UPPER CHILDS RIVER RESTORATION PROJECT

One-Year Post-Construction Report

Falmouth Rod and Gun Club
April 2023

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Childs River Brook Trout, September 13, 2022. Photo courtesy of Steve Hurley, MassWildlife.

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A. EXECUTIVE SUMMARY

The Childs River is located within the Waquoit Bay Estuary watershed and flows through the Towns of Falmouth and Mashpee in Cape Cod, Massachusetts. The Childs River flows south through the Mashpee National Wildlife Refuge across the property of the Falmouth Rod and Gun Club (FRGC) and discharges into Eel Pond, a saltwater sub-embayment hydrologically connected to Waquoit Bay and the Vineyard Sound.

Although the Childs River has a rich history of Brook Trout and herring fishing, populations of Brook Trout in the river have been greatly reduced due to habitat modifications resulting from several human impacts including cranberry farming, commercial fishing, and damming the river for a mill and carriage shop. Manipulations of the river's flow and morphology for these uses created ponding and low flow areas where water temperatures increased, and dissolved oxygen dropped to severely low levels. These changes to the environmental conditions resulted in the loss of coldwater habitat for brook trout, altered riparian and freshwater wetland habitat, and degraded water quality. In addition to the loss of habitat, humans also created barriers to anadromous fish passage through the creation of dams, impoundments, and crumbling culverts, which impeded the passage of Brook Trout, American Eel, and river herring to freshwater spawning areas upstream.

To address the negative impacts of historic human alterations to the system described above, the Childs River restoration included the following actions: removing barriers to fish passage, removing the impounded sediment and ponds behind the earthen dam, replacement of the undersized and deteriorated culvert under Carriage Shop Road, reconstruction of the river channel through the former impoundment and bogs, and restoration of the adjacent floodplains and wetlands for a variety of ecosystem types. This holistic watershed restoration project sought to restore the Childs River for sea run Brook Trout, improve aquatic organism passage, restore aquatic and wildlife habitat throughout the system, improve water quality, and increase the climate resilience of the system.

This report offers initial findings after one-year post-construction including analysis of water quality, fish, and vegetation data throughout restoration (pre-, during, and post-construction). Data was collected through frequent water sampling (biweekly May through September and monthly October through April), continuous data logging, biannual fish surveys, and annual vegetation surveys. Data were analyzed to compare seasonal and annual averages with a particular focus on summer dynamics as this is when conditions can be most stressful for aquatic organisms and most productive for plant and microbial communities.

Findings from the one-year post-construction report indicate that there was a rapid and positive response by Brook Trout in the river as a result of the restoration. This recovery is likely related to the decrease in in-stream water temperature and increase in dissolved oxygen, which was caused by increasing water flow and reestablishing a more direct connection with the groundwater table. Additionally, although there was an initial release of nutrients (mainly nitrate, ammonium, and silica) during construction, the riverine system has shown evidence of recovering functions (i.e., attenuation and cycling) the following spring when plants and bacteria started to revive. The plant community has also shown a promising response through increased diversity and abundance of native wetland species. Taken together, the restoration has been largely successful in improving coldwater and wetland habitat, but more data collection and research are needed to ascertain the long-term water quality impacts.

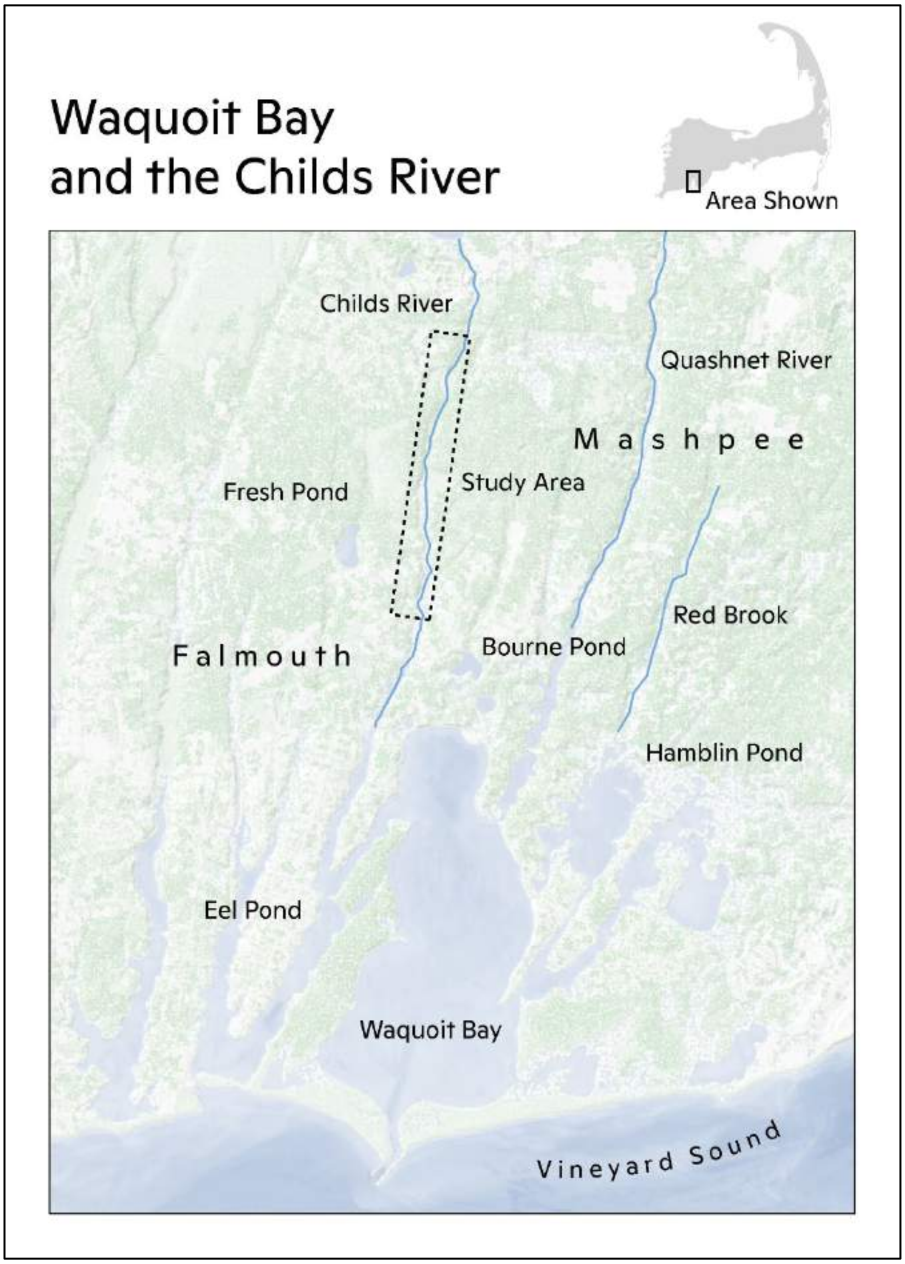

Figure 1: Overview map of the Childs River Restoration Site including highlight of study area.

B. INTRODUCTION

1) Background and History

The Childs River is part of the Waquoit Bay estuary watershed and is located within the U.S. Fish and Wildlife Service (USFWS) Mashpee National Wildlife Refuge in the Towns of Falmouth and Mashpee. The refuge is managed in partnership with federal, state, municipal, private conservation groups, the Mashpee Wampanoag Tribe, and other local landowners, including the Falmouth Rod and Gun Club (FRGC). The Childs River flows south through the Mashpee National Wildlife Refuge across the property of the FRGC and discharges into Eel Pond which is hydrologically connected to Waquoit Bay and Vineyard Sound

(Figure 1). The Childs River is about 2 miles long from Johns Pond to Eel Pond. The natural origin of the river is in springs in the vicinity of what is now the former Garner Bog south of Old Barnstable Road, but it was connected with an artificial ditch to Johns Pond in the mid-1800s to create a herring fishery. This connection was later used to supply additional water for the cranberry bogs. Water no longer flows continuously from Johns Pond to the Childs River and the primary herring run to Johns Pond along the neighboring Quashnet River is being actively maintained and restored. However, due to the natural springs located at the Garner Bog, flow south of the bogs is fairly steady and supported plans to restore this area as habitat for Brook Trout and other fish and wildlife.

In the early 1800s, Waquoit Bay and its tributary rivers including, the Childs River, were noted fishing destinations for anglers seeking sea run Brook Trout, locally known as "salters." Johns Pond and the surrounding coldwater fisheries were popular with famous anglers such as Daniel Webster, and President Grover Cleveland.[1] Earliest records of Brook Trout present on the Childs River come from the first book on fishing by an American.[2] First altered by a mill dam installed in the early 19th century, the river and its fisheries resources were further impacted with the shift to cranberry farming in the early 20th century. With cranberry bog development, stream channels were converted into the main bog ditches, associated ditches and dikes were added across the bog area, and the valleys were widened to provide layers of sand to deposit every few years on the bogs. The barriers to fish passage, impoundment of water behind dams, removal of the riparian canopy, and stream channel alterations limited access to aquatic habitat, led to the warming of the stream temperatures and has resulted in declines in trout abundance while also reducing or impairing habitat for other species.

2) The Problem

Massachusetts has lost more than 28% of its wetlands between the 1780s and 1980s,[3] and continues to lose wetlands every year.[4] Cranberry bogs are low-lying areas where natural rivers or wetlands previously existed but were manipulated by humans to cultivate cranberries on a large scale. Because they are actively fertilized and the water levels are carefully controlled by farmers, cranberry bogs are typically sources of nitrogen (releasing nitrogen into the surface waters downstream) contrasting with natural wetlands which act as nitrogen sinks (areas where nitrogen is released to the atmosphere through denitrification or stored in plants and soils).[5,6] There are currently over 48,000 acres of wetlands in the state and nearly 14,000 acres of cranberry bog, most of which are in southeastern MA in watersheds draining to Cape Cod Bay, Nantucket Sound, Narragansett Bay, or Buzzards Bay. [7]

The Childs River was one such impaired system and populations of Brook Trout in the river had been greatly reduced or extirpated due to habitat modifications from the former mill dam and cranberry bog farming. Upstream of the dam were two abandoned bog complexes (Farley and Garner Bogs) with altered channels and small culverts that offered little habitat for Brook Trout, other aquatic species, waterfowl or wildlife. The root causes of degradation to the Childs River were barriers to fish passage, loss of coldwater habitat, loss of channel bottom habitat for feeding and breeding, loss of wetland habitat in the bogs, and

[1] Town of Mashpee. Fisheries and Wildlife History. Chapter 4. https://www.mashpeema.gov/sites/mashpeema/files/uploads/ch4e_-_fisheries_wildlife_part_1.pdf
[2] Smith, Jerome V.C. 1833 (1970 reprint). Natural history of the fishes of Massachusetts, embracing a practical essay on angling. Freshet Press, Rockville Center, NY.
[3] Dahl, T.E. 1990. Wetlands Losses in the United States 1780s to 1980s. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 13pp.
[4] Harris, S.L. National Water Summary: Massachusetts Wetland Resources. U.S. Geological Survey.
[5] Teal, J.M. and B.L.Howes. 1995. Nitrogen balance in a Massachusetts cranberry bog and relationships to coastal eutrophication. Environmental Science and Technology 29:960-974.
[6] Leonardson, L, L Bengtsson, T Davidsson, T Persson and U. Emanuelsson. 1994.Nitrogen retention in artificially flooded meadows. Ambio 23: 332-341.
[7] Cape Cod Cranberry Growers Association. 2003-2023. How Cranberries Grow. https://www.cranberries.org/how-cranberries-grow [2/16/2023]

poor water quality. Access to the upper Childs River had been largely cut off by the old earthen dam and a failed fish ladder adjacent to the dam. An undersized and deteriorated culvert under Carriage Shop Road, and culverts and ditching throughout the bogs were exacerbating this problem (Figure 2).

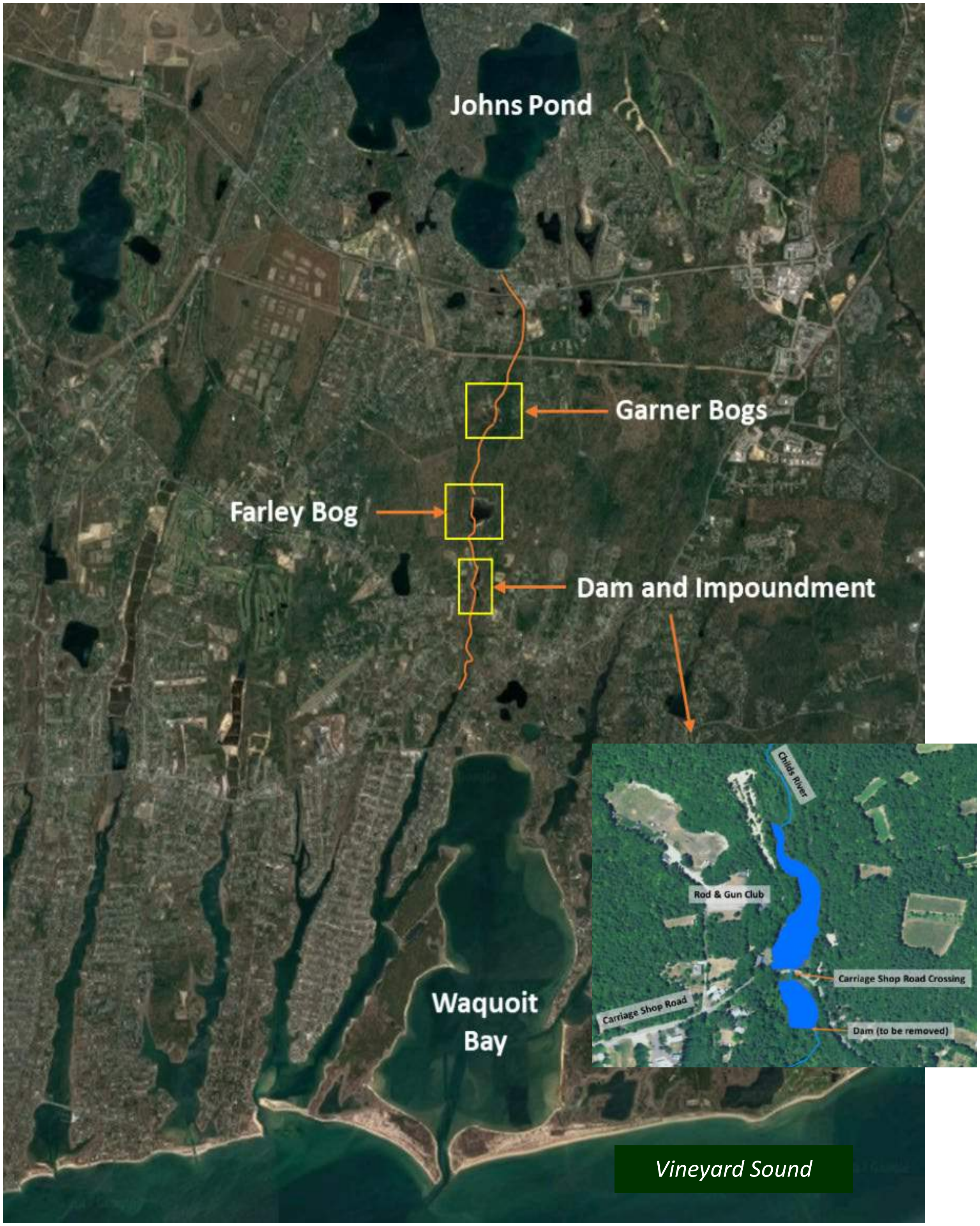

Figure 2: Map of restoration focus areas including the former bogs, dam, and impoundment (ponds surrounding Carriage Shop Road).

Likewise, modification of the river to install the dam and develop cranberry bogs along the main river channel had impaired existing fish and wildlife habitat, reduced channel complexity, and added sources of warmer water that were negatively impacting coldwater habitat for fish like the Brook Trout. However, the most significant barrier to fish passage and contribution of warm water came from the dam and former impoundment.

At the southern end of the project area south of Carriage Shop Road was the earthen berm or mill dam (Figure 3). The dam was constructed in the shape of the letter "L" with a 125-foot long and 10-foot high earthen embankment running east-west across the river and 180 feet long earth embankment (only a few feet high) running north to south. The earthen dam was heavily overgrown with trees, shrubs, vines and ground cover that severely limited visibility and provided limited habitat value to wildlife. The primary outlet to the dam was in poor condition having partially failed (Figure 3) resulting in more limited flow through the fish ladder. Likewise, the supplemental overflow spillway on the southwest corner of the dam was overgrown and covered with woody debris limiting its function.

Figure 3: *Left:* Photo of the earthen berm or dam (credit: Falmouth Rod and Gun Club). *Right:* Photo of the spillway with concrete pieces broken away from the structure (credit: Falmouth Rod and Gun Club).

The fishway included a series of low concrete weirs that were in poor condition and the upstream weir where water entered the fish ladder from the pond was not built into the banks (Figure 4). This allowed water to bypass the weir in high water conditions, and when water was low, nothing flowed through the fishway. As a result, the fishway had been largely non-functional since 2012. The 3 ft x 5 ft wide box culvert under Carriage Shop Road was also in poor condition (Figure 4).

Figure 4: *Left*: Photo of fishway (credit: Gerald Beetham). *Right:* Photo of culvert under Carriage Shop Road captured during construction (credit: Falmouth Rod and Gun Club).

The upstream impoundments (or former ponds) resulting from the culvert and dam were a long linear shape bisected by Carriage Shop Road. These former ponds were very shallow, only 1-3 feet deep, and had extensive emergent vegetation. The pond was fundamentally dying due to sediment accumulation and eutrophication, and the former mill dam with failed spillway and fish ladder were effectively blocking fish passage to habitat upstream. At the same time the ponds formed behind the earthen dam and alterations to the river upstream by the bog complexes were resulting in further warming and impairment of Brook Trout habitat downstream.

The Massachusetts Division of Fisheries and Wildlife (MassWildlife) has been sampling the Childs River for Brook Trout since the 1950s and now surveys it in May and September each year. In 1958, three marked Brook Trout stocked in the nearby Mashpee River were recovered in the Childs River and it was noted that trout probably move between the Quashnet and Childs Rivers through their common Waquoit Bay connection.[8] However, with a relatively comprehensive survey of the river in September 2006 completed by MassWildlife and the FRGC, only a single adult male Brook Trout was found in the Childs River and no evidence of any Brook Trout reproduction. Based on temperature data collected since 2001, it was clear the river had some suitable coldwater habitat. The problem was it lacked wild Brook Trout brood stock.

Increased Brook Trout populations in the neighboring Quashnet River and a PIT (Passive Integrated Transponder) tagging study offered an opportunity to restore Brook Trout populations through the transplant of wild Brook Trout brood stock. Armed with the knowledge of likely historical movement between the rivers, from 2008-2010 a total of 85 adult Brook Trout were electrofished from the Quashnet River, PIT tagged and transplanted to the Childs River. Follow up sampling confirmed successful reproduction with capture of young-of-the-year (YOY) following transplanting each year. Fish were also tracked moving between the Childs and Quashnet Rivers with one of the original 2008 transplants detected back in the Quashnet River headed upstream in November 2008 and then again in the Childs River during a July 2009 survey. While this effort was successful in re-establishing Brook Trout in the Childs River, access to and condition of the habitat was degraded due to barriers to passage and warm water conditions. Seven adult Brook Trout were detected north of the dam in 2012, but no Brook Trout had been found north of the dam since that time with the exception of spring of 2019 when there was unusually high precipitation and water levels. Brook trout had been effectively extirpated from the upper Childs River.

[8] Mullan, James 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, Boston. 25 pp.

The optimal temperature range for Brook Trout feeding is 55-65˚F, and Brook Trout do not tolerate extended periods above 68˚F. As temperatures approach this threshold, feeding, growth and reproduction decreases, and Brook Trout begin to experience significant mortality as temperatures reach 70˚F. The dam and former ponds behind were functioning as a bottleneck to the system slowing water flow and allowing it to warm up. The upstream bog complexes were having a similar effect and lacked shading and proper flow. Combined these warm water inputs were impacting coldwater habitat on the lower Childs River and reducing available habitat upstream. Temperature data demonstrated coldwater habitat conducive to Brook Trout existed upstream of the impoundment just south of the Farley Bog, but the fish were not able to access this habitat due to the dam and failed fish ladder.

Impaired water quality is also a concern. Fish kills were reported on July 24 and 25, 2000 in the Childs River cranberry bogs and pond near Carriage Shop Road. The cause of the kill was determined to be pesticides in the former ponds from application by the former bog farmer while actively farming the bogs upstream and low dissolved oxygen in the Garner bog ditch. Dead species in the pond included tadpoles, brown bullhead, golden shiner, banded killifish, sunfish, American eel, adult frogs, and yellow perch while dead species in the bog ditch were banded killifish, tadpoles, golden shiner and brown bullhead. The bogs were subsequently abandoned, so acute impacts from chemical application (pesticides and fertilizer) are no longer an issue but concerns about low dissolved oxygen and high nutrients persist. Dams and flow control structures can reduce water quality by increasing water temperature and decreasing dissolved oxygen. Nutrient loads from historic agricultural inputs as well as groundwater fed inputs from septic system, combined with shallow impoundment water depths and warmer water, can result in excessive aquatic vegetation growth, reducing dissolved oxygen and water quality. This nutrient impact is of particular concern as the Waquoit Bay Estuary, located downstream of the project area, is impaired due to excess nitrogen.[9,10]

3) The Solution

Upstream of the dam, the river and abandoned bogs provided the opportunity for creation of additional fish and wildlife habitat, but aquatic ecosystem restoration and enhancement of this river habitat was required to restore its function and improve recreational opportunities. To address the negative impacts of historic human alterations to the system described above, the Childs River restoration included the following actions: removing barriers to fish passage, removing the impounded sediment and ponds behind the earthen dam, replacement of the undersized culvert under Carriage Shop Road, reconstruction of the river channel through the former impoundment and bogs, and restoration of the adjacent floodplains and wetlands for a variety of ecosystem types. This holistic watershed restoration project sought to restore the Childs River for sea run Brook Trout, improve aquatic organism passage, restore aquatic and wildlife habitat throughout the system, and improve water quality.

This project restored fish and aquatic organism passage to approximately 1.5 miles of the Childs River previously cut off by the dam and flow control structures in the bogs. In addition, over 17 acres of wetland were created through the conversion of the former impoundment and cranberry bogs to wetlands. This project removed the small earthen dam in the lower portion of the river and four flow control structures associated with the former cranberry bogs in the middle and upper portions of the watershed. Removing these structures restored the natural flow of the river allowing for fish passage and eliminated key sources of warm water inputs to the system. More than 2,500 feet of river channel were actively reconstructed with

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[9] U.S. EPA (Environmental Protection Agency). 2002. Waquoit Bay watershed ecological risk assessment. National Center for Environmental Assessment, Washington, DC; EPA/600/R-02/079. Available from: National Technical Information Service, Springfield, VA; PB2003-102013 and <http://www.epa.gov/ncea>.

[10] Howes et al. 2012. MA Estuaries Project: Linked watershed-embayment approach to determine critical N loading thresholds for Waquoit Bay and Eel Pond Embayment Systems; Towns of Falmouth and Mashpee, MA.

enhanced habitat features throughout. Large wood was placed on the outside meander bends where deeper pools were constructed. These deep pools and cover provided by the root wads of the large wood provide necessary habitat and protection from predators for fish, turtles, and other organisms using the Childs River. The trees and shrubs planted adjacent to the river will create a forested floodplain, providing flood storage and important riparian habitat for mammals, birds, reptiles, and amphibians. As these trees and shrubs mature, the shade they provide to the river will help further reduce water temperatures. Constructed open water ponds on the former bog platform provide feeding opportunities for a variety of dabbling and diving ducks, geese, and swans as well as habitat for turtles, frogs, salamanders, and others. Constructed microtopography in the former bogs and impoundment provide a range of soil moisture conditions which in turn increases the diversity of wetland vegetation species, providing a wider range of nesting, feeding, and cover habitat for wildlife.

4) Project Timeline

Planning and Design

To complete the restoration of the upper Childs River, the FRGC managed the project on behalf of the community working with the towns of Falmouth and Mashpee, the USFWS National Wildlife Refuge, the Association to Preserve Cape Cod (APCC) and multiple other partners. The FRGC initiated discussion of restoration in 2014 and formal planning began in 2017. The FRGC completed purchase of the 12.5-acre plot of land owned by the town of Falmouth north of Carriage Shop Road including the majority of the Farley Bog and finalized a 30-year long term lease for the 24.7 acres owned by the town of Mashpee including the Garner Bog.

An initial feasibility study and assessment was completed by Inter-Fluve in July of 2017 with hydrologic and hydraulic modeling and permit ready designs of the river and bogs completed in 2018. The final design plans were completed in May of 2020 and permits received in August of 2020.

Construction

The project was put out to bid and construction commenced on August 26, 2020, and was completed in September of 2021. Initial work focused on creation of diversion channels for the river throughout the project area and tree and brush removal along Carriage Shop Road, especially in the area of the failed fish ladder and along the earthen berm (Figure 5). Due to time of year restrictions for in-water work put in place by the Massachusetts Division of Marine Fisheries for protection of river herring and American eel, completion of initial in-stream work had to be completed by mid-September of 2020.

Figure 5: *Left:* Photo of dam spillway removal (credit: Falmouth Rod and Gun Club). *Right:* Aerial of diversion channels created north and south of Carriage Shop Road (credit: Falmouth Rod and Gun Club.).

In October of 2020 work shifted to the bogs. This work included creation of the new stream channel, excavation of excess sand and fill, creation of new shallow and deep-water ponds, filling of old ditches, removal of water control structures, addition of microtopography on the bog surface and addition of woody material for habitat in stream and on the bog surface (Figure 6). In the Garner Bog, work was completed in January of 2021 including creation of two new ponds in the eastern and western bogs and expansion of the existing pond into the northern part of the western bog. The downstream culvert was removed from the Garner Bog in April of 2021. Regrading in the Farley Bog was completed in February of 2021 with removal of the downstream culvert completed in April of 2021.

The earthen berm that created the two ponds north and south of Carriage Shop Road was removed in January of 2021, and construction of the new river channel through the former impoundments was completed in March and April of 2021 (Figure 6). The new culvert was installed under Carriage Shop Road on July 1, 2021, and all construction completed in September of 2021. Plantings throughout the project site (including Garner Bog, Farley Bog, and the lower river) took place April through June of 2021 with additional plantings of trees and seed in September of 2021 as well as in the spring and fall of 2022.

