concentration across the summer months (May-September) should be used. Mean TN across June-August sample dates at the sentinel station (CHP1, CHP2, CHP4 and CHP5) was 0.56 mg/L, while mean TN of all sample dates (including October) was 0.52 mg/L (Table 2). This is above the 0.5 mg/L TN limit. Nutrient samples were also collected at CHP6 and CHPUP, which are not included in the MEP sentinel station, but were included to help gauge nutrient inputs from the Middle Pond. Mean TN of all stations over all collection dates in 2021 was 0.51 mg/L. These elevated TN measurements indicate that CHP is not meeting the habitat restoration thresholds and remains an impaired ecosystem.

In addition to sampling within the water of CHP, GPF also collected samples for nutrient analysis in the groundwater north of CHP during the October sample collection. With the help of Bill Austin of Vineyard Land Surveying and Engineering, GPF collected samples at 4 wells adjacent to the CHP shoreline (Figure A3 in Appendix). These water samples came from within the water table and represent a snapshot of the groundwater influx into CHP. Since a significant source of the nutrients in CHP originates from septic systems and travels to the pond via groundwater, sampling within wells can help elucidate nitrogen hotspots within the watershed. These samples were only collected on October 8 and temporal trends cannot be inferred. Groundwater will be more extensively sampled in the 2022 CHP monitoring plan.

Dissolved nitrogen concentrations were much higher than pond water samples at two of the four wells (Table 3). Groundwater is not typically analyzed for particulate nitrogen, and because particulate nitrogen is included in the total nitrogen calculation, TN values cannot be determined. However, both inorganic and organic nitrogen sources and inorganic phosphorus were measured. Measurements of ammonium (NH_4), phosphate (PO_4), and dissolved organic nitrogen (DON) within all 4 well samples were comparable to pond water samples. Dissolved inorganic nitrogen (DIN) and total dissolved nitrogen (TDN) were elevated at wells CHPG1 and CHPG3, which was driven by substantially higher nitrate (NO_3) concentrations at both wells. NO_3 concentrations were highest at well CHPG3 (located near the Abel's Hill parking lot), measuring 7.14 mg/L. NO_3 levels were also elevated at wells CHPG1 (near Thumb Cove) and CHPG4 (near Middle Pond), with measurements of 6.06 and 2.89 mg/L, respectively. In comparison, NO_3 concentrations at pond sampling stations from the same day were 0.13 mg/L or lower (Table 3). This indicates that the groundwater which discharges into CHP is enriched with NO_3 and is a source of inorganic nitrogen to the pond. This inorganic nitrogen likely came from septic system effluent. A more intensive groundwater study will be conducted in 2022 which will help identify nitrogen hotspots within the watershed.

Date	Mean TN of sentinel station (limit=0.5) (mg/L)	TN of CHP6 (mg/L)	TN of CHPUP (mg/L)	Mean TN of all stations (mg/L)
6/23/2021	0.495	0.537	0.366	0.480
7/14/2021	0.557	0.697	0.266	0.532
8/10/2021	0.634	0.695	0.306	0.589
10/8/2021	0.398	0.382	0.756	0.455
Summer mean	**0.562**	**0.643**	**0.313**	**0.534**
2021 mean	**0.521**	**0.578**	**0.423**	**0.514**

Table 2. Mean Total Nitrogen (TN) values from Chilmark Pond in 2021. Mean values were calculated for the sentinel station (CHP1, CHP2, CHP4 & CHP5), stations CHP6 and CHPUP individually, and all stations at which nutrient data were collected (includes CHP6 & CHPUP). The MEP report determined the threshold TN value for the sentinel station was 0.5 mg/L.

2021 was the first year that CHP was included in the GPF Ecosystem Monitoring Program and comparisons to previous years cannot be made. However, the Martha's Vineyard Commission (MVC) has been collecting water quality data on CHP for decades. The nutrient sample analysis and field data collection methodologies for GPF and MVC are very similar, and the data produced are comparable. Trend analysis of long-term data is useful to determine how pond health has changed over time. While there are gaps in the timeseries, TN measurements have generally decreased since 1999, when the average TN at the sentinel station peaked at 1.91 mg/L (Figure 12). Recently, TN values have increased again, with average TN at the sentinel station measuring 1.39 mg/L in 2020. Overall, TN measurements have been extremely variable, with only two years (2007 and 2015) where average TN was below the MEP management target of 0.5 mg/L. An in-depth analysis of these long-term data will be performed in a supplementary GPF report, the results of which will be made available upon completion.

