Annapolis River Estuary Monitoring Project: planning for the recovery of anadromous species in the Annapolis River estuary

2023 Report

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Estuary Monitoring in the Annapolis River, Nova Scotia

The Annapolis River estuary provides important spawning, rearing and overwintering habitat for anadromous fish species during their migration upstream from the Atlantic Ocean. Historically, thriving populations of anadromous fish persisted in the river, but increased anthropogenic disturbances in recent decades have put local populations and their key habitats at risk. Three species of particular interest are striped bass (*Morone saxatilis*) Atlantic salmon (*Salmo salar*), and Atlantic sturgeon (*Acipenser oxyrhynchus oxyrhynchus*); the Annapolis River populations of all three species are listed as threatened or endangered by COSEWIC and were estimated to experience the greatest population-level impacts due to turbine mortalities during the operation of the Annapolis Tidal Generating Station (ATGS) (Gibson et al. 2019).

To address these threats, the Clean Annapolis River Project (CARP) has established its estuary monitoring program: a multi-faceted program aimed at the recovery of anadromous species in the Annapolis estuary. In its initial stages, it will provide baseline population and habitat data which will be used to identify key areas for restoration and enhancement. The findings will also be used to inform management decisions regarding the decommissioning of the ATGS, which ceased operation in 2019 following a notice from DFO to provide authorization under the Fisheries Act.

In 2022, CARP completed egg collection and beach seine surveys at sites on the Annapolis River, Allain's Creek and Bear River, Nova Scotia, targeting striped bass. Water quality sampling was conducted at locations along the Annapolis River to assess current conditions and create a profile of the thermal and saline stratification that has resulted from obstructed tidal flow around the Annapolis causeway and ATGS. Additionally, an acoustic monitoring network has been established to fill critical data gaps regarding the habitat use and movement of striped bass, Atlantic salmon, and Atlantic sturgeon in the Annapolis River estuary.

No striped bass eggs were collected during surveys in 2022. This is consistent with surveys conducted by CARP in 2010-2011, 2013-2015 and 2021, supporting the theory that the Annapolis River spawning population is extirpated. Beach seines were conducted at 17 sites on the Annapolis River, Allain's Creek and Bear River, and returned 31 different species, including juvenile striped bass. Reports submitted through CARP's volunteer angler program indicate that adult striped bass can still be found in the Annapolis River system and appear to have been increasing in number since around 2020. Water quality sampling was conducted throughout the estuary, including the deployment of five temperature sensor arrays. A profile of the thermal and saline stratification in the Annapolis River was produced, showing that stable stratification may persist as far upstream as Bridgetown. These results provide the groundwork for continued monitoring of the thermocline and halocline at different points in the seasonal and tidal cycles.

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1. Introduction

The Annapolis River flows 120km from its source in Berwick to the Annapolis Basin, encompassing a drainage area of almost 1600km^2 . Bordered by silt and clay Acadian soils, the Annapolis River valley produces rich and fertile marshland suitable for agricultural uses; as of 1984, approximately 1500 hectares of this land was used for agricultural purposes (Rice 1984). Historically, a system of dykes protected those agricultural lands from flood risk, but in the 1950s, construction of a 225m long tidal dam and causeway began in an effort to reclaim upland agricultural land and eliminate the need to maintain the already deteriorating dyke system upstream. This tidal dam imposed a physical barrier to tidal flow in the estuary, significantly reducing tidal range upstream from 10m down to only 0.5m (Gibson et al. 2019). Tidal exchange that was once uninhibited, became limited solely to water exchange through the sluice gates, 4x4m fishway, and leakage through the rockfill barrier. Such severe tidal restriction can drive changes in habitat structure, water chemistry, and community composition (Ritter et al. 2008). No environmental impact assessments were performed prior, but studies conducted since its establishment in 1960 indicated changes to the upstream microclimate and anadromous fish populations (Tidmarsh 1984).