Figure 6: *Top left:* Creation of new stream channel and shallow ponds in the former Garner Pond, fall/winter 2020-2021 (credit: Inter-Fluve, Inc.). *Top right:* Diversion channel created in Farley Bog prior to regrading and new channel, October 2020 (credit: Falmouth Rod & Gun Club). *Lower left:* Completed construction and early revegetation of Farley Bog in spring 2021 (credit: Inter-Fluve, Inc.). *Bottom right:* Removal of impoundment north of Carriage Shop Road and creation of the new river channel (credit: Inter-Fluve, Inc.).

5) Goals of project

The goal was to restore the upper Childs River for Brook Trout and other fish and wildlife. The expected outcomes were increased connectivity and access to new and existing aquatic habitat in the upper Childs River for Brook Trout and other aquatic species, increases in Brook Trout population upstream of the former dam and impoundment, restoration of wetland vegetation including Atlantic White Cedars in the former bogs, and improvements to in-stream water quality including decreased water temperatures, increased dissolved oxygen and a decline in nutrients.

The main objectives of the restoration were as follows:

1) Reduce temperature and increase dissolved oxygen by increasing water flow to improve and provide new coldwater habitat for Brook Trout as well as improved habitat for other aquatic species.
2) Provide Brook Trout and other fish species access to new and improved habitat as measured by increased presence and successful spawning of Brook Trout in the upper Childs River.
3) Improve water quality (i.e., reduce nutrients and specific conductivity, increase pH and minimum dissolved oxygen) to enhance Waquoit Bay estuarine aquatic habitat and water quality downriver.
4) Restore wetlands and enhance habitat diversity in the upper Childs River for wildlife and waterfowl by encouraging the growth of wetland plants, creating ponds, and establishing conditions for self-sustaining wetlands (i.e., raising the groundwater table).

C. METHODS

1) Continuous Data Loggers

In July of 2018, HOBO temperature dataloggers (Onset Computer Corporation) were installed in the Childs River (Figure 7). Sensors were installed by members of the FRGC in coordination with the MA Department of Conservation and Recreation (MA DCR) and MassWildlife. These sensors logged the temperature of the water at 15-minute intervals. Additional temperature data was provided by MassWildlife for the lower portion of Childs River from long-term monitoring stations established between 2001 and 2007 in association with ongoing sea run Brook Trout monitoring.

Dissolved oxygen (DO) datalogger sensors (Onset Computer Corporation) were deployed in the Childs River below the Farley Bog and in the culvert under Carriage Shop Road (Figure 7). During and following construction, the unit at the Carriage Shop Road culvert was moved downstream to the area previously impacted by an old dam. The locations of deployment varied pre-construction to post-construction due to filling of old ditches and creation of new stream channels resulting in changes in open stream channels, however, consistency in location was maintained as much as possible. We do not have a complete record from the DO datalogger sensors due to periodic data quality issues. However, data from similar points in the year (i.e., corresponding months or weeks) were compared where data was available across years to determine the impact of the river restoration.

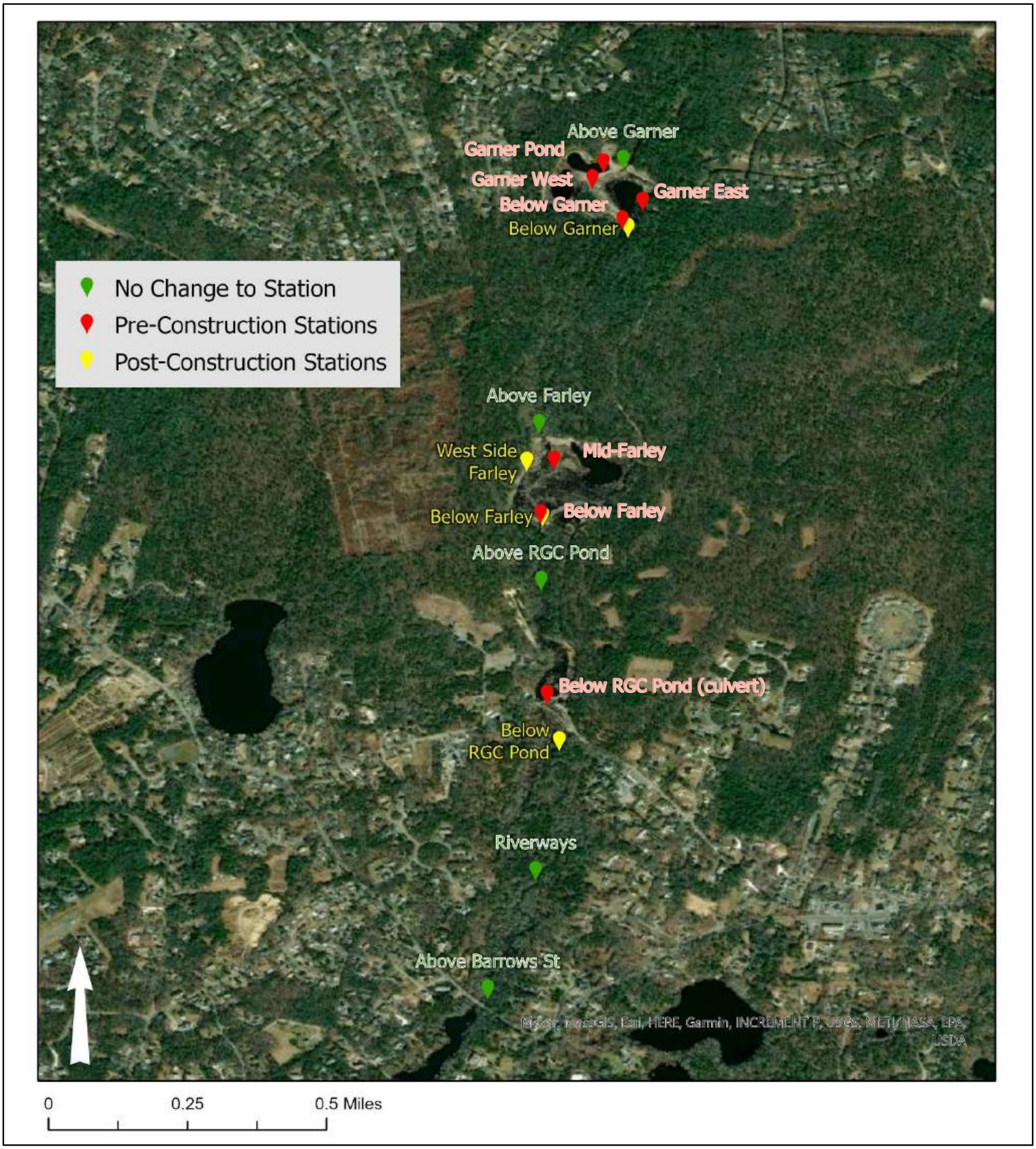

Figure 7: Map showing the locations of the continuous data loggers. Temperature was collected at all sites, but dissolved oxygen was only collected at the Below Rod and Gun Club (RGC) Pond and Below Farley.

2) Water Quality Sampling

Water quality sampling along the Childs River by Woodwell Climate Research Center (Woodwell) under contract to the FRGC started in April of 2019 and continued through 2022. Sample sites were focused on locations above and below the former bogs and impoundment (Figure 8). At the beginning of the monitoring effort, samples were collected every week from April 2019 through September 2019. However, the sampling frequency was reduced starting in October 2019 in accordance with the following schedule for 2020 through 2022: samples were collected every other week (April-September) or monthly (October – March). There was a sampling break in spring 2020 due to the statewide shutdown relating to the SARS-CoV2 pandemic. Sampling resumed starting in May 2020. A total of 9 stations were sampled pre-construction and 8 stations sampled post-construction with consistency in location maintained as feasible. Sampling locations were relocated where filling of old ditches and creation of new stream channels resulted in loss or movement of pre-construction stations.

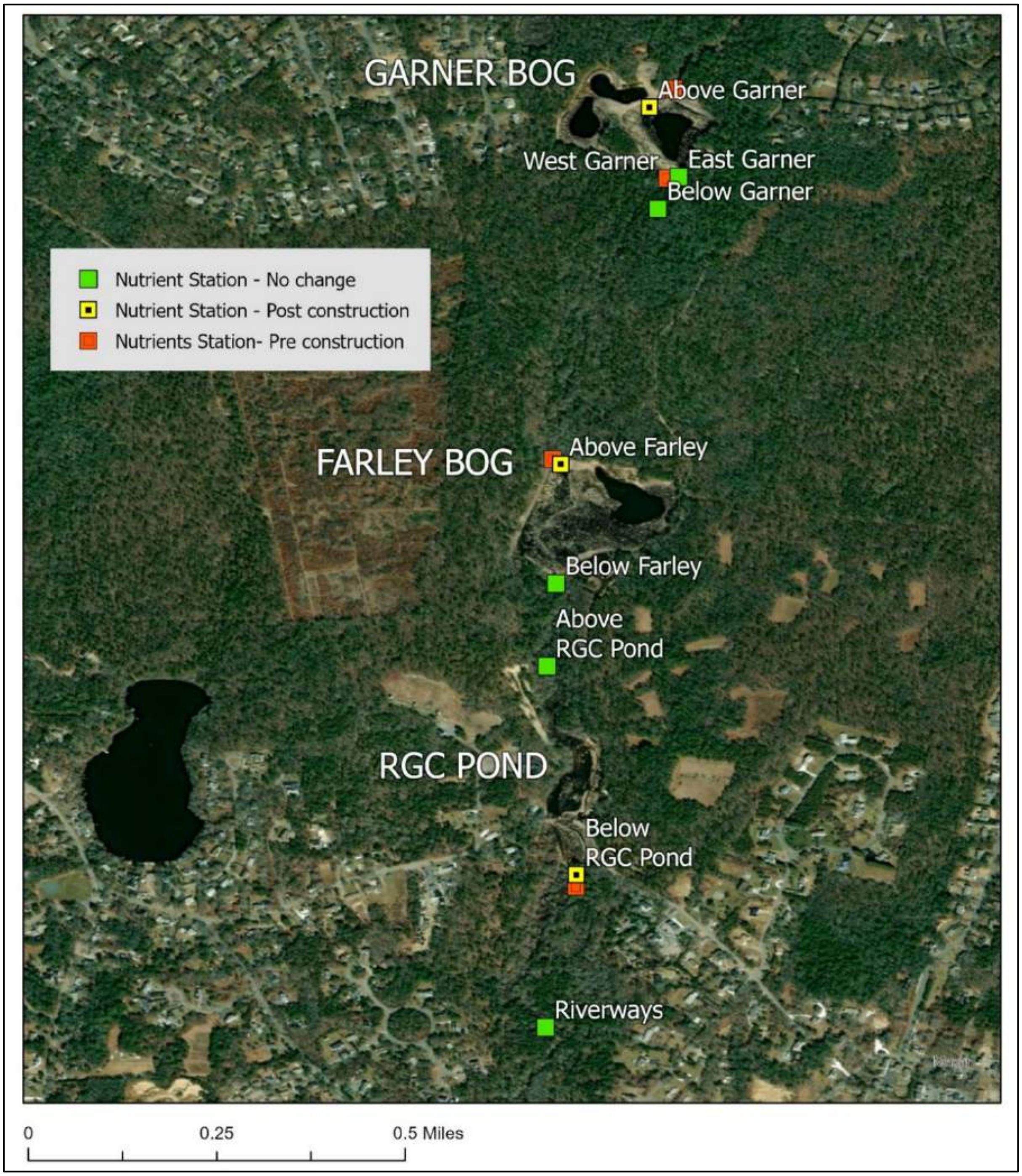

Figure 8: Map showing locations of discrete water sampling stations.

On each sampling day, two 1-liter bottles were collected at each site and later brought back to the Woodwell lab for processing. In the lab, samples were filtered using a 0.45-micron filter and then frozen until analysis. Temperature, dissolved oxygen, pH and specific conductivity were measured at the nine sampling sites along the Childs River each time water samples were collected using a handheld YSI ProDSS multi-parameter meter. The sensors on the YSI meter were calibrated prior to each sample collection date. For more information, see the Childs River Restoration Quality Assurance Project Plan (available upon request). APCC provided the post-construction water quality data analysis.

3) Fish Surveys

MassWildlife conducted fish surveys along the Childs River at four main locations (above Barrows Street, above and below the Riverways gage, in the former pond area, and in the lower Farley Bog and channel below, with more limited sampling in the Garner Bogs Figure 11) in spring (May-June) and fall (September) with a Smith Root backpack electrofisher operating at about 400 volts. The river was sampled in an upstream direction (Figure 9) and all Brook Trout were scanned for PIT (Passive Integrated Transponder) tags, measured for length in millimeters (mm) and weight in grams (g). Brook trout 80 mm or longer were tagged with a 12 mm FDX PIT tag (Figure 10).

Figure 9: Electrofishing in the former pond area, September 23, 2021 (credit: Patty Waltner).

Figure 10: PIT tagging of Childs River brook trout. Tags are injected into the abdominal cavity. (credit: A.D. Colburn).

In spring of 2022, three new solar-powered PIT antenna arrays from Biomark were purchased by the FRGC to assess Brook Trout use of the newly restored areas. The antenna arrays (antenna, PIT reader, solar panels and batteries) were assembled, installed and have been maintained by MassWildlife (Figure 12). On May 31, 2022, new PIT antennas were installed in the Old Pond area (#2) and in lower Farley Bog (#3) and on June 3, 2022 a new PIT antenna (#0.9), was installed just below the existing antenna (#1) just above Barrows Street (Figure 11). Bluetooth on the laptop is used to connect to the reader and download the PIT tag IDs as well as date and time of detection. Fish survey results and interpretation were provided by MassWildlife.

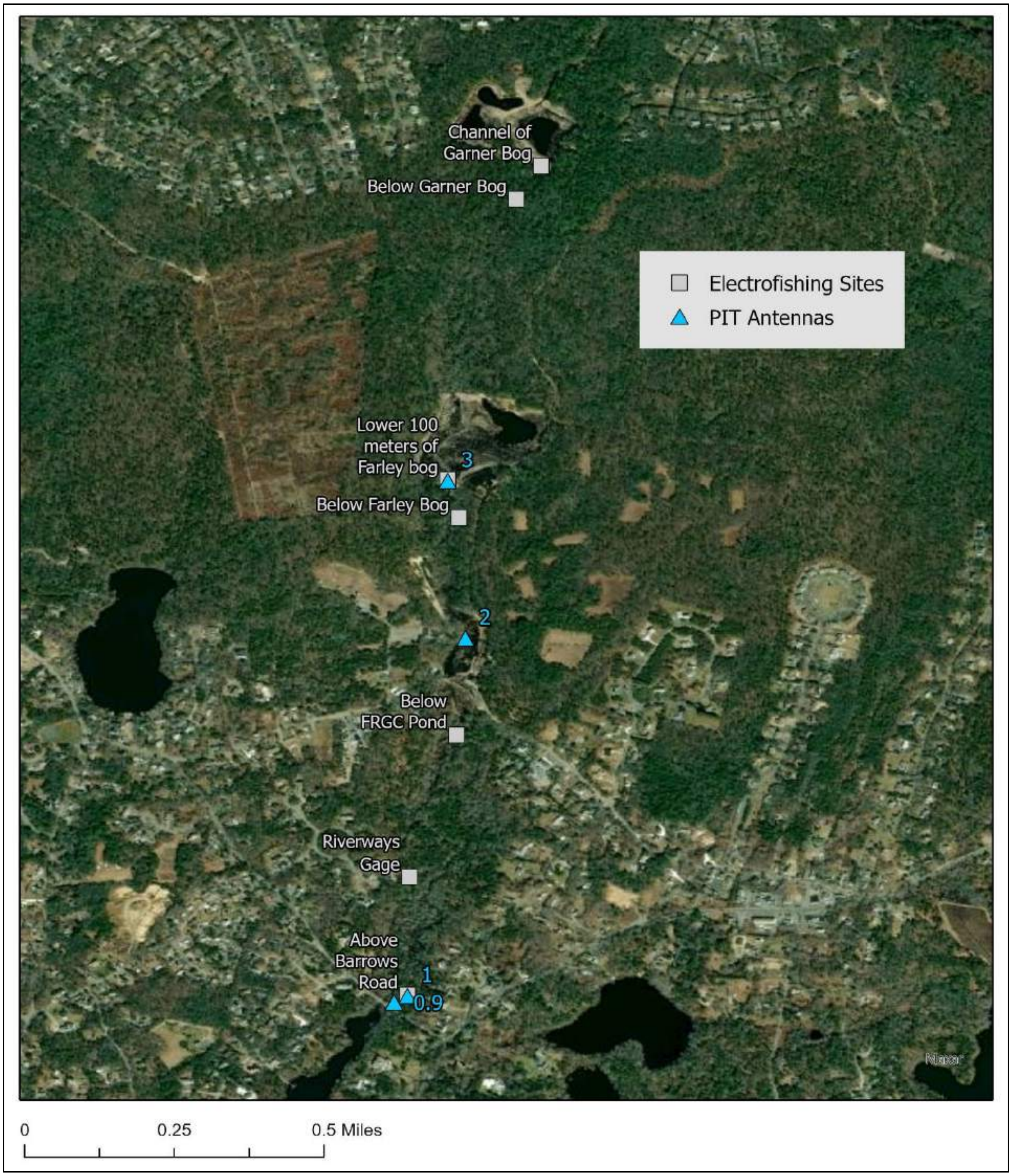

Figure 11: Map showing the locations where fish surveys were conducted by MassWildlife within the Childs River Restoration site.

Figure 12: New antenna reader and solar panels (*left*) along with PIT antenna (*right*) installed on May 31, 2022, in the former pond area near the Falmouth Rod and Gun Club along with laptop for download. PIT-tagged Brook Trout are detected when they swim through the antenna (credit: Steve Hurley).

4) Vegetation Surveys

Woodwell, under contract to the Massachusetts Division of Ecological Restoration (DER), surveyed 20 randomly selected 3 x 3 m quadrats in Farley Bog and Garner Bog (Figure 13 and Figure 14). Surveys were carried out annually during peak growing season (August – September) in 2019 through 2022. Within each of these quadrat plots, all species were identified, and the percent cover estimated for each species. Each species was categorized as native/non-native, physical form (e.g., herbaceous, shrub, etc.), and by wetland indicator status. Additionally, the number of species present and the average plot percent cover of these categories was used to characterize the pre-restoration and post-restoration plant community composition at the former Childs River bogs. Analysis of the data was provided by Woodwell.

Figure 13: Garner Bog; circles represent permanent vegetation monitoring plots. Note this photo was taken prior to restoration of bog.

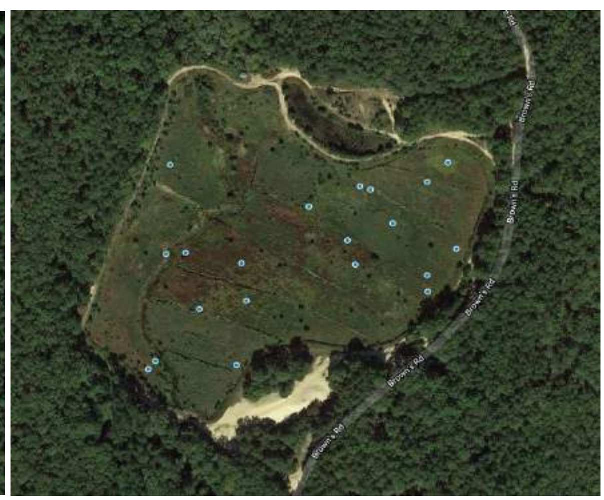

Figure 14: Farley Bog; circles represent permanent vegetation monitoring plots. Note this photo was taken prior to restoration of bog.

5) Acoustic Recordings

Additionally, acoustic data loggers (Wildlife Acoustics Song Meter Mini audio recorder) owned by the Waquoit Bay National Estuarine Research Reserve (WBNERR) were deployed within the Childs River site by WBNERR staff in June and July of 2020 and by the FRGC and APCC in 2022 to compare acoustic properties (including bird calls and human-produced noises such as airplanes and motorized vehicles) pre- and post-construction (Figure 15). In 2020, one logger was deployed in Garner Bog, and in 2022, two loggers were deployed in the former Garner Bog (restored site) and the wooded area downriver of Garner Bog (undisturbed site). The deployment design allowed for pre- vs. post- restoration comparison in the Garner Bog as well as a comparison of undisturbed, wooded habitat to open water, restored habitat. Loggers recorded sounds for 10-minute periods every half hour during dawn (4:10-7:20 EDT) and dusk (18:40 – 21:50 (EDT).

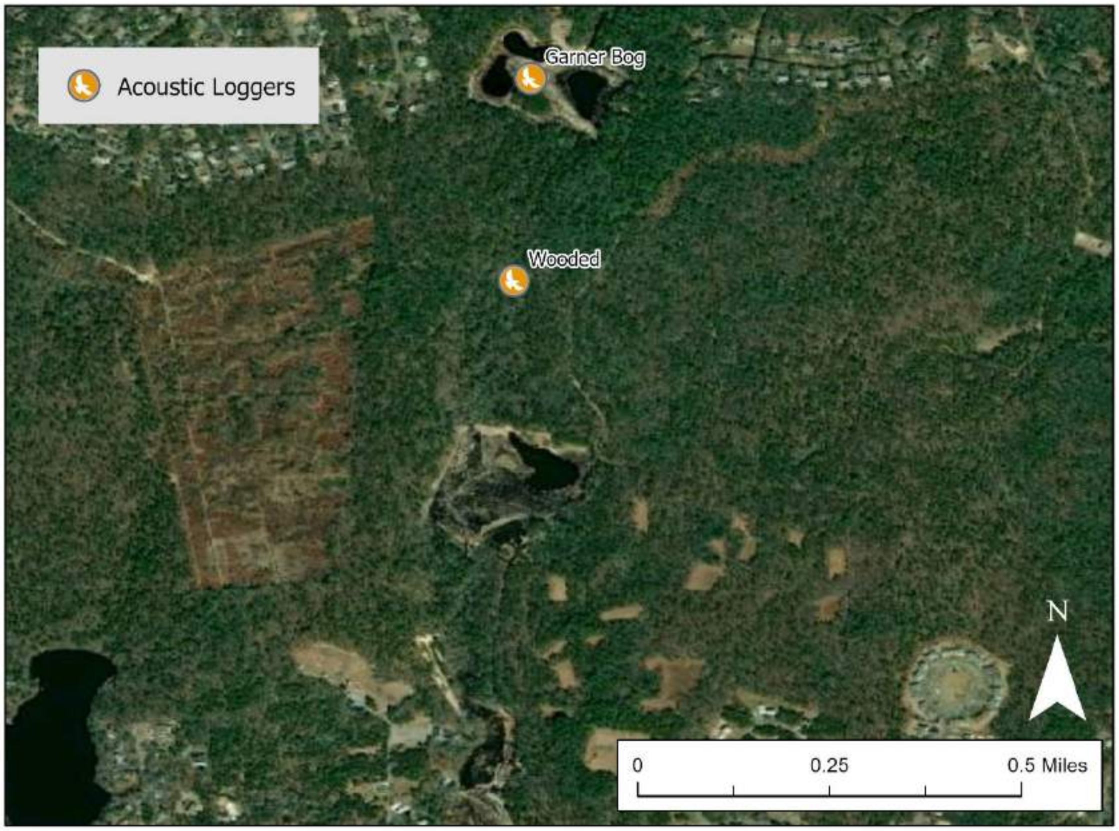

Figure 15: Map of acoustic logger placement along the Childs River. The logger at Garner Bog was deployed pre-restoration in the summer of 2020 and post-restoration in June and July of 2022. The logger at the "Wooded" site was only deployed in the summer of 2022.

Bird surveys were completed by APCC from the recordings using the Merlin Bird Identification smartphone application, created by Cornell Ornithology Lab, according to standardized practices.[11] Six recordings from 6:10 and 18:40 (same time stamp for all samples) were randomly selected within the overlapping seasonal period across 2020 and 2022 data collection, which was July 8 through July 27. Where possible, the same calendar day was used to compare recordings, however, due to acoustic interference from wind and rain, the next closest day without interference had to be used. The first five minutes of each recording were used to identify species presence and calculate species richness (see Appendix B for raw survey results).

To further analyze the data, Allison Noble utilized several indices to quantify acoustic parameters, including the Acoustic Complexity Index (ACI), Acoustic Diversity Index (ADI), Bioacoustic Index (Bio), and Normalized Difference Soundscape Index (NDSI). All acoustic index analyses were conducted using the programming software, R v4.0.4. The ACI, ADI, Bio, and NDSI were calculated for each 10-minute recording

[11] Bird Survey & Assessment Steering Group. (2022). Bird Survey Guidelines for assessing ecological impacts, v.1.0.0. https://birdsurveyguidelines.org [2/3/2023]

using the multiple sounds function in the sound ecology package v1.3.3. The indices should be interpreted as indicated below.

ACI: higher number = higher variability in acoustic activity within a given recording

ADI: higher number = acoustic energy is distributed over more frequency bands

Bio: estimates bird abundance; higher number = more bird vocalizations

NDSI: higher/more positive number = greater influence of biological sound

D. FINDINGS

1) Temperature & Dissolved Oxygen – Continuous Data

Temperature can impact the survival of organisms in the natural environment. Brook Trout, one of the target species for this restoration, prefer cooler temperatures and cannot live for long periods in waters that rise above 72°F and are stressed and will not reproduce in waters that are above 68°F. Optimal growth for Brook Trout occurs in waters that are from 55 – 61°F.[12] Decreasing water temperatures to improve habitat quality for Brook Trout was one of the main goals of the Childs River Restoration Project.

Reducing summer water temperatures in the river was successfully achieved. Temperatures decreased following the restoration of the former bogs, removal of the ponds north and south of Carriage Shop Road, and replacement of the Carriage Shop Road culvert. The areas with the most significant drop in summer temperatures following construction completion in 2021 were below Farley Bog, above the R&GC Pond, and below the R&GC Pond (Figure 16). The former shallow ponds and bogs contained slow moving water flow creating conditions that warm the water temperature in the summer when days are longest, and the solar rays are most direct. When these features were removed and replaced with a newly constructed river channel with increased flow and better exchange with the groundwater table, the water temperature declined. The station located Above Barrows St is at the head of tide and is influenced by warmer tidal water temperatures downstream.