Date	Station	Pond	NH_4 (mg/L)	NO_3 (mg/L)	DIN (mg/L)	TDN (mg/L)	DON (mg/L)	PO_4 (mg/L)
10/8/2021	CHPG1	GW	0.03	6.06	1.39	1.45	0.06	0.015
10/8/2021	CHPG2	GW	0.02	0.06	0.03	0.07	0.04	0.016
10/8/2021	CHPG3	GW	0.01	7.14	1.62	1.69	0.07	0.032
10/8/2021	CHPG4	GW	0.02	2.89	0.67	0.83	0.16	0.025
10/8/2021	CHP1	CHP	0.05	0.13	0.07	0.31	0.25	0.032
10/8/2021	CHP2	CHP	0	0.01	0.01	0.15	0.14	0.04
10/8/2021	CHP4	CHP	0	0.01	0.01	0.39	0.39	0.019
10/8/2021	CHP5	CHP	0.01	0.01	0.01	0.16	0.15	0.024
10/8/2021	CHP6	CHP	0.02	0.03	0.02	0.23	0.21	0.041
10/8/2021	CHPUP	CHP	0.01	0.02	0.01	0.34	0.33	0.055

Table 3. Multiple forms of dissolved nitrogen and phosphate (PO_4) within 4 groundwater wells (in green) and 6 pondwater sampling stations (in blue) around CHP. Well-water samples were collected only on October 8, 2021, but pond monitoring stations were samples 3 additional times in 2021. Forms of nitrogen measured include ammonium (NH_4), nitrate (NO_3), dissolved inorganic nitrogen (DIN), total dissolved nitrogen (TDN) and dissolved organic nitrogen (DON).

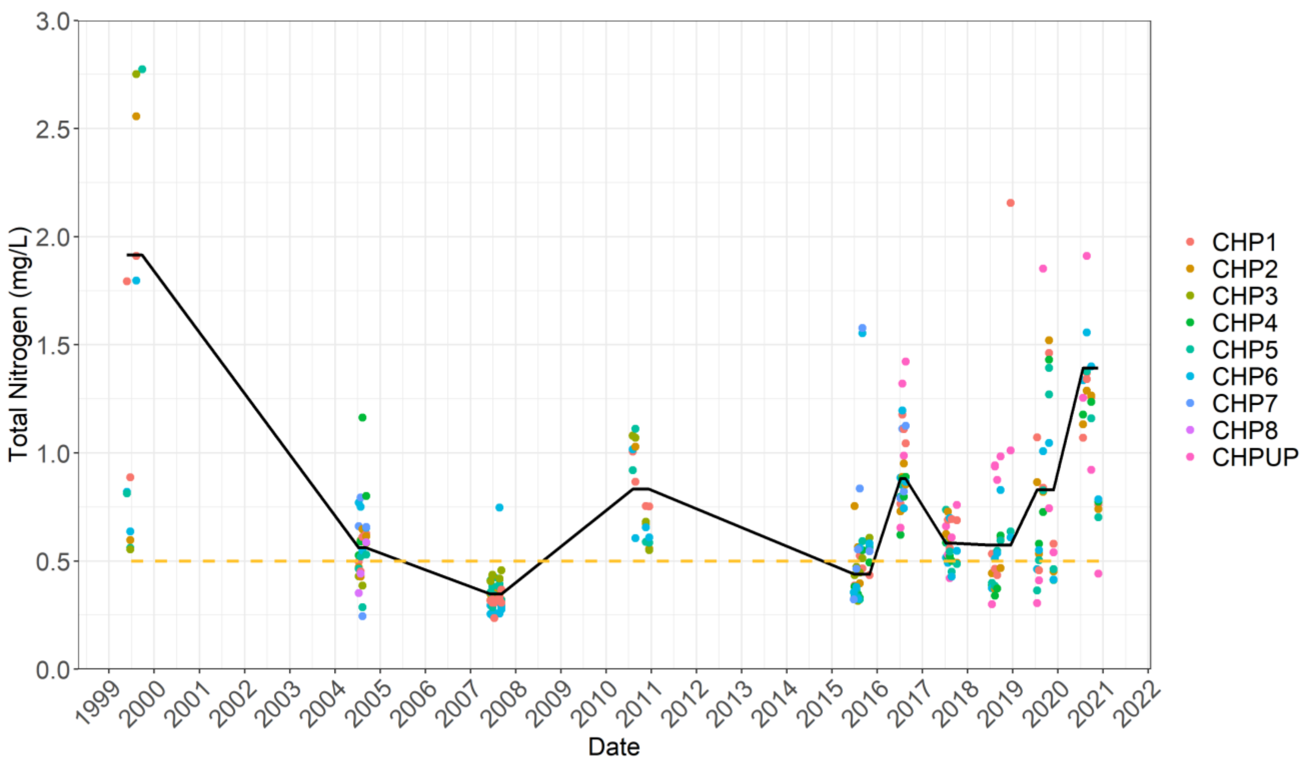

Figure 12. Total nitrogen in milligrams per liter (mg/L) from 1999 to 2020. Data are from 9 CHP sampling stations (different colors), collected by the Martha's Vineyard Commission. The dashed yellow line represents the 0.5 mg/L TN management target for the sentinel station (mean of CHP1, CHP2, CHP4, & CHP6) established by the 2015 MEP report. The black line represents the annual average of the sentinel station. Data from 2021 were excluded from this figure.

Chlorophyll Measurements

- *Chlorophyll-a was below the 10 µg/L threshold for most stations within the main basin of CHP.*
- *Chlorophyll-a peaked during the summer months. This increase was more pronounced at station CHPUP.*

In addition to nutrient levels, the amount of chlorophyll pigment in the water is an indicator of water quality. Chlorophyll is a pigment used by plants during photosynthesis. Measuring the amount of chlorophyll in the water, specifically the pigment chlorophyll-a, provides an estimate of microscopic plant abundance in the water. Microscopic aquatic plants, called phytoplankton, require nutrients to grow. High levels of chlorophyll can indicate that nutrients such as nitrate and phosphate are in excess and readily available for primary production. Elevated concentrations of nutrients can spur rapid phytoplankton growth, called a phytoplankton bloom. Chlorophyll pigments were measured in two ways: laboratory analysis at the Marine Biological Laboratory in Woods Hole and via fluorometry at the GPF lab. While both are accurate, for simplicity this report focuses on the results from the Woods Hole laboratory. Another plant pigment called phaeophytin was also measured, which is produced as chlorophyll degrades at the end of a phytoplankton bloom. Measurements of total pigment, the sum of phaeophytin and chlorophyll-a, are available from GPF upon request.