Estuaries are defined by the mixing of freshwater and saltwater. They are highly productive ecosystems, combining the physiochemical conditions required by marine, brackish and freshwater organisms. These conditions however are highly variable and depend on the balance between fresh and saltwater input, tidal regimes, and other seasonal or physical determinants of mixing such as wind and rainfall. Some estuaries, due to high tidal exchange and turbulent motion, efficiently mix the fresh and saltwater inputs, creating a near-homogenous water column. In contrast, conditions of high freshwater input and low tidal exchange, will produce a stratified water column, known as a salt wedge. In the Annapolis River, the tidal dam and ATGS act as a physical barrier reducing tidal exchange upstream. Prior to the construction of the dam in 1960, the Annapolis estuary was vertically homogenous, and tidal influence extended as far upstream as Paradise (Daborn 1979). Since then, reduced tidal flow upstream of the barrier has resulted in a stable salt wedge estuary, with distinct stratification between the upper freshwater layer and lower dense saltwater layer (Redden et al. 1982, Rice 1984, Gibson et al. 2019, Daborn 1979). This salt wedge has been observed at least 31km upstream of the causeway near Bridgetown, with the thermocline often falling between 1.5-2m depth (Jessop 1976), though both metrics have demonstrated notable seasonal and annual fluctuation (Daborn 1979, Rice 1984).

The ecological characteristics of salt wedge estuaries are well-documented, with consistent patterns of lower turbidity, lower levels of dissolved oxygen in bottom saline waters, and higher primary production compared to their mixed counterparts (Jeong et al. 2014, Wells 1999). Excessive primary production, particularly when compounded by high nutrient inputs from agricultural runoff (which is a known concern in the Annapolis River; River Guardians reports) or other human activities, can deplete oxygen levels in the lower saline layers to levels that become harmful to aquatic life. This pattern of depressed oxygen has been observed at times in the Annapolis River (Daborn 1979, Sharpe 2007), and demonstrates the potential for severe habitat alteration as a result of changing hydrology. Additionally, benthic diversity is reported to be highest in mixed waters downstream of the Annapolis Basin, while phytoplankton is most abundant in the stable stratified waters upstream (Redden et al. 1982), suggesting possible trophic effects and changes in the distribution and abundance of food resources.

These physio-chemical effects may have been drivers of population decline in the Annapolis estuary; however, it is known that tidal barrages and turbines have direct impacts on the behaviour and survival of migrating fish (Viehman and Zydlewski 2015, Eicher 1993). Since the construction of the causeway and tidal dam, declines have been observed in many native fish populations, and several studies have reported on the mortalities attributed specifically to turbine strikes (Dadswell et al. 2018, Gibson et al. 2019, Dadswell and Rulifson 1994, Stokesbury and Dadswell 1991). Most notable are striped bass, Atlantic salmon, and Atlantic sturgeon: the only three species predicted to experience extreme or high population-level impacts from turbine mortality in the Annapolis system (Gibson et al. 2019). All three of these species demonstrate a high degree of uncertainty with respect to their current population size, structure, and life history in the area. Addressing this gap in knowledge is thus imperative for the conservation and preservation of these species in the Annapolis estuary.

Atlantic Salmon (Salmo salar)

Atlantic Salmon are a medium-sized salmonid with a pointed head and long streamlined body shape. Their coloration changes throughout their life cycle, depending on age and spawning status. Spawning and early life stages take place in well-oxygenated freshwater streams. At the smolt stage, they migrate to the ocean to mature for 1-4 years before returning to their natal rivers to spawn (COSEWIC 2010).

