

**Childs River Restoration:
Monitoring Progress and Outcomes Three Years Post-Construction
June 2025**

Prepared by: Association to Preserve Cape Cod

Prepared for: Massachusetts Division of Ecological Restoration

Report and associated data collected, analyzed, and compiled by Mike Palmer, Jordan Mora, and April Wobst with support from the Division of Ecological Restoration.



Acknowledgements

The Childs River restoration was made possible by the following partners and funders: the Falmouth Rod and Gun Club, the Sporting Safety Conservation and Education Fund, U.S. Fish and Wildlife Service, the towns of Mashpee and Falmouth, the Massachusetts Division of Fisheries and Wildlife, the Waquoit Bay National Estuarine Research Reserve, the Massachusetts Division of Ecological Restoration, the Massachusetts Division of Marine Fisheries, the Massachusetts Department of Conservation and Recreation, Inter-Fluve Inc., the Association to Preserve Cape Cod, Lucianos Excavation Inc., Trout Unlimited, Ducks Unlimited, the Falmouth and Mashpee Community Preservation Committees, the Woodwell Climate Research Center, the U.S. Fish and Wildlife Service's National Coastal Wetland Conservation Grant program, the U.S. Environmental Protection Agency through collaboration with Restore America's Estuaries Southeast New England Program watershed grants, the Massachusetts Environmental Trust, the Cape Cod Foundation, the Living Observatory, the USDA Natural Resource Conservation Service, the Sea Run Brook Trout Coalition, MA Department of Fish and Game, Essex Horticulture, Tighe & Bond, Wildlife & Sport Fish Restoration, the Falmouth Department of Public Works, the Federal Highways Administration, the Friends of the Mashpee National Wildlife Refuge, and public donations.

This report is based on field data and project information generously provided by Ryan Clark (Waquoit Bay National Estuarine Research Reserve), AD Colburn (Falmouth Rod and Gun Club; Sporting, Safety, Conservation, and Education Fund), Steve Hurley (retired, Massachusetts Division of Fisheries and Wildlife), Sarah Klionsky (Boston University), and Chris Neill (Woodwell Climate Research Center).

Executive Summary

The Childs River, flowing through Falmouth and Mashpee on Cape Cod, Massachusetts, originates from groundwater discharge within the Mashpee National Wildlife Refuge. It runs south for approximately one and a half miles before discharging into Eel Pond, a sub-embayment of Waquoit Bay and Vineyard Sound.

Centuries of human activity degraded the river's once-thriving sea-run Brook Trout habitat. In the 19th century, earthen dams built for mills created stagnant, oxygen-deprived pools. A manmade ditch connecting the upper river to Johns Pond, dug in the mid-1800s for a herring fishery, further disrupted natural flow patterns. Cranberry farming introduced dikes, ditches, and water control structures, fragmenting the river, reducing streamflow, and blocking fish passage. These changes contributed to the decline of native flora and fauna.

A comprehensive restoration project completed in fall 2021 aimed to restore critical riverine functions and enhance ecosystem health. Key interventions included the removal of in-stream barriers to fish passage, excavation of accumulated sediment, replacement of the undersized culvert at Carriage Shop Road, reconstruction of the river channel, and the restoration of adjacent wetlands and floodplains. The primary objectives of the project were to improve coldwater habitat, facilitate the migration of Brook Trout and other diadromous species such as American Eel, enhance water quality, and promote biodiversity by restoring a mosaic of native vegetation communities and improving habitat for waterfowl and other wetland-dependent species within the watershed.

This report presents findings from two to three years of pre-restoration and three years of post-restoration monitoring (2019–2024), including analyses of water quality, Brook Trout populations, and vegetation. Data were collected through regular water sampling, continuous data logging, biannual fish surveys, and annual vegetation surveys, with a focus on summer conditions when aquatic organisms are most vulnerable.

Results show a rapid positive response by Brook Trout, with spawning success and multi-year survival likely driven by improved streamflow, cooler temperatures, increased dissolved oxygen, and enhanced gravel substrate for spawning. Although the restoration improved habitat for fish and other aquatic organisms, the faster moving water and improved connection to the groundwater table has resulted in increasing nitrate concentrations in the lower, downstream section of the river. Increased native wetland plant diversity and abundance signal broader ecosystem recovery.

Overall, the restoration has successfully improved coldwater and wetland habitat, setting the foundation for long-term ecological resilience.

Contents

Acknowledgements	2
Executive Summary	3
Introduction.....	5
Project Timeline.....	6
Project Goals	7
Methods.....	8
Continuous temperature loggers	8
Water quality and nutrients	8
Brook Trout.....	10
Vegetation	11
Results.....	11
Continuous temperature loggers	11
Water quality and nutrients.....	12
Brook Trout.....	15
Vegetation	16
Discussion	17
Improve Coldwater Habitat.....	17
Enhance Fish Passage	18
Improve Water Quality	19
Restore Wetlands and Habitat Diversity.....	21
Conclusions.....	21
References	22
Tables	24
Figures.....	29

Introduction

The Childs River flows for about a mile and a half through the U.S. Fish and Wildlife Service (USFWS) Mashpee National Wildlife Refuge, spanning the towns of Falmouth and Mashpee, before emptying into Eel Pond, which is hydrologically connected to Waquoit Bay and Vineyard Sound (Fig. 1). The river begins at natural springs near the former Garner Bog in Mashpee. In the mid-1800s, the northern reaches of the river were artificially connected to Johns Pond via a manmade ditch to establish a river herring fishery. Although water no longer flows continuously from Johns Pond through this ditch, natural groundwater seeps south of the bogs provide a steady flow that supports ongoing restoration efforts aimed at benefiting Brook Trout and other wildlife. Meanwhile, the neighboring Quashnet River remains the primary herring run to Johns Pond, with restoration efforts focused on maintaining that connection as freshwater spawning habitat. Therefore, restoring the historic connection between the Childs River and Johns Pond to support river herring was not an objective of this project.

Historically, Waquoit Bay and its tributaries, including the Childs River, were prime fishing locations for sea-run Brook Trout (*Salvelinus fontinalis*), attracting notable anglers such as Daniel Webster and President Grover Cleveland (Town of Mashpee, 2025). The earliest documentation of trout fishing in the Childs River dates to 1833 (Smith, 1833/1970). Decades of human modifications severely degraded the Childs River, resulting in significant declines or local extirpation of Brook Trout metapopulations.

The river was first altered in the early 19th century by the construction of an earthen mill dam, which blocked upstream fish passage and created a shallow, stagnant impoundment with elevated temperatures unsuitable for Brook Trout ($>65^{\circ}\text{F}$; McCormick et al., 2007). The earthen dam's fish ladder was largely non-functional from 2012 on due to structural failures, and the earthen dam and its spillway were heavily overgrown, further limiting flow. In the early 20th century, cranberry farming transformed upstream areas through the development of the Farley and Garner Bog complexes (Fig. 2). These conversions included extensive channel modifications, ditching, and small culverts, leading to warming water which disrupted natural flow and habitat connectivity. An undersized, deteriorated culvert under Carriage Shop Road further impeded flow and fish passage. Together, these modifications simplified the river channel, reduced coldwater and wetland habitats, and eliminated important spawning and feeding areas for Brook Trout and other aquatic species. Water quality was further impacted by past pesticide runoff, residual nutrient loading, and low dissolved oxygen, affecting downstream ecosystems such as Waquoit Bay (Mora and Wobst, 2023).

MassWildlife has conducted long-term monitoring of the Childs River since the 1950s, with biannual surveys in May and September (Table 1). Early studies, including the 1958 recovery of stocked trout from the Mashpee River, indicated potential connectivity between the Childs River and nearby populations such as the Quashnet River via Waquoit Bay (Mullan, 1958). However, a comprehensive survey of the Childs River in 2006 revealed no Brook Trout, despite temperature data collected since 2001 indicating the presence of suitable coldwater habitat in the lower river. This highlighted a critical lack of local broodstock.

Recognizing the healthy Brook Trout population in the neighboring Quashnet River, MassWildlife initiated a restoration effort for the Childs River. From 2008 to 2010, 85 adult Brook Trout were transplanted from the Quashnet to the Childs River, and subsequent surveys confirmed successful reproduction with the capture of young-of-the-year (YOY). Tracking with Passive Integrated Transponder (PIT) tags further validated some degree of inter-river movement, with one individual observed migrating between the Childs and Quashnet Rivers (Mora and Wobst, 2023).

Despite initial efforts to restore Brook Trout to the Childs River, habitat degradation persisted, hindering long-term recovery of the population. While seven adult Brook Trout were detected upstream of the earthen dam in 2012, subsequent surveys found no trace of them due to failure of the fish ladder. The exception was during unusually high precipitation in spring 2019. This effectively led to the extirpation of Brook Trout from the upper Childs River, underscoring the critical need for comprehensive habitat restoration beyond mere restocking.

The restoration of the Childs River aimed to reverse the negative impacts of historic human alterations by improving fish passage, restoring aquatic habitat, and enhancing recreational opportunities. Key actions included removing barriers such as the earthen dam and flow control structures, replacing an undersized culvert, reconstructing the river channel through the former impoundment and bogs, and restoring adjacent floodplains and wetlands (Mora and Wobst, 2023). This comprehensive watershed restoration was designed to benefit sea-run Brook Trout, improve water quality, and support a diverse range of aquatic and terrestrial wildlife.

As a result, fish and other aquatic organisms regained access to over a mile of upstream river habitat, and more than 17 acres of wetlands were created from the former impoundment and cranberry bogs. Over 2,500 feet of river channel were reconstructed with enhanced habitat features, including large wood placements that provide shelter for fish, turtles, and other species, while also creating scour zones that improve spawning habitat. Several deep pools were constructed as sediment traps to capture fine organic material and sediment that may erode as the newly planted vegetation community becomes established (Fig. 3). Tree and shrub plantings along the riverbank will, over time, form a shaded, forested floodplain that helps regulate water temperatures and offers critical habitat for birds, mammals, reptiles, and amphibians. Additionally, constructed open-water ponds and varied wetland topography further increased habitat diversity, benefiting a wide range of wildlife—from waterfowl to amphibians.

Project Timeline

The restoration effort began in 2014, several years after the cranberry bogs were retired. At that time, the Falmouth Rod and Gun Club (FRGC) initiated conversations with local towns and the U.S. Fish and Wildlife Service's Mashpee National Wildlife Refuge to explore restoration opportunities. By 2017, formal planning was underway, with the Association to Preserve Cape Cod (APCC) managing project coordination and grant administration, and Inter-Fluve contracted as the lead engineering firm under FRGC's oversight. A feasibility study, hydrologic modeling, and preliminary design work followed, culminating in the completion of final design plans in 2020. With all necessary permits secured, the project moved into implementation.

It was also recognized as a Priority Project by the Massachusetts Division of Ecological Restoration (DER). This designation helped attract additional technical and financial support from project partners.

Construction occurred between 2020 and 2021, led by Lucianos, with Inter-Fluve overseeing river and bog restoration and Tighe & Bond managing the culvert replacement. Initial site work began in August 2020 with vegetation clearing and creation of diversion channels. By September, preliminary in-stream work was completed. Major restoration activities — including bog restoration, river channel reconstruction, and culvert removal — took place between October 2020 and April 2021. A new culvert was installed under Carriage Shop Road in July 2021, and by September, the construction phase was complete. Post-construction work continued into 2021 and 2022, focused on planting native trees and wetland vegetation to support long-term ecological recovery and habitat stability.

Project Objectives

The primary goal of this project was to restore the upper Childs River to support Brook Trout and other wildlife by addressing historical alterations and reestablishing natural river function. The specific objectives of the restoration effort included the following:

1. **Improve Coldwater Habitat** – Enhance hydrologic conditions by increasing water flow, reducing water temperatures, and improving dissolved oxygen levels to support Brook Trout populations.
2. **Enhance Fish Passage** – Reconnect fragmented habitat to facilitate migration and spawning of Brook Trout and other aquatic species.
3. **Improve Water Quality** – Reduce nutrient loading and improve aquatic habitat throughout the Waquoit Bay estuary by restoring natural hydrologic processes.
4. **Restore Wetlands and Habitat Diversity** – Convert former cranberry bogs into self-sustaining wetlands with diverse vegetation communities and habitat structures to support a range of wildlife species.

This report builds upon the one-year post-construction report, which provided a detailed review of the restoration project (Mora and Wobst, 2023). It presents an analysis of six years of monitoring data (2019–2024), covering the period from pre-construction through three years post-construction, to evaluate progress toward the project's overall restoration objectives. The report examines trends in water quality, fish populations, and vegetation, with a focus on both intra- and inter-annual variations. Particular attention is given to summer dynamics, as this period poses the greatest stress on aquatic organisms while supporting peak productivity in plant and microbial communities. Data collection methods included biweekly water quality sampling (May–September), monthly water quality sampling (October–April), continuous temperature logging, biannual fish surveys, and annual vegetation surveys.

Methods

Continuous temperature loggers

In July 2018, members of the FRGC, in collaboration with the Massachusetts Department of Conservation and Recreation (MA DCR) and MassWildlife, deployed HOBO temperature dataloggers (Onset Computer Corporation) in the Childs River. To assess post-restoration conditions, additional stations were installed in summer 2022. The sensors recorded water temperature every 15 minutes; however, many batteries expired by October 2023.

MassWildlife also provided long-term temperature data from monitoring stations in the lower Childs River, established as part of ongoing sea-run Brook Trout studies. Continuous temperature observations were available from 10 stations distributed throughout the river system (Fig. 4). All raw data were supplied by MassWildlife and processed and analyzed by APCC.

During the study period (2019–2024), multiple loggers (FRGC and MassWildlife loggers) were sometimes deployed concurrently at the same station. In these cases, the logger with the longest time series was used for analysis. Several sites were merged when station locations were relocated slightly (e.g., within ~15 feet) due to restoration activities, such as channel realignment and ditch filling (e.g., Below Mashpee Bog combined with Garner Outlet station). Additionally, preliminary data review identified instances where loggers had recorded "out of water" activity, noted by periods of extreme high/low temperatures; these data points were identified and removed from further analysis. Using the conditioned data set, daily mean water temperatures were calculated for each station over the study period.

Water quality and nutrients

Water quality monitoring along the Childs River, conducted by the Woodwell Climate Research Center under contract with the FRGC, began in April 2019 and continued through 2022. A total of nine stations were sampled before construction, while eight were monitored post-construction (Mora and Wobst, 2023), with sampling locations maintained as consistently as possible. At the Above Farley and Below Dam stations, restoration activities such as ditch filling and new stream channel creation altered the landscape, requiring minor adjustments in the station location post-restoration (Fig. 5). Parameters measured included dissolved oxygen, pH, specific conductivity, ammonium, nitrate, phosphate, silica, and dissolved organic carbon, providing a comprehensive view of water quality conditions before, and after restoration.

In January 2023, the Waquoit Bay National Estuarine Research Reserve (WBNERR) took over the water quality monitoring program with a reduced set of four stations. This report focuses on the analysis of those stations sampled consistently over the study period (2019–2024; Fig. 5): Above Farley Bog (R5B), Below Farley Bog (R6), Below Dam (R8B), and the Riverways site (R9).

There was a temporary pause in sampling during spring 2020 due to the statewide shutdown related to the COVID-19 pandemic, but monitoring resumed in May 2020. Initially, from April

through September 2019, samples were collected weekly. However, starting in October 2019, the sampling frequency was adjusted for the remainder of the study (2020–2024) as follows:

- May–September: Samples were collected biweekly.
- October–April: Samples were collected monthly.

At each station, *in situ* measurements of temperature, dissolved oxygen, pH, and specific conductivity were taken using a handheld multi-parameter meter, calibrated before each sampling event. Woodwell used a YSI ProDSS instrument for measurements in 2019 through 2022. From January to March 2023, a YSI EXO1 sonde was used, after which an In-Situ Aqua Troll 500 sonde replaced it. In-stream data were recorded immediately before sample collection at each station. All instruments were compared and calibrated against laboratory solution standards to ensure consistency in data quality over time.

On each sampling day, water samples (1 – 2 liters) were collected within 1-minute of recording data with the handheld meter at the same stream location. Duplicate samples were collected at one of the stations per sampling event, with the duplicate site rotating each time. Duplicate samples were collected for quality control purposes and evaluated. Results fell within a reasonable margin of error but were not included in the data analysis presented in this report.

Samples were collected using best practices in the field, including orienting the opening of a 1-liter HDPE bottle upstream, rinsing it three times with stream water, and then filling it to capacity with minimal air space before sealing. Samples were stored in a cooler with ice packs and transported to the respective lab, Woodwell or WBNERR, for further processing. Filtered and unfiltered (Woodwell only, for measuring particulate concentrations in 2019) samples were frozen within two to three hours of field collection. Both labs filtered the sample for dissolved inorganic analytes using a 0.45-micron filter although methods differed slightly. Woodwell used a vacuum pump with Geotech filters and WBNERR filtered samples by hand with Millipore syringe filters. Dissolved organic carbon samples were also filtered in the lab, using methods tailored to the specific requirements of the off-site laboratories.

Woodwell analyzed samples in-house, while WBNERR contracted Center for Coastal Studies for laboratory analysis of nitrate/nitrite, ammonium, silica, orthophosphate, and total dissolved nitrogen. Samples were analyzed within 60 to 90 days with a few exceptions related to transfer logistics. For analysis of dissolved organic carbon, the analytical lab varied over time and included the Woodwell Climate Research Center, University of New Hampshire, and Woods Hole Oceanographic Institution. For further details, refer to the *Childs River Restoration Quality Assurance Project Plan* (available upon request). No bias was found in the data related to changes in the contracted lab.

Summary analysis of trends and interpretation of the water quality data was conducted by APCC. While seasonal dynamics were assessed, data analysis focused on monthly means. Although sampling was often limited to one or two samples per month, the monthly resolution provided the best perspective for evaluating the annual hydrological dynamics of the river and surrounding wetlands. This approach also offered flexibility for interpreting impacts of construction that occurred in different phases across the river sections.

To aid in interpreting the results, discharge data (Cape Cod Rivers Observatory, 2025a) and precipitation data (NOAA NERRS, 2025) from the Riverways station and the nearby WBNERR meteorological station, respectively, were compared to observed monthly water quality patterns (Fig. 6). Additionally, the monthly water quality data from this study were compared to routine monitoring data collected by the Woodwell Climate Research Center (Cape Cod Rivers Observatory, 2025b) at the Riverways station on the Childs River, as well as at the nearby Quashnet and Coonamessett Rivers.

Brook Trout

MassWildlife has conducted fish surveys at three primary locations along the Childs River since 2006, and biannually since 2009 (Table 1). The lower river section below the old earthen dam has been regularly sampled, with limited sampling done at other sites throughout the system (Mora and Wobst, 2023). The restored sections of the river (former pond area and Farley Bog and channel below) have been regularly sampled since May 2019, as construction allowed.

Surveys took place in spring (May–June) and fall (September) using a Smith-Root backpack electrofisher set to approximately 400 volts. Sampling was performed in an upstream direction beginning at the Barrows Street crossing. Catch efficiency of the survey is estimated at approximately 40%, with catchability increasing with fish size (Steve Hurley, personal communication). During the surveys, all Brook Trout were scanned for Passive Integrated Transponder (PIT) tags, and their length (mm) recorded. Brook Trout measuring 80 mm or longer were weighed and tagged with a 12 mm PIT tag, if not already tagged. Fish under 80 mm were generally not weighed due to precision limits on the field scale. MassWildlife provided raw fish survey data, which was subsequently analyzed by APCC.