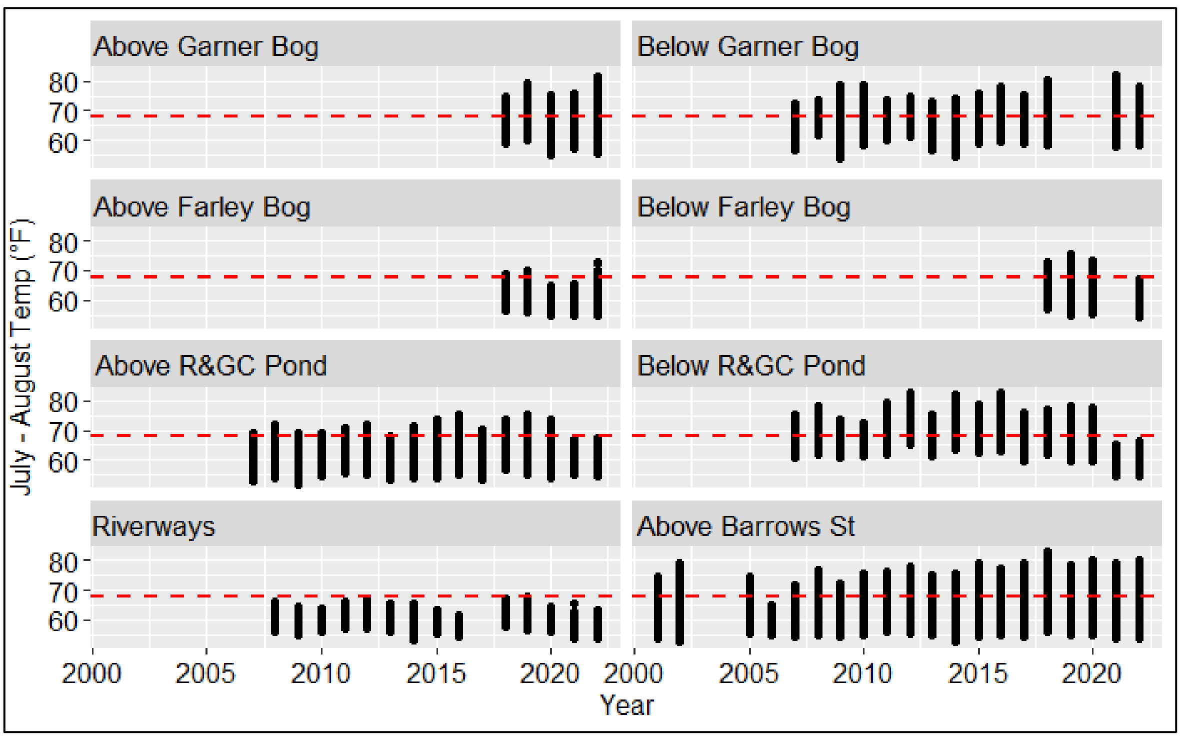

Figure 16: July and August temperature data from continuous datalogger monitoring stations on Childs River. Graphs depict range of temperatures over July and August for each year. The red dashed line represents the threshold for optimal fish habitat at 68°F. R&GC refers to the Rod and Gun Club.

[12] Chadwick, J.G. and McCormick, S.D. 2007. Upper thermal limits of growth in brook trout and their relationship to stress physiology. The Company of Biologists 220: 3976-3987.

In addition, following the construction phases (summer of 2021 for Below Farley and post-August 2021 for Below Carriage Shop), the summertime minimum dissolved oxygen (DO; Figure 17) levels increase. Cooler water holds more oxygen due to the laws of thermodynamics, so this increase in summer DO can be partially attributed to the colder water temperature. Additionally, faster moving water causes higher dissolved oxygen as the rippling water mixes with the air. Figure 17 shows the increase in the minimum daily DO at both monitoring stations. Moreover, data from Below Carriage Shop clearly shows when the river was diverted to the byway channel and away from the RGC pond as dissolved oxygen levels increased quickly following this event in August 2020. Below the 6 mg/L threshold represents a stressed environment for freshwater fish species.[13] Since the restoration, the DO has not dropped below 5 mg/L at either site, a marked improvement from previous levels which could fall as low as 1-2 mg/L (lethal level for fish). The drought in 2022 reduced groundwater levels which may have inhibited groundwater exchange and/or surface water flow causing the DO to be lower than in 2021.

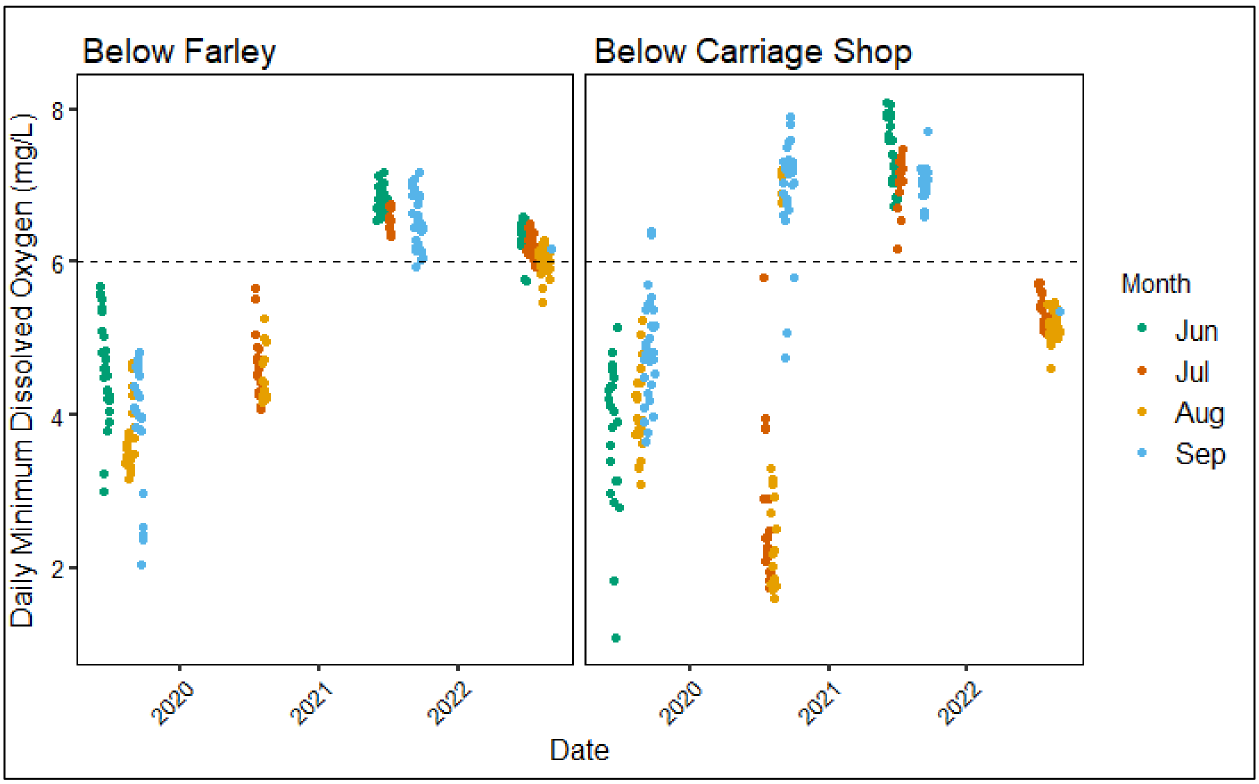

Figure 17: Graphs of daily minimum dissolved oxygen levels recorded from continuous dataloggers deployed on Childs River. Restoration of the Farley Bog was completed in spring 2021 and construction ended Below Carriage Shop Road in August 2021. The data from Below Carriage Shop clearly shows when the river was diverted to the byway channel in August 2020 (away from the RGC Pond) as dissolved oxygen levels increased quickly following this event.

The other noticeable improvement in DO is seen in the range observed in the summer months. Prior to restoration, dissolved oxygen levels fluctuated greatly on a diurnal pattern with very low, stressful levels occurring overnight and very high levels occurring during the day. Data collected after the restoration show less fluctuation and generally remain at or above the 6 mg/L threshold (Figure 18).

[13] Massachusetts Department of Environmental Protection (MA DEP). Massachusetts Consolidated Assessment and Listing Methodology (CALM) Guidance Manual. 2018. Available from <https://www.mass.gov/service-details/water-quality-assessments>

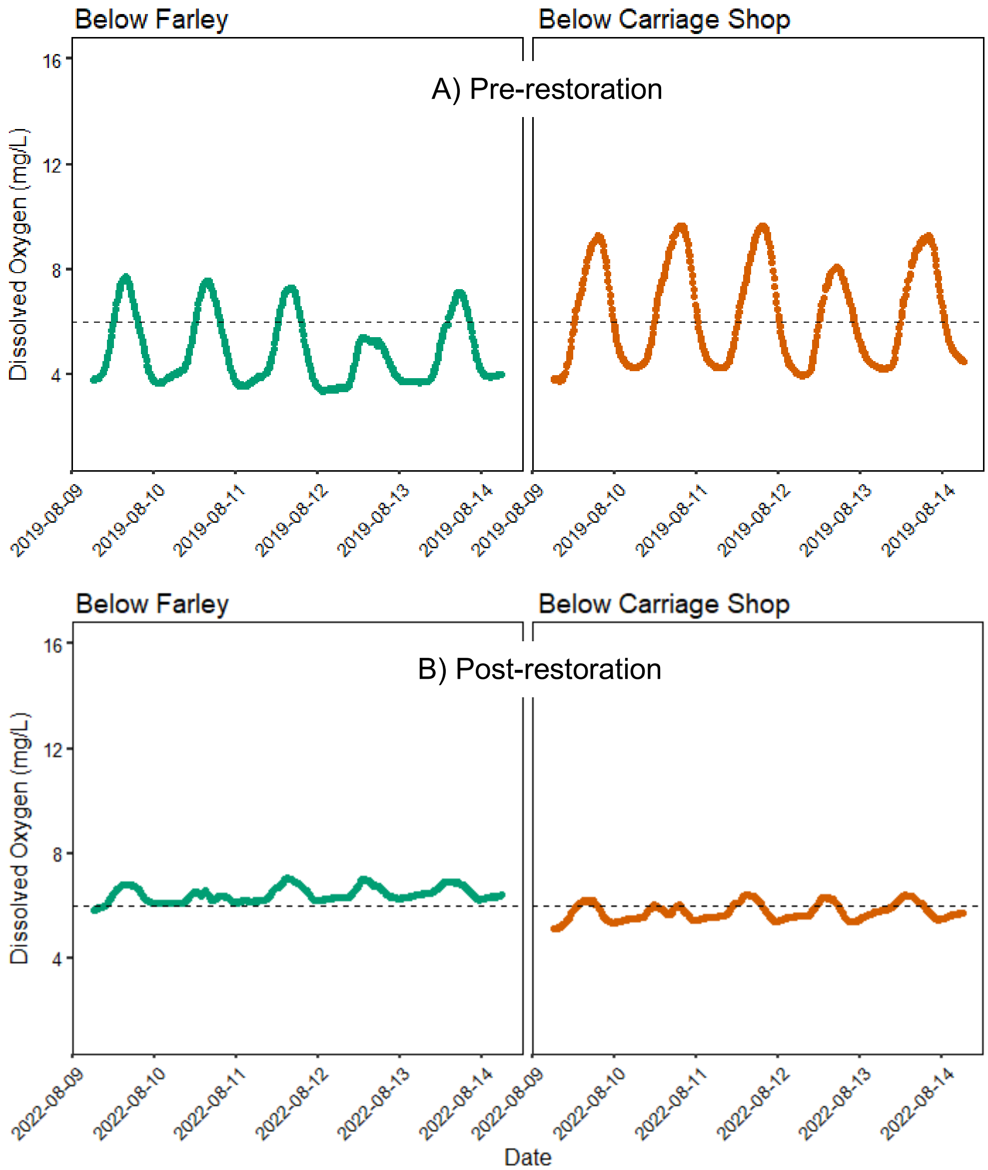

Figure 18: Dissolved oxygen fluctuations over a five-day period pre-restoration (A) and post-restoration (B). The dashed line represents the threshold for fish survival at 6 mg/L; below 6 mg/L is a stressful environment for freshwater fish.

2) Water Quality Sampling

For the discrete sampling results, data was analyzed by construction phase. Construction phase refers to the construction timeline where "pre" (April 2019 to August 2020) is prior to the start of restoration, "during" (September 2020 to August 2021) refers to the period of time when construction was underway, and "post" (September 2021 through August 2022) refers to samples collected after construction was finished.

a) Temperature

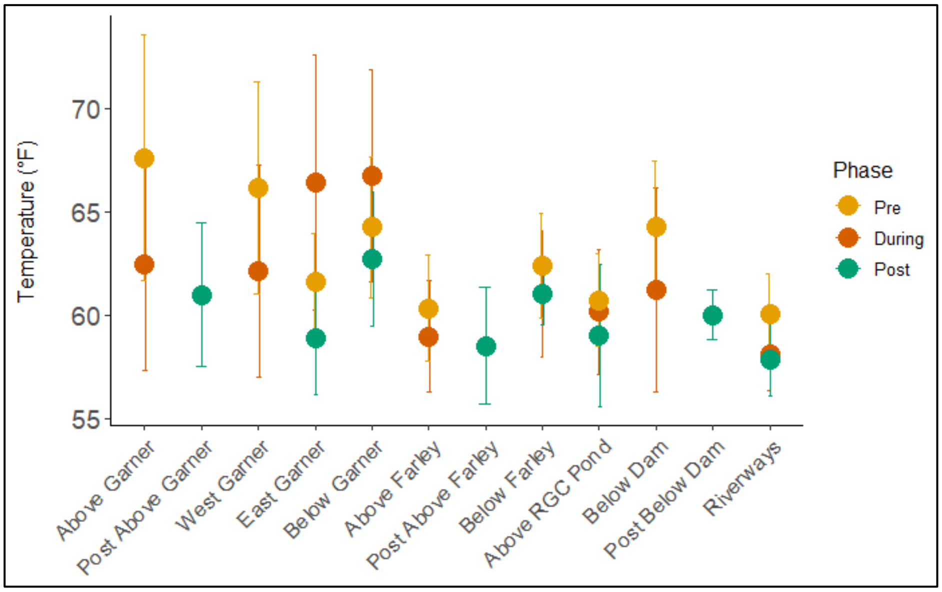

Figure 19: Comparison of average water temperatures across sample locations and construction phase. Results are based on measurements collected in June through August using a multi-parameter YSI ProDSS. Error bars represent standard deviation of the mean.

Similar to the continuous water temperature data above, the average summer temperature data collected at the time of sampling declines at all the monitoring stations following restoration (Figure 19). The most pronounced change occurred at the station located below the former earthen dam. The former Garner Bog, in general, had the highest water temperatures pre- and during construction. The conditions in the Garner Bog promote higher temperatures because there is direct sunlight (no shading), the river is only a few inches deep, and the water flow is slower. Following restoration warmer temperatures were still detected exiting the Garner and Farley Bogs on the southern end ("Below") compared to the northern end ("Above"). As trees and shrubs mature, shading will increase, and temperatures should diminish in these areas over time.

Site conditions also impact the temperature of water across the site. The river's flow increases as it moves downriver and becomes deeper, such that the station Above RGC Pond is at least two feet deep resulting in decreasing temperature as you move downstream from the Garner Bogs to the Riverways station. The stations located Below Farley Bog, Above RGC Pond, Below Dam, and Riverways are also densely vegetated with tall trees and shrubs along the river's edge resulting in reduced sunlight and relatively cooler ambient temperatures across all time periods. Finally, groundwater seeps are also likely contributing to reduced water temperatures in the newly created river where the former Farley Bog and RGC Pond previously existed.

b) Dissolved Oxygen

Temperature and DO have an inverse relationship due to the laws of thermodynamics (warmer waters hold less oxygen). However, other factors beyond temperature can influence the DO levels in the water, such as the production of oxygen through photosynthesis and uptake of oxygen from respirating organisms.

In the former Farley Bog and lower portion of the Childs River (above the former RGC pond to the Riverways station), the change in temperature appears to be the main driver in the increase in dissolved oxygen (Figure 20). Although the temperatures did decrease in the former Garner Bog following restoration of the river, the DO levels remained low. Since Garner Bog experiences slower moving (i.e., higher residence time), shallower waters and full sun, these conditions likely promote the decomposition of accumulating organic matter. Decomposing organic matter requires bacteria respiration which can draw down oxygen concentrations in the water column.

c) Specific Conductivity

Specific conductivity is the measure of how effectively an electrical current passes through water (in units of micro-Siemens per centimeter, µS/cm). This measurement is affected by the concentration of ions dissolved in the water column. Generally, specific conductivity is used to measure the salinity level in a body of water since saltwater systems have higher concentrations of dissolved sodium ions than freshwater systems. Additionally, in freshwater systems nitrogen ions, such as nitrate, are generally higher where septic systems leach nutrients into the groundwater.

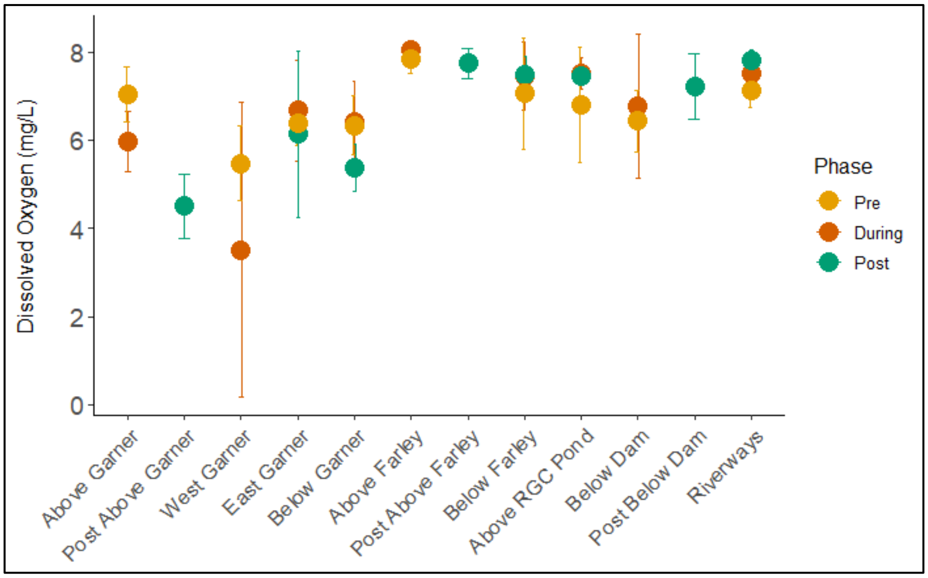

Figure 20: Comparison of average dissolved oxygen levels across sample locations and construction phase. Results are based on measurements collected in June through August using a multi-parameter YSI ProDSS. Error bars represent standard deviation of the mean.

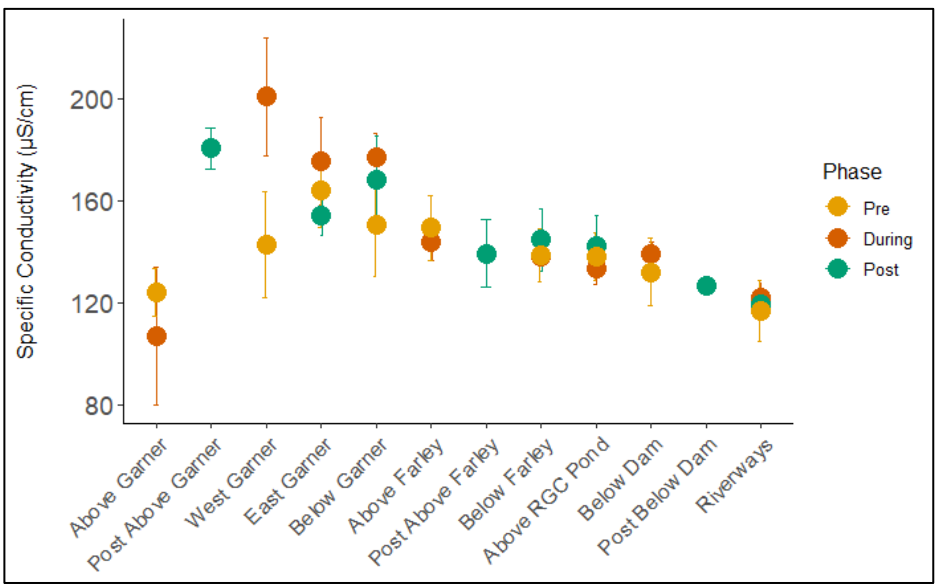

Figure 21: Average specific conductivity data collected in June through August using a multi-parameter YSI ProDSS. Error bars represent standard deviation of the mean.

The specific conductivity in the Childs River did not change drastically following the restoration (Figure 21). The only sampling locations which showed significant change in specific conductivity was at Above Garner and West Garner. The change at Above Garner was more likely a result of the change in sampling location than a change to the environmental conditions from the restoration. The increase in specific conductivity at the West Garner site was likely caused by the construction either through increased suspended particles from soil disturbance or a change to the groundwater flow from digging the new channel. Since specific conductivity is mostly influenced by the presence of nitrate in the groundwater discharging into the Childs River and the restoration did not change the chemistry of incoming groundwater, it is not surprising that there was little change in this parameter over time at the majority of the sampling locations.

d) pH

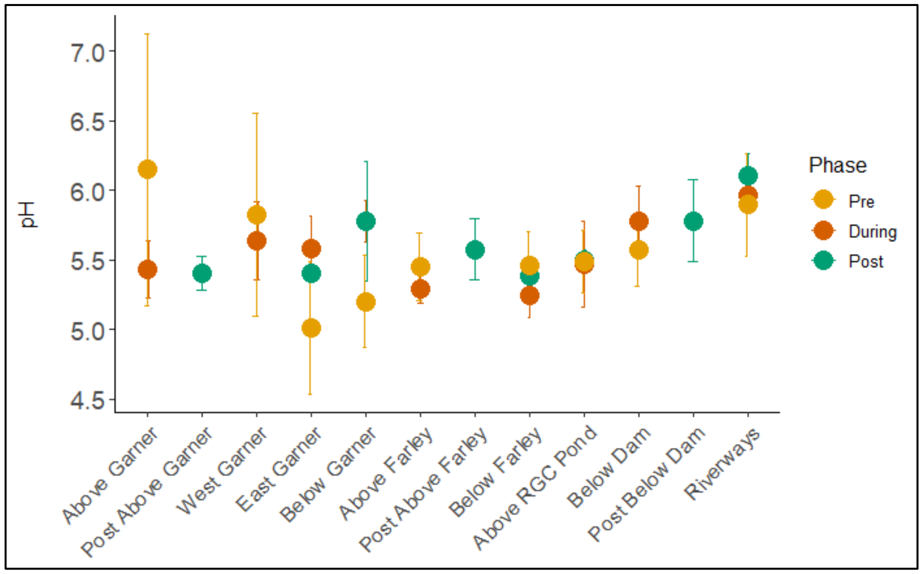

Figure 22: Average pH data collected in June through August using a multi-parameter YSI ProDSS. Error bars represent standard deviation of the mean.

Aquatic organisms require certain pH conditions in the water column and cannot tolerate large fluctuations outside of this range. pH levels that fluctuate outside of a species' tolerance range will negatively affect growth and reproduction. If fluctuations are severe enough, then organisms will not survive. Changes in pH in the water column can also impact the chemical composition of the water and can cause some nutrients to become more or less available depending on the pH change. For example, nitrification (the conversion of nitrite to nitrate) requires pH levels greater than 6 and the optimum pH range for denitrification (the transformation of nitrate to nitrogen gas) is 6.5 to 7.5.[14] The pH of a river can be affected by various internal and external factors such as the concentration of dissolved organic carbon and bacterial respiration (internal forces) and precipitation, or acid rain (external force).

Figure 22 shows little change in pH within sampling locations across the construction phases. As seen prior to the restoration, pH is lowest at Garner Bog and increases downriver. The range of pH values recorded over the study period (pre, during and post) were within the tolerance range of the Brook Trout that live in our region, and in general, these pH levels are quite low in comparison to other local rivers (Figure 23).

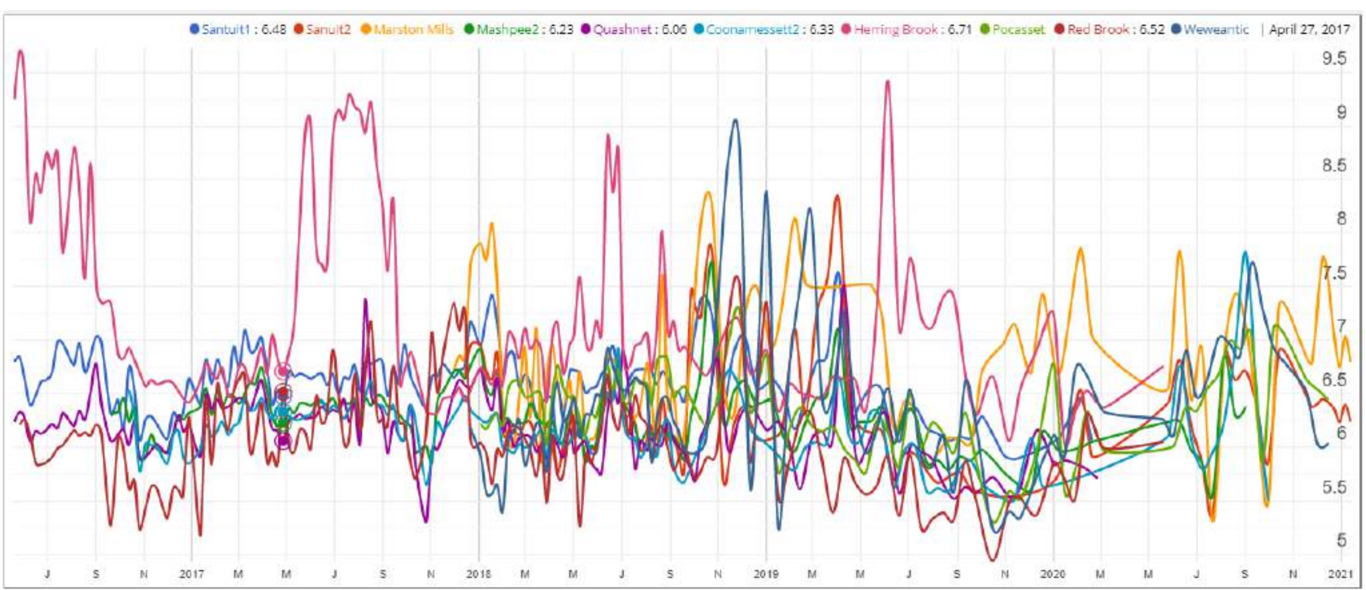

Figure 23: Line graph showing variability in weekly pH measurements across other Cape Cod rivers from July 2017 through January 2022 (data and graphic provided by Woodwell Climate Research Center Cape Cod Rivers Observatory Program, http://www.caperivers.org/data/, 12/13/2022). Note Childs River pH values generally range between 5 and 6 and are closer to 5 near or within the restored bogs.