The Annapolis River population falls under the Southern Upland population designatable unit (DU) assigned by COSEWIC. Since 1996, salmon in this DU have declined by 61%, and as of 2000, the Department of Fisheries and Oceans predicted that 55% of rivers in this DU were extirpated, with an additional 36% at risk of extirpation (COSEWIC 2010). This population was listed as endangered by COSEWIC in 2010, citing altered hydrology, invasive fish species, and habitat fragmentation due to dams and culverts among the primary freshwater threats. Salmonid aquaculture and changes in marine ecosystems also pose a threat to their survival in marine environments, but the specific changes are not well understood. Based on their migration patterns, it is expected that the entire Annapolis River population of Atlantic salmon would have encountered the turbine in their lifetime (Gibson et al. 2019), making it a significant threat to their survival. Through CARP's fish habitat restoration program, salmon parr have been observed in the freshwater tributaries of the Annapolis River following habitat enhancement and restoration efforts, but much is still unknown about the population size and movement of these fish throughout the watershed.

Atlantic Sturgeon (*Acipenser oxyrinchus oxyrinchus*)

Atlantic Sturgeon are the largest anadromous species in the Northwest Atlantic. Females, the larger of the sexes, can reach up to 3m in length and 200kg (COSEWIC 2011). With an ancestry dating back over 200 million years, Atlantic sturgeon are of great ecological importance. Spawning occurs in rocky substrates of shallow freshwater, and young fish spend up to 6 years in fresh and brackish water before migrating to the ocean. Atlantic sturgeon are a long-lived and late-maturing species, with a generation time of about 40 years: this makes them particularly susceptible to threats. Once matured, they may return to upstream sites in the fall or spring preceding spawning, and often overwinter in the deep estuarine channels downstream of spawning sites (COSEWIC 2011).

The Annapolis River population of Atlantic sturgeon belongs to the Maritime designatable unit (DU); however little is known about Atlantic sturgeon in the Annapolis River. Prior to the operation of the ATGS, there was no knowledge of an existing current population of Atlantic sturgeon. Between 1985 and 2018, 21 mortalities were reported, including some ripe and spent females (Dadswell et al. 2018). The origin of those individuals is unknown, but their high fidelity to natal rivers suggests that they comprised a native population. Juveniles and reproductive adults have both historically been reported in the system, and a small spawning population is still thought to persist (Dadswell 2006, Dadswell and Rulifson 1994). The Maritime population of Atlantic sturgeon was listed by COSEWIC as threatened in 2011, citing threats as habitat modification, barriers to migration, poor water quality, and a general lack of quantitative data. The long lifespan and late maturity of this species, as well as the predicted small population size only increase the severity of these threats. Likelihood of turbine strike is increased due to the large size of Atlantic sturgeon (Collins 1984), and is estimated to be between 47-100%, with small increases in mortality resulting in large population-level effects (Dadswell et al. 2018). Few juveniles have been observed in the system in recent years, however, no surveys have specifically targeted this life stage in the Annapolis River until 2022, when Atlantic sturgeon were caught and equipped with acoustic tags to track and monitor their movements throughout the Annapolis estuary.

Striped bass (Morone saxatilis)

Striped bass are large-bodied fish belonging to the temperate bass family. The striped bass has a dark olive green back, sides that fade to a silvery colour and a white belly (COSEWIC 2012, Scott and Scott 1988). They have an elongate body form, with a triangular head, large mouth, and small teeth. Adult striped bass are characterized by the seven to eight dark horizontal stripes along their sides. Reaching up to 180cm in length, striped bass are high-trophic predators in estuary and coastal ecosystems, preying on various invertebrates, Atlantic silversides, clupeids, and herring, among other species (COSEWIC 2012).

Spawning, incubation, and early larval development often occur in fresh or brackish water while juvenile and adult fish make use of coastal, estuarine, and saltwater habitats (COSEWIC 2012). Winter is spent in the warmer waters of estuaries or freshwater habitats and in the spring, fish return to their natal river to spawn. Spawning is triggered by a rise in water temperature in the spring and lasts 2-4 weeks. Fertilized eggs remain suspended in the water column for their 2-3 day incubation period (COSEWIC 2012). Larvae develop in near-shore freshwater environments, feeding and growing until they reach the juvenile stage and migrate downstream to saltwater: there, they spend several years maturing into reproductive adults.