In 2022, two stationary PIT-tagging antennas were installed in upstream locations to monitor fish movement and assess habitat use post-restoration (Fig. 7). The downstream antennas (Antennas 0.9 and 1) had been in place prior to restoration. The period during which three or more arrays were operational spanned just over two years, from June 3, 2022, to September 10, 2024. During this time, Antenna 1 was decommissioned and replaced by Antenna 0.9, with both operating concurrently from June 3 to December 16, 2022.

Over the monitoring period, a total of 170 unique PIT tags—representing fish originally captured in the Childs River—were detected by one or more of the arrays. The distribution of time intervals between the first and last detections for these individuals (Fig. 8) had a mean duration of 122.8 days. Collectively, these data provide coarse-scale insight into fish habitat use across different segments of the river system, including upstream locations (Antennas 2 and 3) and downstream/tidal areas (Antennas 0.9 and 1).

The length-frequency distributions of all fish encountered during the survey were analyzed by year and season to assess spawning success and inter-annual survival. These distributions were also compared to those of the nearby Coonamessett and Quashnet rivers, which, like the Childs River, are sampled biannually by MassWildlife and are at more advanced stages of river and bog

restoration. Similarly, the seasonal length-weight relationships of the fish of the three different river systems were compared.

To evaluate trends in Brook Trout condition over the study period, we analyzed the distribution of relative condition factors in the Childs River by year and season. An aggregate length-weight relationship was first developed using all observed fish from 2019 to 2024 with recorded weights. The length-weight relationship was fit on the log-transformed data in R (R Core Team 2025) using the model form:

$$\log \text{Weight} = \log a + b \log \text{Length}$$

where:

- a = intercept
- b is the exponent describing the rate of growth

The relative condition factor (K_n) is then calculated as the ratio of the observed fish weight to predicted fish weight. Higher K_n values (> 1.0) indicate that a fish is relatively heavy for its length, often suggesting favorable feeding conditions and overall good health. Conversely, lower values (< 1.0) may reflect poor nutrition, stress, or environmental challenges.

Vegetation

Under contract with DER, Woodwell Climate Research Center (Woodwell) surveyed 20 randomly selected 3×3 m quadrats in the former Farley and Garner bogs (Table 2). Plots were added in 2021 to match sampling effort at non-Childs River sites. The vegetation surveys were conducted annually during the peak growing season (August–September) from 2019 to 2022 and repeated in 2024. Within each quadrat, all plant species were identified, and their percent cover was estimated. Species were categorized based on nativity (native or non-native), growth form (e.g., herbaceous, shrub), and wetland indicator status. For wetland indicator classes, obligate wetland (OBL) and facultative wetland (FACW) species were grouped together as “wetland” species, while upland (UPL) and facultative upland (FACU) species were grouped together as “upland” species. Cranberry (*Vaccinium macrocarpon*) was excluded from the wetland analysis given its overwhelming predominance. To assess changes in plant community composition before and after restoration, the total number of species present and the average percent cover of each category were analyzed. Woodwell processed the raw data and provided site-level summary data (Neill et al., 2024). Summary analysis of trends and interpretation of the data was conducted by APCC. Plant results through 2022 are also reported in Klionsky et al. (2025).

Results

Continuous temperature loggers

Brook Trout, the focal species of this restoration effort, require cool, well-oxygenated waters to thrive. Their optimal growth occurs between 54°F and 61°F (Chadwick & McCormick, 2017), while temperatures exceeding 65°F substantially increase mortality rates (McCormick et al., 1972). Prolonged exposure to water temperatures above 74°F for more than seven days typically

renders habitats unsuitable for this species (Wehrly et al., 2007). A key objective of the Childs River Restoration Project was to reduce water temperatures and enhance habitat conditions for Brook Trout.

Restoration efforts were implemented in late 2020 and throughout 2021. In January 2021, the earthen berm responsible for forming two impoundments north and south of Carriage Shop Road was removed. By April 2021, a newly constructed river channel replaced the former impoundments and bog areas, restoring natural flow dynamics.

Prior to restoration, summer maximum water temperatures at all monitoring stations—including those farther from the impoundment—exceeded the optimal growth threshold for brook trout (61°F), with several stations nearing or surpassing 70°F (Fig. 9). The highest temperatures were recorded just downstream of the former impoundment, at the "Below Rod and Gun Club Ponds" station. Following restoration in spring 2021, water temperatures declined, with most stations remaining below 61°F for much of the year. Elevated temperatures continued to persist near the former Garner Bog at the northern end of the project area. High temperatures at stations both upstream and downstream of the former bog suggest that this stretch of river continues to provide suboptimal habitat conditions post-restoration.

The most substantial reductions in temperature post-restoration were observed above and below the Rod and Gun Club Pond stations, bookending the former impoundments north and south of Carriage Shop Road (Fig. 10). Prior to restoration, the shallow, stagnant waters of the impounded ponds and bogs contributed to excessive warming due to prolonged solar exposure. The removal of these impoundments and the construction of a new river channel increased flow velocity and enhanced groundwater exchange, leading to lower water temperatures.

Post-restoration data reveal a general downstream cooling trend, with annual mean water temperatures highest near the river's source and gradually decreasing as the flow moves south (Fig. 11). This pattern reflects the cumulative cooling influence of groundwater seeps entering the river along its course. Tree canopy cover is also denser south of the restoration sites. Anomalously low annual temperatures (53.5°F) recorded at the "Above Farley Bog" station suggest a nearby groundwater input. In contrast, the "Barrows Street" station—located near the head of tide—remained influenced by warmer tidal waters from downstream, with an annual mean temperature of 53.75°F.

Water quality and nutrients

Water quality monitoring at Childs River is a critical tool for understanding the health of the aquatic ecosystem, evaluating the effectiveness of the restoration efforts, and guiding future restoration and management decisions. By tracking changes in chemical properties of the surface water over time and at different stations along the river, monitoring provides valuable insights into the complex interactions between land use, hydrology (including groundwater, precipitation, and stormwater runoff), and nutrient dynamics within a watershed as well as where and how those conditions shifted as a result of the Childs River restoration.

Dissolved oxygen – Dissolved oxygen (DO) is a key bioindicator of riverine system health, reflecting a range of complex and dynamic processes that influence overall habitat conditions. It also has critical threshold levels for aquatic life—for example, fish habitat is generally considered optimal at DO concentrations above 6 mg/L, while prolonged exposure to levels below 5 mg/L can cause stress (US EPA, 2025). Changes in the monthly average DO levels, from the biweekly and monthly handheld readings, are most noticeable at the Below Dam and Riverways stations (Fig. 12). Prior to restoration, the average DO concentrations at the Below Dam station reached around 6 mg/L in the summer, but after the restoration, the DO concentrations improved to a low around 7 mg/L. The lowest readings (~5 mg/L) were collected at the Below Dam station in July 2021 when the bypass channel was still in place. Immediately following the replacement of the Carriage Shop Road culvert and reconnection to the main channel in August 2021, there was a notable increase in DO levels.

pH – Over time, pH levels have shown a general increasing trend across the monitoring stations, indicating a shift toward more alkaline conditions and a reduction in water acidity (Fig. 13). The Riverways and Below Farley stations, in particular, have experienced noticeable increases in pH. In contrast, pH levels at the Below Dam and Above Farley stations have remained more stable throughout the restoration period. Despite these variations, the overall trend across all stations suggests a gradual improvement in water quality, likely benefiting aquatic organisms that are sensitive to acidic conditions.

Specific conductivity – This metric measures how well water can conduct electricity—a property that increases with the presence of dissolved salts and minerals. Specific conductivity appears to decline over time, with the most notable decrease observed at the Below Dam station (Fig. 14). In contrast to the pH trends, the Below Farley and Riverways stations showed the least amount of change in specific conductivity. Impacts from the high volume of freshwater inputs related to storm events in 2023 are evident at all four stations where specific conductivity drops precipitously and then spikes in the month or two that follows.

Ammonium (NH_4) – As noted in the one-year post-restoration report (Mora and Wobst, 2023), ammonium levels spiked at the Riverways and Below Dam stations due to the upstream disturbance during construction, which released ammonium from the sediment. Since then, ammonium concentrations have declined compared to pre-restoration levels observed in 2019 and have remained generally stable over time (Fig. 15), suggesting a positive impact of the restoration on this aspect of water quality. Aside from the single large spike at Riverways, ammonium levels in the Childs River are now comparable to those observed in the nearby Quashnet and Coonamessett Rivers in Falmouth, MA (Fig. 16).

Nitrate (NO_3) – Nitrate appears to increase over time at all four monitoring stations along the Childs River (Fig. 15). The readings from 2019 appear abnormally low for the system. In Figure 17, bar plots demonstrate how seasonal variations affect the four stations differently. Above and Below Farley, the stations show slight increases in the winter concentrations (October – March) but when plants are active starting in April, there is no change after 2019.

In contrast, there is generally little change in nitrate concentrations during the winter months at the Riverways and Below Dam, suggesting no change in background or source inputs from the

surrounding landscape, but the summer concentrations gradually increase over time at these two lower stations. The increases seen during the summer suggests that the faster flowing water leads to reduced chemical exchange with the sediments and biota (i.e., living organisms) and thus, less uptake or conversion of nitrate. Relative to nearby rivers, Coonamessett and Quashnet River, the nitrate concentrations at Childs River are quite high (Fig. 18). Also, while nitrate appears to increase at Childs River, there is no change over time at the neighboring Quashnet River further strengthening the theory that the change in water flow from the restoration is related to the increased nitrate levels and not a more regional environmental driver.

Dissolved organic carbon (DOC) – DOC was particularly high in 2019 and gradually decreases from 2020 through 2023 with a few large spikes observed in September 2021 as well as summer and fall 2022 (Fig. 19 and Fig. 20) when water temperatures are at their highest (Fig. 9). DOC has a positive correlation with river discharge at all four monitoring stations (Fig. 21). Taken together, these findings suggest that the cooler, faster flowing water has resulted in reduced decomposition (an autochthonous or internal source of DOC) and that stormwater runoff (an allochthonous or external source of DOC) greatly influences dissolved organic carbon levels in the river.

Phosphate (PO_4) – Phosphate is particularly important as the nutrient that often limits freshwater productivity and drives algal blooms when elevated. At the Riverways station, monthly averages of phosphate concentrations show a steep decline between the summer of 2020 through spring of 2021 and then slowly rebound from mid-2021 through 2024 (Fig. 22). However, the other three monitoring stations show much lower concentrations of phosphate and little to no change over time indicating a land use impact or groundwater factor that releases phosphate directly upstream of the Riverways station.

Phosphate concentrations are generally higher at Childs River compared to Coonamessett or Quashnet River (Fig. 23) although all three sites show higher concentrations in summer of 2018 followed by declining trends through 2020 and increases in 2021 and 2022, which may mean this area of the Cape was experiencing a meteorological change, such as drought and reduced groundwater table depth, that affected phosphate levels more broadly.

Silica (Si) – Silica levels can increase due to mineral weathering or soil erosion associated with land disturbance; however, dissolved silica—unlike particulate silica from sediment—is generally less affected by short-term erosion events. Silica is significantly higher in concentration at the Riverways station compared to the other three sites (Fig. 24). Similar to the phosphate trends, this suggests a source of silica directly upstream of the Riverways station. Additionally, silica shows a negative correlation with river discharge at the Riverways station but no significant relationship at the other three stations (Fig. 21) which suggests that the source of silica is connected to the depth of groundwater table.

There does not appear to be any change in silica concentrations over time at any of the stations except for the Below Dam location where average silica levels are lower following restoration. Silica levels are slightly lower in Childs River compared to Coonamessett and Quashnet Rivers (Fig. 25). Coonamessett and Quashnet experienced high concentrations in the summers of 2018, 2021, and 2022 during periods of low groundwater table depths.

Taken together, the monitoring results illustrate the complex and dynamic nature of water quality in the Childs River, with variations across seasons, years, and monitoring stations. While some parameters—such as dissolved oxygen and ammonium—showed clear improvements following restoration, it is important to note that the restoration effort was not primarily focused on improving water quality. Instead, changes in water quality reflect indirect benefits or natural variability. Other nutrients like nitrate and phosphate exhibited more variable patterns influenced by seasonal cycles and watershed inputs, underscoring the multiple factors affecting the river system.

Brook Trout

Prior to restoration, very few Brook Trout had been captured upstream of the old earthen dam (Table 1). By September 2021, however, Brook Trout had begun to recolonize the restored habitats. One individual was captured in the newly established stream channel in the old pond area, and two were found in the reconstructed Farley Bog channel, compared to 42 Brook Trout observed farther downstream, south of the restoration area.

Over the monitoring period, a total of 170 unique PIT tags—representing fish originally captured in the Childs River—were detected by one or more of the arrays. Collectively, these data provide coarse-scale insight into fish habitat use across different segments of the river system, including upstream locations (Antennas 2 and 3) and downstream/tidal areas (Antennas 0.9 and 1).

Among fish detected at both the Farley Bog upstream and downstream locations—i.e., those that moved between Antennas 3 and 0.9/1—there were no observed instances of fish passing Antenna 2 without detection (Table 3). This result suggests a high level of detection efficiency, indicating that the arrays have effectively captured longitudinal movements of fish within the system.

Of the 142 tags detected at upstream locations (Antennas 2 or 3), only 28 were subsequently detected at the downstream array (Antenna 0.9/1) with no further detections. The fate of these individuals is uncertain; possible outcomes include emigration to the marine environment, undetected continued residency within the system, or mortality. One such case is illustrated in Fig. 26 (Tag 900.067000207145952). These results suggest a high degree of residency among Brook Trout in the Childs River. At least 114 of the 142 individuals detected upstream (80.3%) were either not subsequently detected downstream or were later detected at upstream locations after downstream movement. This indicates that the majority of tagged fish remained within the river system, either occupying upstream habitats or moving throughout the river before returning upstream (e.g., Fig. 27, Tag 900.067000198965957). These findings support the ecological suitability of upstream habitats following restoration.

Evidence of successful spawning was observed in spring 2022, indicating that reproduction had occurred during the previous fall or winter. The spring electrofishing survey documented 19 Brook Trout in the old pond area and 17 in the Farley Bog area, including newly hatched juveniles (young-of-the-year, YOY), confirming that spawning had taken place in or near these restored sections. Additionally, four YOY were among the 17 Brook Trout captured in the newly formed river channel within the former Farley Bog, further validating successful reproduction. In

contrast, only two YOY were found in the lower river, a historically known spawning area. Overall, 31 Brook Trout were recorded in the lower reaches, while 36 were found in the restored sections, illustrating a shift in habitat use as fish moved into the newly available spawning and rearing habitat (Table 1). Subsequent electrofishing surveys revealed further population expansion, with the restored areas becoming the predominant habitat post-restoration.

Although smaller fish are less susceptible to electrofishing, the consistent detection of YOY fish in the spring survey (~50 mm mode, Fig. 28) is indicative of successful reproduction. Tracking year-classes across seasons and years further demonstrates inter-annual survival, reinforcing the restored habitat's ability to support a sustainable Brook Trout population. However, data show few fish $\geq$ age-2 (~300 mm) within this system. PIT tagging data suggest that there is not a high-degree of emigration from the system, meaning that the absence of large fish is likely mortality-related (Steve Hurley, personal communication). Numerous fish were encountered during the surveys bearing the scars of avian predation, while otter activity has also been observed. In contrast to the newly-restored Childs River, slightly larger individuals (~350 mm) have been documented in other nearby restored cranberry bogs and rivers, such as the Quashnet and Coonamessett (Fig. 29). While the Childs River is not designated as catch-and-release, fishing mortality is believed to be negligible due to the river's limited accessibility and the difficulty of reaching fishable spots.

Comparison of the length-weight relationships between these nearby rivers did not show Childs River to be in a lower condition (i.e., skinnier; Fig. 30). This would suggest, that at least relative to these nearby systems, Childs River fish are not food limited. The back-transformed fitted equation to the 2019 to 2024 Childs River Brook Trout length-weight data ($n=526$; Fig. 31) was:

$$Weight = 0.00000744269 \times Length^{3.0742}$$

The relative condition factor showed no clear trends in either the spring or fall distributions (Fig. 32). As expected, fish exhibited lower condition in the spring following the challenges of overwintering, while their condition improved by fall after a summer of feeding and growth.

Vegetation

The vegetation within the former bog systems primarily regenerated naturally from the existing seed bank, which was exposed and redistributed during the restoration process. As part of site preparation, the bog surface was regraded to create microtopography, breaking up compacted peat layers and improving hydrological conditions. This allowed dormant seeds buried in the substrate to germinate, facilitating the re-establishment of a diverse plant community adapted to wetland conditions. Additionally, some intentional plantings were introduced along the perimeters and within newly constructed ponds to enhance diversity and encourage the establishment of key wetland vegetation.

Following restoration efforts (2021), the mean species richness of native plants approximately doubled across both bog sites one-year post-restoration (Fig. 33). There was a marginal decline in species richness of about 25% in 2024 at both sites. In contrast, the presence of non-native species remained minimal throughout the study period, with a mean species richness consistently

below three. Prior to restoration, the plant community was heavily dominated by cranberry (*Vaccinium macrocarpon*; Table 4), which accounted for an average of 55–75% of surveyed plots. Although cranberry is a native species, the restoration aimed to increase overall plant species richness and promote greater ecological diversity within the former bog areas. Post-restoration the dominant species included *Juncus canadensis*, *Triadenum virginicum*, *Toxicodendron radicans*, *Lysimachia terrestris*, *Leersia oryzoides*.

Post-restoration data indicated a two-fold increase in the percent cover of wetland-associated species compared to pre-restoration conditions (Fig. 34). This trend suggests that the restored habitat provides more favorable conditions for wetland-adapted species - those that thrive in environments with higher soil moisture and periodic inundation - while potentially limiting the establishment of upland species less suited to these conditions.

Discussion

The restoration efforts undertaken in this project were driven by the overarching goal of revitalizing critical coldwater habitat and enhancing ecological resilience within the Waquoit Bay watershed. By focusing on improving hydrologic conditions, reconnecting fragmented habitats, and restoring natural wetland functions, this initiative sought to support the long-term sustainability of Brook Trout populations and other aquatic species. Key to this effort was the conversion of former cranberry bogs into self-sustaining wetlands, fostering greater habitat diversity while improving water quality throughout the system. Each of the project's goals - enhancing coldwater habitat, facilitating fish passage, improving water quality, and restoring wetland ecosystems - plays a vital role in reestablishing the natural ecological processes necessary for a thriving aquatic environment. The following discussion examines how these objectives were addressed, the challenges encountered, and the broader ecological implications of this restoration work.

Improve Coldwater Habitat

The Childs River Restoration Project successfully lowered water temperatures, creating a more suitable environment for Brook Trout. As cold-water specialists, Brook Trout experience physiological stress and cease reproduction when temperatures exceed 68°F, with optimal growth occurring between 55°F and 61°F (Chadwick & McCormick, 2017). Prolonged exposure above 74°F can be lethal (Wehrly et al., 2007).