The MEP uses a management target of 10 micrograms per liter (µg/L) of chlorophyll-a for coastal ponds, and measurements in excess of 10 µg/L are an indicator of impairment (Howes et al., 2015). For most CHP sampling stations, chlorophyll was below this management target during the summer months (Figure 13). Station CHPUP (in Middle Pond) experienced more phytoplankton growth compared to other stations, and measurements of chlorophyll-a were above the 10 µg/L threshold for all sampling dates except the June collection. Maximum chlorophyll-a concentrations occurred in either July or August for most stations. This was expected due to hotter temperatures in the summer and increased nutrient inputs from surrounding properties. The maximum observed chlorophyll-a concentration was 47.99 µg/L at station CHPUP on July 14. This measurement was substantially higher than other measurements at CHPUP and other CHP stations, which indicates the presence of a phytoplankton bloom. Station CHP6 also exhibited a peak in chlorophyll-a concentrations on July 14, but much smaller in magnitude than CHPUP, with 11.2 µg/L chlorophyll-a. Stations in the main basin of CHP experienced a smaller summer peak in chlorophyll-a measurements and were consistently below the 10 µg/L threshold for all sampling dates (Figure 13). The lower measurements from CHP1-5 do not preclude the occurrence of a phytoplankton bloom in 2021, as one may have occurred between sample collections. Samples for fluorometric chlorophyll analyses were taken more frequently and at all 8 sampling stations. These measurements were consistently above the 10 µg/L chlorophyll threshold during the summer months at all stations.

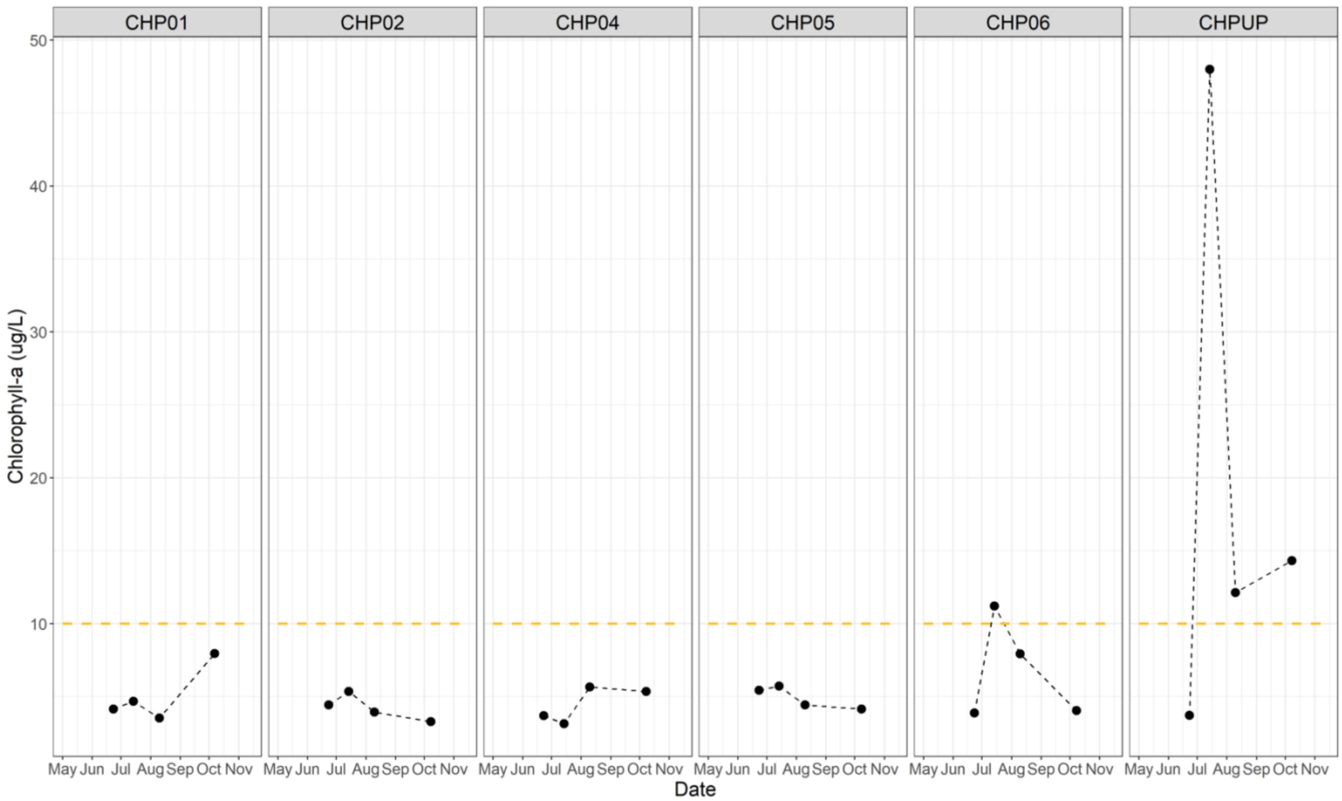

Figure 13. Chlorophyll-a pigments in micrograms per liter (µg/L) in 2021. Data are from 6 CHP sampling stations. The dashed yellow line represents the 10 µg/L management target for healthy coastal ponds.