Striped bass can be found distributed along the Atlantic Coast of North America from the St. Lawrence River to the St. John's River in northeast Florida (COSEWIC, 2012). Striped bass in Canadian waters are divided into three populations: the Bay of Fundy, the Southern Gulf of St. Lawrence, and the St. Lawrence River. Historically in Canada, striped bass are known to have spawned in five river systems: the Saint John and Miramichi rivers in New Brunswick, the Annapolis and Shubenacadie rivers in Nova Scotia and the St. Lawrence River in Quebec.

The Annapolis River once supported a healthy population of striped bass, knowledge which is substantiated by community reports, as well as data on historical landings (Jessop 1976) and annual angling tournaments hosted at Dunromin Campground in Granville Ferry (Harris 1988). Since the 1970s however, population numbers have been in decline, and reports indicate that there has been no evidence of successful spawning or recruitment in the Annapolis River since 1976 (COSEWIC 2012). What was once a booming recreational and sport fishery began to decline, and minimum size limits of 46cm then 68.5cm were imposed in 1994 and 1997, respectively. The annual Dunromin angling tournaments ended in 2008 due to reduced interest and a decrease in the number of large striped bass (>4.0 kg) in the area; prior to the turbine installation, 70% of striped bass catches were large individuals, compared to 51% in 1986 and 37% in 1987 (Harris 1988). This data, as well as the observed increase in average length and weight of striped bass between 1975 and 2000 indicated an aging population structure and little, if any, recruitment (Jessop 1980). Eggs were obtained from the Annapolis River in several years between 1976 and 1994; but the last larvae captured were in a 1976 study (Jessop 1995).

While these reports indicate a declining population even prior to the ATGS, the trends continued post-ATGS, and were compounded by the direct effects of the turbine which could selectively remove large individuals from the population; striped bass greater than 4.0kg are estimated to have a strike rate of 20-40% (Von Raben 1957). This value may have been even higher in the Annapolis River because striped bass were known to congregate around the high flow and prey-rich areas surrounding the tidal station (Andrews et al. 2019b). This behaviour suggests that feeding adults would have passed through the turbine multiple times per year. For these reasons, the entire population of Annapolis River adult striped bass would be expected to encounter the turbine within their lifetime (Gibson et al. 2019).

The last recorded evidence of spawning activity in the Annapolis River was in the summer of 1994, when 400 eggs were found (Jessop 1995), however the absence of juveniles during those and subsequent surveys suggest that survival beyond the egg stage is low. Fisheries and Oceans Canada (DFO) has considered the Annapolis River striped bass spawning population to be extirpated since 2006 because of repeated spawning failures and negligible survival of larvae to the juvenile stage (DFO 2006). This is owing to changes in water chemistry and circulation in the downstream portion of the river, attributed to the construction of the causeway and subsequent tidal power generating station in Annapolis Royal (DFO 2014).

Historically, striped bass were known to overwinter in the deep estuarine pools downstream of Bridgetown (Rulifson and Dadswell 1995). Overwintering aggregations, which are often dense and minimally active, are particularly susceptible to local conditions, making habitat suitability of overwintering grounds a crucial determinant of survival (Andrews et al. 2019a). This warrants more research on habitat use, as well as behaviour and movement of striped bass in the Annapolis River.

Since 2010, CARP has been collaborating with the Striped Bass Research Team, based out of Acadia University, to support monitoring and research efforts in the Annapolis River watershed. In 2010, 2011, 2013, 2014, 2015 and 2021, CARP conducted a variety of surveys for both adult and juvenile striped bass as well as striped bass eggs. In 2022, juvenile striped bass were collected in CARP's beach seine surveys for the first time at the mouth of Allain's Creek. Prior to this, no eggs, juvenile or adult striped bass had been collected during CARP's surveys. The COSEWIC assessment and status report for striped bass was last examined in 2012, in which the Bay of Fundy DU was designated as endangered. Threats to striped bass include overfishing, habitat loss and degradation, contaminants, and migration barriers. In a 2014 scientific advisory report (DFO 2014), it was stated that the Annapolis River may now serve as only foraging habitat, as spawning and nursery habitat features have been significantly degraded (Bradford et al. 2015).