Key restoration efforts - including removing impounded ponds north and south of Carriage Shop Road, replacing the Carriage Shop Road culvert, and restoring former bogs - helped cool summer water temperatures (Fig. 9). Consequently, Brook Trout moved into the northern reaches of the river (Table 1) and remained there even during peak summer heat (Mora and Wobst, 2023), indicating the establishment of high-quality, year-round habitat. The restored sections of the former pond now provide high-quality Brook Trout habitat with ample hiding cover essential for survival. However, conditions in Garner Bog remain constrained due to limited water availability, low flow rates, and elevated temperatures.

Brook Trout in the Childs River appear in good overall condition, comparable to populations in other coastal Cape Cod streams (Fig. 30). However, larger (>250 mm), older fish are notably absent from the Childs River (Figs. 29), likely due to predation. Increasing structural cover (e.g. tree canopy) and habitat complexity would provide critical refuge, improving survival rates and strengthening Brook Trout populations in this restored waterway. Additionally, it would increase shade and regulate water temperature. Placement of large wood was included in the initial restoration design, but adding additional structures—similar to the ongoing stream improvements on the nearby Quashnet River—would further enhance habitat complexity and support the long-term resilience of this population.

Enhance Fish Passage

The Childs River Restoration Project has significantly improved fish passage and habitat connectivity, enabling Brook Trout to recolonize areas that were once inaccessible. Before restoration, only a few Brook Trout were observed upstream of the old earthen dam (Table 1), underscoring how barriers severely restricted movement and limited access to critical spawning and rearing habitats. By removing these obstructions and restoring natural stream channels, the project has reopened migration pathways into the river's upper reaches.

By September 2021, Brook Trout had begun recolonizing the newly restored habitats. Individual fish were documented in the reconstructed stream channels of the former pond and Farley Bog areas, demonstrating the initial success of habitat reconnection. More notably, evidence of successful spawning in the way of juvenile fish observed the following spring, confirmed that Brook Trout were not only accessing these areas but also using them for reproduction. This shift in distribution suggests a reduced dependence on the previously limited habitat in the lower river.

While these results highlight major improvements in fish passage and habitat availability, ongoing fish monitoring is crucial to understanding long-term population trends and addressing potential challenges. Habitat constraints in restored sections, such as excessive aquatic vegetation and siltation, can impair flow, restrict fish movement, and reduce spawning success (Alberto et al., 2017). As part of the original restoration design, four sediment traps were installed along the river to manage sediment transport and reduce siltation in critical habitats (Fig. 3). Since construction was completed in 2021, these traps have been regularly serviced three times (Table 5), with each effort removing several yards of accumulated sediment. This reflects an important commitment to ongoing site maintenance. The long-term success of the restoration effort will depend not only on these engineered features, but also on continued stewardship—ensuring that sediment control structures remain functional, flow regimes are optimized, and habitat conditions continue to support a thriving Brook Trout population.

Overall, the restoration has reestablished natural migration pathways, expanded access to high-quality spawning and rearing habitat, and contributed to a more resilient Brook Trout population. By reconnecting fragmented habitats, the project has strengthened the ecological integrity of the Childs River, fostering a healthier, self-sustaining coldwater fishery.

Improve Water Quality

Restoration efforts on the Childs River have led to significant improvements in water quality and yielded valuable long-term insights into the river's nutrient dynamics. One of the most notable changes is better temperature regulation: summer temperatures are now cooler, and winter temperatures warmer, thanks to increased flow rates and a restored connection to the groundwater table. These thermal improvements have also boosted dissolved oxygen (DO) levels and moderated pH, making the water less acidic. Together, these changes have created a much healthier habitat for fish and other aquatic life.

Other trends in surface water nutrients emerged more gradually. Notably, nitrate concentrations have continued to rise over time. A negative correlation with temperature suggests that the restored, faster flowing water and closer connection to groundwater, while beneficial for aquatic life, have reduced the sediments' ability to attenuate nitrate. Although the restored Farley Bog continues to play a critical role in nitrate removal, evidenced by minimal to no change in summer nitrate concentrations downstream of the bog, the project as a whole has not resulted in a measurable reduction in nutrient loading to the system or to Waquoit Bay. It's important to note that nutrient attenuation was not a primary design goal of this restoration. Projects aiming to reduce nutrient exports should consider incorporating targeted strategies such as enhanced wetland design features or engineered treatment areas such as ponds that increase residence time of water. Nonetheless, the reestablishment of wetland processes and habitat connectivity at this site provides ecological value beyond nutrient management.

The gradual decline in dissolved organic carbon (DOC) over time may also be linked to the colder, faster-moving water introduced by the restoration. While runoff from the surrounding landscape remains a major source of allochthonous (external) DOC—as supported by correlations with discharge—one key autochthonous (internal) source is the decomposition of organic matter such as leaves. Because decomposition rates tend to increase with warmer temperatures and slower water flow, the cooler, swifter post-restoration conditions have likely slowed this process. This effect is most evident during the summer months at sites downstream of Farley Bog, below the former earthen dam, and at the Riverways station, where temperature changes were most pronounced. The DOC decline appears to stabilize in 2023 and 2024, suggesting the system may have reached a new equilibrium and that decomposition rates have adjusted in response to the altered flow regime.

In the initial post-restoration report (Mora and Wobst, 2023), the observed decline in phosphate (PO_4) was attributed to reduced access to groundwater seeps caused by the new bypass channel. However, analysis of the long-term dataset—alongside comparisons with the Coonamessett and Quashnet Rivers and regional precipitation and discharge records—reveals a more complex narrative. The 2020 drought, as documented in NOAA's 12-month precipitation totals for Barnstable County, likely reduced groundwater contributions and led to a sharp drop in phosphate concentrations in the Childs River. Similar trends are evident in the Coonamessett and Quashnet Rivers, but the effect is most pronounced at Childs, likely due to its higher baseline phosphate levels. Phosphate concentrations rebounded after the drought ended in spring 2021, but further monitoring is needed to determine whether this is a sustained increase, a plateau, or a temporary rise. The delayed response suggests a time lag associated with groundwater transport. While the exact source of phosphate remains unclear, a likely contributor is a shallow subsurface

plume linked to historical cranberry farming, as concentrations tend to peak when the water table is high. The notably higher phosphate levels at Childs compared to the Coonamessett—despite similar surrounding residential and septic land use—further supports the presence of an additional leaching source. Taken together, these patterns indicate that no sustained decline in phosphate concentrations has been observed to date, highlighting the persistence of legacy nutrient sources within the system.

Silica (Si) concentrations offer additional insight into the influence of the retired cranberry bog located just north of the Riverways monitoring station. Silica levels in the Childs River are generally lower than those in neighboring rivers and show a negative correlation with discharge, indicating that silica enters the system primarily via groundwater. As Davis (1964) noted, New England streams rely more heavily on groundwater during periods of low discharge, whereas high discharge is typically driven by surface runoff from rain or snowmelt. Although flow data are limited—since the Childs River flow meter was not activated until 2022 (Fig. 6)—seasonal patterns support this interpretation. Silica concentrations peak in summer and fall, when groundwater input dominates relative to precipitation. The elevated silica observed at Riverways may be due to the sandy soils of the retired cranberry bog situated between the Riverways and Below Dam stations, within land managed by the Massachusetts Department of Conservation and Recreation.

Stormwater runoff continues to influence water chemistry in the Childs River, particularly near Carriage Shop Road. Specific conductivity remains highest near the dense residential development at the northern end of the river, where elevated nitrate loading is the primary contributor. However, conductivity levels have declined over time, especially downstream of Carriage Shop Road, suggesting sediment stabilization and a reduced influence of road-related stormwater runoff. Notably, intense storm events in early 2023, including heavy February rains and the summer tornadoes in Barnstable, produced sharp increases in freshwater input, followed by pulses of nutrients and runoff, highlighting the river's sensitivity to extreme weather events.

In conclusion, the restoration of the Childs River has resulted in notable improvements to physical habitat and has highlighted more subtle, longer-term shifts in nutrient dynamics. Increased groundwater connectivity and flow have helped regulate temperature, boosting dissolved oxygen levels and stabilizing pH. These improvements create more favorable conditions for fish, not only directly, but also indirectly: nutrient concentrations influence the abundance, composition, and growth of the prey base, which in turn affects fish growth and survival. However, the delayed and evolving patterns in nutrient concentrations underscore the importance of long-term monitoring and the need to explicitly incorporate nutrient reduction goals into project design when consistent nutrient declines and water quality improvements are primary restoration objectives. Rising nitrate levels and fluctuations in phosphate and silica suggest ongoing influences from groundwater and legacy land uses, especially former cranberry farming. While stormwater runoff remains a factor, its impact appears to be diminishing downstream of Carriage Shop Road, likely due to sediment stabilization. These findings reinforce that while ecological restoration can yield immediate habitat benefits, the river's full response unfolds over a longer period of time—shaped by hydrology, land use history, and climate variability. Project objectives, such as prioritizing coldwater habitat restoration over

nutrient attenuation, play a critical role in shaping outcomes and should be carefully aligned with long-term ecosystem goals.

Restore Wetlands and Habitat Diversity

The Childs River Restoration Project has significantly enhanced wetland habitat diversity by promoting the natural regeneration of vegetation and improving hydrological conditions. The restoration process exposed and redistributed the existing seed bank, allowing a diverse array of wetland plants to recolonize the former bog systems. Regrading the compacted peat layers to create microtopography improved soil permeability and facilitated the germination of dormant seeds, leading to the establishment of a more ecologically complex plant community. Strategic plantings along the perimeters and within newly constructed ponds further bolstered habitat diversity. As a result, the restored wetlands now support a broader range of vegetation types, creating a more resilient and dynamic ecosystem.

These improvements have translated into measurable gains in plant diversity and wetland function. Since the completion of restoration efforts in 2021, the mean species richness of native plants has approximately doubled across both bog sites, while non-native species have remained minimal. This shift represents a departure from the former cranberry-dominated landscape, fostering a habitat structure more conducive to a variety of wetland-adapted species.

Additionally, the increased presence of wetland-associated plants indicates that the restored areas now provide improved conditions for species that thrive in high-moisture environments. By expanding the diversity of wetland flora, the project has not only enhanced the ecological integrity of the Childs River floodplain but also created more suitable conditions for a variety of aquatic and terrestrial wildlife that depend on these habitats.

The patterns observed in the vegetation data mirrors trends seen at other cranberry bog restoration sites (Neill et al., 2024). The decline in species richness after approximately three years aligns with the natural progression of wetland restoration, as vigorous growth of perennial wetland species crowds out ephemeral mudflat species that rely on open, disturbed areas (Chris Neill, personal communication).

Conclusions

The Childs River Restoration Project has effectively advanced its core goals: improving coldwater habitat, enhancing fish passage, restoring wetland diversity, and improving water quality. Brook Trout now occupy newly accessible upstream areas, and cooler, better-oxygenated water supports year-round habitat use. Reconnected wetlands are showing strong gains in native plant diversity, while water quality trends—though complex—point to lasting ecological shifts shaped by groundwater, legacy land use, and climate. Continued monitoring and adaptive management will be essential to track progress, address emerging challenges, and sustain long-term ecological resilience in the Waquoit Bay watershed.

References

- Alberto, A., Courtenay, S., St-Hilaire, A., & van den Heuvel, M. (2017). Factors influencing Brook Trout (*Salvelinus fontinalis*) egg survival and development in streams influenced by agriculture. *Journal of Fisheries Sciences*, 11(1), 9–20.
- Cape Cod Rivers Observatory. 2025a. Discharge Dataset, Version 20250106. <https://www.caperivers.org/data/>.
- Cape Cod Rivers Observatory. 2025b. Data Dashboard. <https://www.caperivers.org/data/>.
- Chadwick, J. G., & McCormick, S. D. (2017). Upper thermal limits of growth in Brook Trout and their relationship to stress physiology. *Journal of Experimental Biology*, 220, 3976–3987.
- Davis, S. (1964). Silica in streams and ground water. *American Journal of Science*, 262, 870–891.
- Klionsky, S. M., Neill, C., Pulak, A. M. & Lawrence, B. 2025. Hydrologic restoration of retired cranberry farms leads to species rich wetlands. *Applied Vegetation Science* 28:e70024.
- McCormick, H. J., Hokanson, K. E. F., & Jones, B. R. (1972). Effects of temperature on growth and survival of young Brook Trout, *Salvelinus fontinalis*. *Journal of the Fisheries Board of Canada*, 29, 1107–1112.
- Mora, J., & Wobst, A. (2023). *Upper Childs River restoration project one-year post-construction report*. Association to Preserve Cape Cod. Retrieved from https://apcc.org/wp-content/uploads/2023/05/CR_1-yrPostReport_APCC_FINAL.pdf.
- Mullan, J. W. (1958). *The sea-run or "salter" Brook Trout (Salvelinus fontinalis) fishery of the coastal streams of Cape Cod, Massachusetts. Bulletin 17*. Massachusetts Division of Fish and Game.
- NOAA National Estuarine Research Reserve System (NOAA NERRS). (2025). System-wide Monitoring Program. Data accessed from the NOAA NERRS Centralized Data Management Office website: <http://www.nerrsdata.org>; accessed 11 February 2025.
- Neill, C., Klionsky, S., Farrar, P., & Pulak, A. (2024). *Plant responses to restoration of cranberry farmland in southeast Massachusetts and recommendations for future plant monitoring*. Report to MA Department of Ecological Restoration, June 30, 2024.
- R Core Team. (2025). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. Retrieved from <https://www.R-project.org/>.
- Smith, J. V. C. (1833/1970). *Natural history of the fishes of Massachusetts, embracing a practical essay on angling*. Freshet Press.

Town of Mashpee. (n.d.). *Fisheries and wildlife history (Chapter 4)*. Retrieved March 10, 2025, from https://www.mashpeema.gov/sites/g/files/vyhli3426/f/uploads/ch4e_-_fisheries_wildlife_part_1.pdf.

US Environmental Protection Agency (US EPA). (2025). Factsheet on Water Quality Parameters: Dissolved Oxygen. Available from: https://www.epa.gov/system/files/documents/2021-07/parameter-factsheet_do.pdf; accessed 6 June 2025.

Wehrly, K. E., Wang, L. Z., & Mitro, M. (2007). Field-based estimates of thermal tolerance limits for trout: Incorporating exposure time and temperature fluctuation. *Transactions of the American Fisheries Society*, 136, 365–374.

Tables

Table 1. Summary of Brook Trout electrofishing sampling of the Childs River, showing total brook trout catch by area and survey date, 2006 to 2024. Blanks indicate that those areas were not sampled on a given date.

Date	Lower Childs River	Former Pond Area	Farley Bog & Channel Below	Total	Notes
9/26/2006	0			0	
9/17/2008	10			10	
3/27/2009	7			7	
9/9/2009	132			132	
3/11/2010	23			23	
5/17/2010	30			30	
9/15/2010	82			82	
5/25/2011	57			57	2-day sampling effort (5/11, 5/25)
9/27/2011	95			95	
5/16/2012	47			47	
9/14/2012	99		7	106	
5/16/2013	40			40	
9/17/2013	140		0	140	
5/21/2014	36			36	
9/16/2014	64			64	
5/18/2015	33			33	
9/21/2015	44			44	
5/16/2016	51			51	
9/19/2016	48			48	
5/15/2017	21			21	
9/14/2017	39		0	39	
5/15/2018	12			12	
9/19/2018	71			71	
5/15/2019	39	6	3	48	3-day sampling effort (5/9, 5/10, 5/15)
9/1/2019	45	1	0	46	
6/2/2020	24	0	0	24	
9/15/2020	42			42	Construction period
5/18/2021	29	0		29	Construction period
9/23/2021	42	1	2	45	2-day sampling effort (9/16, 9/23)
5/18/2022	31	19	17	67	
9/14/2022	34	34	16	84	2-day sampling effort (9/13, 9/14)
5/16/2023	6	56	18	80	
9/18/2023	0	16	21	37	
5/15/2024	7	16	10	33	
9/16/2024	19	31	10	60	

Table 2. Summary of Childs River vegetation sampling (plot samples) by bog site and year, 2019 to 2024.

Bog site	Year	Plot samples
Farley Bog	2019	10
Farley Bog	2020	10
Farley Bog	2021	20
Farley Bog	2022	20
Farley Bog	2024	20
Garner Bog	2019	10
Garner Bog	2020	10
Garner Bog	2021	20
Garner Bog	2022	20
Garner Bog	2024	20

Table 3. Summary of distinct tag detections by antenna array in the Childs River. The 'TRUE/FALSE' designation indicates whether a tag was detected at that antenna. All observed detection combinations are shown.

Antenna 0.9/1	Antenna 2	Antenna 3	Number of Tags
False	True	False	60
True	False	False	28
True	True	False	22
False	False	True	25
False	True	True	20
True	True	True	15
Total tags			170

Table 4. Top 10 most frequently encountered plant species during vegetation surveys at the Childs River, grouped by pre-restoration (2019–2020) and post-restoration (2021–2024) periods. Species are listed in descending order of frequency, from most to least commonly observed.

Pre-Restoration	Post-Restoration
Vaccinium macrocarpon	Juncus canadensis
Toxicodendron radicans	Triadenum virginicum
Lysimachia terrestris	Toxixodendron radicans
Scirpus cyperinus	Lysimachia terrestris
Symphyotrichum novi-belgii	Leersia oryzoides
Juncus canadensis	Scirpus cyperinus
Leersia oryzoides	Viola lanceolata
Rubus hispidus	Ludwigia palustris
Andropogon glomeratus	Cyperus strigosus
Carex spp.	Hypericum canadense

Table 5. Summary of sediment trap maintenance activities along the restored Childs River. The table lists each of the four sediment traps (ordered south to north) along with their respective service dates. Sediment removal was conducted using a long-arm excavator in March 2022 and February 2025, while a short-arm excavator was used during the June 2023 maintenance effort.