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[14] Massachusetts Department of Environmental Protection. 2007. Final Report: Natural Attenuation of Nitrogen in Wetlands and Waterbodies. Developed by Woods Hole Group, East Falmouth, MA, and Teal Partners, Rochester, Ma.

e) Dissolved Inorganic Nutrients

The suite of dissolved inorganic nutrients analyzed for this project include nitrate (NO3), ammonium (NH4), phosphate (PO4), silica (SiO2), dissolved organic nitrogen (DON), and dissolved organic carbon (DOC). Each of these nutrients provides unique information about the quality of the riverine habitat. A high-quality habitat will efficiently carry out certain functions, such as nutrient cycling (the transformation of nutrients to different forms) which requires a complex microbial community, sustaining highly diverse and abundant native plants, and providing habitat for fish and other wildlife.

Nitrate, ammonium, and dissolved organic nitrogen are all forms of nitrogen. The forms of nitrogen that are bioavailable (readily taken up by plants, fungi, and bacteria) are called reactive nitrogen and include nitrate and ammonium.[15] Humans influence the amount of reactive nitrogen in waterbodies through activities including using fertilizer on lawns. However, the primary source of nitrogen in Cape Cod estuaries is from leaching Title 5 septic systems or cesspools which are not designed to remove nitrate. Unlike ammonium, nitrate easily permeates the sandy soils of Cape Cod. The Childs River empties into Waquoit Bay, which has seen decades of impairment from excess nitrogen from human development in the watershed.[16,17]

One of the research questions posed for the Childs River restoration project considered whether restoration of former bogs to a more natural ecosystem would reduce nitrogen levels in the river and help to mitigate the excess nitrogen in the Waquoit Bay Estuary. In order to answer this question, it's important to assess change in the dissolved nitrogen within the river at the points of incoming ("above") and outgoing ("below") surface water for each major restored feature (i.e., Garner Bog, Farley Bog, and the RGC Pond). The southernmost station, Riverways, acts as a permanent downriver reference for tracking change overtime but cannot provide the details regarding which structural manipulation in the upriver restoration site has influenced or caused a change in water quality. Lastly, nutrient cycling is greatly affected by the season as temperature and sunlight duration impact the primary production and respiration of plants and animals within the ecosystem, so the data had to be carefully analyzed to understand which nutrient changes were driven by the season versus the restoration.

For these aforementioned reasons, the results shown below provide average concentrations for each parameter grouped by construction phase for the summer months, when sampling was most frequent and consistent (June through August), at all sampling locations. In addition, water quality parameters were compared across construction phases for each season within the major restored features: 1) Garner Bog, 2) Farley Bog, and 3) the lower river including above the former RGC pond, below the former dam, and the Riverways station. Seasonal averages were determined as follows: spring averages include data collected on March 21st through June 20th; summer averages include data collected on June 21st through September 20th; fall averages include data collected on September 21st through December 20th; winter averages include data collected on December 21st through March 20th. Where there was little to no seasonal variability, the average for all seasons is provided.

[15] Hubbard Brook Research Foundation. 2003. Nitrogen Pollution: From the sources to the sea. Available from <https://hubbardbrook.org/sites/default/files/pictures/HBRF/ScienceLinks/report-nitrogen-pollution-from-the-sources-to-the-sea_2003.pdf>

[16] U.S. EPA (Environmental Protection Agency). 2002. Waquoit Bay watershed ecological risk assessment. National Center for Environmental Assessment, Washington, DC; EPA/600/R-02/079. Available from: National Technical Information Service, Springfield, VA; PB2003-102013 and <http://www.epa.gov/ncea>.

[17] Howes et al. 2012. MA Estuaries Project: Linked watershed-embayment approach to determine critical N loading thresholds for Waquoit Bay and Eel Pond Embayment Systems; Towns of Falmouth and Mashpee, MA.

Nitrate

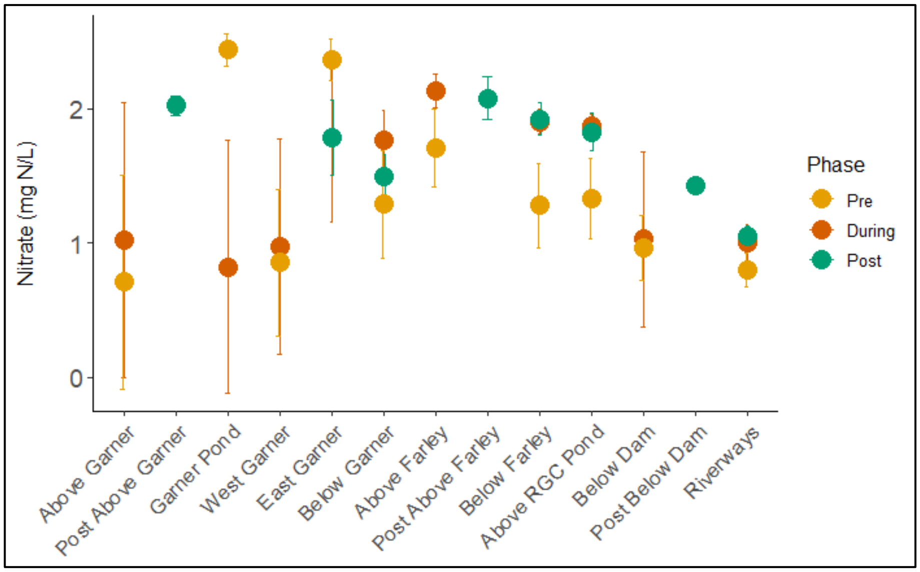

Figure 24: Average nitrate data from June through August. Error bars represent standard deviation of the mean.

The major source of water for the Childs River is groundwater, and nitrate, the dominant form of nitrogen in the Childs River, is introduced via this groundwater discharge. The main source of that nitrate is from septic systems from residential developments in the watershed. The highest nitrate concentrations were found at the Garner Bog, both before and after restoration (Figure 24). Since the former Garner Bog is in closest proximity to a residential development (as observed in aerial imagery provided in map, Figure 2), it is not surprising that this area of the river would experience the highest nitrate levels. This nitrate concentration gradually attenuates downriver likely from a combination of the following factors: dilution (greater groundwater discharge downstream), uptake by vegetation, and denitrification (the transformation of nitrate to nitrogen gas by bacteria in the anoxic, low oxygen, sediments).

Garner Bog - Nitrate levels were much higher in the Above Garner samples post-restoration, but this may be due to a change in the sampling location (Figure 25). Prior to restoration and across all seasons, East Garner and Garner Pond had nitrate levels that were considerably higher than the other sampling locations. Across all seasons the high nitrate levels seen at East Garner and Garner Pond pre-construction diminished before reaching the Below Garner station. These findings indicate that the influence of groundwater discharge can be seen at a micro-habitat scale, meaning those impacts are localized to a specific area. The habitat (including plants, bacteria, etc.) quickly absorbs most of the high nitrate before it is exported from that localized area. The only point when this scenario did not hold was during construction when the water flow as well as the plant and microbial communities were disrupted. In other words, during construction the Garner Bog became a source of nitrate, discharging higher nitrate concentrations than those entering the bog.

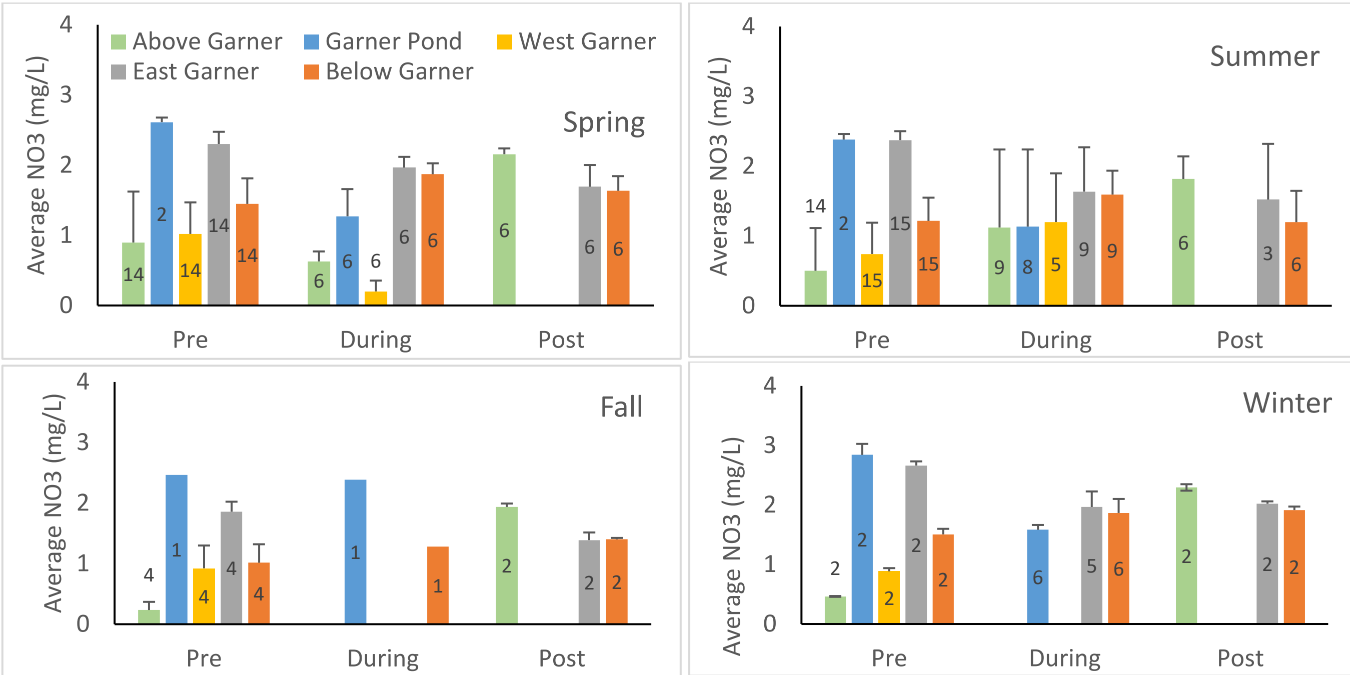

Figure 25: Average nitrate concentrations in the restored Garner Bog across three construction phases for each season. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Farley Bog- The former Farley Bog continued to provide nitrogen attenuation within the new river channel following construction (Figure 26). Although the rate of attenuation is not as high as before restoration, the system may resume these or better rates over time as more plants and bacterial communities get established. Critically, the only point where the river was not removing more nitrate than it was exporting (through denitrification and/or plant uptake) was during the fall and winter of 2020 when construction was at its peak at Farley Bog.

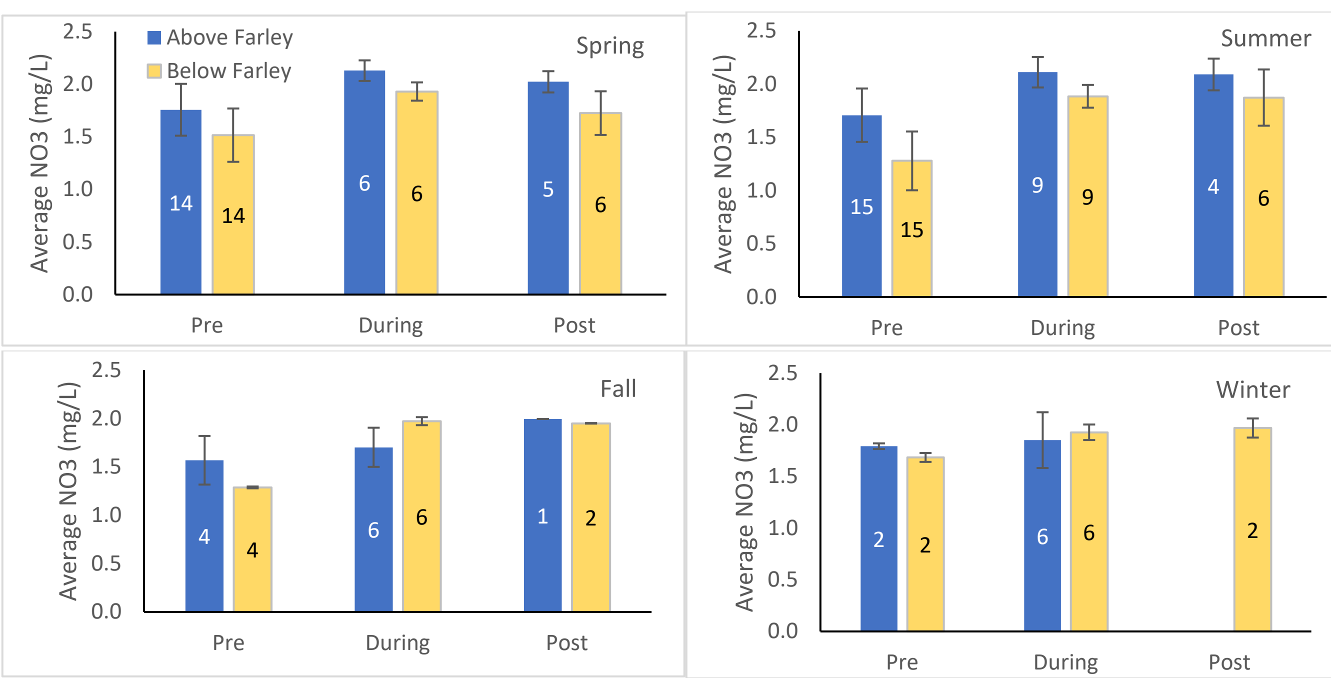

Figure 26: Average nitrate concentrations in the restored Farley Bog across three construction phases for each season. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Lower River - Nitrate levels were higher during and following construction, but the lower portion of the Childs River restoration site continued to show consistent attenuation throughout all project phases (Figure 27; averages by season not shown due to similar trends across all seasons). The increase in nitrate within the system overtime may be a result of released nitrate related to construction or may reflect interannual variability related to precipitation and other external environmental factors. More data is needed to ascertain how climate factors impact nitrate levels in the river.

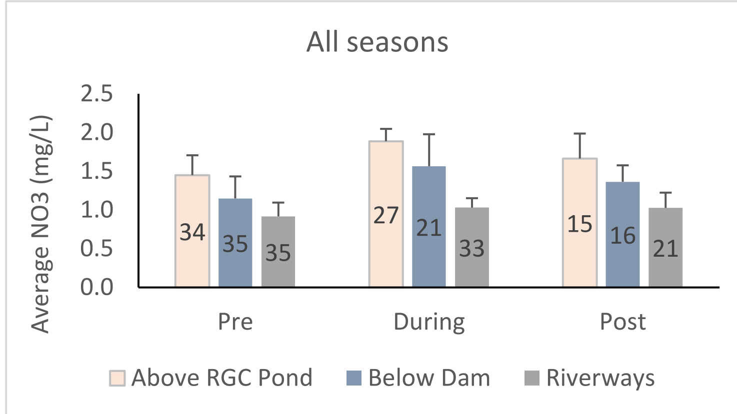

Figure 27: Average nitrate concentrations in the restored lower portion of the Childs River across three construction phases. Averages include data from all seasons. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Ammonium

On average, ammonium was high in the Garner Bog across all phases of construction (except for Garner Pond where concentrations were quite low during construction) (Figure 28). The release of ammonium seems to be correlated with temperature where higher temperatures (and lower dissolved oxygen) results in higher ammonium levels. It's unclear why ammonium was high before construction started at the Below dam and Riverways stations but may be related to higher summer temperatures and lower dissolved oxygen before the more natural river channel was created.

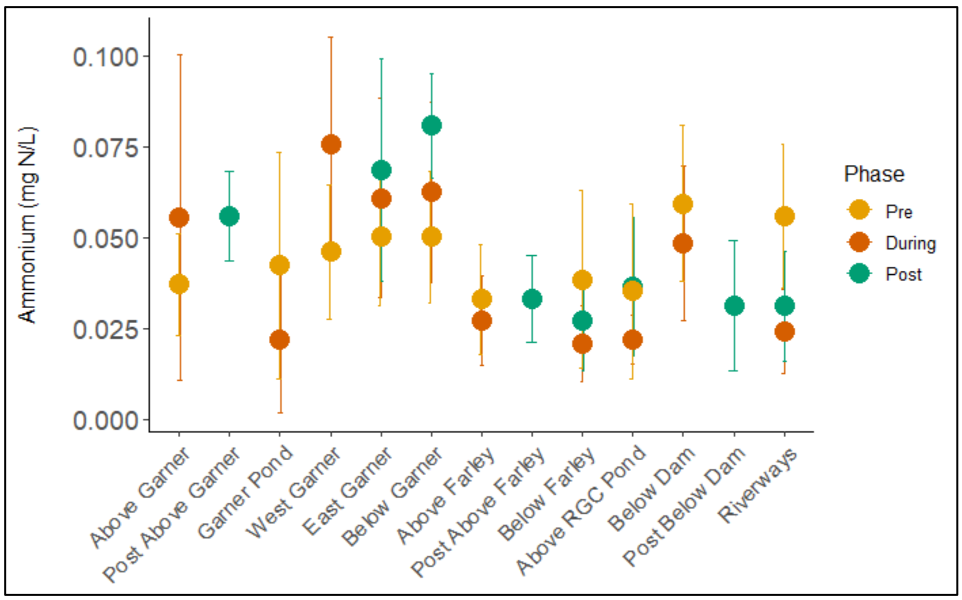

Figure 28: Average ammonium data from June through August. Error bars represent standard deviation of the mean.

Garner Bog - Ammonium levels were highest during construction in Garner Bog especially in the fall and winter 2020-2021 (Figure 29). The increased ammonium during construction was likely caused by a combination of factors include plant senescence and disturbance to the bacterial community as well as release from soils due to pressure change in pore spaces. The dissolved ammonium was also generally higher during the spring and summer which may be related to the season's warmer temperatures. Ammonium is largely unchanged between pre- and post-construction across seasons.

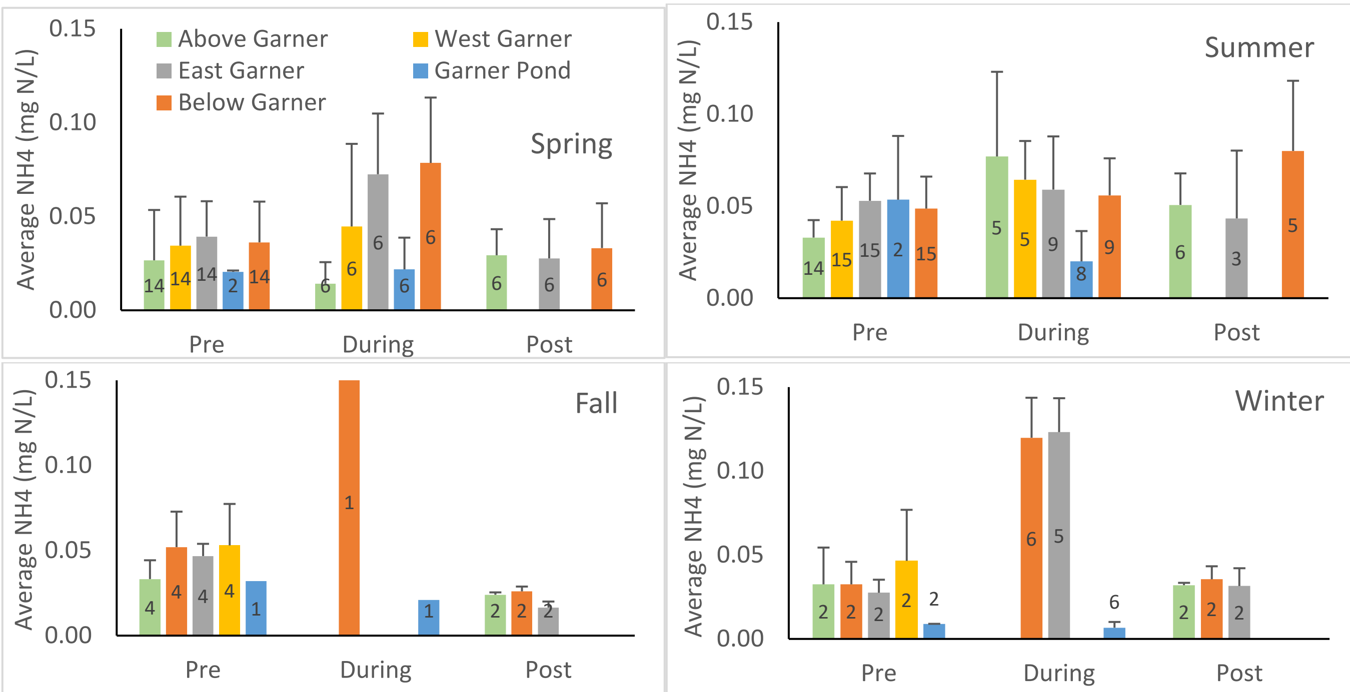

Figure 29: Average ammonium concentrations in the restored Garner Bog across construction phases for each season. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Farley Bog – Similar to Garner Bog, Farley Bog also showed greater ammonium levels leaving the site than entering during construction (Fall 2020 and Winter 2020-2021) (Figure 30). Comparing pre- to post-construction, the post-construction ammonium levels were lower leaving the bog although the cause for this change is unclear. In fall 2021, the ammonium concentrations were greatly reduced compared to samples collected in the fall pre-construction (although the fall sample size is too small to make conclusive remarks).

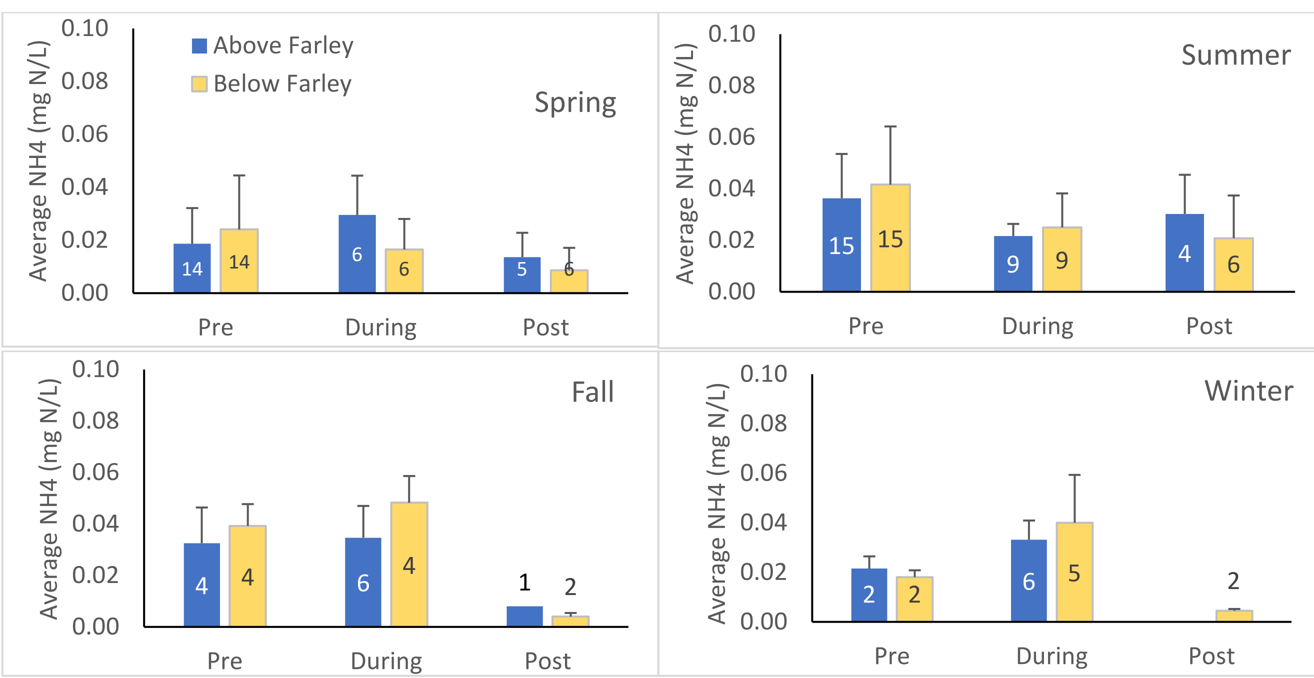

Figure 30: Average ammonium concentrations in the restored Farley Bog across three construction phases for each season. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Lower River – As seen at the other restored sites, ammonium was highest during construction in winter 2020-2021 in the lower river (Figure 31). Additionally, ammonium was generally lower post-construction across all seasons (except winter where there was no change).