MV CYANO

- *CHP water samples were designated in the yellow or "ALERT" category for the majority of the monitoring season, indicating that environmental conditions could support rapid growth of cyanobacteria and that a bloom is possible but not present.*
- *A CHP sample from July 14 was sent to an outside laboratory for toxin analysis, which found microcystin concentrations were below the detectable limit (<0.3 µg/L). The limit for recreational swimming is 8 µg/L.*
- *Among all ecosystems monitored for MV CYANO in 2021, CHP was consistently one of the ponds most at risk for a cyanobacteria bloom.*

Chilmark Pond was included in the first year of the Martha's Vineyard Cyanobacteria Monitoring Program (MV CYANO). MV CYANO is a partnership between GPF and the Boards of Health of Chilmark, West Tisbury, and Edgartown. Cyanobacteria, a.k.a. blue-green algae, are a group of microorganisms naturally occurring in all Vineyard waters. When cyanobacteria grow rapidly or bloom, they can produce cyanotoxins, which when concentrated may cause adverse health effects in humans, pets, or livestock who wade in or ingest blooming waters. This pilot program successfully developed a workflow for regular sample collection, analysis, and subsequent presentation of spatial and numeric data to the Boards of Health to aid in their decision-making process regarding postings and closures. This workflow included a color-coded matrix, where different data-driven risk thresholds were represented by associated colors and categories, each with a corresponding sign to be posted at pond access points (Figure A4 in Appendix).

This program utilizes a sensor called a fluorometer to detect and quantify the abundance of cyanobacteria in water samples. While the species of cyanobacteria cannot be identified without a microscope, samples analyzed with a fluorometer can estimate the concentration of cyanobacteria in an ecosystem, which is needed to detect when a bloom occurs. Each color in the MV CYANO color-coded matrix corresponds to different concentrations of cyanobacteria and therefore represent increasing likelihood of bloom occurrence.

For a majority of the monitoring period, CHP water samples were designated in the yellow or "ALERT" category (Figure 14). This classification indicates that environmental conditions could support rapid growth of cyanobacteria and that a bloom is possible but not present. Stations CHP1, CHP3, and CHP4 were designated into the orange or "BLOOM WATCH" risk level at least once. Samples in the orange category have slightly elevated cyanobacteria levels and the likelihood of a bloom is increased. The highest recorded concentration of cyanobacteria was 11.0 µg/L at station CHP3 on July 27. Station CHP1 also exhibited mildly elevated cyanobacteria abundance, with measurements of 10.88 and 10.49 µg/L on July 14 and July 20, respectively. The July 14 sample was the first occurrence of a sample in the orange "BLOOM WATCH" category in the 2021 season. Samples in the orange risk tier can be sent to the Cyanobacteria Analysis Lab at Stonybrook University for species identification and toxin analysis. The July 14 sample from CHP1 was sent for further analysis, which found 1 colony of *Microcystis* sp. (a genus known to produce cyanotoxins) was present, but the abundance was far below what is considered a bloom. Further, the concentration of microcystin was below the instrument's detectable limit, indicating that the concentration of this toxin was less than 0.3 µg/L. Both the federal Environmental Protection Agency and the Massachusetts Department of Public Health have a recreational bathing limit of 8.0 µg/L for microcystin.