Sediment Trap	March 2022	June 2023	February 2025
South Carriage Shop		X	X
North of old impoundment	X	X	X
South of Farley Bog	X	X	X
South of Garner Bog	X		

Figures

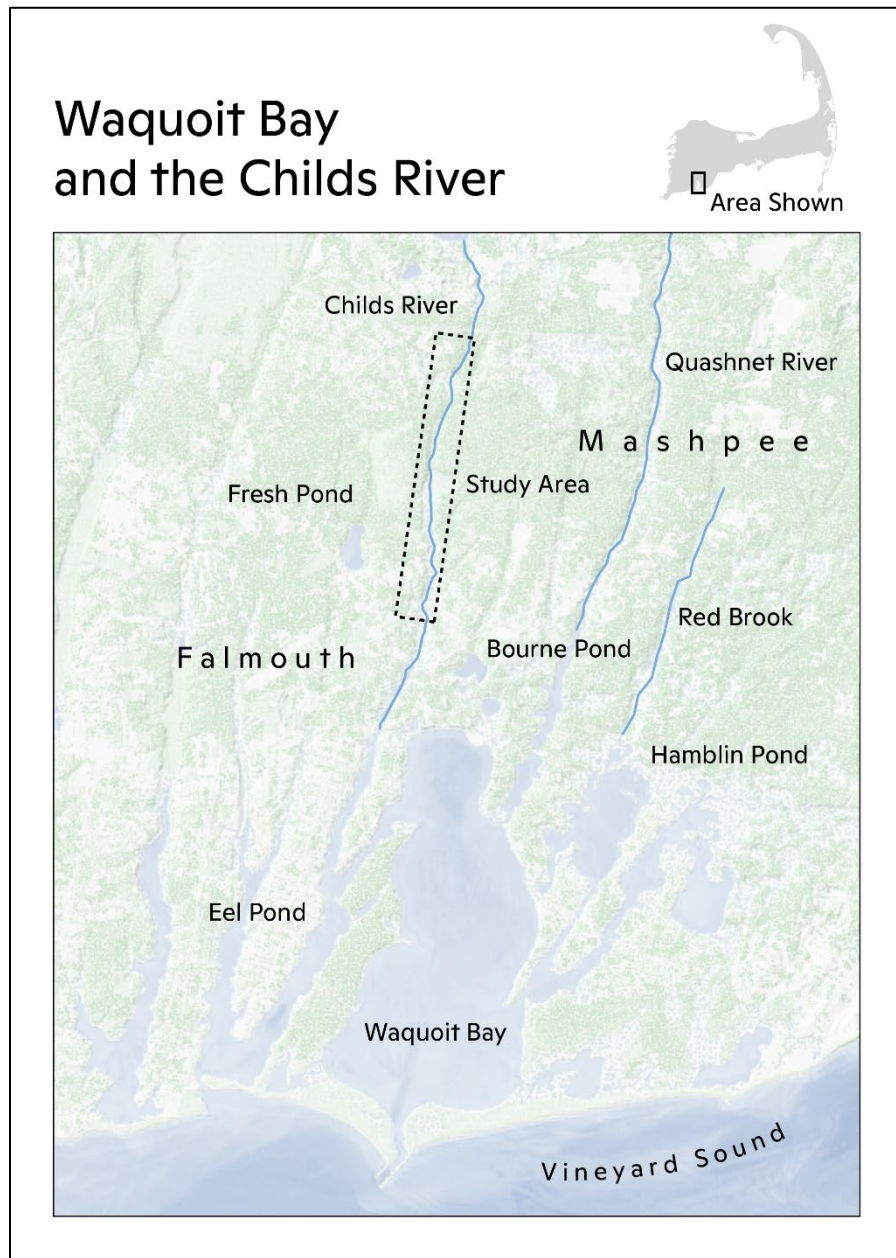


Figure 1. Map of the Childs River and surrounding region with the study area highlighted.



Figure 2. Map of the Childs River restoration focus areas including the former bogs, earthen dam, and impoundment (ponds surrounding Carriage Shop Road) present in the area pre-restoration.



Figure 3. Map (left) showing the locations of the four sediment traps installed as part of the Childs River restoration design. These structures help manage sediment loads and reduce siltation in sensitive habitats, supporting the long-term success of the restoration effort. Photos of each sediment trap are shown on the right, ordered from north to south along the restored channel.

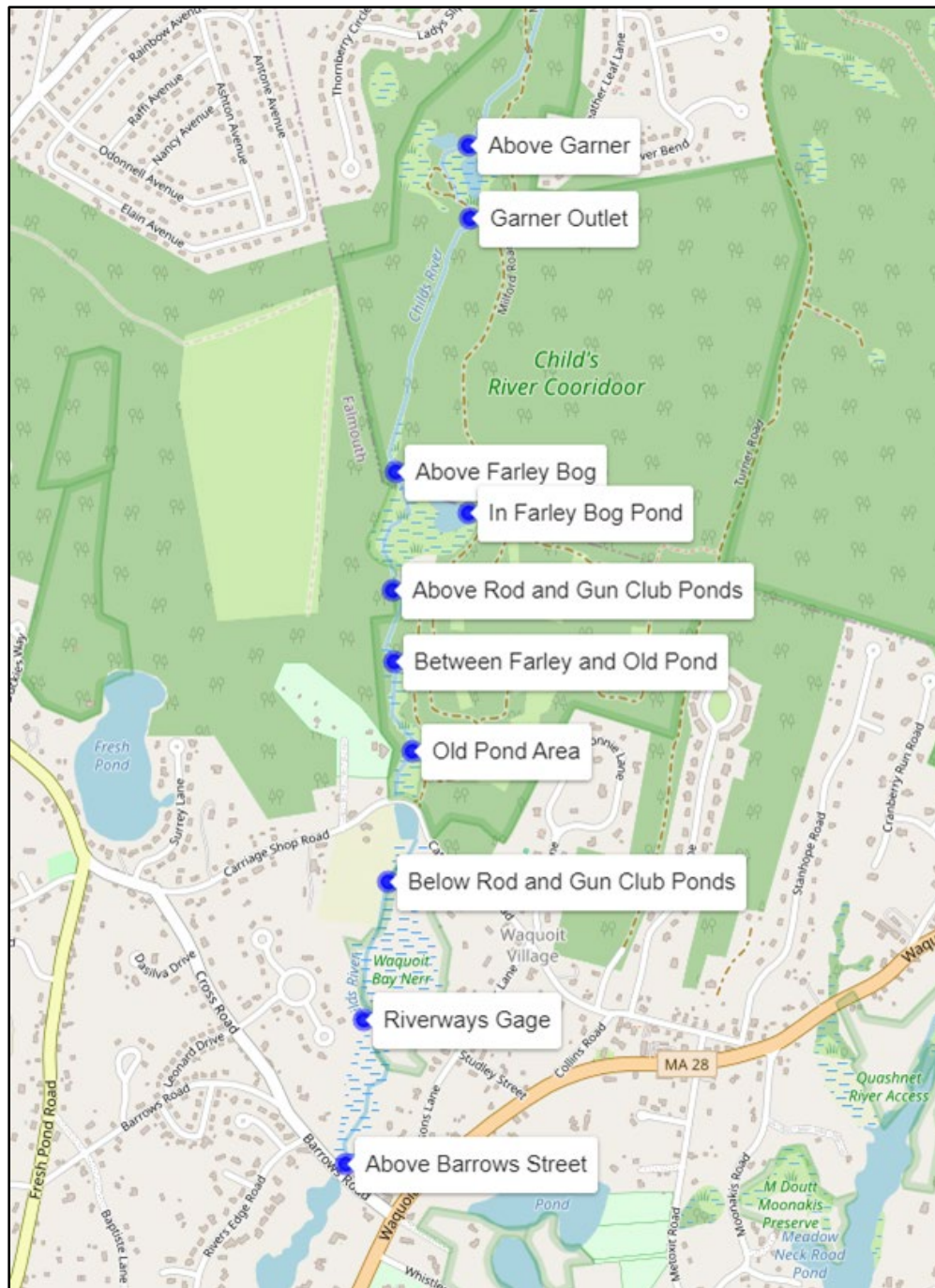


Figure 4. Map showing the station location of the continuous temperature loggers deployed in the Childs River.

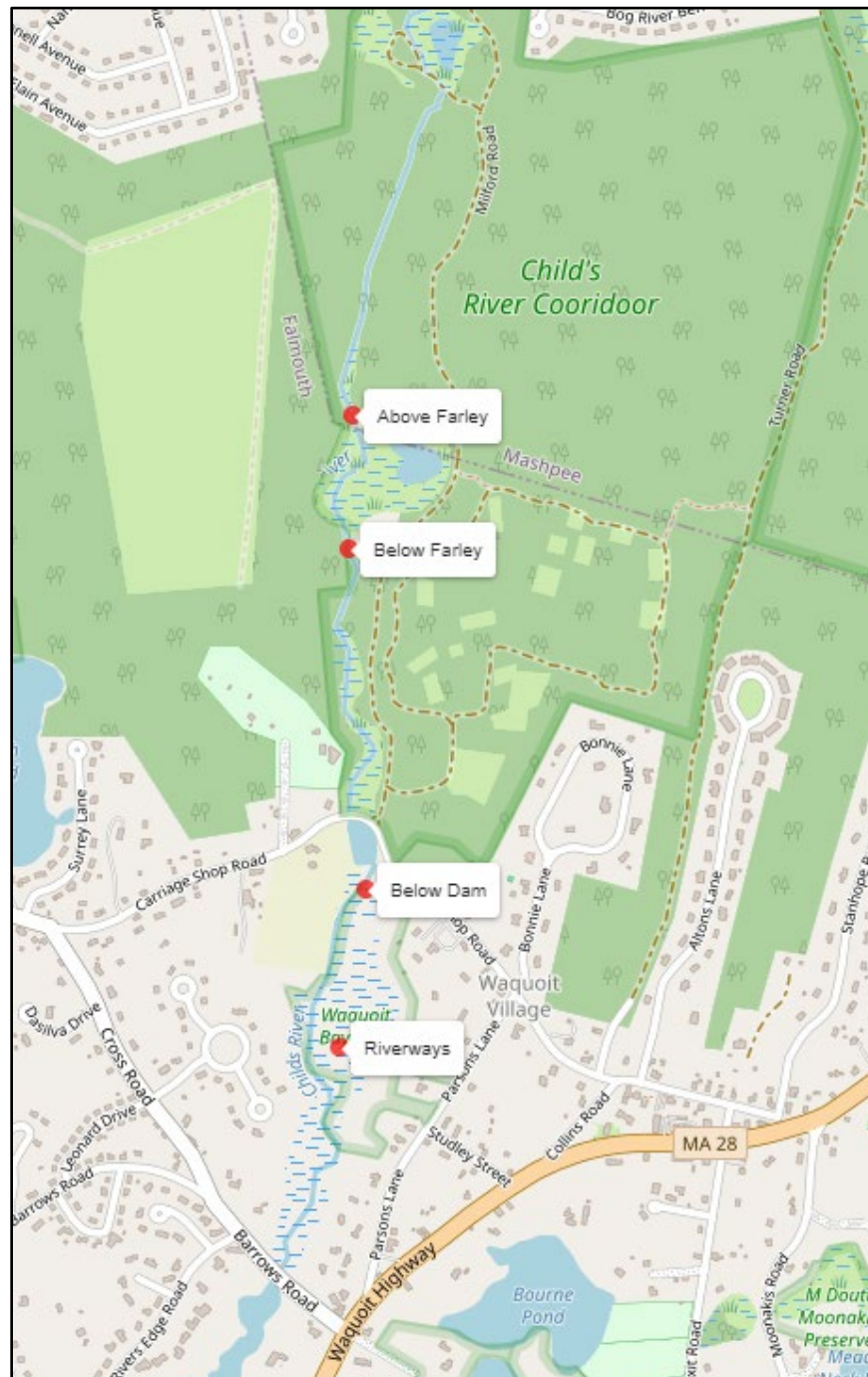


Figure 5. Map showing the location of the Childs River water quality stations that were continuously sampled both pre- and post-restoration. The 'Below Dam' location was adjusted several meters to the north post-restoration (late 2021).

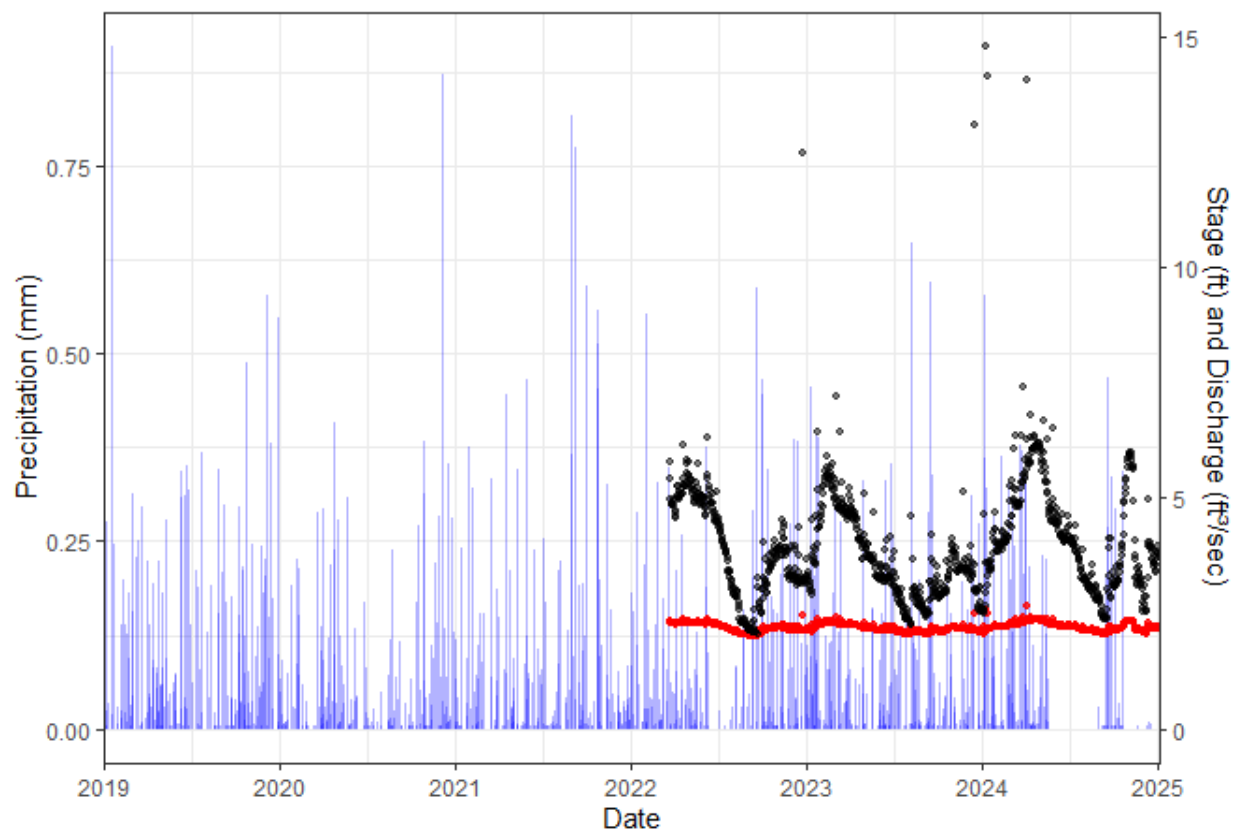


Figure 6. Local precipitation data (blue) collected in Falmouth, MA, provided by the Waquoit Bay National Estuarine Research Reserve. Childs River discharge (black) and stage (red) data provided by the Woodwell Climate Research Center.

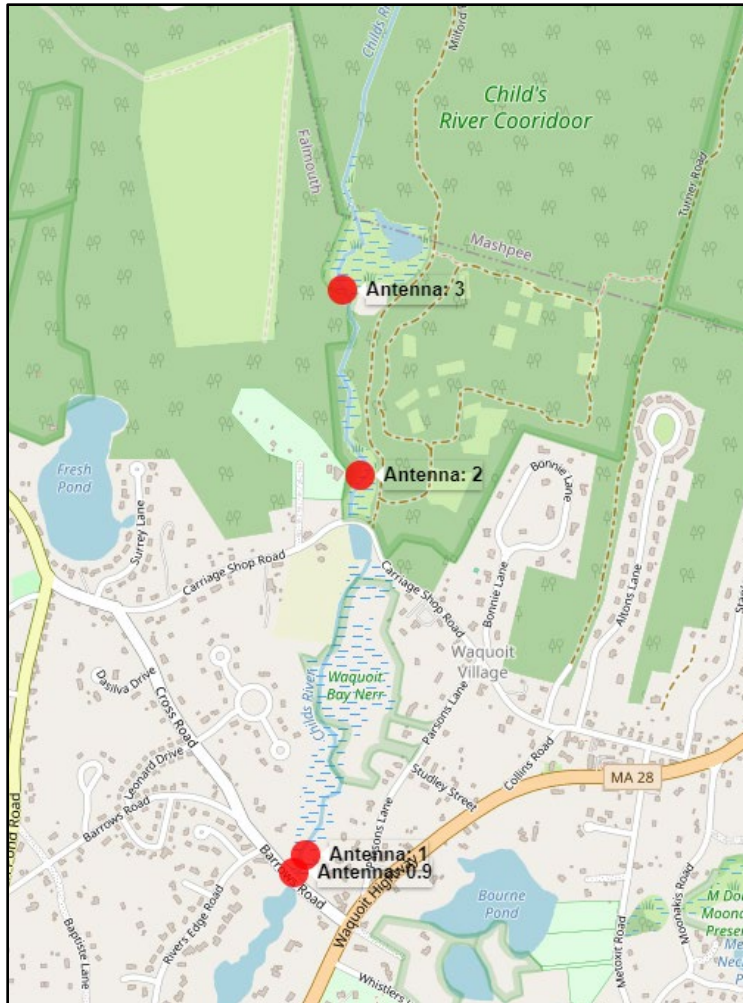


Figure 7. Map showing the location of the passive integrated responder (PIT) antenna arrays on the Childs River.

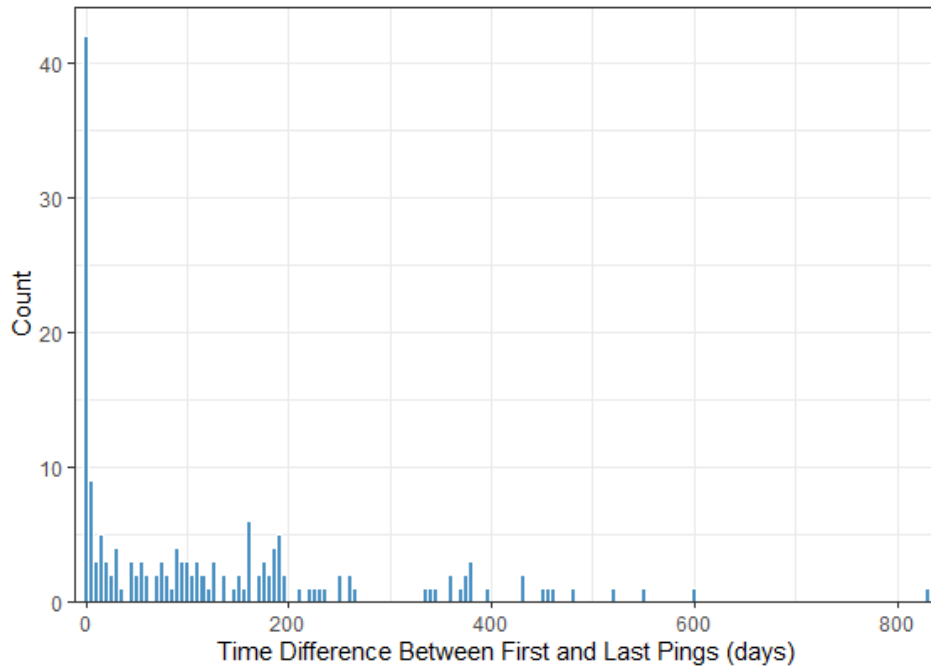


Figure 8. Distribution of the time difference (days) between the first and last antenna pings for all Brook Trout detected by the passive integrated transponder array deployed in the Childs River. “Count” represents the number of individual fish [tags] detected within each time-interval bin.