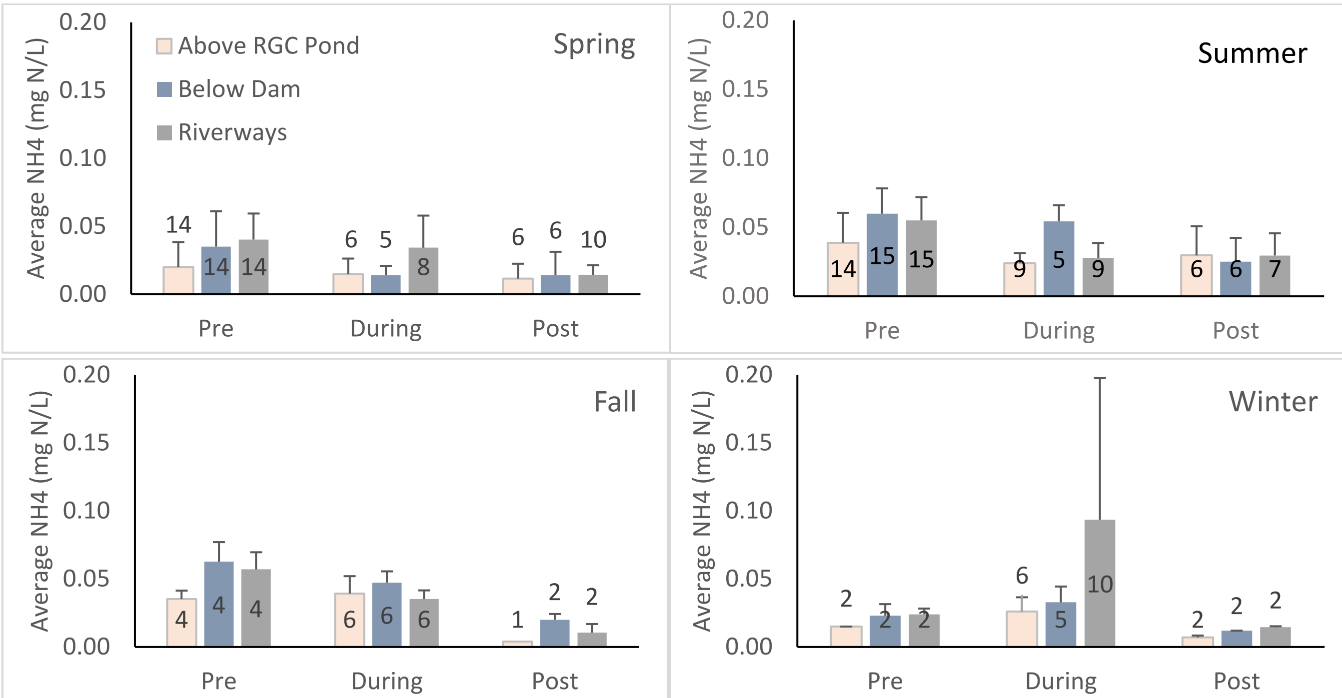

Figure 31: Average ammonium concentrations in the lower portion of Childs River across three construction phases for each season. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Phosphate

Phosphate is a limiting nutrient in freshwater systems, so the presence or absence of this nutrient can dictate primary production. Phosphate levels were largely unchanged following restoration.

The highest phosphate concentrations were seen at the Riverways station (Figure 32). The higher phosphate at this site is likely caused by a nearby low-oxygen groundwater seep. Low-oxygen conditions create a chemical reaction whereby phosphate is released into the water column from the sediments.

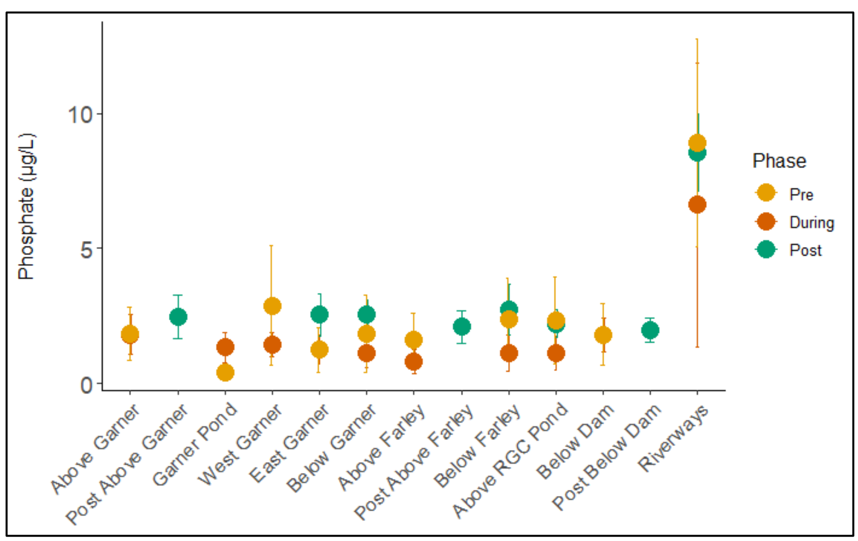

Figure 32: Average phosphate data from June through August. Error bars represent standard deviation of the mean.

Garner Bog – Phosphate concentrations in the Garner Bog were lowest during construction (Figure 33). One possible explanation for the low phosphate during this phase could be that while the river channel was being constructed, the water flow may have been periodically cut off from a large groundwater seep. Since this relationship was true across all seasons (averages by not shown), the change in phosphate during construction does not appear to be a result of differences in plant growth or bacterial processes.

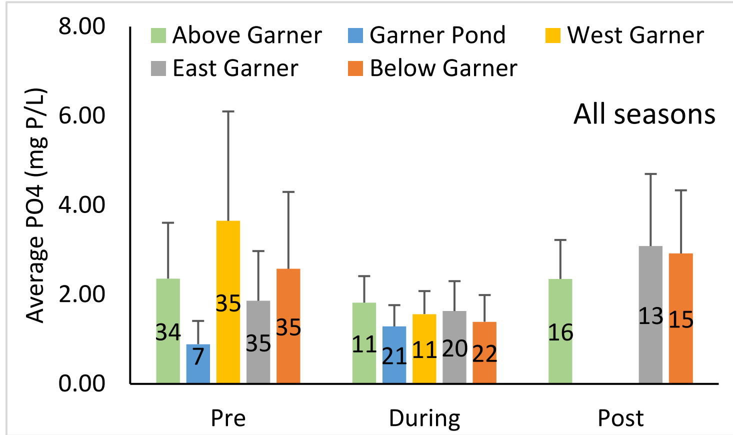

Figure 33: Average phosphate data from restored Garner Bog. Averages include data from all seasons. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Farley Bog - Phosphate was higher leaving the Farley Bog than entering across all construction phases but was most pronounced pre- and post-construction (Figure 34). Similar to Garner Bog, one theory for this change could be that the interaction with the groundwater was interrupted and resulted in less phosphate entering the water column.

Lower River – Phosphate was consistently highest at the Riverways station across all seasons and all construction phases (Figure 35; averages by season not shown). The only time phosphate concentrations dropped considerably was in the spring during construction (April – June 2021). More data is needed to gain a better understanding of why phosphate declined so drastically for this three-month period (i.e., variability in snow melt may play a role and could be a result of interannual variability). However, one possible explanation is that while the bypass channel was created to remove the RGC pond and former dam, this disconnected a significant groundwater seep from the river.

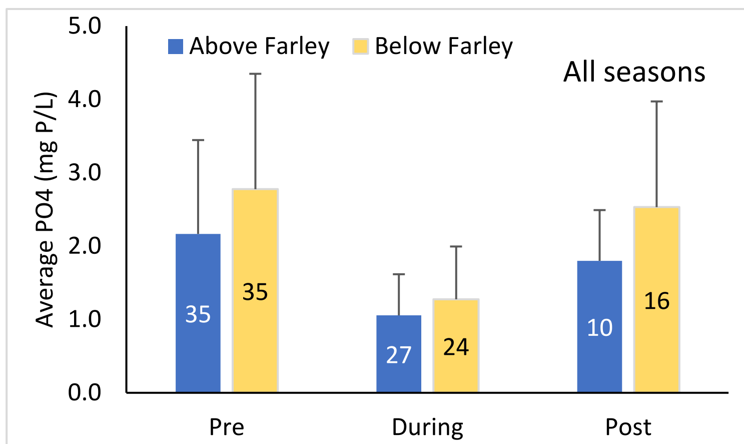

Figure 34: Average phosphate data from restored Farley Bog. Averages include data from all seasons. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Phosphate is also lower, on average, post-construction (2022; Figure 35). The change may have been caused by the summer drought and a drop in the groundwater table and/or an increase in primary productivity following the restoration such that more plants were taking up phosphorus from the water column.

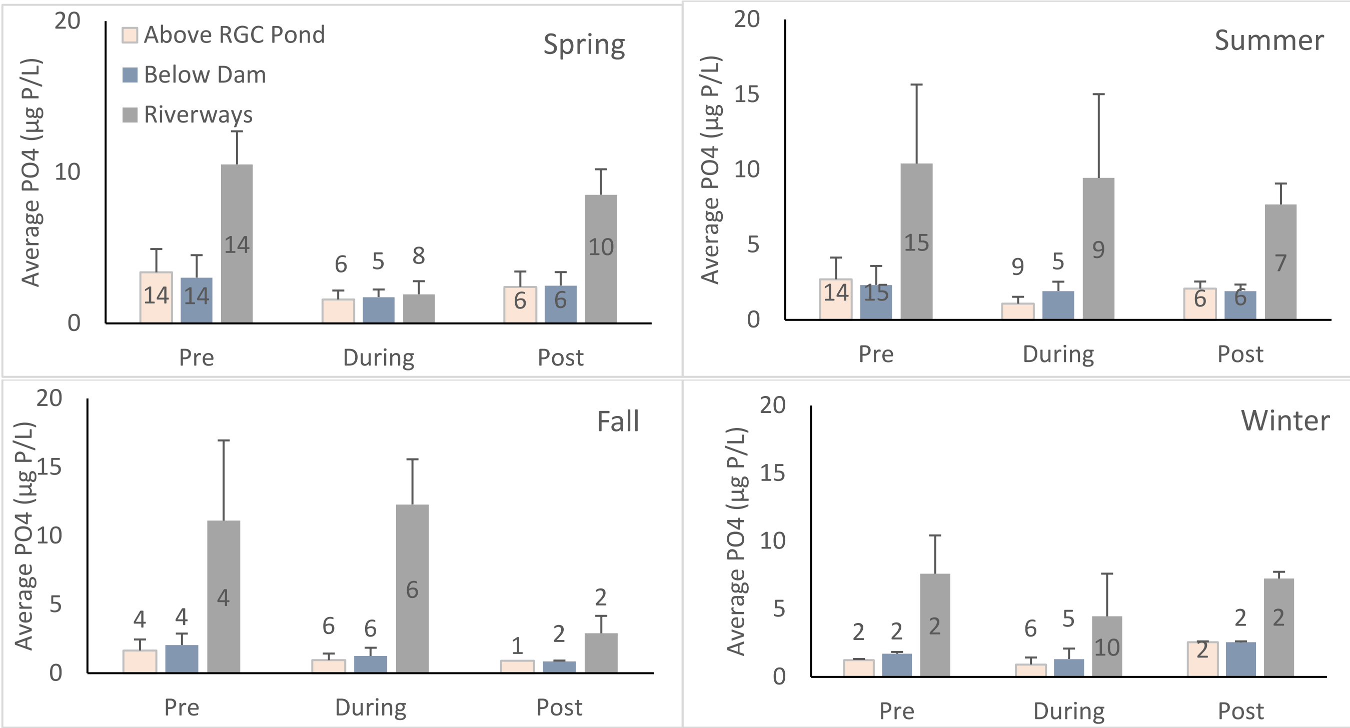

Figure 35: Average phosphate data from restored lower portion of Childs River across construction phases for each season. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Silica

Silica is an important nutrient for some aquatic organisms, such as diatoms (a type of microalgae prevalent in freshwater and marine waterbodies on Cape Cod), which use silica to build their cellular structure. Silica dissolves into the water column as minerals weather and disintegrate in the river. Since sandy sediments are the main source of silica on Cape, concentrations of silica can be greatly influenced by erosion or resuspension in riverine systems.

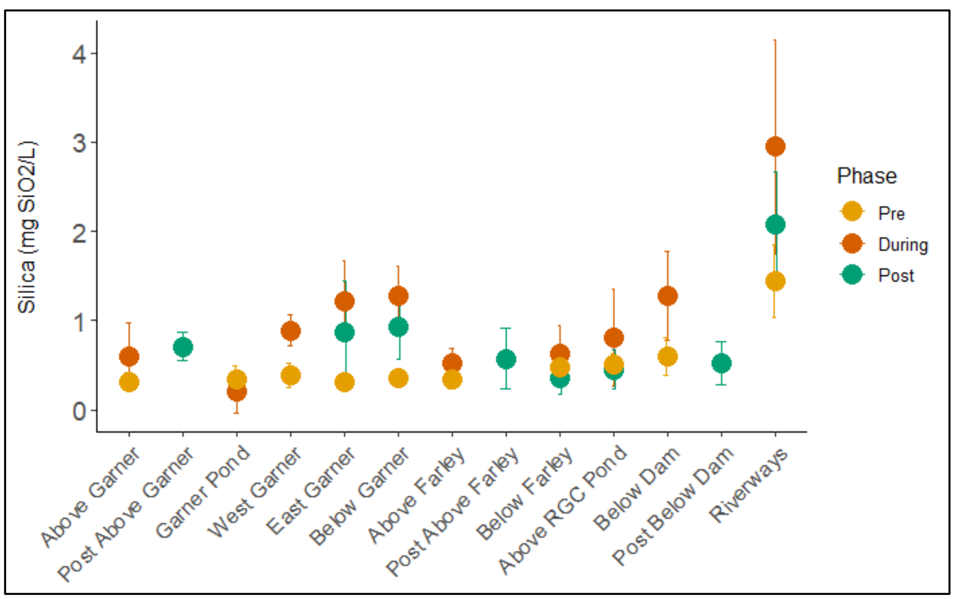

Figure 36: Comparison of average silica data from samples collected in June through August across construction phase. Error bars represent standard deviation of the mean.

The highest concentrations of silica were found at the Riverways station (Figure 36). However, there were several spikes of silica throughout the river during and after construction. For instance, average summer silica concentrations collected at East Garner, Below Garner, and Below Dam during construction were more than twice the pre-construction averages. The elevated levels are likely due to disturbed, resuspended sediments from regrading river contours and channels as part of the construction.

Garner Bog – As seen in the summer average comparison above, silica was high during construction in the Garner Bog, especially at East Garner and Below Garner in spring and summer (Figure 37). These two stations were downriver of the reconstruction of the river channel where disturbed sediments resulted in higher dissolved silica in the water column before settling out further downstream.

Additionally, silica was highest in fall of the post-construction phase when heavy rain caused significant erosion of the largely unvegetated surrounding upland. Other than these specific occurrences when construction or rain caused sediment movement, silica remained fairly consistent with little change across seasons and construction phases. The only high values that could not be explained were from summer post-construction when water levels were quite low from a severe drought. The reduced water depth may have resulted in disturbed sediments during sampling at the Garner Bog confounding the results.

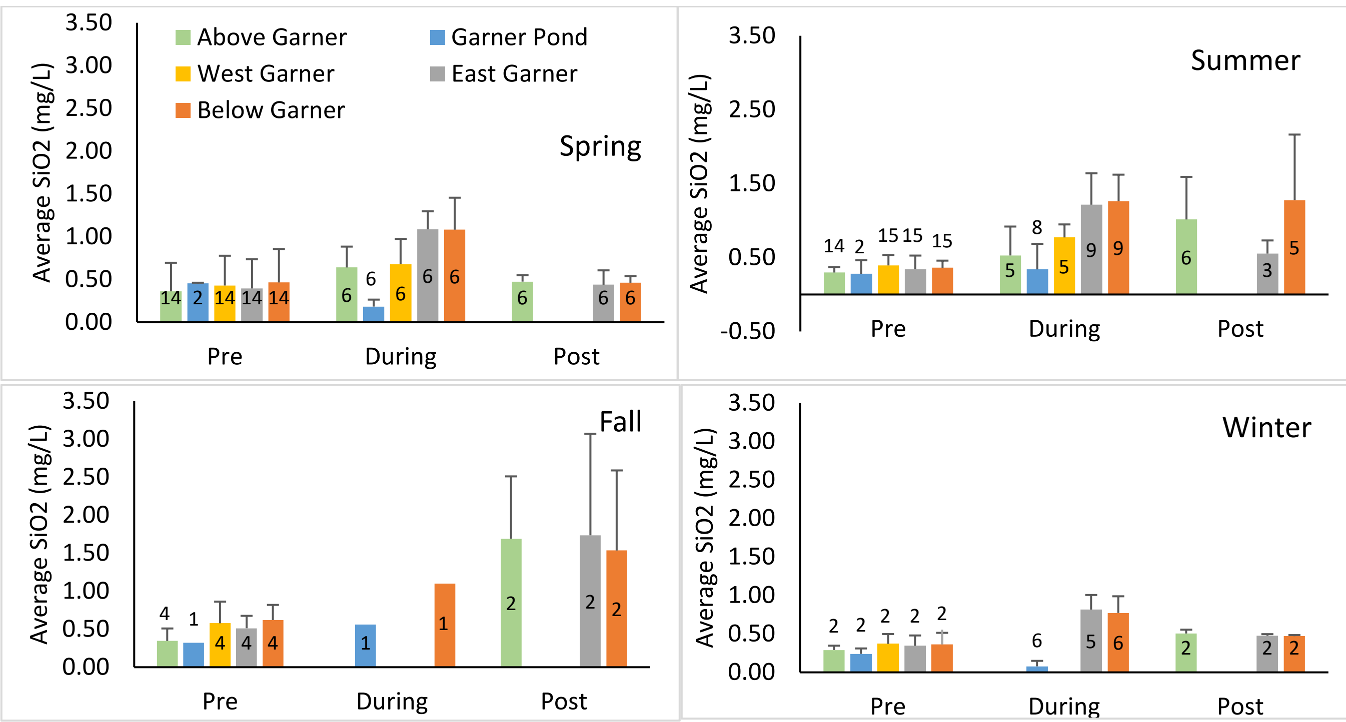

Figure 37: Comparison of average silica data from restored Garner Bog across construction phase for each season. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Farley Bog - Silica was highest at Below Farley in spring post-construction (spring 2022; Figure 38). This finding was unique to Farley Bog (i.e., not seen at Garner Bog) and may have been a result of snow melt and spring rains and/or groundwater discharge at this specific location. Otherwise, silica was comparable across seasons and construction phases at Farley Bog.

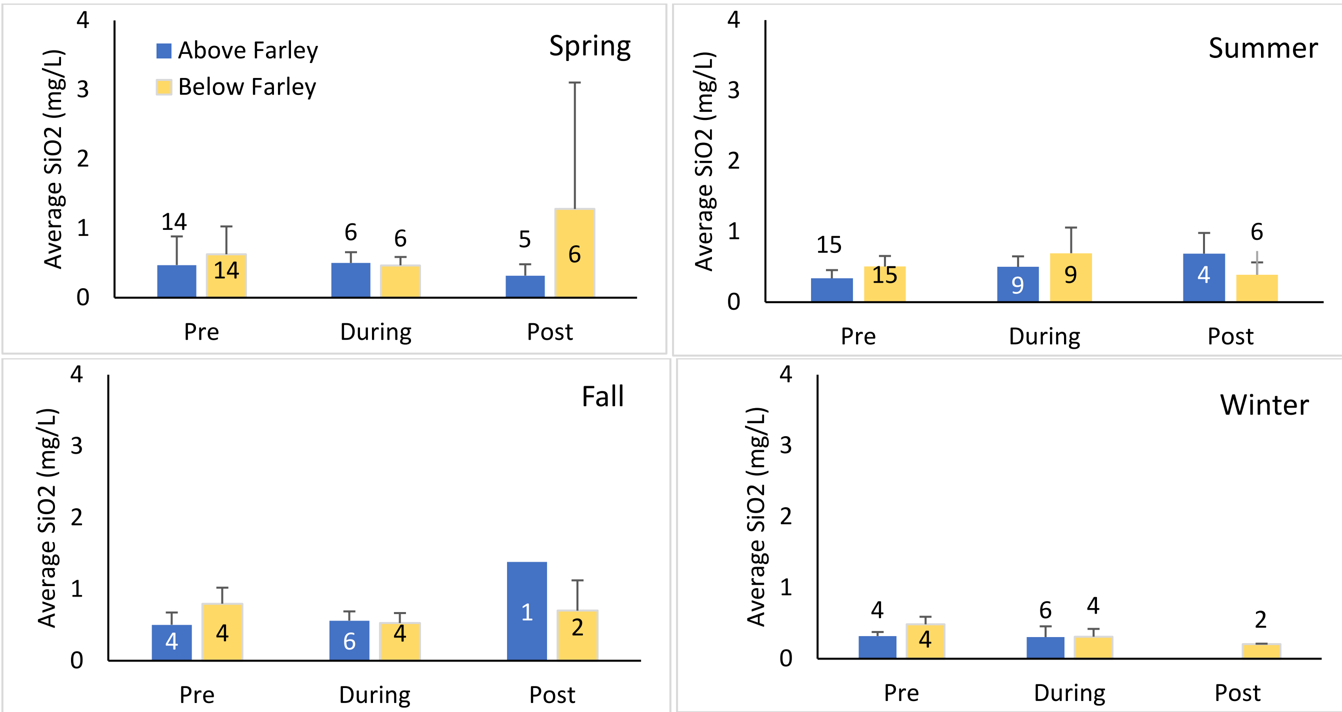

Figure 38: Comparison of average silica data from restored Farley Bog across construction phase for each season. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Lower River - Other than Riverways, which consistently had high silica levels across seasons and phases (averages by season not shown), the samples collected at the Below Dam station were highest during construction (Figure 39). The high silica concentrations measured at the Riverways may be a result of a large groundwater seep near the sampling location and/or disturbed sediments from fast-moving, shallow water releasing dissolved silica into the water column.

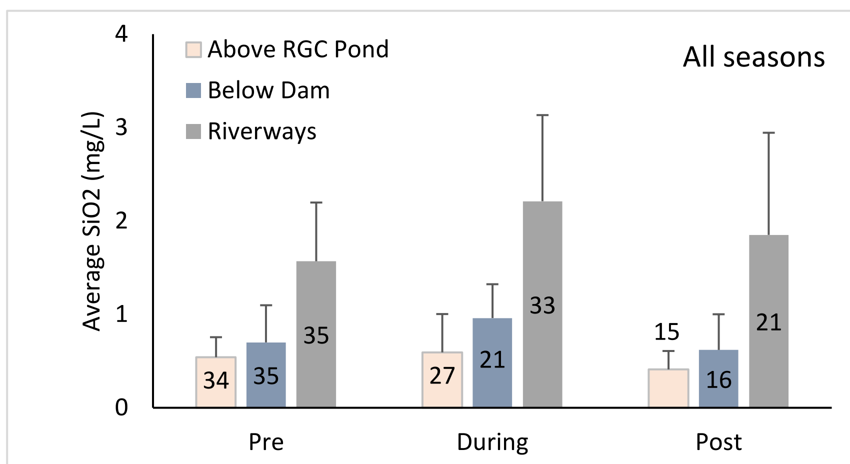

Figure 39: Comparison of average silica data from lower Childs River across construction phase. Averages represent data from all seasons. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

f) Dissolved Organic Nutrients

Dissolved Organic Nitrogen

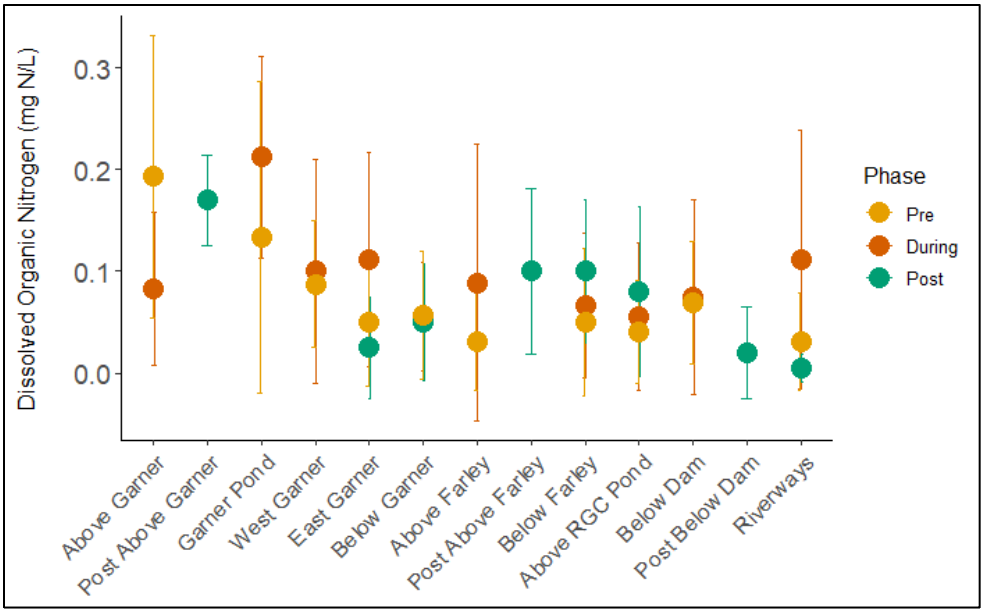

Figure 40: Comparison of average DON data from samples collected in June through August across construction phase. Error bars represent standard deviation of the mean.

One of the main sources of dissolved organic nitrogen (DON) in aquatic systems is from the decomposition (or remineralization) of organic material, such as dead plants or algae. DON was very low across all sampling events relative to the other forms of nitrogen (Figure 40) and did not change substantially following the restoration.The highest concentrations of DON were found at Above Garner (pre- and during construction) and the Garner Pond. The higher DON concentrations within Garner Bog are likely caused by the warmer temperatures and lower water flow, conditions which are more conducive to the slow decomposition of organics.

Garner Bog – Post-construction DON was higher at the Above-Garner sampling location across all seasons except summer (Figure 41). Since this sampling location changed from pre- and during construction, it's impossible to determine whether the difference is from the impacts of the river restoration, interannual variability, or the change in location. However, the main take away from the DON data at Garner Bog was that DON was generally higher above or within the former bog than below indicating that DON was cycled within the bog. The only time when the bog became a source of DON was during construction in the summer of 2021 while the soils and plants were disturbed.