Objective

In its initial stages, the estuary monitoring project will provide baseline population and habitat data which will be used to identify key areas for restoration and enhancement, as well as inform management decisions regarding the decommissioning of the Annapolis Tidal Generating Station, which ceased operation in 2019 following a notice from DFO to provide authorization under the Fisheries Act.

To date, most work that has been conducted as part of the estuary monitoring project has been focused on striped bass and Atlantic sturgeon. The primary objective in 2022 was to fill gaps in pre-existing knowledge of the seasonal habitat residency and recolonization of species at risk to the Annapolis River, Nova Scotia. This was achieved through a combination of egg collection and beach seine surveys, acoustic monitoring, and community angler catch data contributed through CARP's volunteer angler program. Collectively, these sampling methods target striped bass at all developmental stages, providing a comprehensive overview of the local population structure; egg collection surveys target the egg and larval stage, and may suggest the presence of a successful local spawning population, whereas beach seines and community angling data target the juvenile and adult stages. Additionally, acoustic monitoring targets the movement and habitat use of juvenile and adult striped bass and Atlantic sturgeon.

In addition to surveys targeting live striped bass, CARP has implemented survey techniques to quantify suitable habitat for striped bass populations and other species at risk including Atlantic salmon and Atlantic sturgeon. This is being accomplished through both passive and active water quality sampling throughout the Annapolis River and estuary. Passive data collection methods include the deployment of temperature loggers as a way to track changes in water temperature at consistent time intervals throughout the spawning season. Active sampling was conducted in the upstream portions of the river, with the primary goal being to create a current profile of the thermal and saline stratification in the estuary.

This report summarizes the activities that took place in 2022 and provides recommendations for future years.

2. Methods

From May to November 2022, CARP conducted active and passive water quality monitoring, as well as partnered with Acadia University to conduct field surveys targeting striped bass and Atlantic sturgeon. Striped bass surveys included egg collection through the deployment of stationary plankton nets (see Section 5: Additional Activities), acoustic monitoring, and beach seines, supplemented by catch data collected through CARP's volunteer angler program (see Section 5: Additional Activities). Acoustic tagging of Atlantic sturgeon was undertaken in partnership with Acadia University and local commercial fishers and researchers Darren and Erica Porter. Water quality monitoring involved deploying passive temperature data loggers, as well as active water sampling to define the thermocline and halocline gradients upstream of the now inoperative ATGS.

2.1 Beach Seines

Site Selection

Beach seines were conducted at 13 sites in the Annapolis River, 3 sites in Bear River, and 1 site in Allain's Creek (Figure 1). Eight of the nine sites above the Annapolis Royal causeway (AR1-AR8) were selected and sampled by the DFO in 2001 and 2002 (Douglas et al. 2003), Labenski in 2010 (Labenski 2011), and CARP in 2011, 2013, 2014, 2015, and 2021. The beach seines conducted by CARP and Acadia University in 2022 make for the second consistent sampling period after the ATGS ceased operation (2019). The location of AR2 was modified prior to the start of the 2015 sampling, and again in 2022, because of steep slopes and additional safety concerns. Supplemental sites in Bear River were added to the sampling array in 2013 in collaboration with Bear River First Nation, and the Allain's Creek site was added during the 2014 monitoring season. AR13 was added as a site in 2022 to expand sampling efforts to both sides of the causeway. All sites were accessible either by foot, or by boat, and when possible, sites were visited around high tide. Tide times were determined using those given for Annapolis Royal at tide-forecast.com and adjusted by 2.5 hours for sites above the causeway to accommodate for the gradual delay in tides further upstream (because of constricted flow around the Annapolis Royal causeway). However, based on recommendations from CARP's 2011 survey, sites AR1, AR3, AR4, and AR5 were sampled at lower tide levels to accommodate for the steep shoreline slope or lack of beach at high tide.