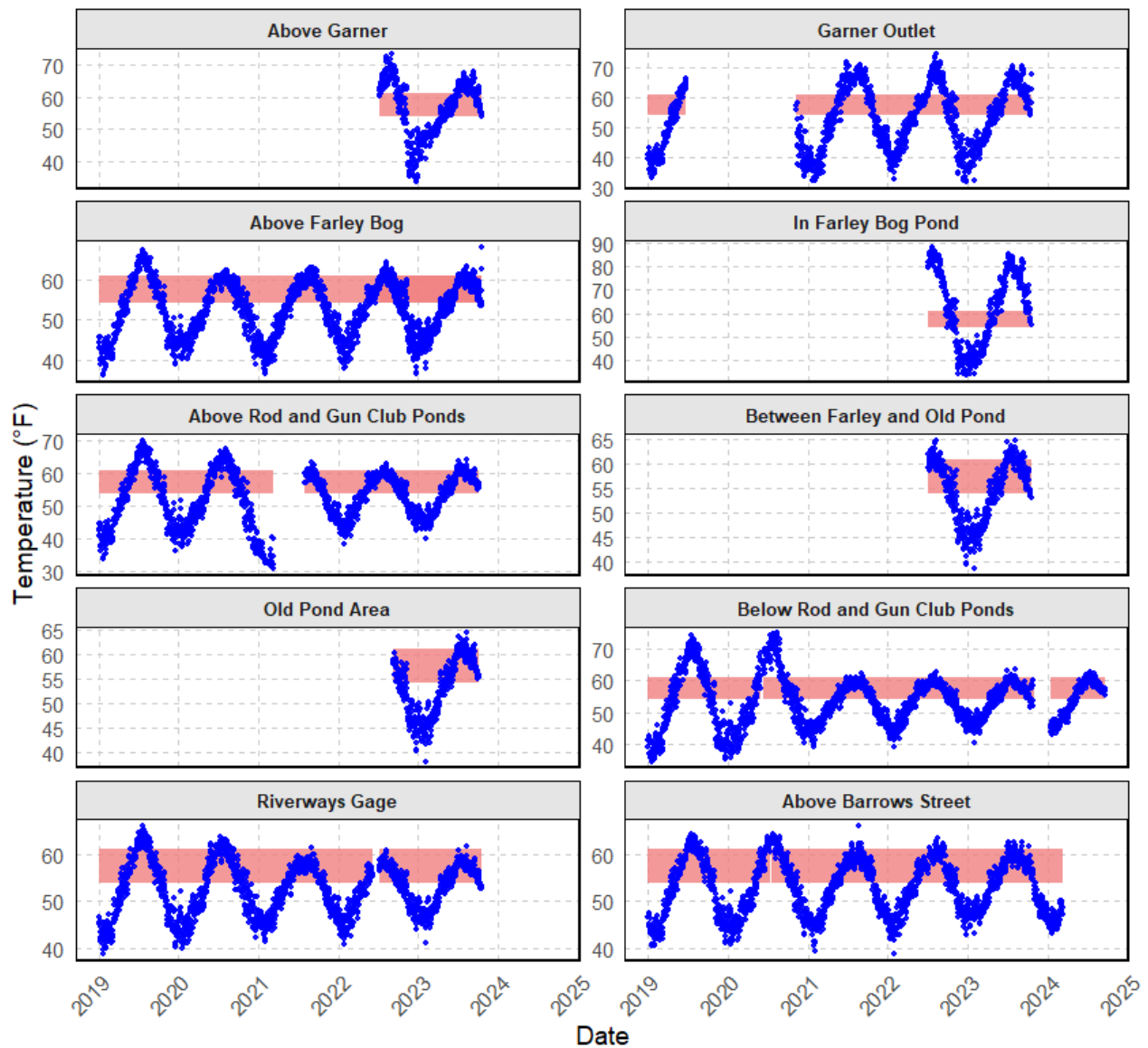


Figure 9. Daily mean water temperatures across Childs River sampling sites, with northernmost sites at the top and southernmost sites at the bottom. The red-shaded band highlights the optimal thermal habitat for Brook Trout, ranging from 54 to 61°F. Periods missing observations indicate that the logger was either inoperable, had been removed during that period, or an ‘out-of-water’ event was detected.

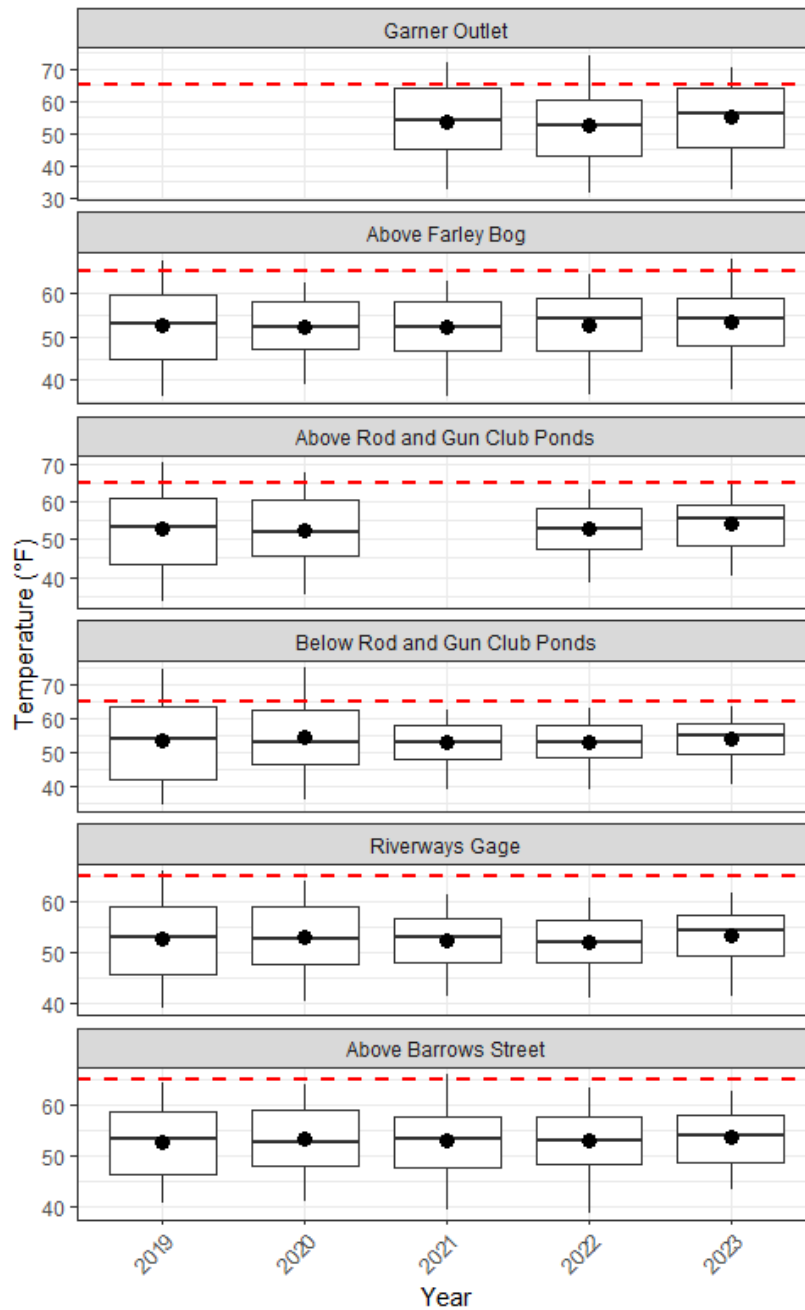


Figure 10. Box plot distributions of daily mean water temperatures across Childs River sampling sites from 2019 to 2023. Sites are arranged from north to south, with northernmost sites at the top and southernmost at the bottom. Each box plot represents the median, interquartile range (IQR; 25th–75th percentile), and whiskers extending to $1.5 \times$ IQR. Data points beyond the whiskers are classified as outliers. The circle marks the annual mean temperature. The dashed red line indicates the upper threshold of Brook Trout thermal tolerance (65°F; McCormick et al., 1972)

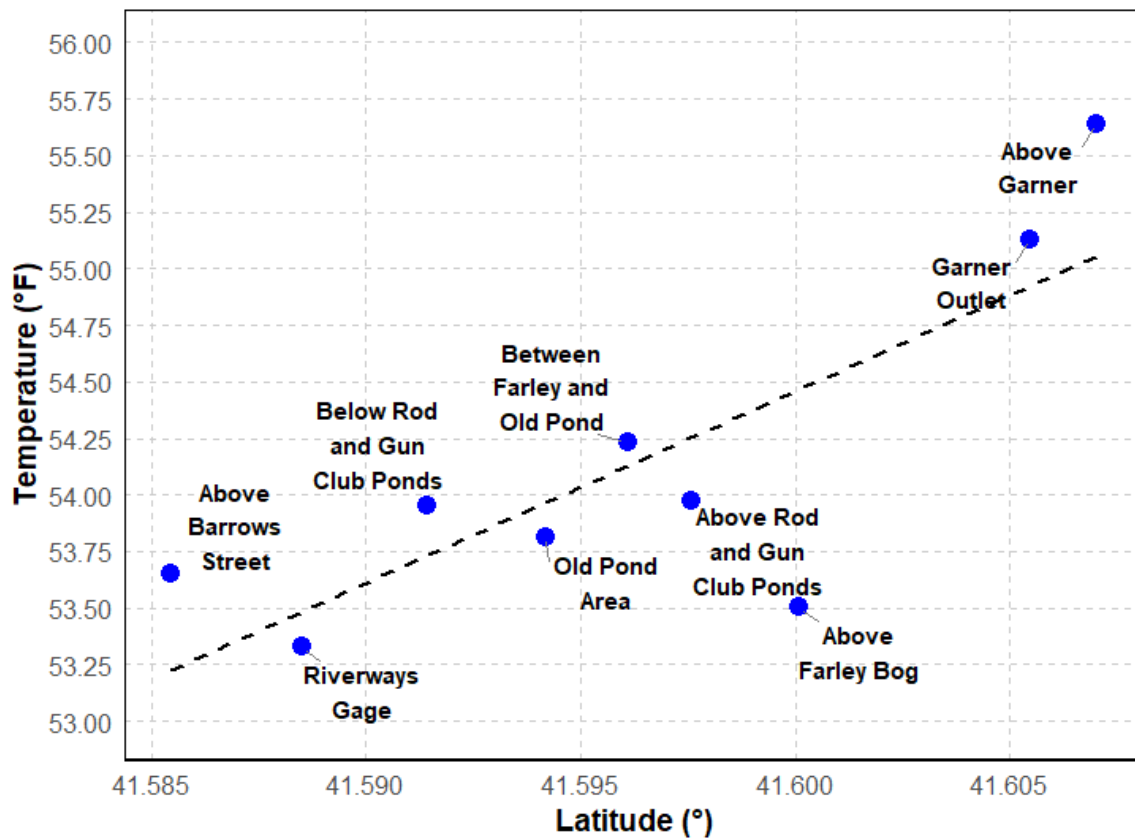


Figure 11. Annual mean 2023 water temperatures for the Childs River by sampling site, ordered by the latitude of the site.

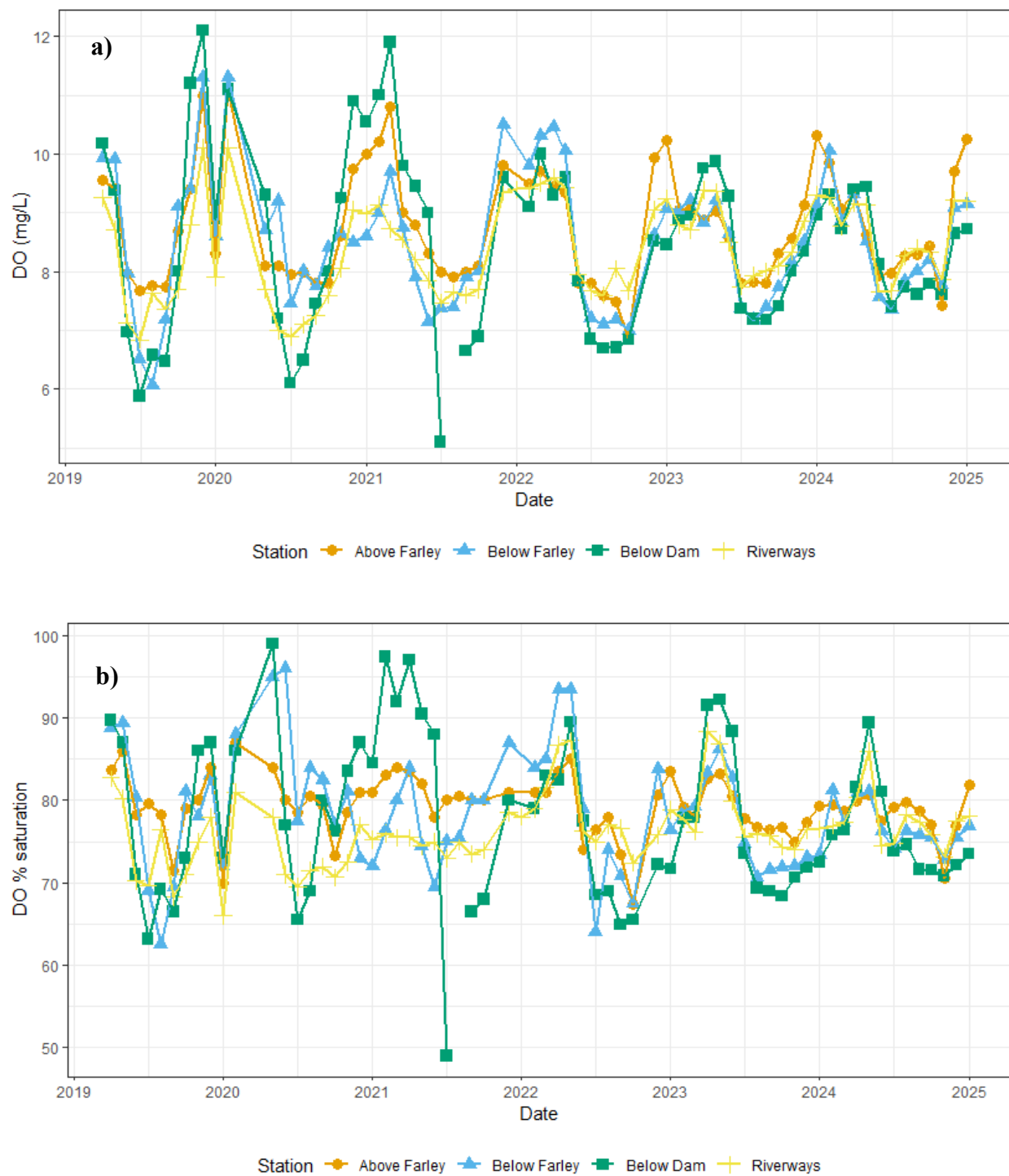


Figure 12. Monthly average dissolved oxygen (DO) in concentration (mg/L; a) and percent saturation (b) along the Childs River. Data provided by the Woodwell Climate Research Center (2019 – 2022) and the Waquoit Bay National Estuarine Research Reserve (2023-2025).

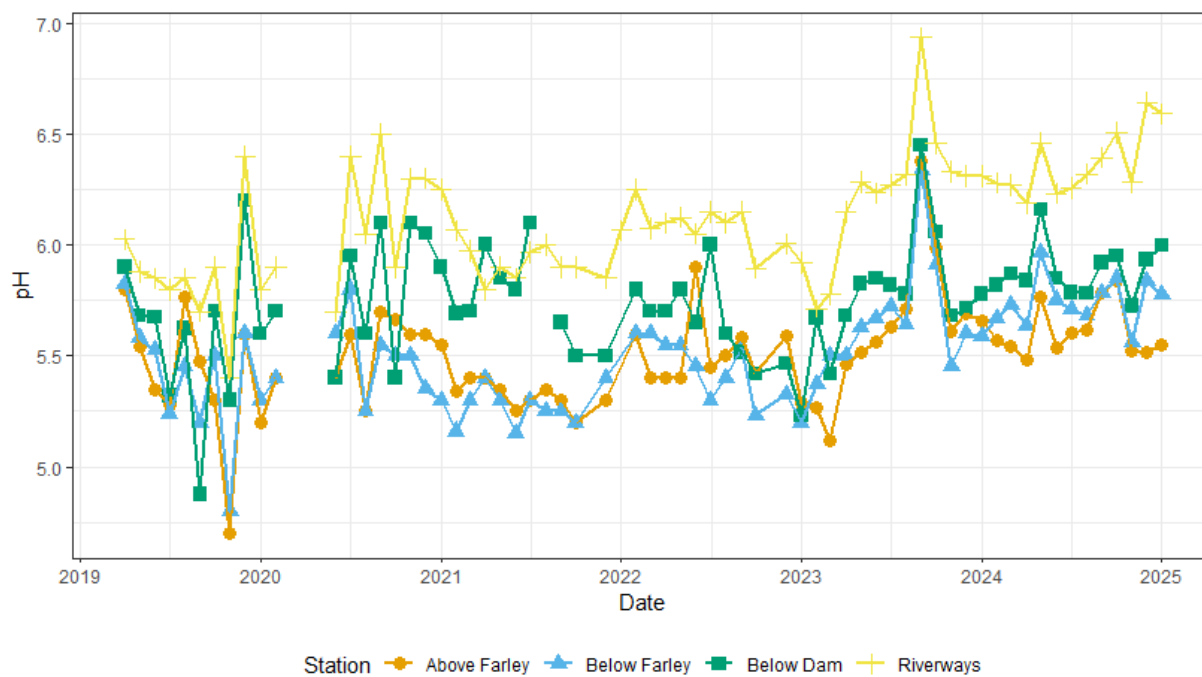


Figure 13. Monthly average pH along the Childs River. Data provided by the Woodwell Climate Research Center (2019 – 2022) and the Waquoit Bay National Estuarine Research Reserve (2023-2025).

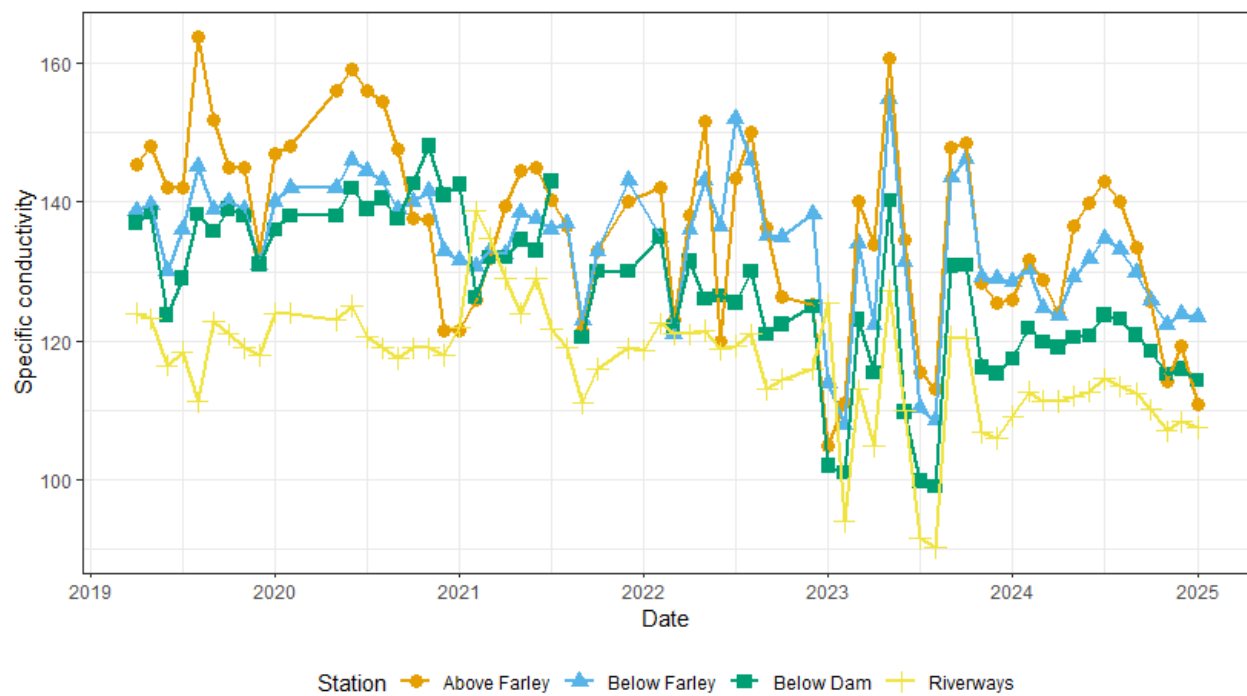


Figure 14. Monthly average specific conductivity ($\mu\text{S}/\text{cm}$) along the Childs River. Data provided by the Woodwell Climate Research Center (2019 – 2022) and the Waquoit Bay National Estuarine Research Reserve (2023-2025).