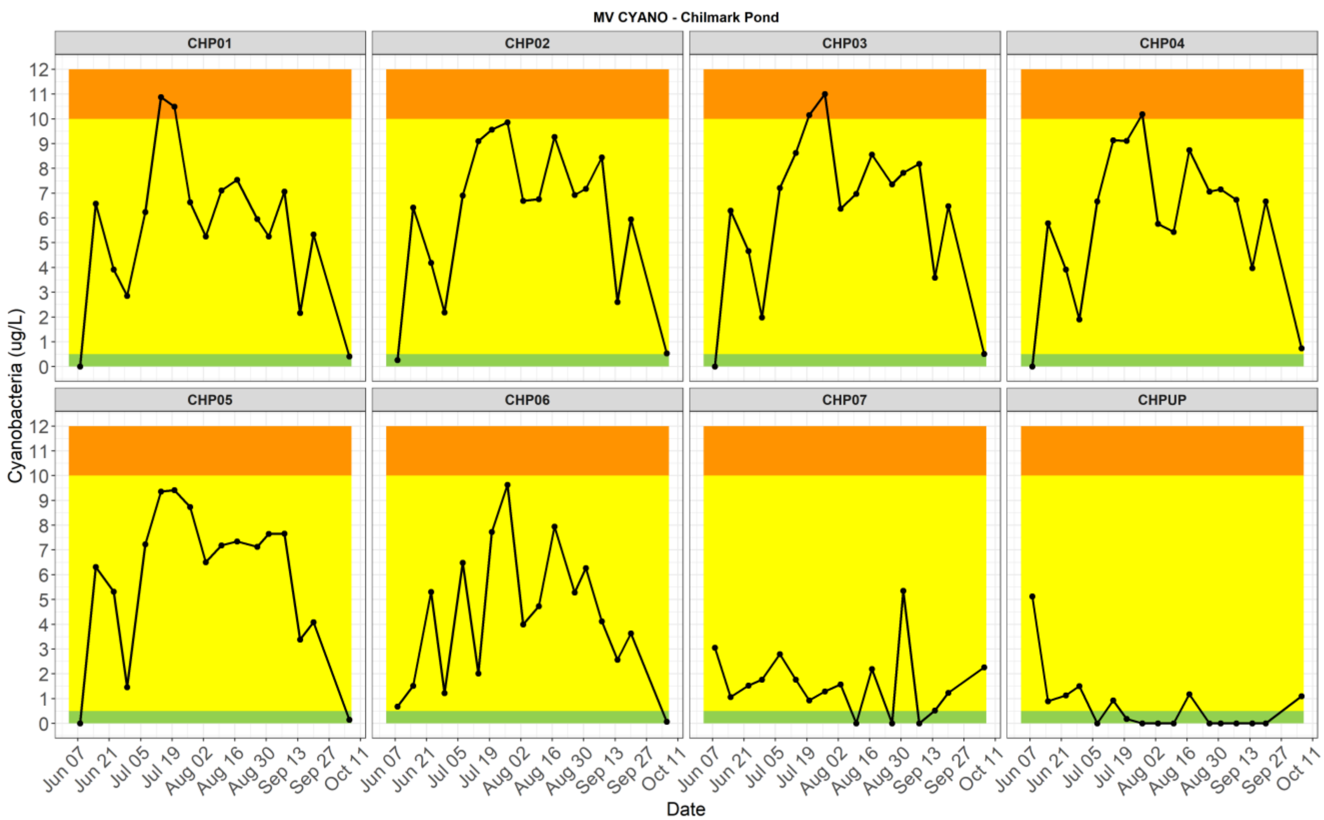

Figure 14. Cyanobacteria concentrations in micrograms per liter (µg/L) at all CHP stations in 2021. Samples were taken from surface waters and measurements were obtained via a fluorometer. Background colors correspond to the color-coded risk matrix used by the MV CYNAO monitoring program (see Figure A4 in Appendix).

All sampling stations within the main basin of CHP exhibited a similar seasonal trend, where cyanobacteria abundance was highest in the warm, summer months. Cyanobacteria concentrations at stations CHPUP (Middle Pond) and CHP7 (Doctor's Creek) were notably less than the main basin of CHP. This was somewhat surprising, as the salinity at these stations was considerably lower and many potentially toxic species of cyanobacteria are known to favor freshwater ecosystems. 2021 was the first year of MV CYANO monitoring and as this program continues, more data will shed light on the dynamics of cyanobacteria in brackish coastal ponds. Among all ecosystems monitored for MV CYANO in 2021, CHP was consistently one of the ponds most at risk for a cyanobacteria bloom. A bloom was observed in nearby Squibnocket Pond, with a maximum cyanobacteria concentration of 841.4 µg/L, which was given a red "BLOOM ADVISORY" classification. While CHP had slightly elevated cyanobacteria concentrations throughout the summer, the abundance never reached levels associated with potentially dangerous blooms.

Conclusions

Overall, Chilmark Pond is suffering from multiple water quality issues, including low dissolved oxygen and elevated nitrogen concentrations within the water column. Additionally, measurements of water clarity often fell below recommended limits during this monitoring program. These combined factors ultimately decrease habitat quality, limiting biodiversity and reducing overall ecosystem health.

Previous studies by the MVC and the Massachusetts Estuaries Project have found that eutrophication, or excess nutrient concentrations, is occurring in CHP. The primary source of impairment in CHP is due to nitrogen loading from within the watershed. Nutrient concentrations from the GPF Ecosystem Monitoring Program were above threshold nitrogen limits established by the 2015 MEP report. The combination of elevated nitrogen concentrations and other water quality indicators with concerning measurements, such as dissolved oxygen, chlorophyll, and turbidity, suggests water quality in CHP was impaired in 2021. Excess nitrogen fueled microscopic and macroscopic plant growth, leading to elevated chlorophyll concentrations. As these plants died and decayed, dissolved oxygen was reduced. Dissolved oxygen in CHP was particularly concerning, as critically low levels of oxygen were detected in the bottom waters south of Wade's Cove. A reduction in local nitrogen inputs would help reduce these impairments. Excess nutrients are primarily introduced to the environment as a result of human development, such as septic systems, fertilizers, and agriculture, and enter the pond via surface water runoff and groundwater.

Continued monitoring is recommended to further document the impact of eutrophication on water quality. This can be accomplished via a combination of site visits with handheld sampling equipment and deployed data loggers. Additionally, continued monitoring of nutrient concentrations throughout the pond is recommended. Assessment of nutrient concentrations within the groundwater north of the pond will help to identify nitrogen hotspots within the watershed. CHP has been the subject of several studies in the past, and there are many possibilities for future research on this ecosystem such as analysis of the recharge rate and water budget, investigations into the biodiversity and community structure of the phytoplankton community, and long-term trend analysis using historical data.