Figure 1. Beach seine sampling sites.

Sampling Design

From July to November 2022, beach seines were conducted bi-weekly at the 13 sites located along the Annapolis River. The remaining sites located along Bear River and Allain's Creek were sampled twice during the 2022 season: once in July and again in November. Beach seines were conducted using a 24.3m long and 2.10m tall seine net, with a purse mesh diameter of approximately 0.3cm. With one end of the net held at the shoreline, one person waded slightly downstream with the other end of the net, and then waded upstream parallel to the bank, pulling the float line along the water surface, and keeping the lead line on the river bottom. Once the net was fully extended in the water, it was guided back towards shore in a wide arc (Figure 2). The contents of the purse were collected by simultaneously pulling both ends of the net onto shore, overlapping the two sides to prevent any individuals from escaping under the net. Samples collected in the purse were counted and identified to family level, then held in aerated water while a second duplicate seine was conducted. In addition to count data, all individuals in the second seine were identified to species level, and total length (measured from the tip of the snout to the tip of the longer lobe of the caudal fin) and fork length (if applicable; measured from the tip of the snout to the center of the fork in the tail) was recorded for each specimen, up to a maximum of 20 individuals per species. Specimens from the first seine pass were released immediately after the second pass was completed to reduce stress from holding, and specimens from the second seine pass were released directly after identification and measurement. Specimens of herring species were preserved in 70% ethanol and transported back to the lab for further identification. Water quality data was collected at each site using a YSI multiparameter sonde, and physical weather data were recorded.

Figure 2. Conducting beach seines in the Annapolis River by walking the seine net out parallel to shore. The 'purse' is identified by the cluster of floats in the middle of the float line.

2.2 Water Quality Monitoring

2.2.1 Estuary Water Quality Sampling

Site Selection

Water quality sampling took place on a bi-weekly basis between May and November 2022, at 14 established sites upstream of the ATGS (Figure 3). Of the established sites, 11 were repeated from previous year's sampling, and 3 were added to include specific locations of interest; one proximate to the sewage treatment outflow for Bridgetown, and one at both the north and south sides of the causeway.

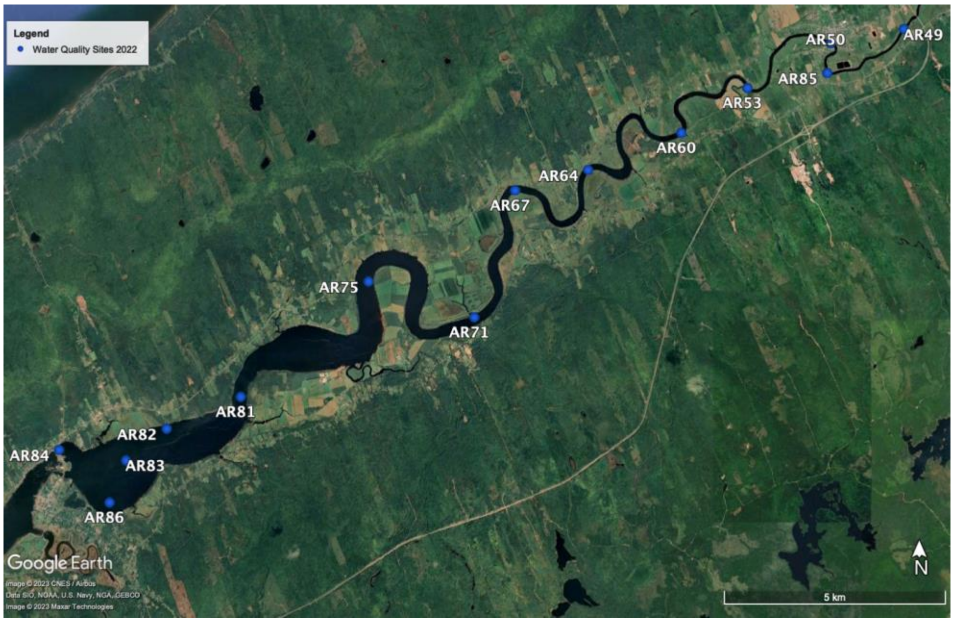

Figure 3. Water quality sampling sites.