Figure 15. Monthly average ammonium (NH_4 ; top) and nitrate (NO_3 ; bottom) concentrations along the Childs River. Data provided by the Woodwell Climate Research Center (2019 – 2022) and the Waquoit Bay National Estuarine Research Reserve (2023-2025).

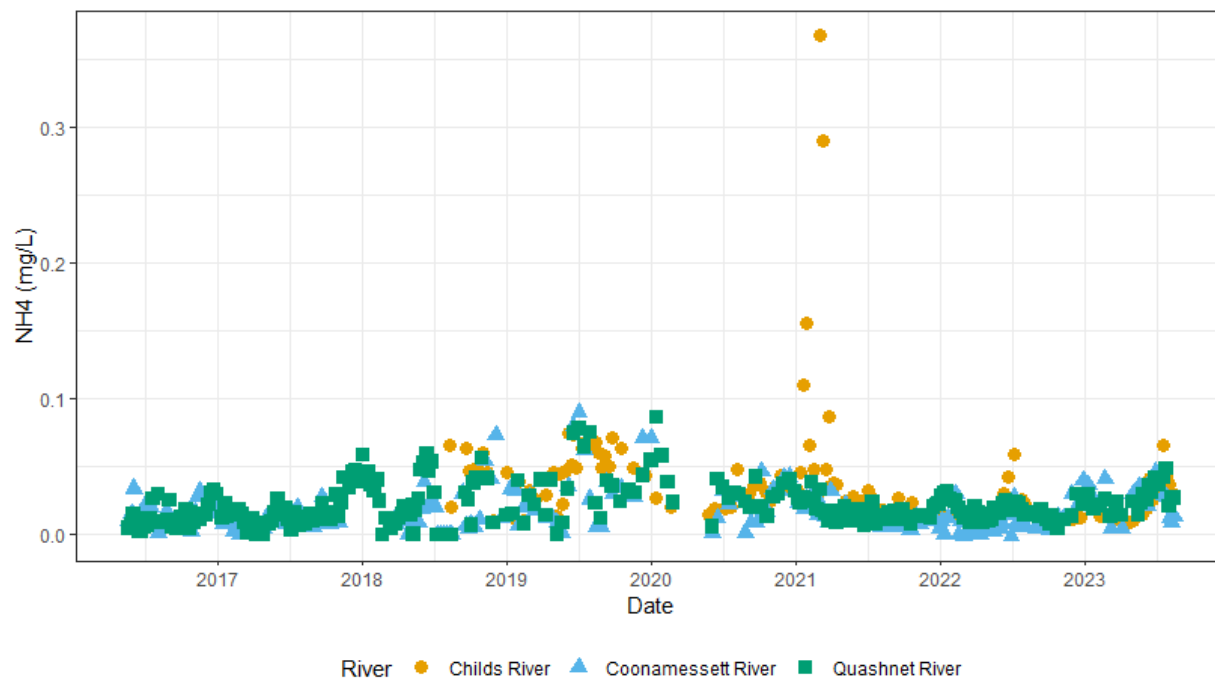


Figure 16. Ammonium (NH_4) concentrations from weekly water quality sampling at three rivers located in Falmouth, MA (Childs, Coonamessett, and Quashnet). Data provided by the Woodwell Climate Research Center and obtained through the Cape Cod Rivers Observatory data portal (<https://woodwellwater.quarto.pub/ccro-data/>).

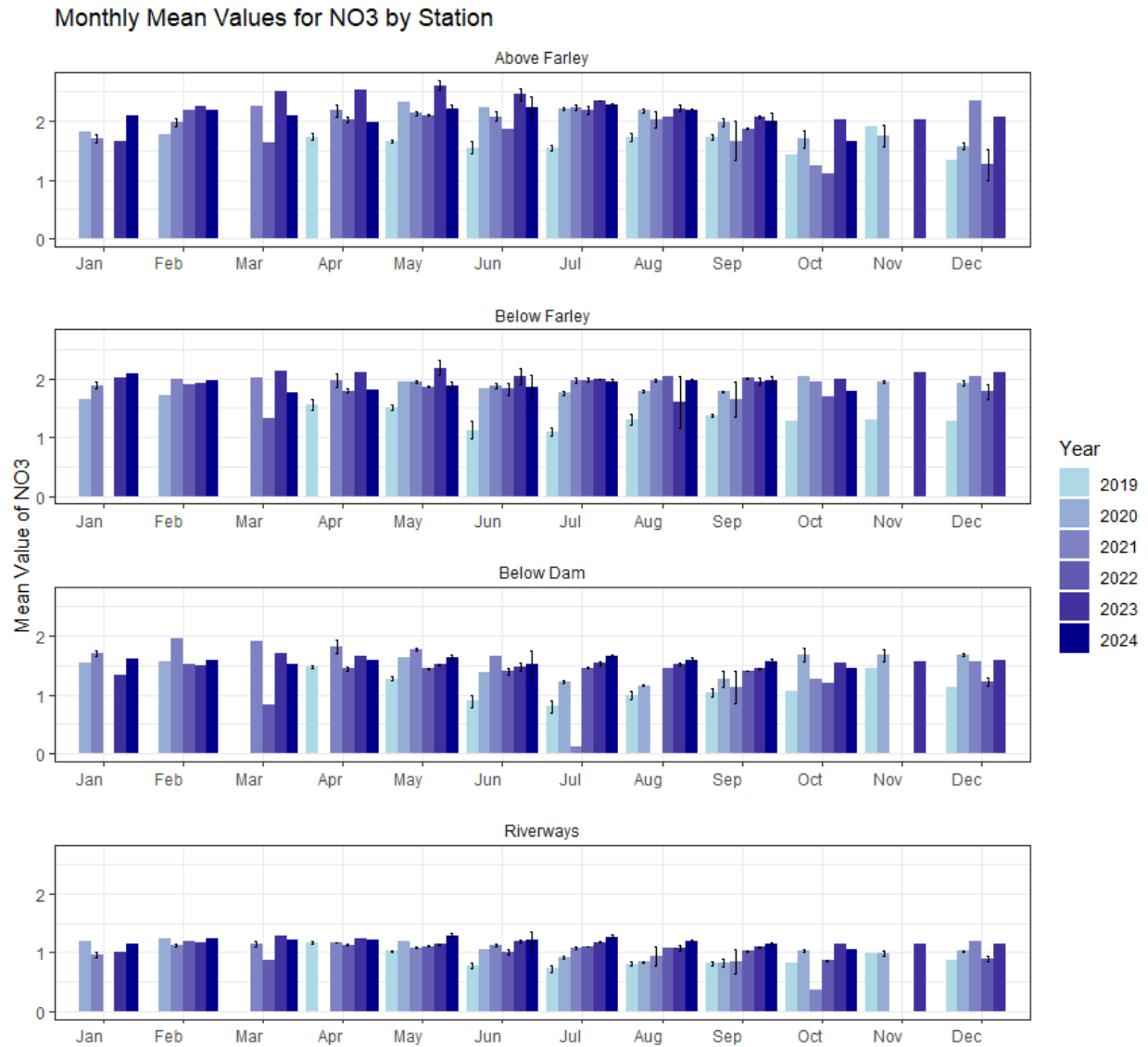


Figure 17. Monthly average nitrate (NO₃) concentrations along the Childs River. Data provided by the Woodwell Climate Research Center (2019 – 2022) and the Waquoit Bay National Estuarine Research Reserve (2023-2025).



Figure 18. Nitrate (NO_3) concentrations from weekly water quality sampling at three rivers located in Falmouth, MA (Childs, Coonamessett, and Quashnet). Data provided by the Woodwell Climate Research Center and obtained through the Cape Cod Rivers Observatory data portal (<https://woodwellwater.quarto.pub/ccro-data/>).

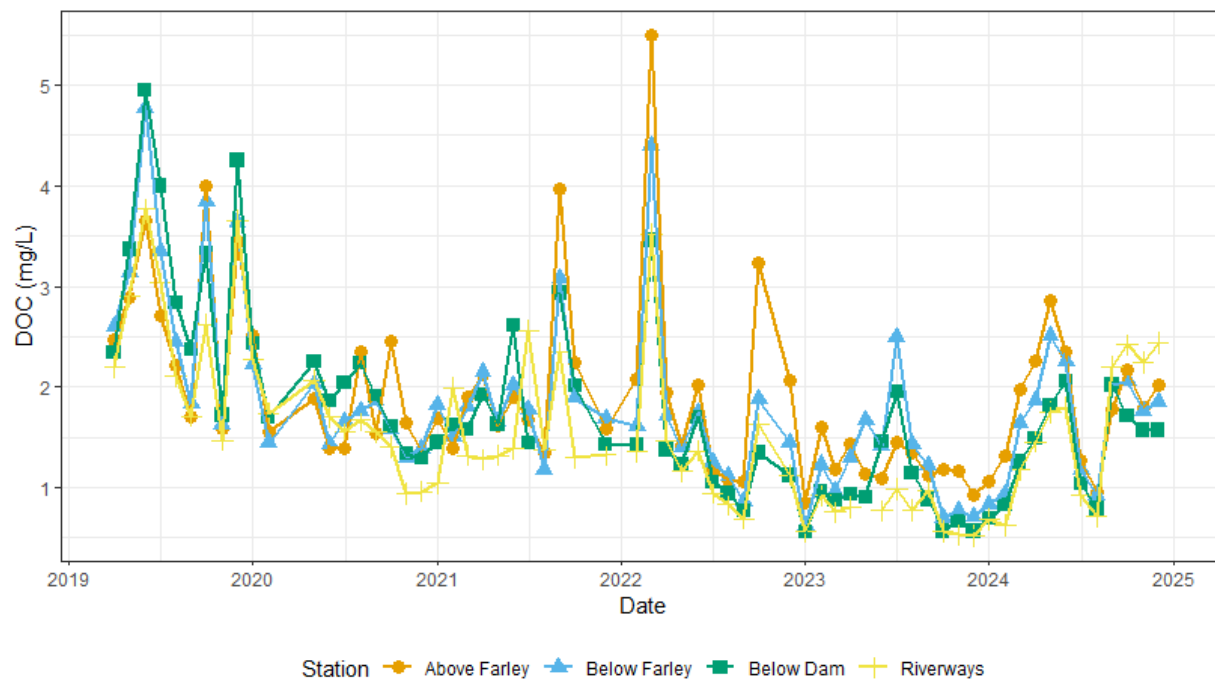


Figure 19. Monthly average dissolved organic carbon (DOC) concentrations along the Childs River. Data provided by the Woodwell Climate Research Center (2019 – 2022) and the Waquoit Bay National Estuarine Research Reserve (2023-2025).

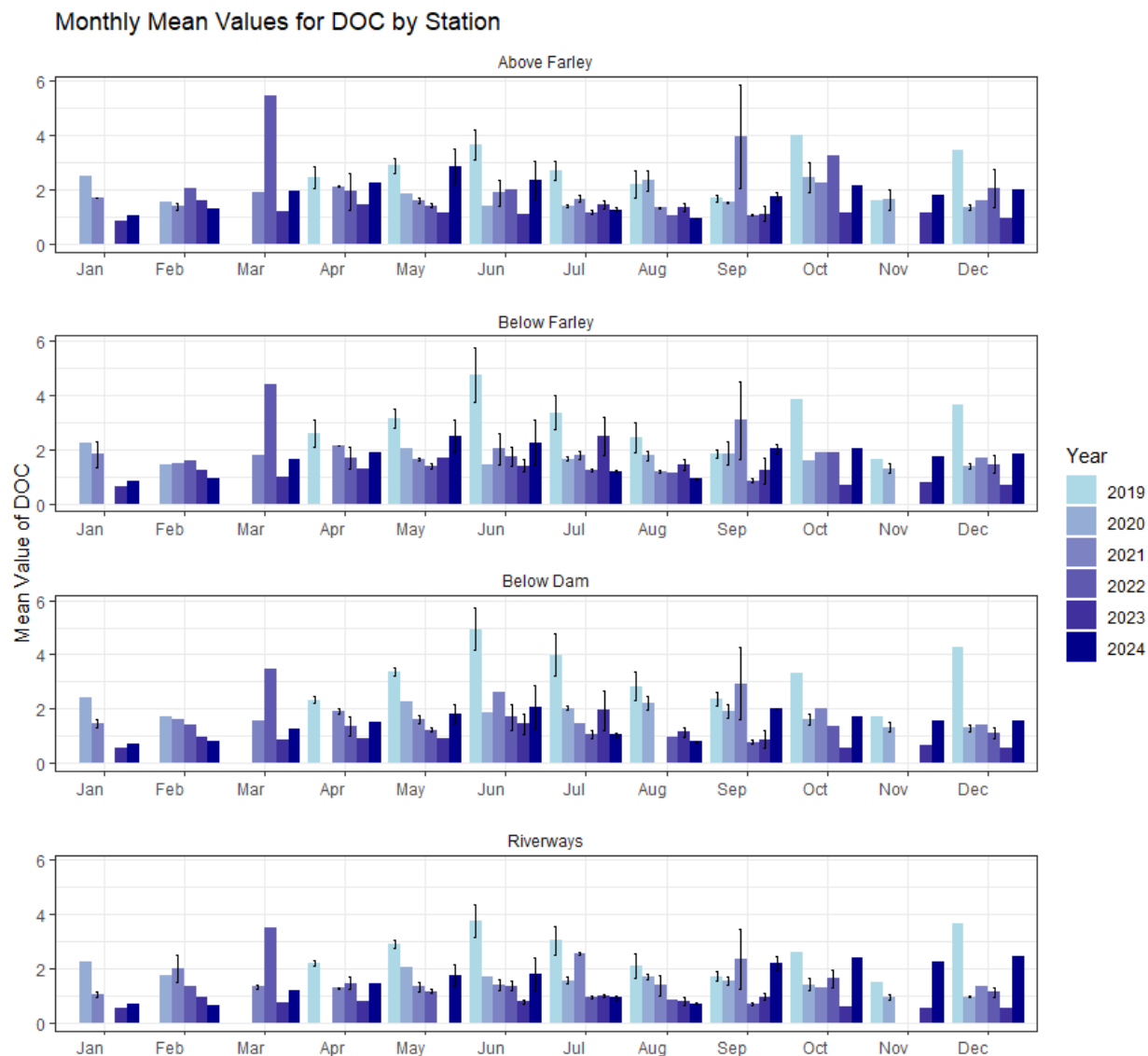


Figure 20. Monthly average dissolved organic carbon (DOC) concentrations along the Childs River. Data provided by the Woodwell Climate Research Center (2019 – 2022) and the Waquoit Bay National Estuarine Research Reserve (2023-2025).

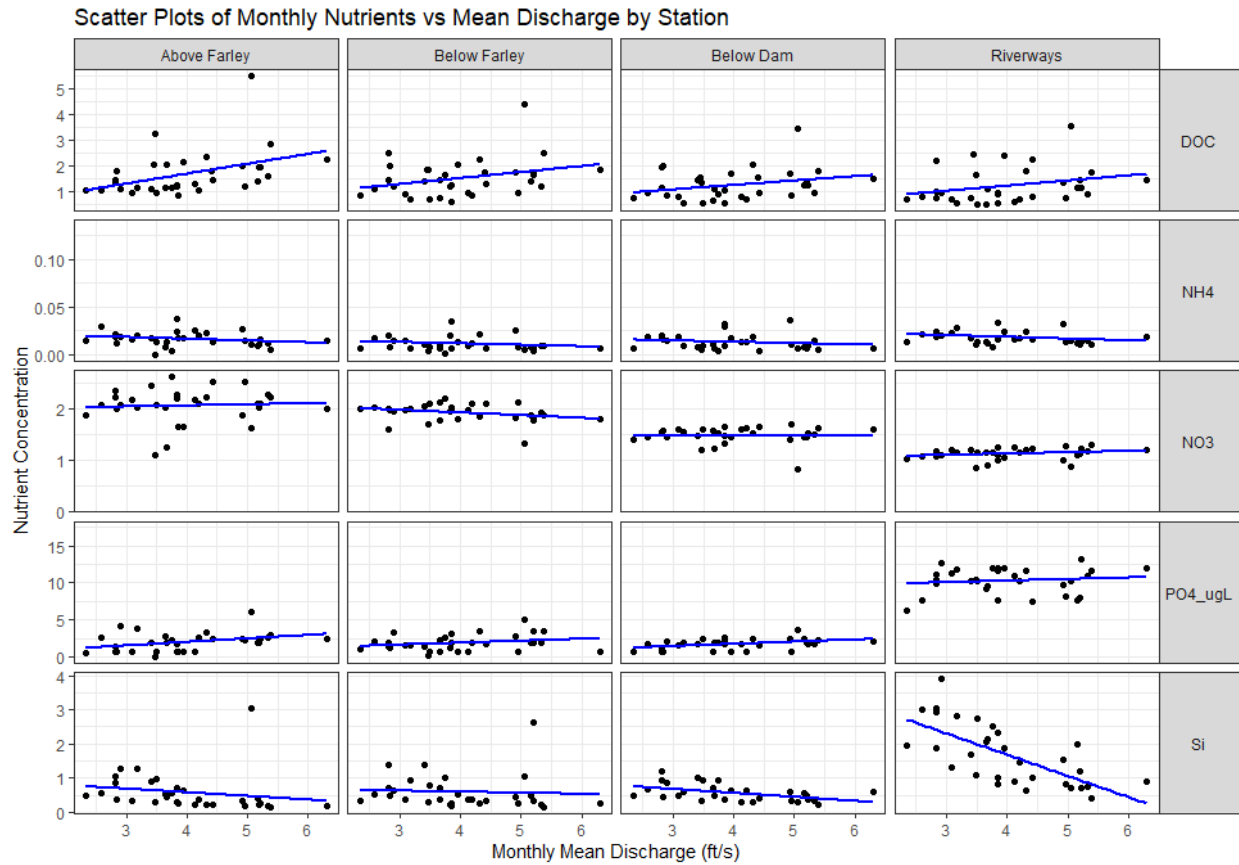


Figure 21. Scatter plots showing correlative relationships between monthly mean nutrient concentrations and river discharge across all four monitoring stations. Nutrient concentrations are in mg/L unless noted otherwise. River discharge and nutrient data collected between 2019-2022 provided by the Woodwell Climate Research Center. Nutrient data collected between 2023-2025 provided by the Waquoit Bay National Estuarine Research Reserve.