Regardless of the water quality challenges that exist within CHP, it remains a priceless ecosystem admired not only for its important ecological functions, but also for its many recreational and aesthetic qualities. The CHP habitat is used by a multitude of bird, crustacean and finfish species, as well as populations of native fauna such as coastal river otters. If nitrogen pollution is not eventually addressed, water and habitat quality will likely continue to degrade, and further deterioration of the pond should be avoided. Additionally, taking steps to address water quality will help protect the pond and its surrounding habitats and human communities from the threats posed by climate change. The pond is a beloved ecosystem with deep-rooted ties to the history and character of the surrounding community. Many of the solutions to these issues already exist, and the Pond continues to benefit from a dedicated and engaged community of stakeholders.

Acknowledgments

The Ecosystem Monitoring Program on Chilmark Pond and the release of this report would not be possible without the support of many people who kindly offered their assistance and expertise. David Bouck, GPF Watershed Outreach Manager, assisted with field data collection and contributed greatly by providing valuable feedback on an earlier draft of this report. Allan Holt generously provided a boat for use on CHP and Andrew Kahl performed the necessary maintenance. Steve and Liz Lewenberg generously provided a boat and access to the Middle Pond. Interns Maggie Sandusky, Kendall Rudolph, and Becca Eyrick were vital members of the field team. Martha Cottle, Chilmark Pond Association Commissioner, provided data on 2021 CHP elevation, opening and closure dates. Bill Austin, of Vineyard Land Surveying and Engineering, also provided access to an elevation data logger. Sheri Caseau, Water Resource Planner at the Martha's Vineyard Commission, provided CHP historical data. The Great Pond Foundation expresses gratitude to everyone who contributed. This work was supported by Chilmark Pond Foundation.

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https://www.mass.gov/doc/chilmark-pond-embayment-system-chilmark-ma-2015/download

Appendix

Glossary of Water Quality Parameters

Ammonium (NH_4^+): Ammonium is a nutrient plants need to survive, however it is also a waste product from animal metabolism. Ammonium is converted to ammonia (NH_3), which in high concentrations acts as a toxin.

Biodiversity: the variety of life found in a particular place. An ecosystem with a large diversity of species is more resilient than one with fewer species.

Chlorophyll: Chlorophyll is a pigment plants use for photosynthesis, measured in micrograms per liter (µg/L). Monitoring chlorophyll concentrations can tell you if excessive plant growth is occurring, such as an algal bloom. The management goal for chlorophyll is **3-10 µg/L**.

Dissolved Oxygen (DO): the amount of oxygen dissolved in the water, measured in milligrams per liter (mg/L). Organisms require adequate oxygen concentrations for their metabolism and will become stressed if DO becomes depleted. The management goal for a healthy pond is **6 mg/L**. DO levels below 4 mg/L are when organisms begin to suffer from lack of oxygen, and when DO drops below 2 mg/L the water becomes hypoxic, where oxygen deficiencies can be fatal. The amount of oxygen that can physically dissolve in water is dependent on temperature, salinity and pressure.

Ecosystem: A community of living organisms and their connection to the nonliving physical and chemical components of their habitat. Species are often connected via food webs and depend on factors such as weather and the water cycle, all of which are components of an ecosystem.

Eutrophication: When nutrients such as nitrogen or phosphorus are in excess in an ecosystem, which causes many downstream problems such as algal blooms and low levels of dissolved oxygen. Eutrophication is often caused by nutrient pollution from human sources such as wastewater, farming waste, and fertilizer runoff.

Nitrate (NO_3): The most common form of inorganic nitrogen in coastal waters. Nitrate is naturally occurring, but excess nitrate comes from sources such as septic systems, wastewater treatment plants, runoff from livestock in farms, and runoff from fertilizer in both agriculture and household landscaping.

Nutrient Concentrations: Dissolved concentrations of nitrate, phosphate, silica, and ammonium, measured in milligram/liter (mg/L). Living organisms need these nutrients to survive, however they are often elevated in coastal waters. Elevated nutrient levels usually come from fertilizer and septic systems, and lead to excessive plant growth and deteriorated water quality, a process called eutrophication. In CHP, nitrate and ammonium have been elevated in the past and are monitored closely, with a management goal of keeping total nitrogen (TN) to **0.5 mg/L** of nitrogen or less.

pH: a measurement of how acidic or basic a solution is. Neutral pH is 7. pH of coastal waters often range from **6.5-8.5**, which is the management goal. pH will often become acidic if there is excessive decaying organic matter in the water or sediment.

Phosphate (PO_4): Phosphate is a form of inorganic phosphorus. PO_4 is more important in freshwater ecosystems, where it often causes eutrophication. The biggest source of PO_4 is from detergents in our dishwashing and laundry soaps.

Salinity: the amount of salts dissolved in the water, measured in parts per thousand (ppt). Ocean water has a salinity of 32-35 ppt, while freshwater is 0 ppt. Most organisms are adapted to live in either freshwater or saltwater and cannot tolerate both. The GPF management threshold is **15 ppt**, which is the lowest salinity in which eelgrass can survive.