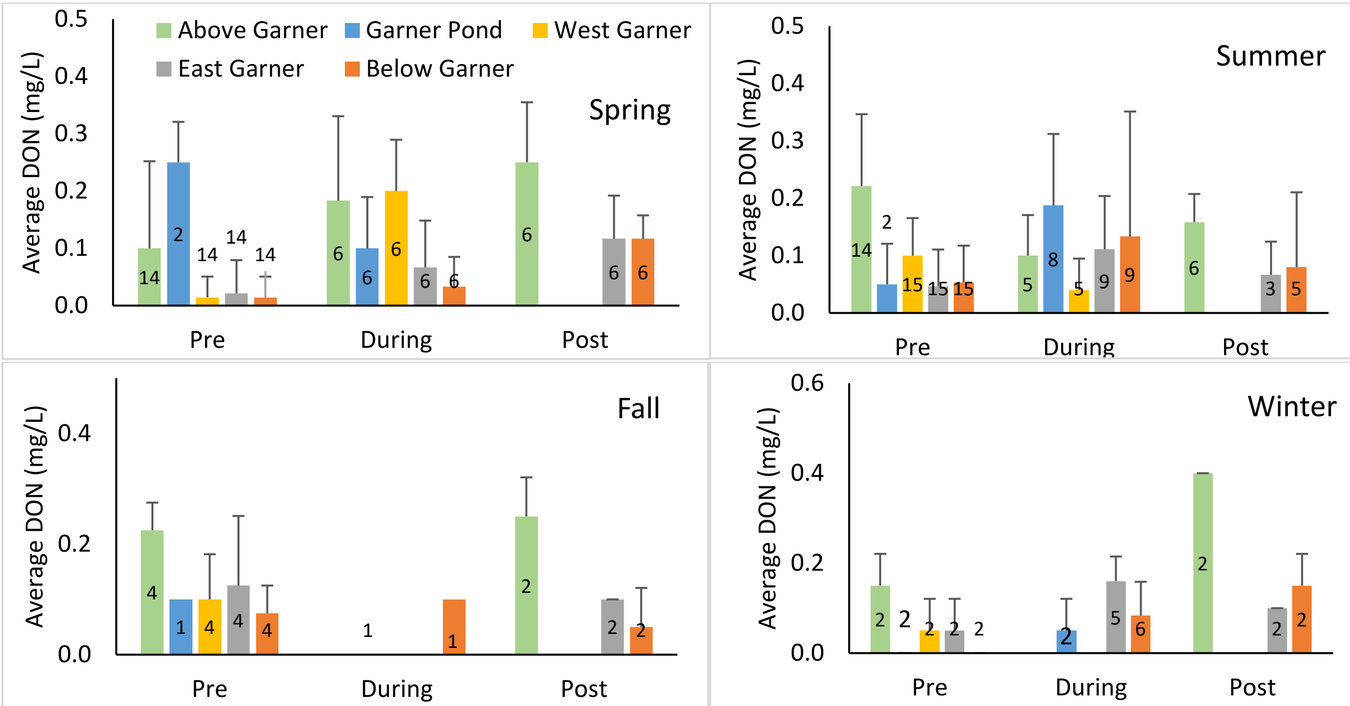

Figure 41: Average dissolved organic nitrogen data from restored Garner Bog across construction phases by season. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Farley Bog – DON was highest across the construction phases in fall but showed the most change from pre- to post-construction in the spring (Figure 42). Spring is also the only season where the Above and Below Farley levels were substantially different. Further study is needed to determine why the river restoration had the most impact on the spring DON production. During all other seasons and construction phases, the concentration of DON remains largely unchanged entering and leaving the Farley Bog system.

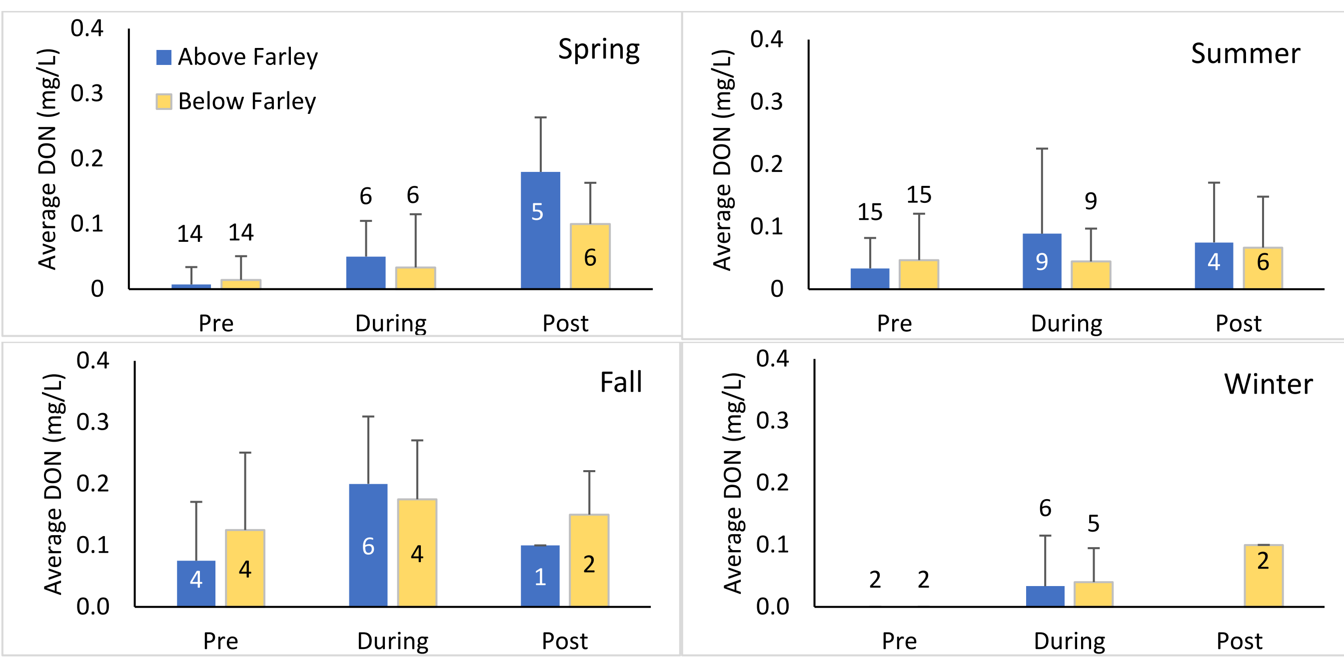

Figure 42: Average dissolved organic nitrogen data from restored Farley Bog across construction phase by season. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Lower River – DON was highest across all sampling locations (including Garner and Farley Bogs) at Riverways during summer construction (Figure 43). This high value may represent the extreme rainstorm which occurred in September 2021, as rain can act as a source of DON,[18] and the increased flow may have flushed nutrients downriver.

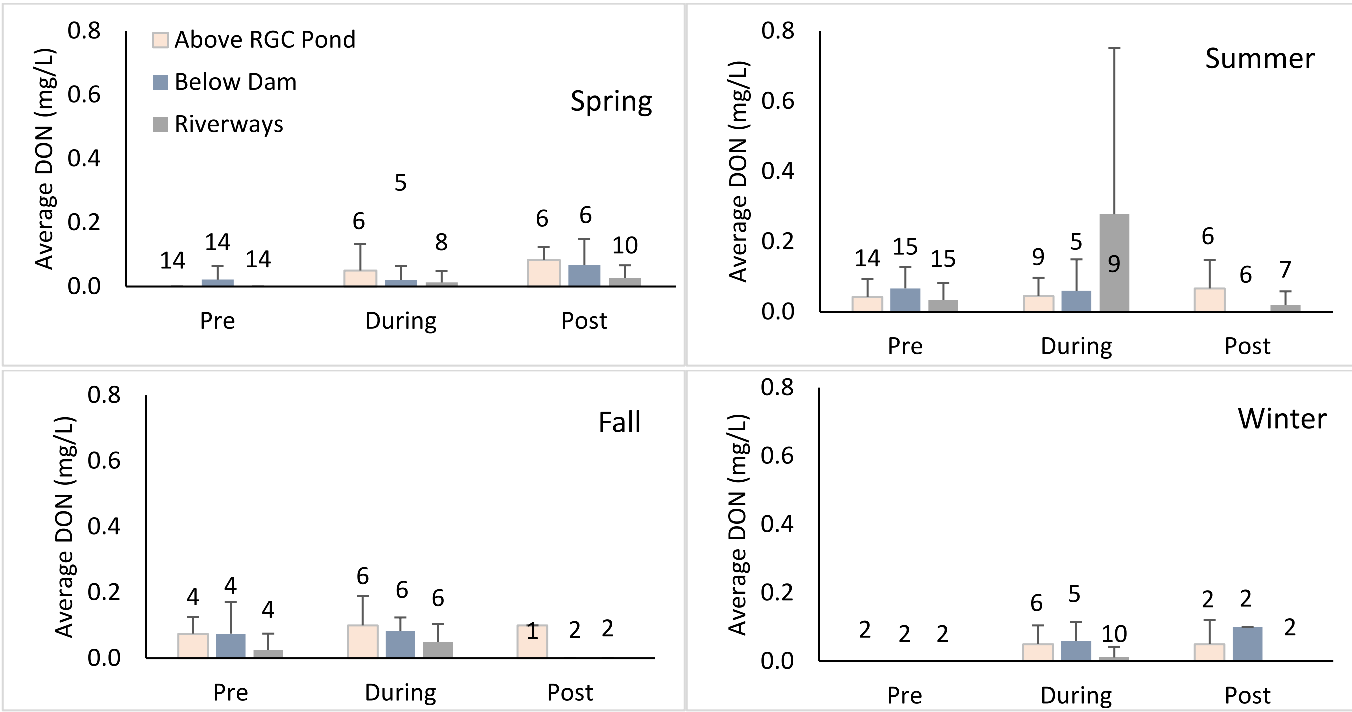

Figure 43: Average dissolved organic nitrogen data from lower Childs River across construction phase by season. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Dissolved Organic Carbon

Dissolved organic carbon (DOC) is an important nutrient because it provides the base to the food web and because it can impact pH in low-alkalinity systems. Sources of DOC include decomposing detritus and organisms in the benthic layer and water column, runoff from surrounding areas, and groundwater discharge. The major factor controlling decomposition and the release of DOC is water residence time. Where there is slow-moving, warm water, DOC levels are high as a result of accelerated decomposition. Processes that can break down or reduce DOC in the water column include photo-oxidation, photo-bleaching, and consumption/respiration. The major factor controlling the consumption of organic carbon includes lability. If the DOC pool is labile, then the carbon is bioavailable to most organisms and easier to consume. However, recalcitrant DOC exists in the system longer because it is harder to break down.

[18] Seitzinger, S.P., and R.W. Sanders. 1999. Atmospheric inputs of dissolved organic nitrogen stimulate estuarine bacteria and phytoplankton. *Limnology and Oceanography* 44(3): 721-730.

Since longer water residence times encourage decomposition and increase DOC concentrations, it is not surprising that DOC is highest in the Garner Pond and at West Garner where there was little to no flow. In fact, DOC was higher at all of the stations prior to construction when water flow was lower and water temperatures were warmer (Figure 44). The change in water flow rate is likely the leading factor in the change in DOC concentrations before and after restoration although lability and soil microbes may also play a part in the story.

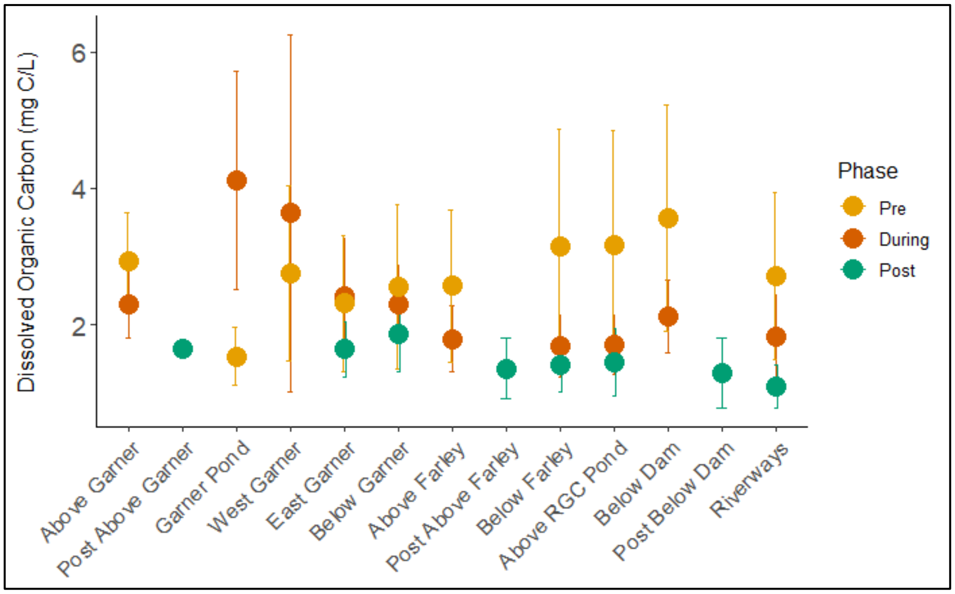

Figure 44: Comparison of average dissolved organic carbon data from samples collected in June through August across construction phase. Error bars represent standard deviation of the mean.

Garner Pond – DOC did not vary greatly across seasons or construction phases at Garner Bog (Figure 45). DOC was substantially higher at West Garner relative to the other stations in the spring during construction (averages by season not shown), however, it's difficult to know if this was caused by the construction, a spike in the groundwater, or a rainstorm event.

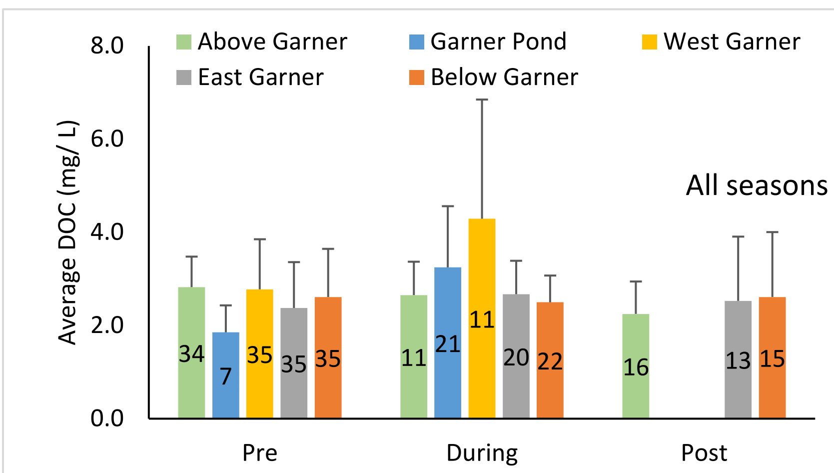

Figure 45: Comparison of average dissolved organic carbon data from the former Garner Bog across construction phase. Averages represent data from all seasons. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Farley Bog - DOC levels are comparable above and below Farley Bog across all construction phases suggesting there was very little cycling of DOC (e.g., decomposition or consumption) within the bog before, during, or after restoration (Figure 46; averages by season not shown). DOC was generally higher prior to restoration which indicates that there was greater decomposition in the former bog before the river was restored. The former bog had slower-moving water which resulted in greater residence times and warmer temperatures driving higher decomposition rates and DOC.

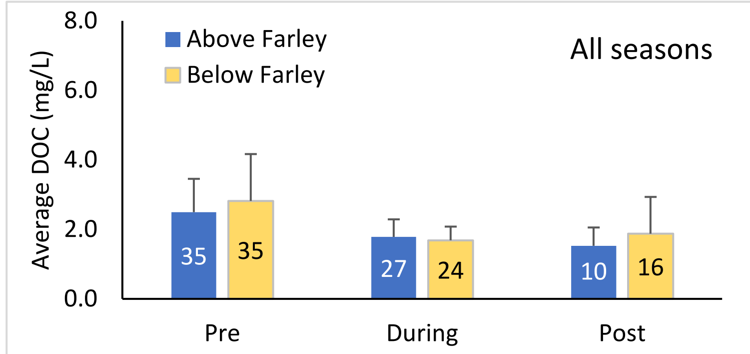

Figure 46: Comparison of average dissolved organic carbon data from the former Farley Bog across construction phase. Averages represent data from all seasons. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

Lower River - DOC generally decreases downriver although confidence in the trend is minimal due to the high variability (Figure 47). Additionally, there was very little change over the seasons or across construction phases (averages by season not shown).

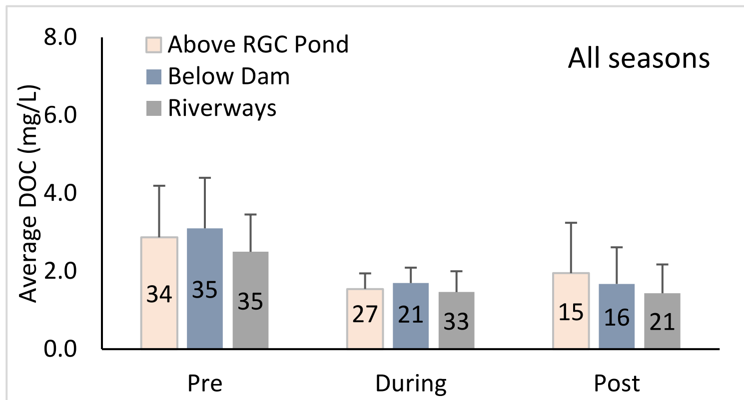

Figure 47: Comparison of average dissolved organic carbon data from the lower Childs River across construction phase. Averages represent data from all seasons. Error bars represent standard deviation of the mean. The number of samples included in the mean are provided within each bar column.

3) Fish Surveys

The sections of the Childs River to be restored were sampled by electrofishing immediately before the restoration in June of 2020, and no Brook Trout were caught below the RGC pond area, in Farley Bog, or the section immediately below Farley Bog. In May of 2021, during the restoration, no Brook Trout were captured in the new stream channel or in the bypass channel in the former pond area.

In September of 2021, Brook Trout were starting to colonize the newly restored areas, one Brook Trout was captured in the new stream channel in the old pond area and two Brook Trout were captured in the new Farley Bog channel compared to 42 Brook Trout individuals found downstream. The Brook Trout tagged on September 16, 2021, in the old pond area was later recaptured on September 23 in the same area near the Falmouth Rod and Gun Club building during an electrofishing demonstration for the restoration completion event (Table 1).

Table 1. Summary of Brook Trout catch and effort in the Childs River September 16 and 23, 2021. Runs 1-3 on September 16th were located downstream of the restored area of the river. Runs 4-5 on September 16th and run 1 on September 23rd were completed in the former pond and restored Farley bog.

Run	Location	Effort (seconds)	No. of Trout	YOY	Adult	Recaptures	Newly Tagged	Comments
September 16, 2021								
1	Above Barrows Street to bend	1161	4	0	4	0	4	Missed 2 other adults
2	Big Bend to tree across river	543	11	10	1	1	10	
3	Tree across river to above gage	810	27	19	8	4	22	*includes 1 dropped YOY
4	In Old Pond section	1158	1	1	0	0	1	
5	In Farley Bog lower	391	2	2	1	1	2	
	Total	4063	45	32	14	6	39	
September 23, 2021								
1	In Old Pond Section	199	1	0	0	1		Recapture of fish from 09/16/2021

On May 18, 2022, nineteen Brook Trout were captured in the old pond area including 5 young-of year (YOY) indicating that spawning had occurred in or near the old pond area (Figure 48). Seventeen Brook Trout were captured in the new river channel of the former Farley Bog including four young of year indicating that spawning had occurred in or near the Farley bog area as well. Only two young of year were captured in the lower reaches of the river (runs 1-3) where spawning was previously known to occur. A total of 31 Brook Trout were captured in the lower reaches of the river (runs 1-3) and 36 Brook Trout were captured in the restored areas (runs 4-5) in the restored river channel (Table 2).

Figure 48: *Left*: Childs River Brook Trout May 2022 (credit: A.D. Colburn). *Center*: Young of year Brook Trout captured in the former pond area of the Childs River on May 18, 2022, indicating that spawning had occurred in or near this newly restored area (credit: MassWildlife). *Right*: Catch of Brook Trout in Farley Bog September 14, 2022 (credit: MassWildlife).

Table 2. Summary of Brook Trout catch and effort in the Childs River May 18, 2022. Runs 1-3 were located downstream of the restored area of the river and runs 4-5 on were completed in the former pond and upstream restored Farley bog. YOY: Young of the Year (<100mm); Adults: >100mm.

Run	Location	Effort (seconds)	No. of Trout	YOY	Adult	Recaptures	Newly Tagged
		May 18, 2022					
1	Above Barrows Street to just below Bend	759	3	0	3	0	3
2	Big Bend to tree across river	838	10	2	8	2	6
3	Above and below Gage	638	18	0	18	5	13
4	Old Pond area above and below Carriage Shop Road	1363	19	5	14	2	12
5	Below and lower Farley Bog	891	17	4	13	1	12
	Total	4489	67	11	56	10	46

On September 13 and 14, 2022 the Childs River was again sampled by electrofishing and 84 trout were captured including 47 young-of-year (YOY) and 23 recaptures (Figure 48). Thirty-four trout were captured in the lower reaches including 15 YOY and 10 recaptures, 34 trout were captured in the old pond area including 18 YOY and 12 recaptures while 16 trout including 14 YOY and one recapture were captured in the former Farley bog area (Table 3). Based on the length frequency distributions (Figure 49), 2022 appeared to produce a good year class in the Childs River which may reflect the increased spawning areas created by the restoration of the former Farley Bog and former RGC pond area. Overall, the sampling to date shows movement of Brook Trout into the restored areas and use of this habitat for spawning with detection of YOY and increased frequency of YOY in 2022.

Table 3. Summary of catch and effort by sampling run at the Childs River, September 13 and 14, 2022. Run 1 on September 13th was located downstream of the restored area of the river and Run 2 on September 13th was located in restored river channel near the Carriage Shop Road. Runs 1 and 2 on September 14th were located within the restoration area of the river. Run 3 on September 14th was located downstream of the restoration area.

Run	Location	Effort (seconds)	No. of Trout	YOY	Adult	Recaptures	New Tags	Comments
September 13, 2022 (sampling terminated early due to lightning and heavy rain)								
1	Above Barrows Street to bend	908	7	0	7	2	5	Missed 2 other adults
2	Old pond section below Carriage Shop Road	873	23	14	9	6	17	
September 14, 2022								
1	Old pond area above Carriage Shop Rd.	631	11	4	7	6	5	
2	Below Farley bog and Lower Farley Bog	633	16	14	2	1	15	Missed two large adults
3	Above and Below Gage	467	27	15	12	8	18	
	Total	3512	84	47	37	23	60	

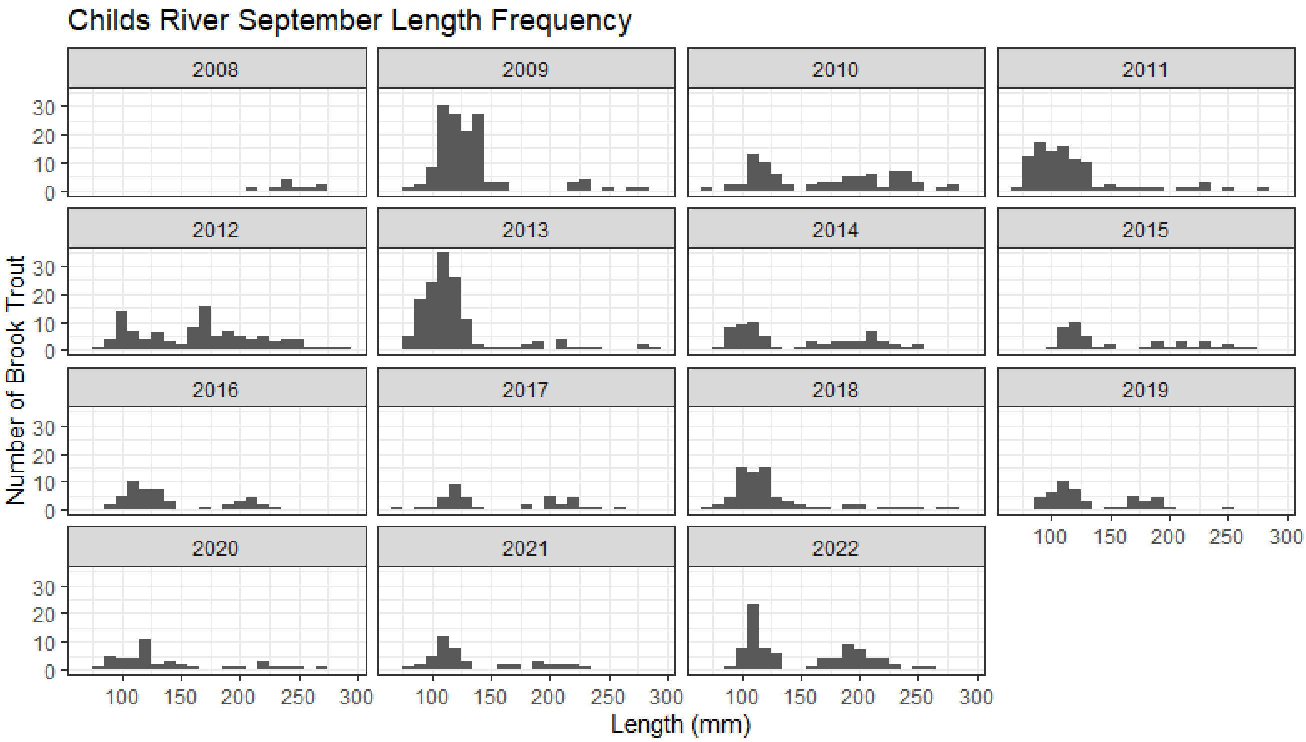

Figure 49: Length frequency distribution of Brook Trout from the Childs River sampled in September since the reintroduction of Brook Trout in 2008.

While the focus on post restoration fish sampling was on Brook Trout, other fish species observed were noted during sampling and fish species occurrence after restoration was similar to those found pre-restoration. Large numbers of Mummichog and American Eel were observed in a September 23, 2021 sample in the old pond area, indicating improved fish passage. In the September 2022 sample, large numbers of Mummichogs and American Eel and a few Fourspine Sticklebacks were observed in the lower Childs River and Golden Shiner, American Eel, Pumpkinseed and one Brown Bullhead were observed in the former pond area and the new channel below. A school of Golden Shiner were observed in the lower end of the former pond area in November 2022 as well as Brook Trout.

Long-term Trends

Figure 49 shows the long-term trends of Brook Trout presence in Childs River by sampling location (Lower Childs River south of Carriage Shop Road, the former FRGC pond north of Carriage Shop Road, and the area below the former Farley Bog) and by season. The spring catch, conducted in May or June, shows the rapid response and reintroduction of the Brook Trout to the former FRGC pond and Farley Bog area of the river whereby construction ended in August 2021 and by spring of 2022, Brook Trout presence went from zero or near zero to nearly twenty individuals at these more northern sections.

Additionally, Figure 50 also shows the impact of the restoration on fish species surviving the summer months and/or spawning in the river. The fish stayed in the more northern areas of the river during the most stressful time of the year indicating the habitat maintains its high quality throughout the season. Also, the total catch went from almost 70 in the spring to over 80 in September, which combined with the size frequency data, suggests that the Brook Trout successfully spawned in the river.