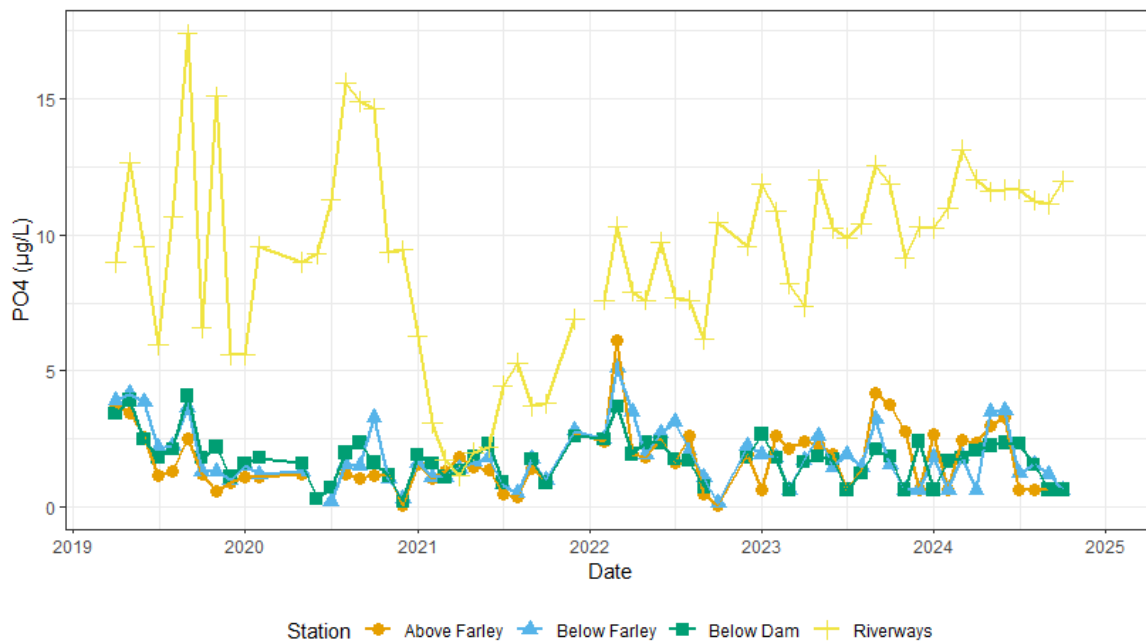


Figure 22. Monthly average phosphate (PO₄) concentrations along the Childs River. Data provided by the Woodwell Climate Research Center (2019 – 2022) and the Waquoit Bay National Estuarine Research Reserve (2023-2025).

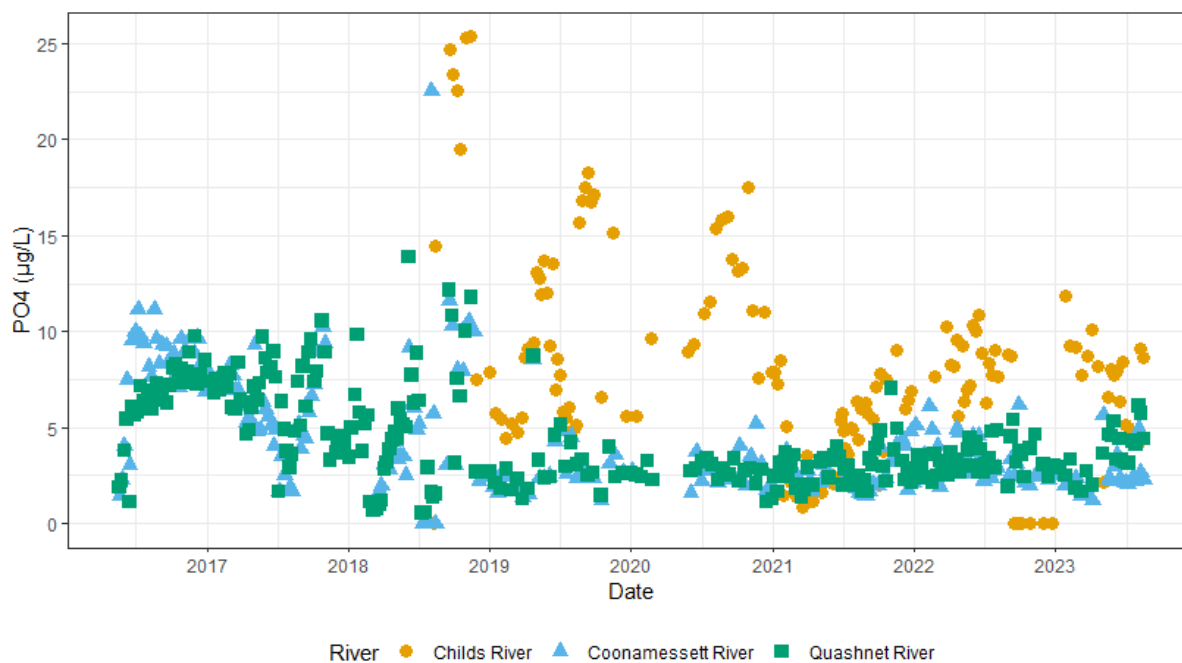


Figure 23. Phosphate (PO_4) concentrations from weekly water quality sampling at three rivers located in Falmouth, MA (Childs, Coonamessett, and Quashnet). Data provided by the Woodwell Climate Research Center and obtained through the Cape Cod Rivers Observatory data portal (<https://woodwellwater.quarto.pub/ccro-data/>).

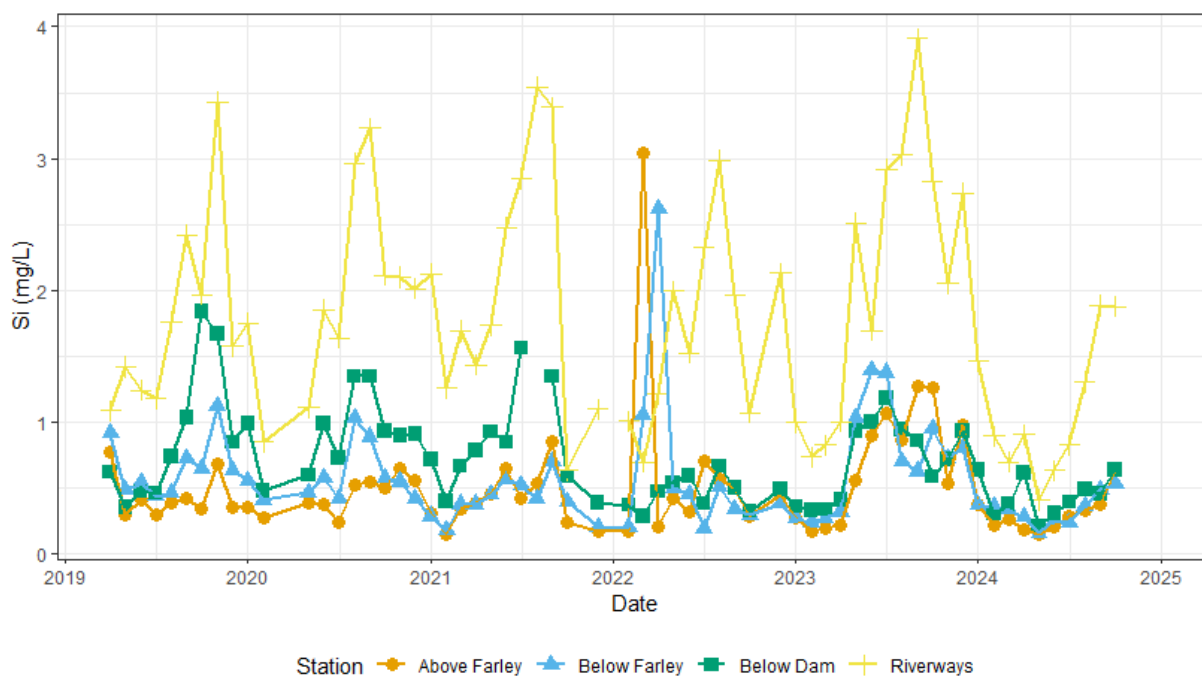


Figure 24. Monthly average silica (Si) concentrations along the Childs River. Data provided by the Woodwell Climate Research Center (2019 – 2022) and the Waquoit Bay National Estuarine Research Reserve (2023-2025).

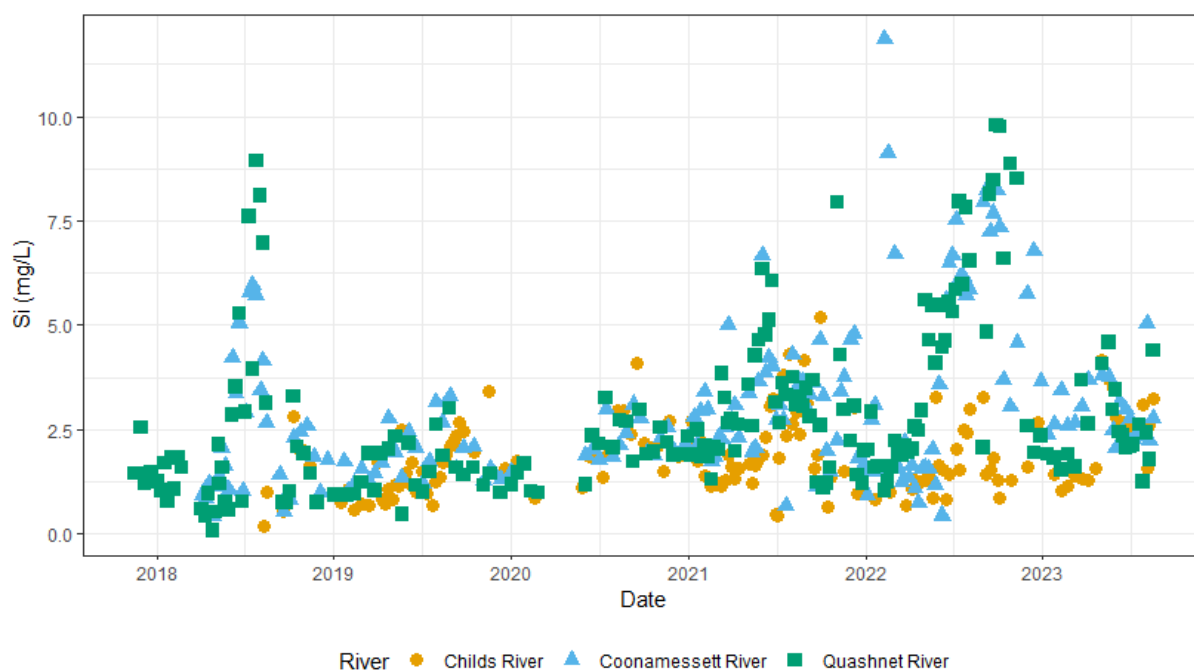


Figure 25. Silica (Si) concentrations from weekly water quality sampling at three rivers located in Falmouth, MA (Childs, Coonamessett, and Quashnet). Data provided by the Woodwell Climate Research Center and obtained through the Cape Cod Rivers Observatory data portal (<https://woodwellwater.quarto.pub/ccro-data/>).

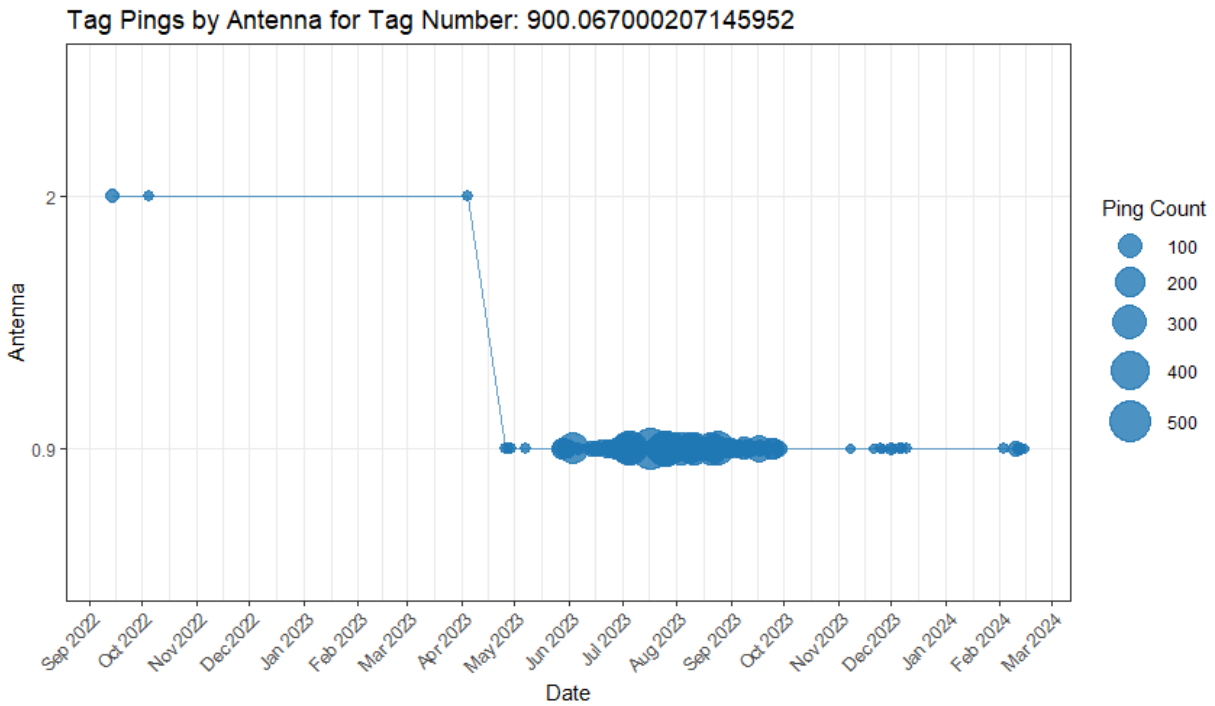


Figure 26. Detected movements of Tag 900.067000207145952 between Childs River passive integrated transponder (PIT) antenna arrays. The fish was first captured on September 13, 2022 as a 131 mm fish in a section of river below Carriage Shop Road. It remained in the system for 520 days before its last detection on February 15, 2024.

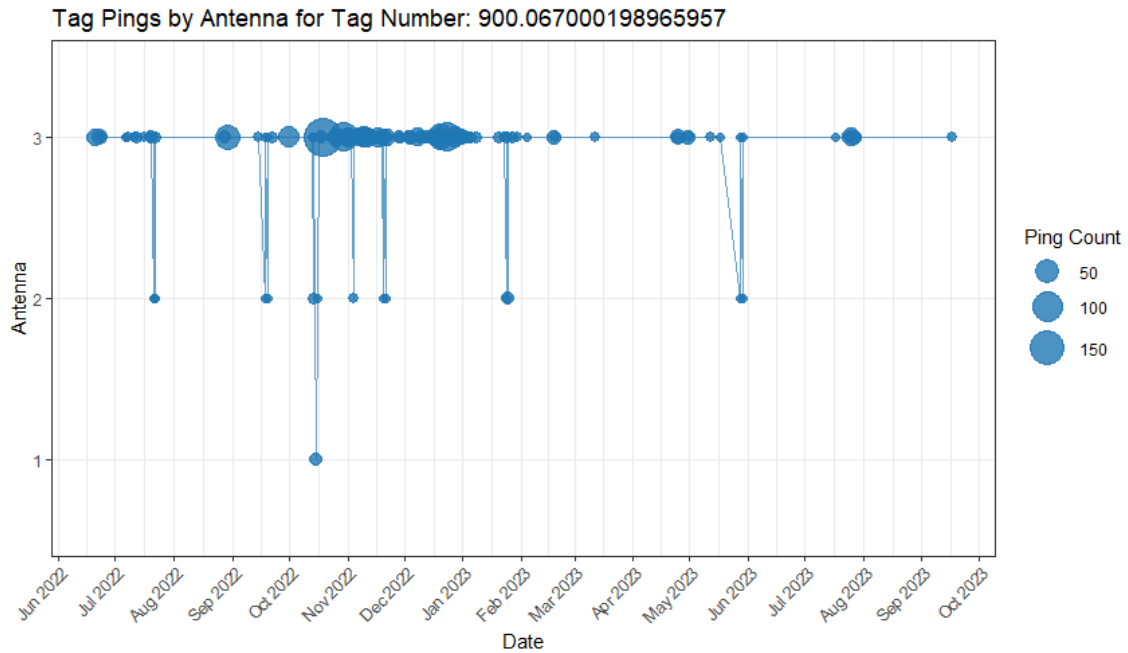


Figure 27. Detected movements of Tag 900.067000198965957 between Childs River passive integrated transponder (PIT) antenna arrays. The fish was first captured on May 18, 2022 as a 171 mm fish. It remained in the system for 454 days.

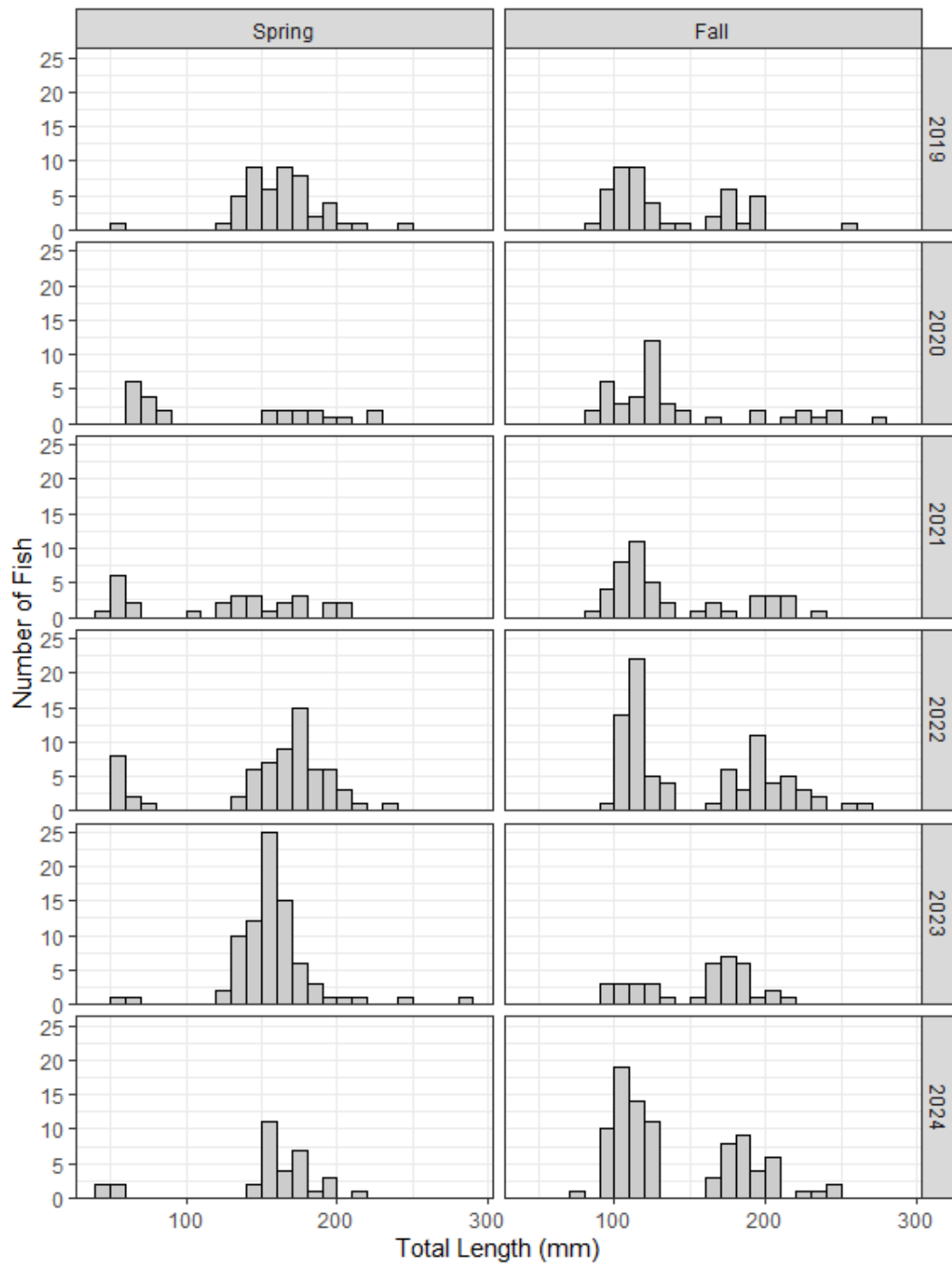


Figure 28. Length frequency distribution of Childs River Brook Trout by sampling season, from 2019 to 2024.