Sampling Design

Water quality sampling events were conducted 2.5 hours after the predicted high tide for Annapolis Royal to accommodate the tidal lag produced by the causeway. During the months of July and August, an additional sampling event was conducted at low tide to allow for the comparison of results between tidal cycles. All sites were accessed by boat and were marked by GPS points located mid-river. At each site, anchors were used to maintain the boat's position while sampling was conducted. Date, time, and physical weather data observations were documented at each site. Using a YSI multiparameter sonde, water quality parameters were recorded at 1m depth intervals to a maximum of 10m. Secchi depth was also recorded using a Secchi disk attached to a rope, which was marked with 1m intervals, to measure water transparency. In addition, the thermocline and halocline depths were measured (if applicable), by slowly lowering the YSI probe into the water column and recording the depth at which each the salinity (halocline) and temperature (thermocline) values showed a rapid change.

2.2.2 Temperature Sensor Arrays

Site Selection

Temperature data loggers (Onset, HOBO UA-002-64 Data Logger; range: -20 – 70C, accuracy: +/- 0.53C, resolution 0.14C @ 25C) were deployed on July 21st at five locations throughout the Annapolis River (Figure 4). The locations were selected based on the water quality monitoring results, to ensure data would be collected as close to the upper and lower limits of the salt wedge as possible. This was done in an attempt to measure temperature variance at set depth increments related to the movement of the salt wedge and consequent depth of the thermocline.

Figure 4. Temperature logger sites.

Sampling Design

The temperature data loggers were programmed to start recording on July 25th at 00:01hrs at 30-minute intervals. At two locations (Bloody Creek and Belleisle Marsh) where the water depth was greater than the upper river, multi-sensor arrays were deployed to record temperature across multiple strata. Each of these arrays were set up with a cinder block as the anchor and a rope suspended in the water column from a buoy (Figure 5). The loggers were secured to the suspended rope using zip ties. The first 2-3 loggers within the thermocline were spaced 0.5m apart until the thermocline was reached, then spaced equally at 1m intervals. Sites in shallower water (Paradise, Daniels Brook, and Bridgetown) only had one sensor secured to a cinder block and placed on the riverbed and secured to shore with a rope (Figure 5).

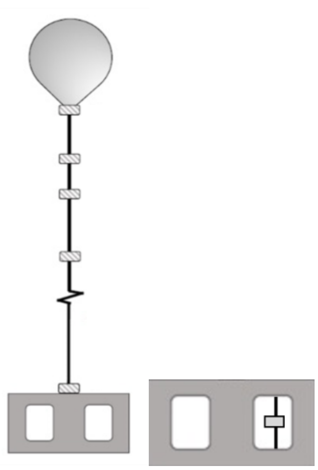

Figure 5. Illustration of the temperature sensor arrays deployed at Bloody Creek and Belleisle Marsh (left), and the single temperature sensors deployed in Paradise, Daniels Brook, and Bridgetown (right).

During a water quality sampling event in August, it was discovered that the arrays located at Bloody Creek and Belleisle Marsh were missing due to vandalism or theft. Neither array was ever recovered. A new array was deployed at the same site in Belleisle, however, the Bloody Creek site was relocated further downstream in Moschelle. The new arrays were deployed on September 12th and programmed to start recording on September 14th at 00:01hrs at 30-minute intervals. To avoid further loss of equipment, the new arrays were deployed with buoys approximately 1m below the water surface at low tide to reduce visibility. This resulted in the top temperature logger being positioned 1m below the surface at low tide, and therefore approximately 2m below the surface at high tide, assuming a 1m tidal amplitude.