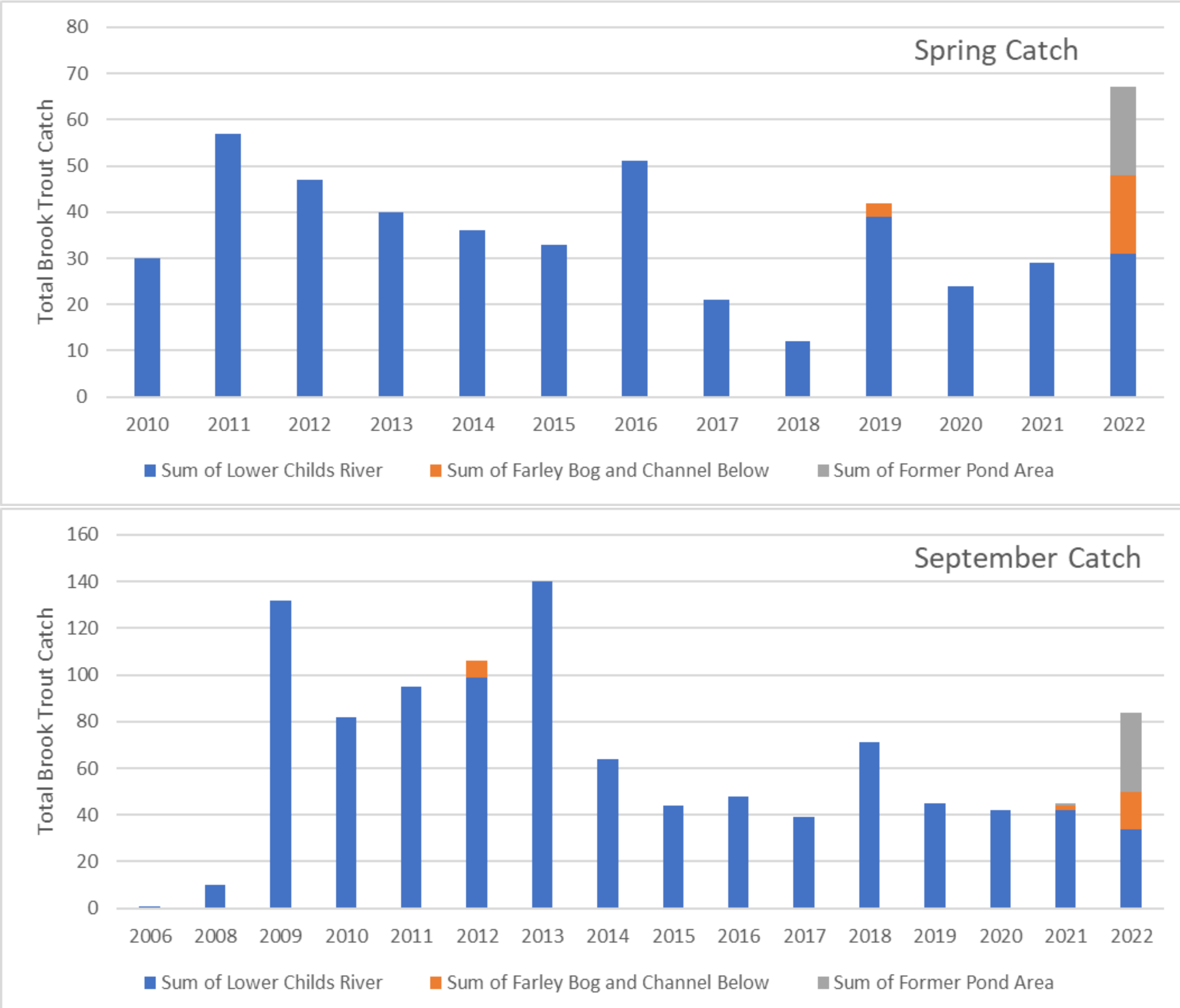

Figure 50: Total Brook Trout catch per year shown by area and by season.

PIT Antennas

The Farley Bog (# 3) and Pond antenna (#2) have worked continuously since installation without errors until the last check on October 28. The Barrows Street new antenna (0.9) has had two unplanned shutoffs in October, October 9-12 and October 19-28. In the first outage, the last test tag read at 7:23 am on October 9 and antenna was restarted at 2:18 pm on Oct 12. In the second outage, the last test tag read was at 5:45 am on October 19 and the antenna was restarted at 11:17 am on October 28. The antenna shuts off when voltage drops to about 22 volts and then does not automatically restart, a manual reset of all the circuit breakers returns the unit to normal operation. The voltage drops are caused by the low sun angle in combination with shade by trees with leaves at this time of year. The panels at this location were raised to increase solar charging voltage and leaf drop should reduce this problem of unplanned outages. The existing antenna allowed detections of some fish during these time periods.

As of October 18, 2022, the new antenna in the Farley Bog (antenna #3) had detected 20 Brook Trout, 44 Brook Trout were detected by the Old Pond antenna (#2), and 26 Brook Trout were detected by the new

Barrows Street antenna (#0.9). A total of 63 unique Brook Trout (out of 166 trout tagged in 2021 and 2022) were detected by the antennas between May 31 and October 31, 2022. Six Brook Trout were detected by all 4 antennas indicating easy passage through the newly restored areas, six Brook Trout were only detected by the Farley bog antenna, 23 were only detected in the pond area and eight Brook Trout were only detected near Barrows Street. Figure 51 and Figure 52 demonstrate this movement throughout the river and use of the newly restored habitat (antenna sites #3 and #2) for two tagged trout. See Appendix A for full table of all pit tag antenna recordings.

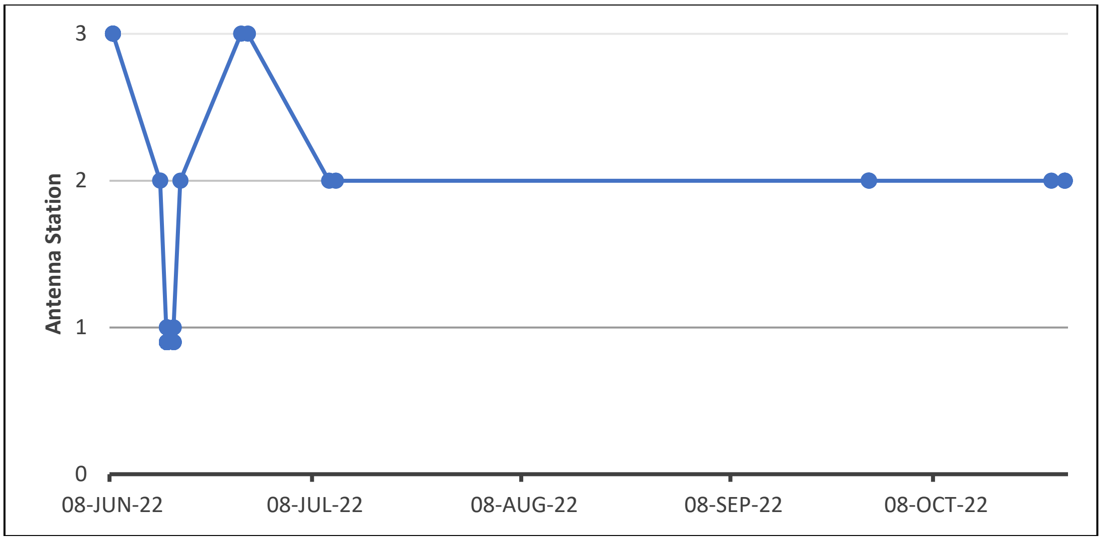

Figure 51: Movement pattern of 109-mm Brook Trout (#900.067000199301) tagged in the lower river near the Riverways Gage in May 2022, showing movement between tidal area at Barrows Street (Antennas #0.9 and 1) and restored areas Farley Bog (#3) and former Pond area (#2) in June with summer residency likely in pond area.

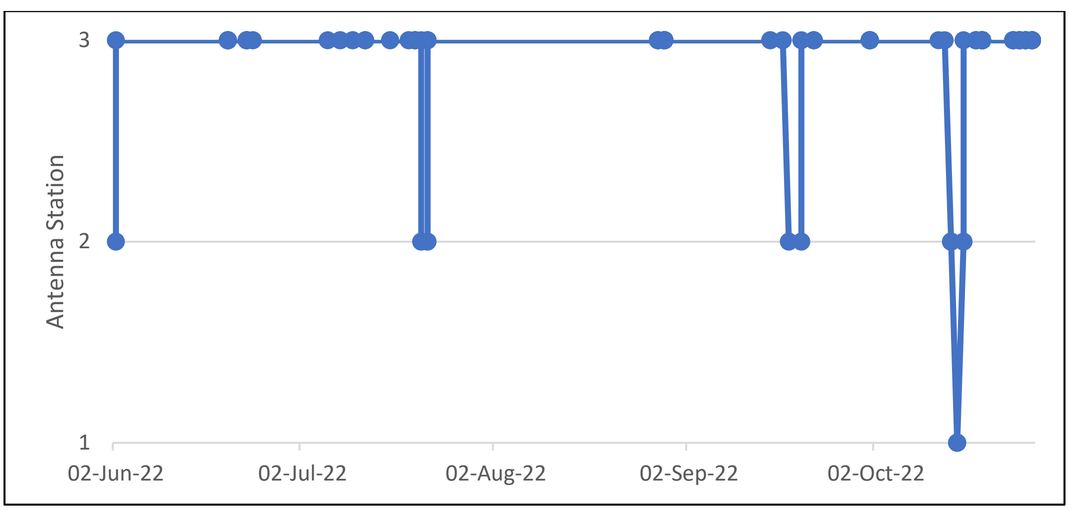

Figure 52: Movement pattern of 171 mm Brook Trout (# 900.067000198966) tagged in Farley Bog (#3) on May 18, 2022, showing primary residency in Farley Bog Area (#2) with excursions to former pond area and tidal Barrows Street area (#1).

Channel Status and Brook Trout Habitat

As of May of 2022, the newly restored areas in the old pond had good Brook Trout habitat with excellent hiding cover. Garner Bog habitat is limited by low flow and limited amounts of water. In September, noticeable changes were observed in the stream channels in the former pond area and Farley Bog area, overgrown vegetation limited flow in the upper reaches of both areas. Additionally, silt pockets were observed in the upper reaches of the Farley Bog area, which can limit flow and inhibit Brook Trout spawning. Shading from larger shrubs and trees as well as careful monitoring, and possible removal, of silt pockets would improve instream habitat in this area.

4) Vegetation Surveys

The plants in the former bog systems largely recolonized naturally from the seed bank although some plantings did occur on the edge and in the newly constructed ponds of the former bogs. Photos in Figure 53 show the change in vegetation and density of growth in Farley Bog from pre-restoration (2017) to post-restoration (2021). Since the bog construction was completed by spring 2021, the data from the vegetation survey conducted at the end of the first growing season in 2021 were used to compare pre- and post-restoration plant communities.

Figure 53: Top: Plant composition in Farley Bog pre-restoration in 2017 (credit: Chris Neill, Woodwell Climate Research Center). Bottom: Plant composition in Farley Bog post-restoration in 2021 (credit: Chris Neill, Woodwell Climate Research Center).

Prior to the restoration, the plant community was largely composed of cranberry (*Vaccinium macrocarpon)* - between 55-75% of the survey plots, on average. While cranberry is a native species, the aim of the restoration was to enhance the richness and diversity of the plant species in the former bog areas.

Preliminary results from 2021 suggest that there are more different species (i.e., higher species richness) following the restoration than before restoration (Figure 54). In Farley Bog, the species richness went up from 49 species to 82 total species. In Garner Bog, the species richness increased from 60 species to 94 total species. Additionally, based on early findings from the 2021 data wetland species and wetland species cover (abundance) after restoration than pre-restoration (Figure 55) suggesting that the restored conditions are promoting wetland species which are adapted to withstand higher soil moisture and flooding than upland species.

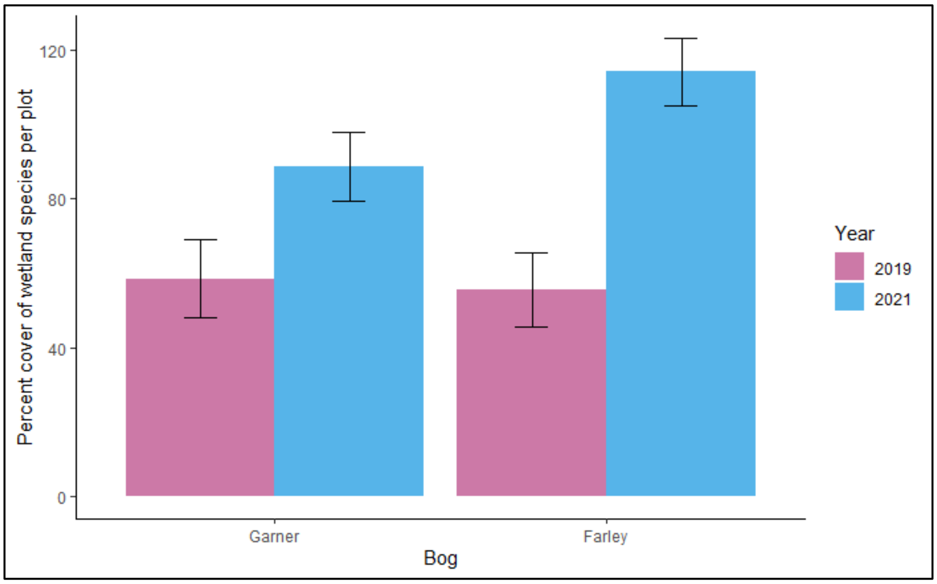

Figure 54: Average percent cover of wetland species in former Garner and Farley Bog pre- (2019) and post-restoration (2021).

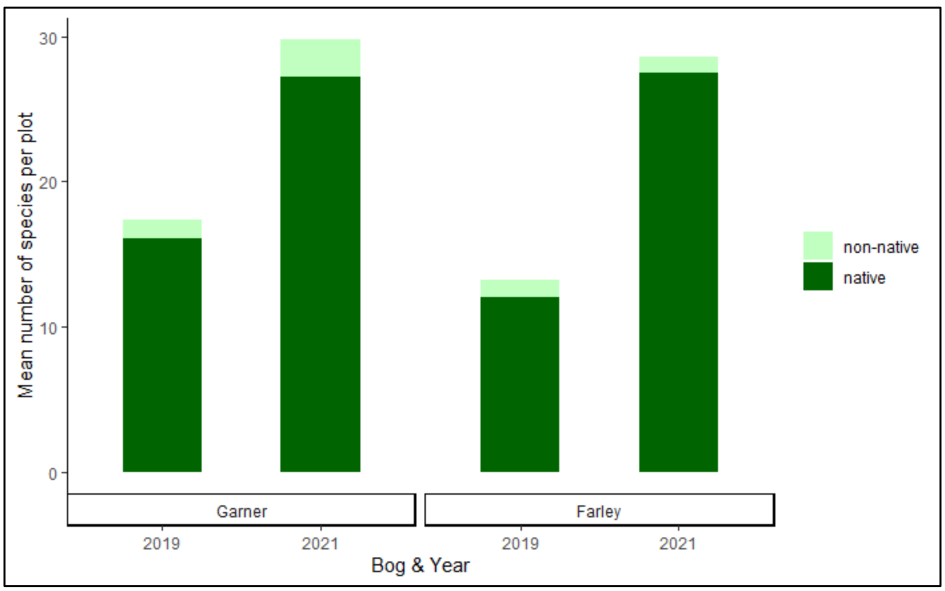

Figure 55: Comparison of average number of species per plot (measure of species richness) in the former Garner and Farley Bogs pre- and post-restoration (2019 vs. 2021).

5) Acoustic Recordings

Table 4 provides a list of all the bird species identified by the Merlin smartphone app (created by the Cornell Ornithology Lab) within six five-minute segments selected from the morning (6:10 EDT) and evening (18:40 EDT) acoustic logger recordings collected at Garner Bog before and after construction as well as the wooded area south of Garner Bog post-construction. The lists should not be viewed as comprehensive bird species lists since they reflect only a subset of the recordings and morning and evening calls. However, the lists can be used to compare relative bird call activity at these particular times of day in July across the construction phases and locations.

Table 4: List of bird species identified using the Merlin smartphone app from 5-minute acoustic recordings (Wildlife Acoustics Song Meter) collected at the Garner Bog in 2020 (pre-restoration) and 2022 (post-restoration) and in wooded area south of Garner Bog in 2022 (post-restoration). Lists include birds identified during six morning and six evening recordings (see Appendix B for raw data). *Note this list is derived from a subsample of recordings and should not be considered a comprehensive list of bird species present at these sites.*

Garner Bog 2020 (pre)	**Garner Bog 2022 (post)**	**CR Woods 2022 (post)**
American Crow	American Robin	American Crow
American Goldfinch	Black-capped Chickadee	American Goldfinch
American Robin	Blue Jay	American Robin
Black-capped Chickadee	Cedar Waxwing	Black-capped Chickadee
Blue Jay	Common Grackle	Blackpoll Warbler
Blue-gray Gnatcatcher	Downy Woodpecker	Blue Jay
Carolina Wren	Eastern Towhee	Common Grackle
Common Grackle	Eastern Whip-poor-will	Eastern Phoebe
Common Yellowthroat	Great Egret	Eastern Towhee
Downy Woodpecker	Gray Catbird	Great Crested Flycatcher
Eastern Kingbird	Great Blue Heron	Hermit Thrush
Eastern Phoebe	Hairy Woodpecker	House Finch
Eastern Towhee	Northern Cardinal	Northern Cardinal
Eastern Wood-Pewee	Northern Flicker	Ovenbird
Great Crested Flycatcher	Red-bellied Woodpecker	Pine Warbler
Grasshopper Sparrow	Red-tailed Hawk	Red-bellied Woodpecker
Gray Catbird	Red-winged Blackbird	Ruby-throated Hummingbird
Hairy Woodpecker	Song Sparrow	Scarlet Tanager
Mourning Dove	White-breasted Nuthatch	Tufted titmouse
Northern Cardinal	White-eyed vireo	
Northern Flicker	White-throated sparrow	
Red-tailed Hawk		
Red-winged Blackbird		
Song Sparrow		
Tufted titmouse		
White-breasted Nuthatch		
White-throated sparrow		
Yellow-breasted Chat		
Total: 29 species	**Total: 21 species**	**Total: 19 species**

The bird species lists indicate that there was generally higher species richness (or greater number of different species) present prior to construction at the Garner Bog compared to after construction. There were also wading birds (Great Blue Heron and Great Egret) identified following the construction that were not identified in the recording segments in 2020. Lastly, species varied between the Garner Bog and Wooded areas in 2022 such that only seven of the bird species identified were present at both locations.

Figure 56 provides average bird species richness obtained from six morning (6:10-6:15EDT) and six evening (18:40-18:45) acoustic recording segments collected in July at the same location in Garner Bog pre- and post-construction (2020 and 2022). Average species richness from the morning segments was similar pre- to post-construction. However, evening species richness was higher pre-construction than post-construction at Garner Bog. This difference in species richness suggests that there was less bird activity in the evening in the former Garner Bog. The reason behind this reduction in activity is unclear, but it may be a response to the disturbance on the site and change in vegetated habitat, or shelter from predators.

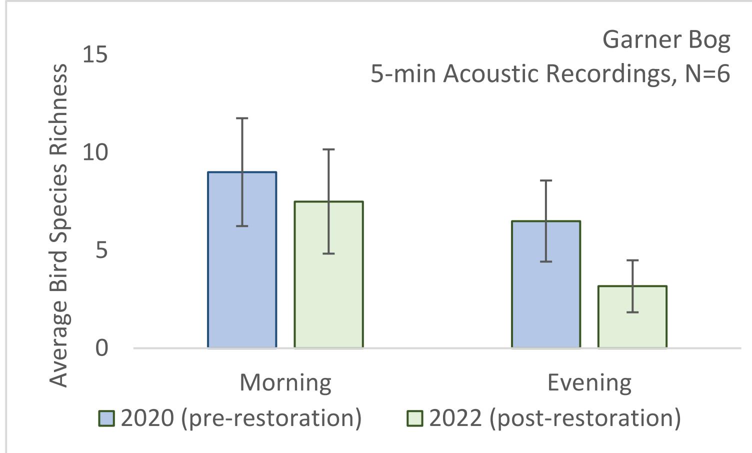

Figure 56: Average bird species richness identified during five-minute segments of morning (6:10-6:15 EDT) and evening (18:40-18:45 EDT) acoustic logger recordings collected at Garner Bog pre- and post-restoration (2020 and 2022, respectively). N = sample size. Bird species were identified using the Merlin smartphone app (see Appendix B for raw data).

The results from the acoustic index analysis for recordings collected at the Garner Bog pre- and post-construction (2020 and 2022, respectively) are provided in Figure 57. There was no change in ACI suggesting that the overall variability in acoustic activity within a recording did not change as a result of the construction. The cause behind the increase in ADI is uncertain as this parameter measures the range of acoustic energy across frequency bands. According to Bradfer-Lawrence and co-authors, higher values generally indicate higher levels of geophony (e.g., wind or rain) and anthrophony (e.g., aircraft or motorized vehicles).[19] Thus, the difference may reflect a windier season in 2022. The Bio index seems to show similar results as the bird presence survey shown above whereby there was more bird activity (calls) prior to restoration at the Garner Bog. The uptick in biological sound in 2022 during the latter evening recordings is more likely reflecting nocturnal insect and frog vocalizations.

[19] Bradfer-Lawrence, Tom, et al. “Guidelines for the Use of Acoustic Indices in Environmental Research.” *Methods in Ecology and Evolution*, vol. 10, no. 10, 21 June 2019, pp. 1796–1807., doi:10.1111/2041-210x.13254.

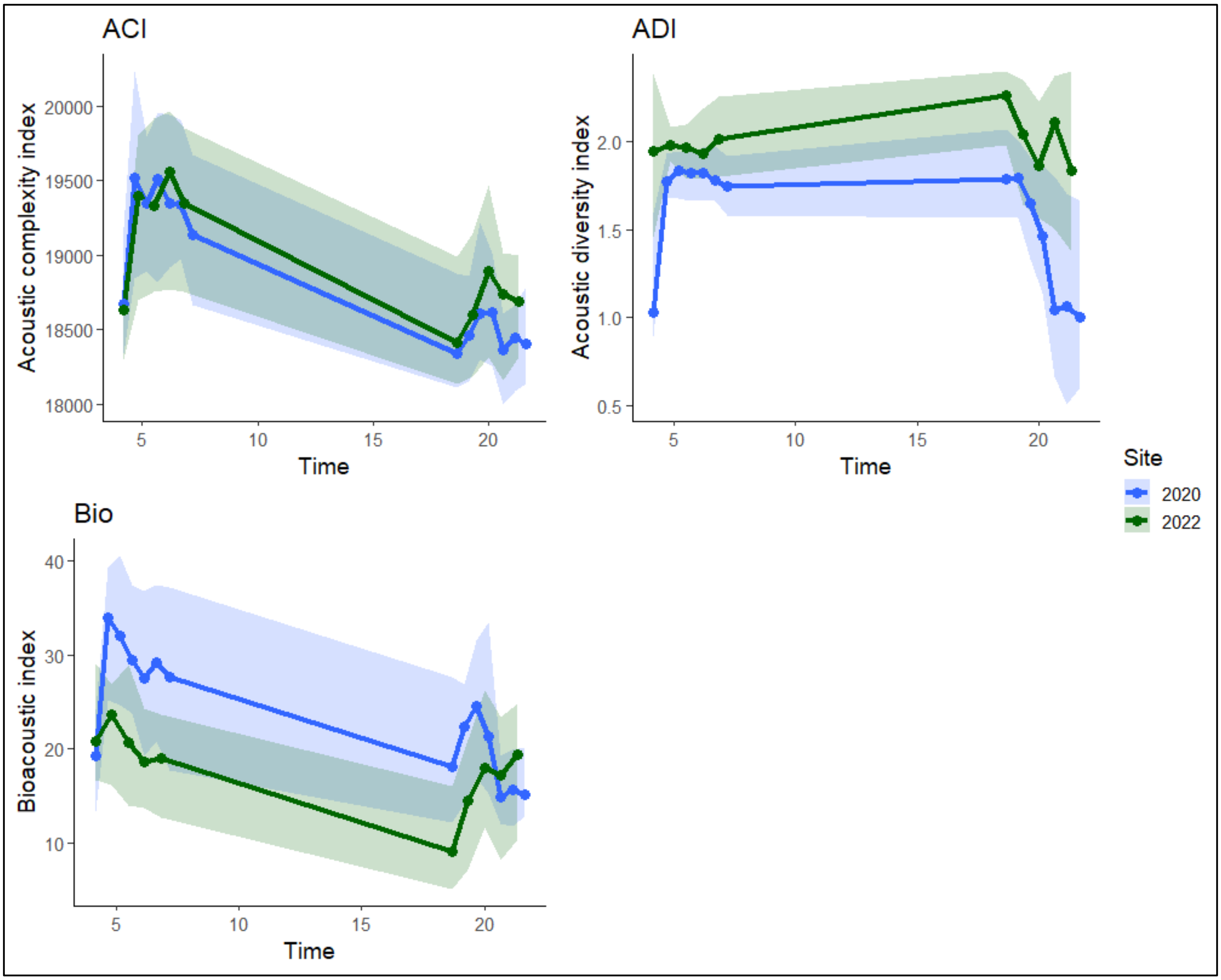

Figure 57: Comparison of acoustic indices at Garner Bog pre- and post-construction derived from ten-minute recordings collected in summer (June and July) 2020 and 2022. Lines and points represent medians (by day) and surrounding ribbons provide 25th percentile and 75th percentile of values. Normalized Difference Soundscape Index not available. Analysis and graphics provided by Allison Noble.

Figure 58 shows average bird species richness at the former Garner Bog compared to the downriver wooded area in July 2022 based on the six morning (6:10-6:15 EDT) and six evening (18:40-18:45 EDT) acoustic recording segments. There was greater species richness (or higher number of different bird species) at the former Garner Bog during the morning and evening time periods. However, the difference was more pronounced in the evening. These results suggest that there is greater bird activity and vocalizations at the former Garner Bog, which was recently disturbed due to restoration construction, than the undisturbed wooded area downriver.