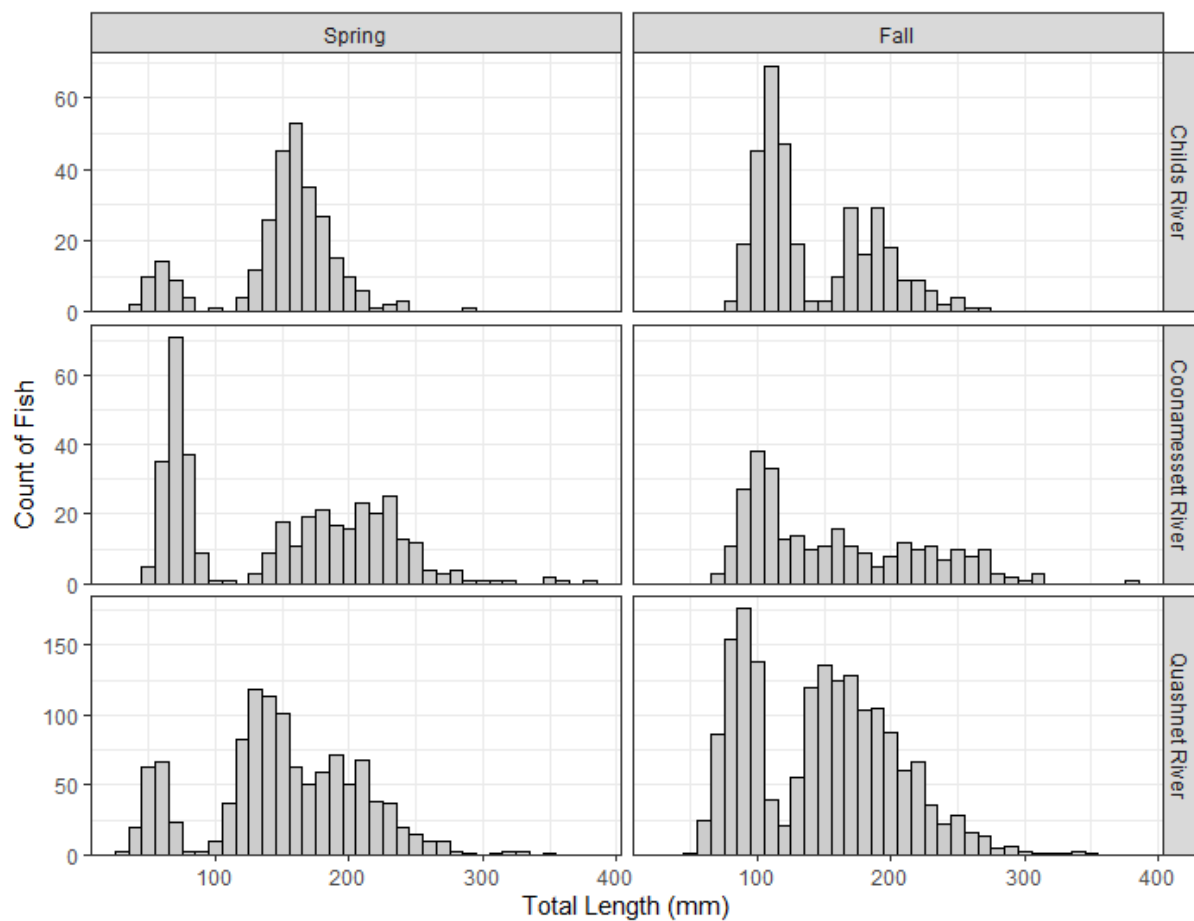


Figure 29. Comparison of seasonal length frequency distributions of Brook Trout from three upper Cape Cod rivers (Childs, Coonamessett, and Quashnet rivers), based on data collected from 2019 to 2024.

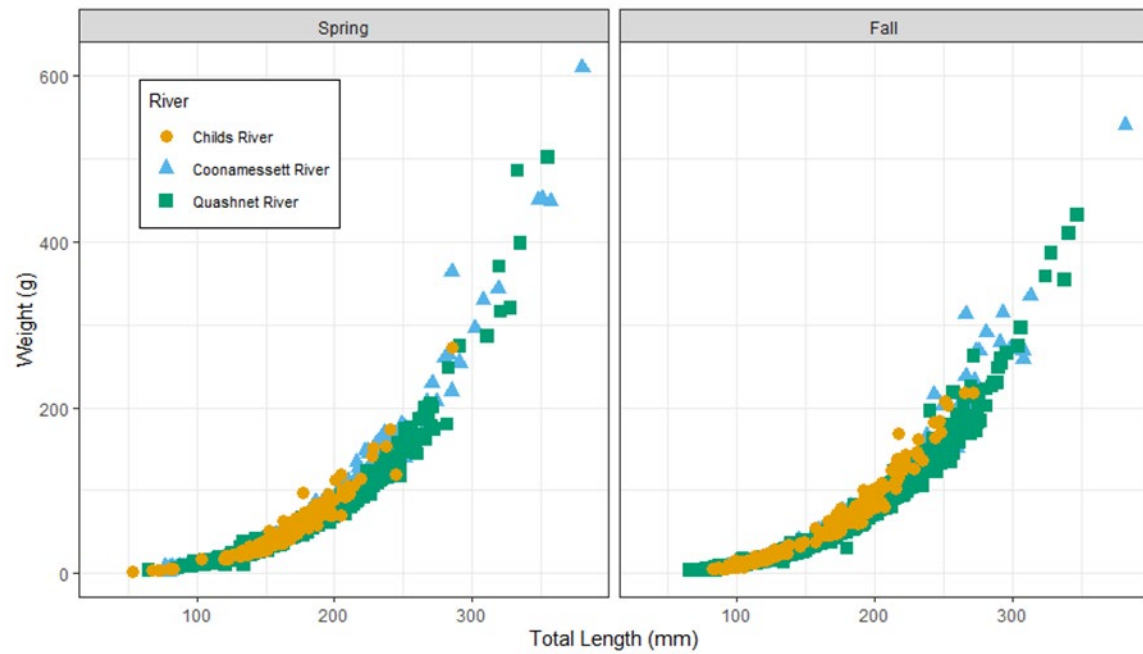


Figure 30. Comparison of Brook Trout length-weight relationships across three upper Cape Cod rivers (Childs, Coonamessett, and Quashnet rivers), based on data collected from 2019 to 2024.

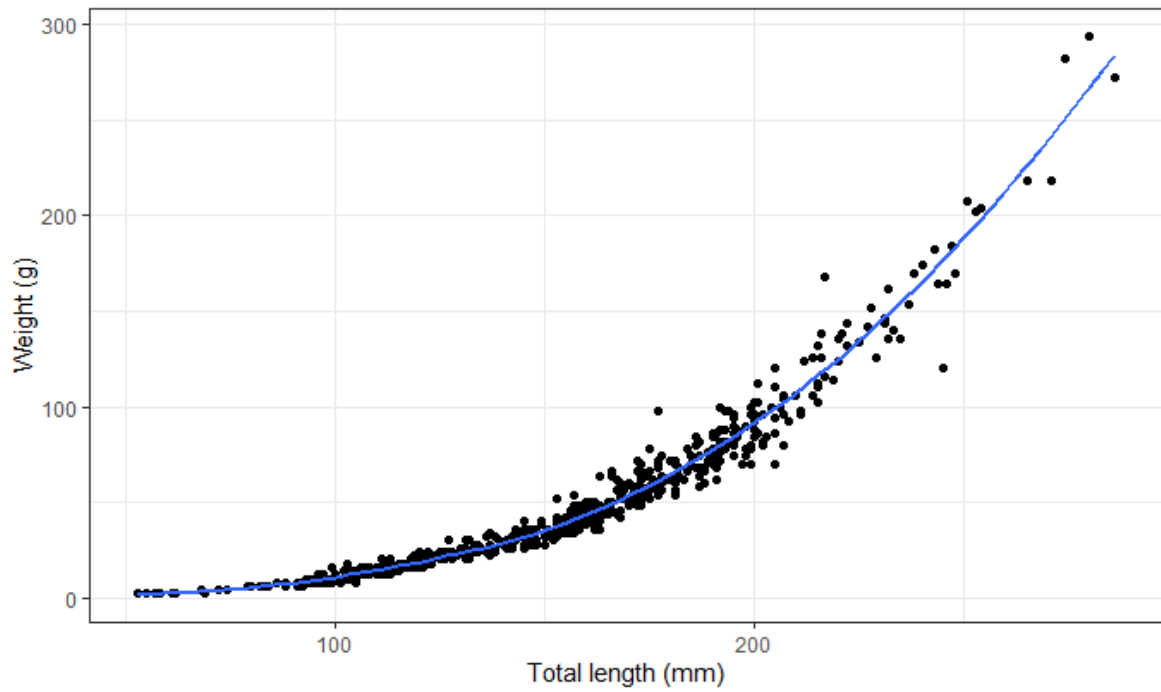


Figure 31. Length-weight relationship of Childs River Brook Trout, based on data collected from 2019 to 2024. The relationship is defined by the equation: $W = 0.00000744269 \times L^{3.0742}$ ($n = 526$).

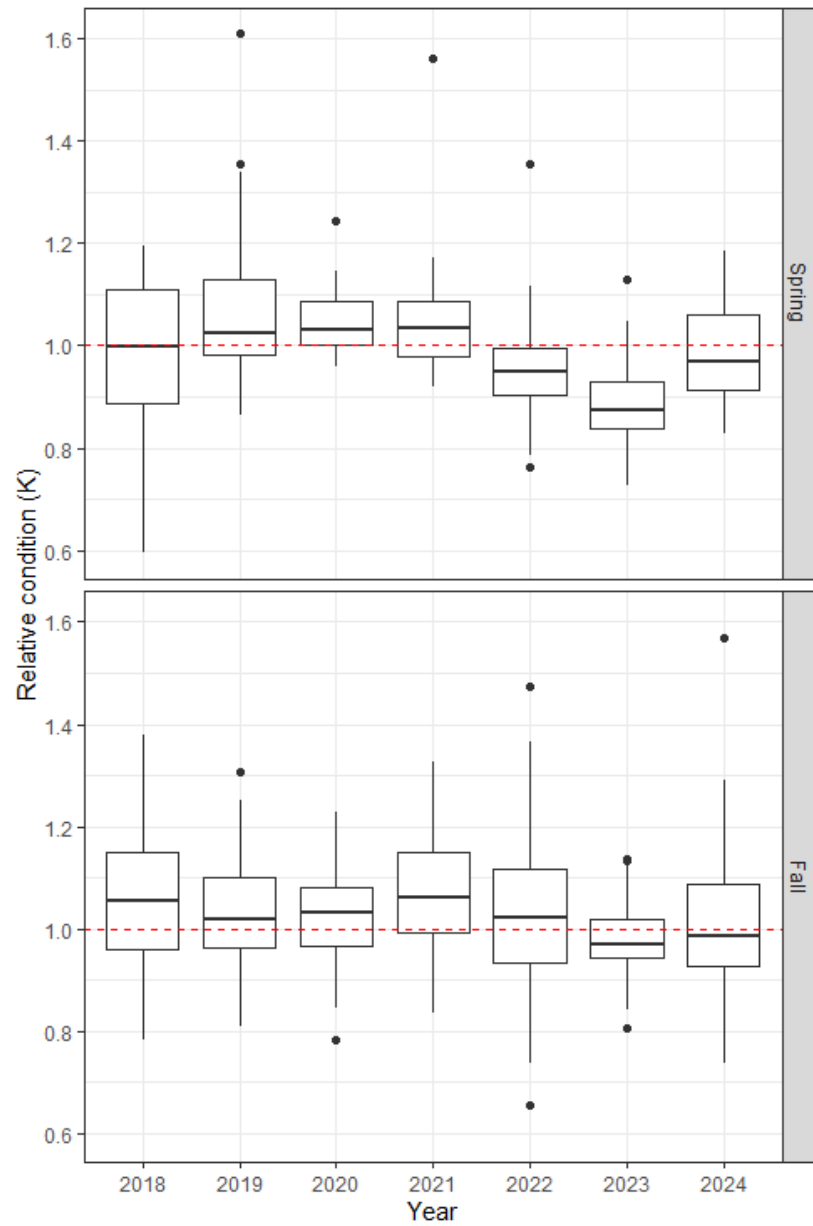


Figure 32. Box plot distributions of the relative condition factor of Childs River Brook Trout, grouped by season and year. The dashed red line represents the mean condition factor over the time series. Each box plot displays the median, interquartile range (IQR; 25th–75th percentile), and whiskers extending to $1.5 \times \text{IQR}$. Data points beyond the whiskers are considered outliers.

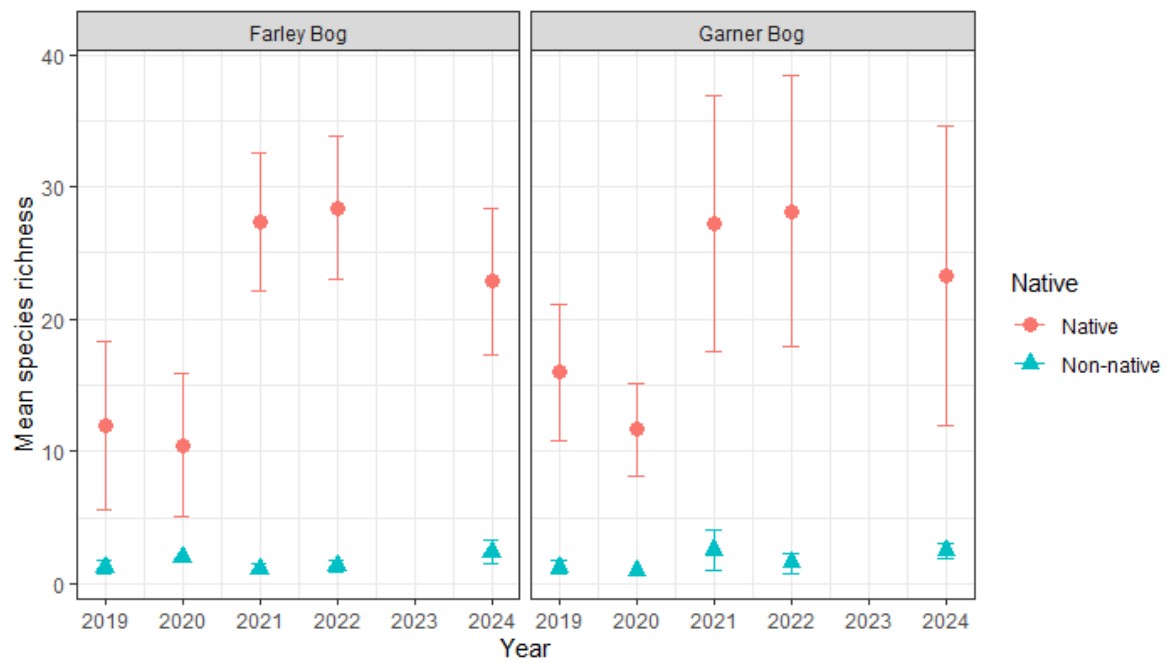


Figure 33. Trends in mean species richness across bog sites and years, with separate analyses for native and non-native species. Error bars indicate $\pm$ one standard deviation.

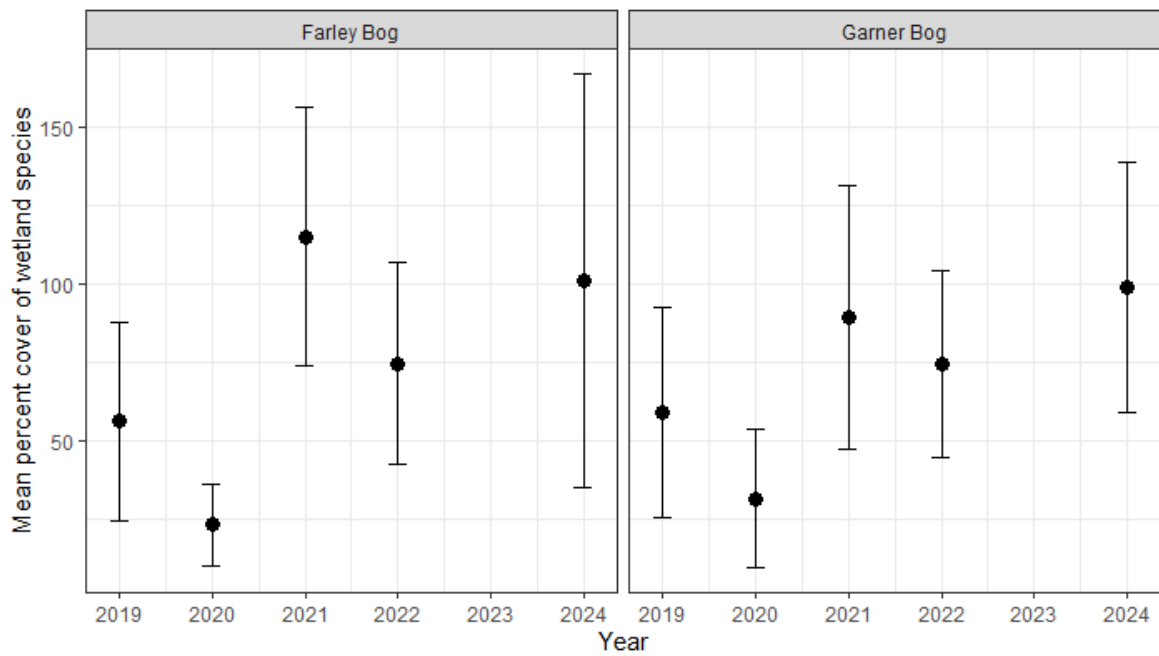


Figure 34. Mean percent cover of wetland species (excluding cranberry) across bog sites and years. Error bars represent $\pm$ one standard deviation.