Silicate (SiO_2): Silicate is an inorganic form of silica. It comes from the weathering of rocks, as rain and sun erode the molecules that form rocks. Silicate is a requirement for certain types of phytoplankton, or microscopic plants, that need it to form shells. Shells in crustaceans and shellfish are mostly made of carbonate (CO_3^{2-}), an inorganic form on carbon.

Total Nitrogen (TN): The amount of inorganic and organic nitrogen in the water and the sum of all the different forms of nitrogen. The MEP found that nitrogen was driving impairment in CHP and set the management goal of **0.5 mg/L TN** for the "sentinel station", which is the mean of CHP1, CHP2, CHP4 and CHP5.

Turbidity: a measure how many particles are dissolved in the water, which affects how much light is transmitted through the water column. Water with low turbidity is clear and you can often see the bottom, while water with high turbidity appears murky. High turbidity is detrimental to submerged aquatic vegetation, as less sunlight can penetrate the water. The management goal is to have sufficient water clarity to see **3 m** down, or to the bottom of the Pond.

Watershed: A land area that channels rainfall and snowmelt to creeks, streams, and rivers, and eventually to outflow points such as reservoirs, bays, and the ocean.

Table A1.

2021 Dates of Site Visits to Chilmark Pond					
May	**June**	**July**	**August**	**September**	**October**
5/14	6/1	7/7	8/3	9/7	10/6
5/25	6/8	7/14	8/10	9/14	10/8
	6/15	7/20	8/17	9/20	10/21
	6/23	7/27	8/26	9/27	
	6/29		8/31		

Figure A1

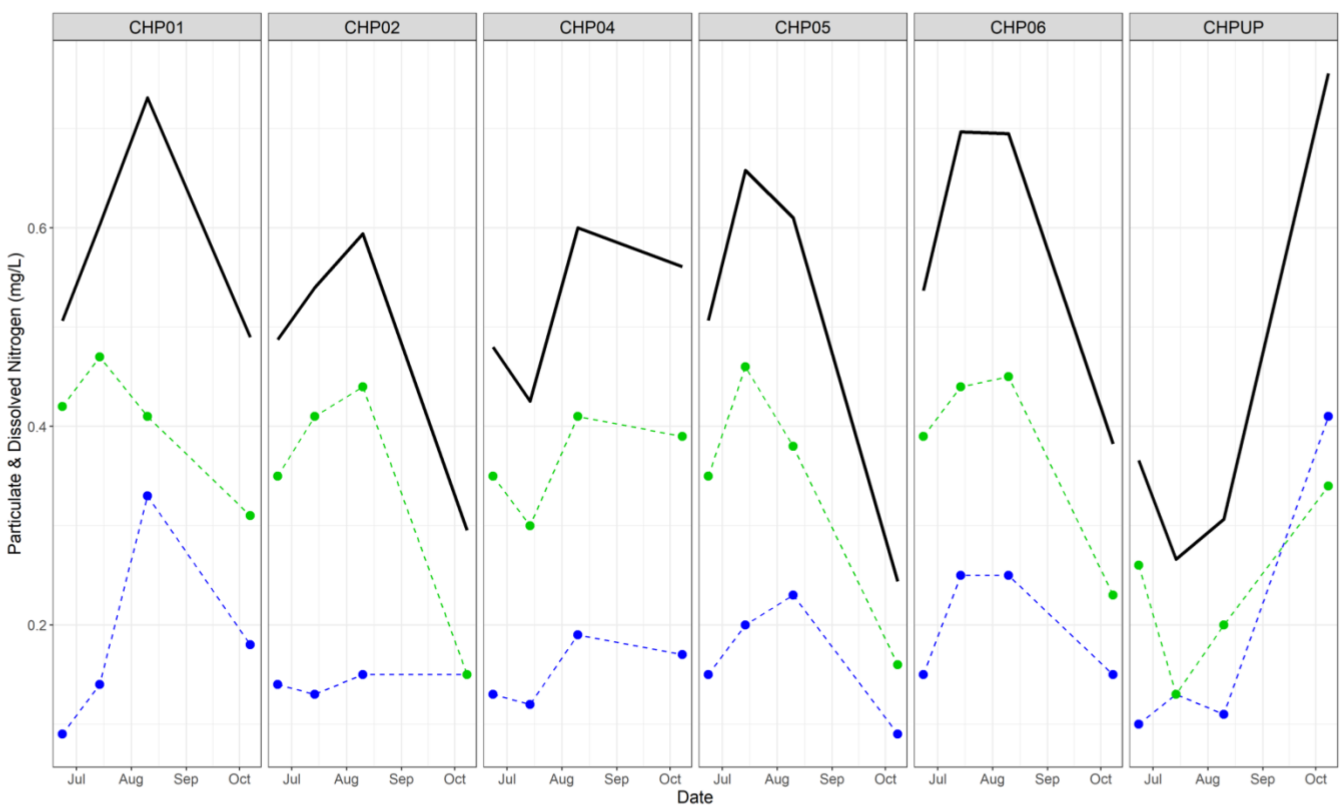

Figure A1. Particulate and dissolved nitrogen sources from 6 stations in Chilmark Pond in 2021. Data are in milligrams per liter (mg/L). The blue line is particulate organic nitrogen (PON), the green line is total dissolved nitrogen (TDN) and the black like is total nitrogen (TN). TN is comprised of both PON and TDN.