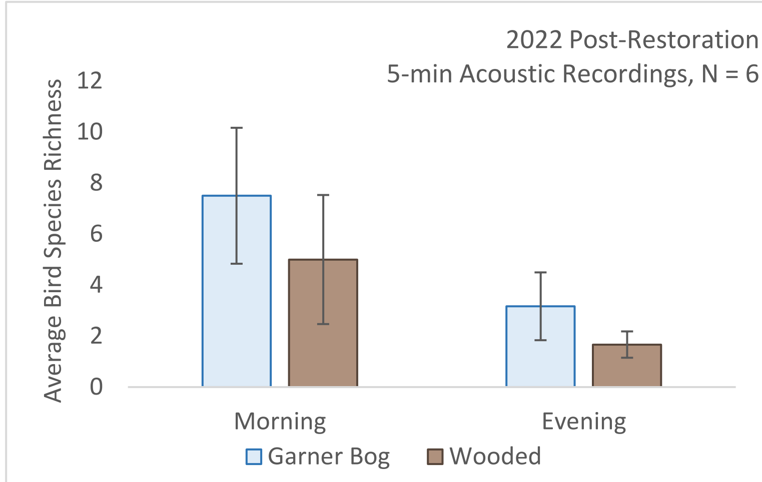

Figure 58: Average bird species richness calculated from five-minute segments of morning (6:10-6:15 EDT) and evening (18:40-18:45 EDT) acoustic logger recordings collected at Garner Bog and wooded area downriver post-restoration (2022). N = sample size. Bird species were identified using the Merlin smartphone app (see Appendix B for raw data).

Figure 59 provides the results from the index analyses for the former Garner Bog and the wooded area downriver. These data are based on ten-minute recordings collected in July 2022. The difference in ACI is likely a result of green and bull frog vocalizations (*Lithobates clamitans* and *Lithobates catesbeianus*, respectively) as this was a very apparent difference in listening to the recordings. ADI was very similar between the two sites although there was greater variability in the wooded area. This increased variability in the wooded area may reflect more wind noise from the trees since other human noise (aircraft and motorized vehicles) was minimal at both sites. The Bio index shows similar vocalization intensity between the two habitats although there were more evening bird vocalizations in the former Garner Bog. This trend of higher evening bird activity in the former Garner Bog was also seen in the bird identification survey (see Figure 58). The NDSI is likely reflecting the difference in ACI and Bio index between the two sites (i.e., frog call and wind influence).

In conclusion, there were three major findings from the acoustic recording analyses. First, the results suggest that bird call activity was greater in the Garner Bog prior to construction/restoration. The reduction in activity may be due to the disturbance to the birds' habitat and nesting areas but is expected to increase over time as vegetation grows throughout the site providing more shelter from predators. Long-term acoustic monitoring in the Garner Bog would improve our understanding of why bird activity decreased one-year after construction and could track the potential recovery of bird species following the bog restoration.

Secondly, the addition of waterfowl species, such as the Great Blue Heron and Great Egret, in the species presence list following restoration in 2022 may be an indication that these birds are more prominent now as result of the added pools. Based on the recordings, these pools appear to support various frog species, known prey for the Great Blue Heron and Great Egret.

Lastly, the analysis from the Garner Bog and wooded area recordings showed that these two habitats support a different composition of bird species. Also, these two habitats differ significantly in regards to insect and frog presence due to the lack of pools in the wooded site. Thus, the comparison of these two locations to discern variations related to undisturbed to disturbed habitat was confounded by their differences in physical structure and continued monitoring at these two locations is not recommended long-term.

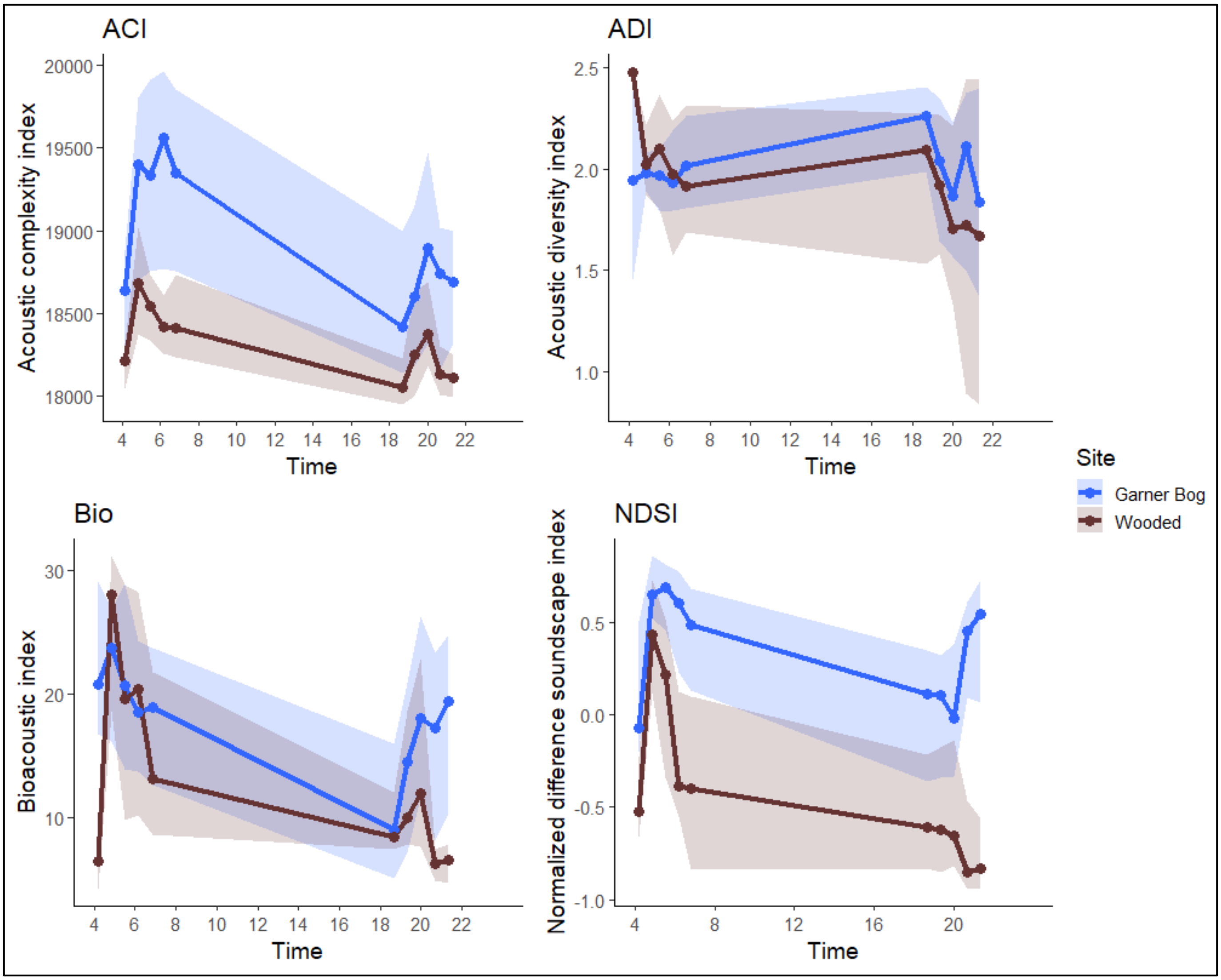

Figure 59: Comparison of acoustic indices at Garner Bog and downriver wooded area post-construction derived from ten-minute recordings collected in July 2022. Lines and points represent medians (by day) and surrounding ribbons provide 25th percentile and 75th percentile of values. Analysis and graphics provided by Allison Noble.

E. KEY FINDINGS SUMMARY

To summarize the key findings from the river restoration monitoring data, each major restoration objective is discussed below.

1. Reduce temperature and increase dissolved oxygen by increasing water flow to improve and provide new coldwater habitat for Brook Trout as well as improved habitat for other aquatic species.

The restoration effort successfully reduced summer water temperatures in the Childs River. Based on the data from the loggers, the summer water temperature decreased most notably at the stations located near the former FRGC pond near Carriage Shop Road and below Farley Bog. Following the restoration, the water temperature from these three stations dropped to below the stress threshold for freshwater species of 68°F. The decreased temperature likely resulted from the shift of the river channel to the western side of the site and the removal of the ponds and bog structures, which allowed for faster moving water and a better infiltration with the cooler groundwater table. Furthermore, the results from the June-August average comparison across construction phases showed downward trends in temperature at many of the other sampling stations. The Garner Bog also showed trends towards decreasing temperature which suggests that even though the flow was still relatively slower at the former Garner Bog after restoration, the new river channel still resulted in improvements in temperature. This trend may continue as shrubs and trees mature and shade the area.

Additionally, the dissolved oxygen also improved following the restoration. The continuous data logger results indicate that the dissolved oxygen does not get as low during nighttime in the summer when respiration is high and oxygen production from photosynthesis is low. Reducing the range in dissolved oxygen is beneficial for aquatic species, especially freshwater fish, as extreme lows overnight followed by cloudy days can be too stressful and result in fish kills like those seen in the summer of 2000. The optimum dissolved oxygen level for fish survival is at or above 6 mg/L. Following the restoration, the daily minimum for dissolved oxygen improved from periods below 2 mg/L in July through September to a steadier state (less fluctuation) at around 6 mg/L. This improvement in dissolved oxygen was likely caused by the reduced temperature and increased circulation from the more natural water flow which was reestablished as part of the restoration.

2. Provide Brook Trout and other fish species access to new and improved habitat as measured by increased presence and successful spawning of Brook Trout in the upper Childs River.

The Childs River restoration effort successfully created new habitat for the Brook Trout as seen by the increased presence of this species north of the Carriage Shop Road and around the former Farley Bog (Figure 60). Evidence that the habitat has improved is available from the temperature and dissolved oxygen data but is also corroborated by the September surveys (data collected from 2006 through 2022) which showed that Brook Trout spawned successfully and in higher numbers than before the restoration.

Figure 60: One of the two Childs River Brook Trout captured in the New Farley bog Channel, September 16, 2021 (credit: Steve Hurley).

Although the former bogs and pond have revegetated quickly, providing good shelter and safety from predators, observations of sediment pockets in the upper reaches of the former Farley and Garner Bogs are cause for concern as release of sediments downstream could result in impairment of spawning habitat. Sediment pockets should be carefully monitored near-term, and if deemed necessary to sustain Brook Trout populations by MassWildlife, accumulated silt and sediments could be removed using low-impact equipment. However, it's critical that these areas be handled sensitively as removal of sediments may interfere with the stream's long-term geomorphological processes.

3. Improve water quality (i.e., reduce nutrients and specific conductivity, increase pH and minimum dissolved oxygen) to enhance Waquoit Bay estuarine aquatic habitat and water quality downriver.

Although the concentrations of some of the nutrient parameters monitored increased both during and one year after construction relative to pre-construction levels (mainly nitrate, ammonium, and silica), the restored riverine system has shown some encouraging trends post-construction. The data suggests that the restored river regained natural attenuation functions following construction in the spring of 2022 such that the nutrients were actively taken up or cycled into other forms within the former bogs and lower river. For example, nitrate was higher overall in 2022 following the restoration but each section of the river showed some attenuation indicating that as the vegetation and microbial communities continue to mature, these levels will likely decline over time. Ammonium spiked during construction and was highest where temperatures are higher. As temperatures decrease (with increased vegetation growth and shading) and as long as the system stays saturated with constant water flow, ammonium should remain low or decrease without such high periodic spikes. Silica was also elevated during construction but mostly resumed to lower levels post-restoration indicating that the disruption of the sediments from creating the channel and the storm-induced erosion were the likely causes of those increases.

The slight but discernable declining trend in dissolved organic carbon is a good sign that water flows have increased, reducing water residence time and decomposition of organic matter. Although dissolved organic carbon is an important food source for the base of the food web, higher levels of dissolved carbon may result from high respiration rates and cause a subsequent reduction in pH. The pH is already relatively low at this site with levels in the Garner Bog near 4.0 pre-restoration and around 5.0 post-restoration. The low pH in the former Garner Bog is likely caused by the legacy acidic peat soils of the bog. That said, pH did improve (increase) slightly following restoration, so this may continue overtime further improving the habitat for fish and increasing rates of denitrification over the long-term.

Last but not least, the Childs River continues to act as a source of phosphorus in the watershed. Although the overall phosphate levels are low, relative to EPA water quality standards, the export of phosphate downriver should be monitored long-term since this is one of the limiting nutrients for algal growth in the estuary downriver. Phosphorus generally acts as the limiting nutrient in the estuarine extent of the Childs and Quashnet River during the spring and early summer. However, once phosphorus peaks in July (when low oxygen levels result in a release of phosphate from the soils), nitrogen becomes the limiting nutrient from July through the fall. Thus, reducing phosphate release upriver could improve the aquatic habitat and water quality in the estuary. As the plant community continues to mature in the freshwater ponds in the former Garner and Farley Bogs and along the shallow river, the freshwater plants should take up more phosphorus from the soils, but more research and data collection are needed to track this possible scenario.

4. Restore wetlands and enhance habitat diversity in the upper Childs River for wildlife and waterfowl by encouraging the growth of wetland plants, creating ponds, and establishing conditions for self-sustaining wetlands (i.e., raising the groundwater table).

Based on preliminary data from the plant surveys conducted in the former Garner and Farley Bogs, the low-lying area that was previously part of the bogs has transitioned to a more diverse array of wetland plants, as indicated by the higher species richness seen in 2021. Additionally, non-native species are still only a very small proportion of the overall plant composition. The non-native, or invasive, species growth will be monitored for three years following restoration and any invasives plants will be removed. Additional monitoring and maintenance may be required.

Although the results from the vegetation data analysis suggest higher species richness and rapid recolonization by native plants at the two former bog sites, bird species richness at Garner Bog did not show the same trend. The number of different bird species declined slightly following the restoration, especially during the evening recordings, and the acoustic Bio index indicated a drop in overall bird vocalizations. Even though there was not an increase in bird species richness following restoration, two waterfowl species, the Great Blue Heron and Great Egret, were identified by the Merlin app in the selected post-restoration recordings but not in the selected pre-restoration recordings. The generated species list represents only a subset of the overall recorded bird calls, but this finding seems to suggest that the restored former Garner Bog encourages wading birds by providing adequate habitat.

The decline in overall bird species richness and vocalizations may be a result of the disturbance caused during construction whereby larger, older shrubs were removed and replaced by herbaceous and younger shrubs. This change to the physical structure of the habitat may have reduced shelter from predators, making the area less desirable for passerine birds (birds better suited for perching, e.g., songbirds). Long-term acoustic monitoring combined with ongoing vegetation surveys could help confirm this theory and would be a useful means to track restored habitat use by birds over time.

APPENDICES

APPENDIX A: Brook trout detected by four PIT antennas in the Childs River, May 31, 2022 - October 31, 2022.

Childs River Antenna Data									
Antenna Tag Number	**Tagging Date**	**Location**	**Length**	**Capture**	**Count of Childs Antenna_ID**	**0.9**	**1**	**2**	**3**
900.067000199032	9/16/2021	bend below to tree across river	101	1	53582			10/28/2022	
900.067000207006	9/13/2022	Below Carriage Shop Road	119	1	2857			10/28/2022	
900.067000206933	9/14/2022	Below Farley and Lower Farley Bog	106	1	30			10/27/2022	10/28/2022
900.067000199372	5/18/2022	Farley Bog Lower	192	1	211			10/27/2022	10/28/2022
900.067000199301	9/16/2021	tree across river to above gage	109	1	214	6/17/2022	6/17/2022	10/27/2022	6/28/2022
900.067000207374	9/13/2022	Below Carriage Shop Road	111	1	11			10/27/2022	
900.067000206965	9/13/2022	Below Carriage Shop Road	117	1	257			10/27/2022	
900.067000199066	5/18/2022	Farley Bog Lower	207	1	847			10/26/2022	10/26/2022
900.067000198939	5/18/2022	Below Farley Bog	178	1	23	8/20/2022	8/20/2022	10/26/2022	7/2/2022
900.067000198899	9/16/2021	bend below to tree across river	82	1	1012			10/25/2022	9/14/2022
900.067000207120	9/14/2022	Above and Below Gage	109	1	1			10/24/2022	
900.067000207181	9/13/2022	Below Carriage Shop Road	113	1	5			10/24/2022	
900.067000207131	9/14/2022	Above and Below Gage	109	1	34			10/17/2022	
900.067000198966	5/18/2022	Farley Bog Lower	171	1	424		10/15/2022	10/16/2022	10/27/2022
900.067000207211	9/14/2022	Above Carriage Shop Road	118	1	824			10/16/2022	

Childs River Antenna Data									
Antenna Tag Number	Tagging Date	Location	Length	Capture	Count of Childs Antenna_ID	0.9	1	2	3
900.067000207121	9/13/2022	Below Carriage Shop Road	119	1	17			10/14/2022	
900.067000207186	9/14/2022	Above Carriage Shop Road	130	1	243			10/13/2022	
900.067000199104	9/16/2021	tree across river to above gage	93	1	604	10/31/2022	10/31/2022	10/8/2022	
900.067000207093	9/13/2022	Below Carriage Shop Road	105	1	23			10/6/2022	
900.067000199204	5/18/2022	Farley Bog Lower	190	1	52			10/5/2022	10/5/2022
900.067000207146	9/13/2022	Below Carriage Shop Road	131	1	13			10/5/2022	
900.067000207090	9/14/2022	Above Carriage Shop Road	215	1	14			10/5/2022	
900.067000198911	5/18/2022	in Old Pond Area	161	1	1726			10/1/2022	
900.067000198948	5/18/2022	in Old Pond Area	171	1	28	9/24/2022	9/24/2022	9/28/2022	
900.067000207184	9/13/2022	Barrows Street To Big Bend	215	1	50	9/20/2022	9/20/2022	9/25/2022	9/25/2022
900.067000199011	9/16/2021	tree across river to above gage	106	1	65	10/29/2022	10/29/2022	9/25/2022	
900.067000199019	9/16/2021	tree across river to above gage	116	1	11			9/23/2022	9/23/2022
900.067000207159	9/13/2022	Below Carriage Shop Road	199	1	16	10/8/2022		9/23/2022	
900.067000207178	9/14/2022	Below Farley and Lower Farley Bog	222	1	21	10/9/2022	9/23/2022	9/17/2022	9/14/2022
900.067000207368	9/14/2022	Above Carriage Shop Road	174	1	266			9/16/2022	
900.067000199309	5/18/2022	Below Farley Bog	185	1	307	6/14/2022	6/14/2022	9/14/2022	

Childs River Antenna Data									
Antenna Tag Number	Tagging Date	Location	Length	Capture	Count of Childs Antenna_ID	0.9	1	2	3
900.067000199239	5/18/2022	Big Bend to tree across river	184	1	27			9/14/2022	
900.067000199224	5/18/2022	in Old Pond Area	150	1	16			9/14/2022	
900.067000199334	5/18/2022	in Old Pond Area	178	1	30			9/14/2022	
900.067000199024	5/18/2022	in Old Pond Area	173	1	68			9/13/2022	
900.067000199354	5/18/2022	Big Bend to tree across river	178	1	21	9/4/2022	9/4/2022	9/7/2022	
900.067000199065	9/16/2021	tree across river to above gage	123	1	71	9/13/2022	9/13/2022	8/10/2022	8/10/2022
900.067000199056	5/18/2022	Above and Below gage	170	1	11	7/5/2022		7/6/2022	
900.067000199235	5/18/2022	Above and Below gage	195	1	4	6/18/2022		6/22/2022	
900.067000199350	5/18/2022	Barrows Street To Big Bend	210	1	164	6/22/2022	6/20/2022	6/17/2022	6/16/2022
900.067000199275	9/16/2021	bend below to tree across river	108	1	1			6/14/2022	
900.067000199103	5/18/2022	Above and Below gage	147	1	1			6/12/2022	
900.067000198913	9/16/2021	tree across river to above gage	113	1	2			6/12/2022	
900.067000199217	9/16/2021	tree across river to above gage	109	1	1			6/10/2022	
900.067000206932	9/14/2022	Below Farley and Lower Farley Bog	122	1	4774				10/28/2022
900.067000207065	9/14/2022	Below Farley and Lower Farley Bog	113	1	1048				10/28/2022
900.067000207309	9/14/2022	Below Farley and Lower Farley Bog	103	1	1832				10/28/2022
900.067000207377	9/14/2022	Below Farley and Lower Farley Bog	112	1	8				10/27/2022

Childs River Antenna Data									
Antenna Tag Number	**Tagging Date**	**Location**	**Length**	**Capture**	**Count of Childs Antenna_ID**	**0.9**	**1**	**2**	**3**
900.06700020 6942	9/14/2022	Below Farley and Lower Farley Bog	125	1	20				10/25/2022
900.06700020 7247	9/14/2022	Below Farley and Lower Farley Bog	133	1	298				10/17/2022
900.06700019 9033	5/18/2022	Farley Bog Lower	237	1	81878				8/27/2022
900.06700020 6956	9/14/2022	Above and Below Gage	110	1	12	10/31/2022	10/31/2022		
900.06700020 7030	9/13/2022	Barrows Street To Big Bend	251	1	90	10/31/2022	10/31/2022		
900.06700019 9200	5/18/2022	Big Bend to tree across river	140	1	3141	10/31/2022	10/31/2022		
900.06700020 7204	9/13/2022	Barrows Street To Big Bend	235	1	4	9/29/2022			
900.06700020 7129	9/13/2022	Barrows Street To Big Bend	233	1	4	9/24/2022	9/24/2022		
900.06700019 9249	5/18/2022	in Old Pond Area	163	1	571	9/18/2022	9/20/2022		
900.06700019 8986	5/18/2022	Big Bend to tree across river	174	1	4	9/11/2022			
900.06700019 9205	5/18/2022	Barrows Street To Big Bend	163	1	131	9/5/2022	9/5/2022		
900.06700019 8994	5/18/2022	in Old Pond Area	175	1	3	7/21/2022	7/21/2022		
900.06700019 8947	5/18/2022	Above and Below gage	206	1	593	6/22/2022	6/22/2022		
900.06700019 9351	5/18/2022	Barrows Street To Big Bend	159	1	24	6/20/2022	6/20/2022		
900.06700019 8933	9/16/2021	tree across river to above gage	175	1	1	6/11/2022			

Appendix B: Raw data results from bird species presence survey conducted using the Merlin smartphone app to identify bird calls from five-minute recordings. Morning = 6:10-6:15 EDT. Evening = 18:40-18:45 EDT. Pre = Pre-restoration (July 2020); Post = Post-restoration (July 2022).

Site	Date	Time	Restoration Phase	American crow	American Goldfinch	American Robin	Belted Kingfisher	Black-capped Chickadee	Blackpoll Warbler	Blue Jay	Blue-gray Gnatcatcher	Carolina Wren	Cedar Waxwing	Common Grackle	Common Yellowthroat	Downy Woodpecker	Eastern Kingbird	Eastern Phoebe	Eastern Towhee	Eastern Whip-poor-will	Eastern Wood-Pewee	Great Crested Flycatcher	Great Egret	Grasshopper Sparrow	Gray Catbird	Great Blue Heron	Hairy Woodpecker	Hermit Thrush	House Finch	Mourning Dove	Northern Cardinal	Northern Flicker	Ovenbird	Pine Warbler	Red-bellied Woodpecker	Red-tailed Hawk	Red-winged Blackbird	Ruby-throated Hummingbird	Scarlet Tanager	Song Sparrow	Tufted titmouse	White-breasted Nuthatch	White-eyed vireo	White-throated sparrow	Yellow-breasted Chat	**Species Richness**
Garner Bog	7/8/2020	Morning	Pre	1	1					1					1				1																						1				1		**7**
Garner Bog	7/10/2020	Morning	Pre					1		1		1		1	1				1			1									1					1				1	1					**11**
Garner Bog	7/12/2020	Morning	Pre							1					1			1	1																	1				1					1	**7**
Garner Bog	7/17/2020	Morning	Pre			1		1		1				1	1				1		1				1												1			1						**10**
Garner Bog	7/21/2020	Morning	Pre					1		1	1	1		1		1			1						1												1			1	1	1		1		**13**
Garner Bog	7/23/2020	Morning	Pre					1		1		1							1						1																1					**6**
Garner Bog	7/9/2020	Evening	Pre	1						1		1			1				1								1									1				1	1					**9**
Garner Bog	7/12/2020	Evening	Pre					1		1																										1				1						**4**
Garner Bog	7/17/2020	Evening	Pre							1				1					1		1										1						1			1						**7**
Garner Bog	7/21/2020	Evening	Pre					1		1							1		1					1	1					1						1										**8**
Garner Bog	7/23/2020	Evening	Pre			1				1									1						1						1	1								1						**7**
Garner Bog	7/27/2020	Evening	Pre							1															1							1				1										**4**
Garner Bog	7/8/2022	Morning	Post					1		1									1												1						1			1			1	1		**8**
Garner Bog	7/10/2022	Morning	Post			1	1	1		1				1					1						1		1				1					1	1			1						**12**
Garner Bog	7/12/2022	Morning	Post			1				1									1						1						1									1				1		**7**
Garner Bog	7/17/2022	Morning	Post							1				1		1										1					1				1					1		1				**8**
Garner Bog	7/22/2022	Morning	Post							1									1				1																	1						**4**
Garner Bog	7/23/2022	Morning	Post					1		1																						1			1	1				1						**6**
Garner Bog	7/8/2022	Evening	Post										1																		1						1									**3**
Garner Bog	7/13/2022	Evening	Post							1				1																										1						**3**
Garner Bog	7/17/2022	Evening	Post			1				1				1											1															1						**5**
Garner Bog	7/18/2022	Evening	Post																																					1						**1**
Garner Bog	7/22/2022	Evening	Post							1									1																					1						**3**
Garner Bog	7/26/2022	Evening	Post							1										1					1							1														**4**
Wooded	7/8/2022	Morning	Post							1				1					1												1		1	1				1	1				1			**9**
Wooded	7/12/2022	Morning	Post		1																																		1							**2**
Wooded	7/10/2022	Morning	Post			1			1	1									1															1					1							**6**
Wooded	7/17/2022	Morning	Post	1						1									1									1			1							1								**6**
Wooded	7/22/2022	Morning	Post							1									1			1									1															**4**
Wooded	7/23/2022	Morning	Post							1				1					1																											**3**
Wooded	7/8/2022	Evening	Post																															1											**1**
Wooded	7/13/2022	Evening	Post																1										1																	**2**
Wooded	7/17/2022	Evening	Post							1									1																											**2**
Wooded	7/18/2022	Evening	Post							1																																				**1**
Wooded	7/22/2022	Evening	Post					1																																1					**2**
Wooded	7/26/2022	Evening	Post															1	1																											**2**