Figure A2

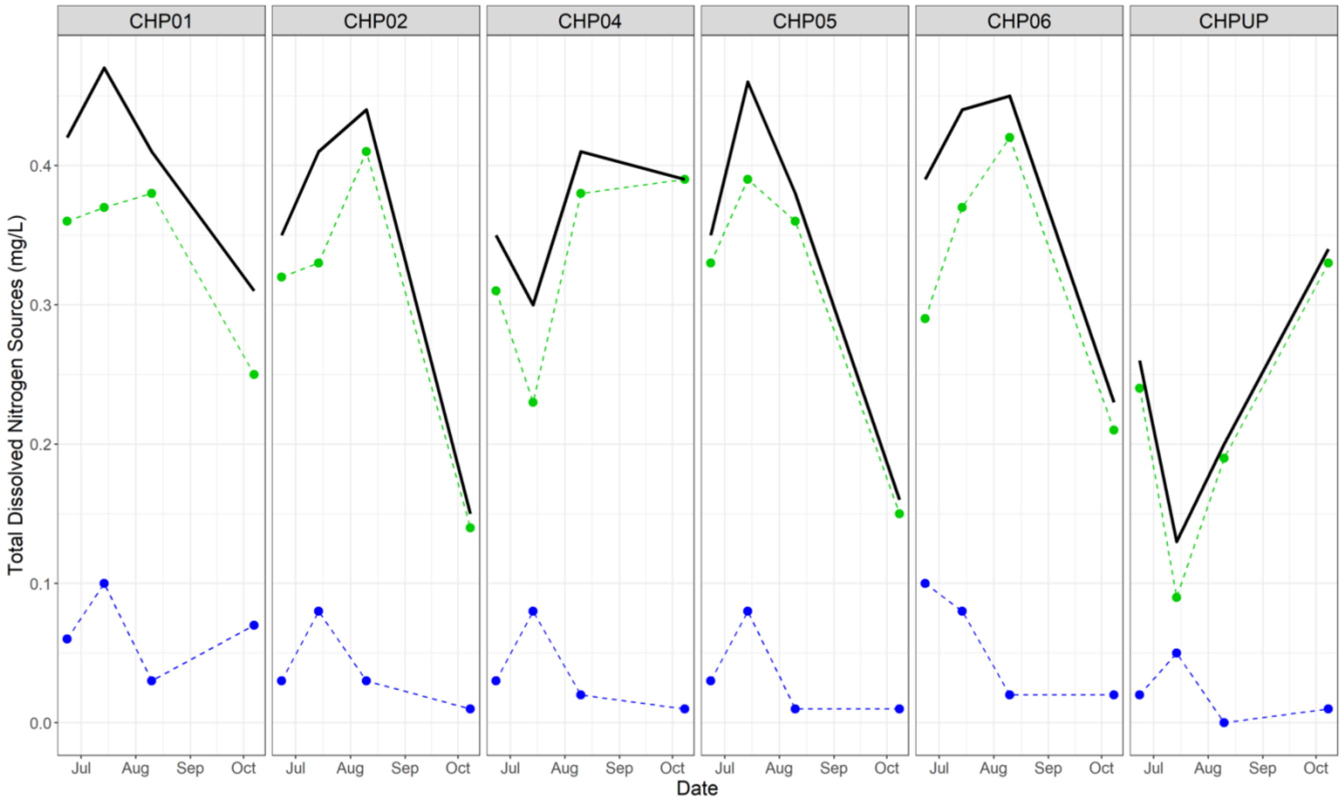

Figure A2. Total dissolved nitrogen sources from 6 stations in Chilmark Pond in 2021. Data are in milligrams per liter (mg/L). The blue line is dissolved inorganic nitrogen (DIN), the green line is dissolved organic nitrogen (DON) and the black like is total dissolved nitrogen (TDN). TDN, along with total particulate nitrogen, make up total nitrogen (TN).

Figure A3

Figure A3. Map of the 8 Chilmark Pond (CHP) sampling stations and the 4 groundwater wells where supplemental nutrient analyses were performed.

Figure A4

GREEN		**BLOOM NOT PRESENT** Conditions are not favorable for a Cyanobacterial Bloom. **OK:** Swimming, boating, paddling, wading, fishing, and consuming shellfish, crabs, of finfish. No known cynaobateria risks to humans, pets, and livestock.
YELLOW		**CYANOBACTERIA ALERT** It is the season where Cyanobacterial Blooms are possible. **OK:** Swimming, boating, paddling, wading, fishing, and consuming shellfish, crabs, of finfish. **USE CAUTION:** risk to humans/pets/ livestock when ingesting water.
ORANGE		**CYANOBACTERIA BLOOM WATCH** **OK**: Boating. **USE CAUTION:** risk for swimming, paddling, and wading, fishing. **ADVISE AGAINST:** humans/pets/livestock ingestion of water, comsuming shellfish, crabs, or finfinsh.
RED		**CYANOBACTERIA BLOOM ADVISORY** There is an active Cyanobacteria bloom, cyanotoxins may be present. **OK**: Boating. **ADVISE AGAINST**: pets/livestock/human ingestion of water, fishing, comsuming shellfish or finfinsh, swimming, paddling, and wading.

Figure A4. The MV CYANO color-coded matrix.