All temperature data loggers were retrieved on October 31st, except for the array in Moschelle, which wasn’t visible due to wave action. The array was left for the winter and will be retrieved in the spring of 2023

2.3 Acoustic Monitoring

Site Selection
In partnership with Acadia University, an acoustic receiver array (VEMCO VR2W) was established in the Annapolis River comprising 18 sites from Paradise downstream to Goat Island. Where possible, receivers were deployed by foot at locations in the intertidal zone and in areas of the Annapolis River with a narrow width and low water velocity to make detection of transmitter tags affixed to fish more likely. An Onset HOBO temperature logger was paired with each receiver to record the water temperature coinciding with each detection. Receivers were moved throughout the sites between May and

November 2022 to follow seasonal fish movement patterns and increase the chances of successful detection.

Figure 6. Left: VEMCO VR2W receiver with Onset HOBO temperature logger affixed to rebar in the Annapolis River (Actual receiver submerged, exposed for visual representation). Right: 18 site receiver array in the Annapolis River, stretching from the Paradise, 10 km above the salt wedge, to Goat Island in the Annapolis Basin.

Sampling Design

Acoustic monitoring uses electronic tags which produce high-frequency pings at a set rate which are picked up by an acoustic receiver (Redden et al. 2014). The frequencies are decoded by tag identification numbers, allowing for the individual identification of each fish tagged (Heupel et al, 2006). The range of tag detection is ~700m dependant on the flow velocity, make/model of the receiver, and receiver placement (Redden et al. 2014).

2.3.1 Striped Bass Tagging

Striped bass were captured in the Annapolis River by angling with artificial lures containing a single barbless hook. Captured striped bass were weighed to the nearest gram (kg) and measured lengthwise (fork length/total length; cm), before being placed in a 40-liter aerated tank containing river water and an anesthetic solution. The water temperature of the tank was monitored, and if it exceeded 18°C, bagged ice was added to reduce thermal stress. Fish were held in the anesthetic solution until equilibrium was lost and then placed ventral side up in a wet neoprene surgery cradle. A 10-16 mm incision was made between the pelvic and anal fin, where a V16-1L acoustic tag (<1.3% of the fish's total body weight) was inserted. The incision was then closed with 2-3 stitches (suture size 3/0). Additionally, an external dart tag (9cm; FLOY TAG, Inc) was inserted laterally into the body at a 45° angle between the posterior two spines of the primary dorsal fin. Water was poured over the fish's gills intermittently for the duration of all procedures. All striped bass were released at their location of capture, held upright in the river until equilibrium was re-gained. All surgeries were performed by a trained individual within the guidelines of the Canadian Council on Animal Care and the Acadia Animal Care Committee Category of Invasiveness D protocol.

Figure 7. VEMCO V16-1L acoustic tag.

2.3.2 Atlantic Sturgeon Tagging

On August 12-14, 2022, Atlantic sturgeon were captured using gillnets in the Annapolis River, upstream of the ATGS. Captured sturgeon were weighed to the nearest gram (kg) and measured lengthwise (fork length/total length; cm). The fish were held ventral side up while a 10-16 mm incision was made between the pelvic and anal fin. A V16-1L acoustic tag was inserted before closing the incision with 2 stitches (suture size 1/0). Water was poured over the fish's gills intermittently for the duration of the surgery. Additionally, an external dart tag (12 cm; FLOY TAG, Inc) was inserted laterally into the body at a 45° angle in the posterior of the caudal peduncle. Once all procedures were complete, the sturgeon were released by being held overboard, fully submerged until equilibrium was re-gained. All surgeries were performed by a trained individual within the guidelines of the Canadian Council on Animal Care and the Acadia Animal Care Committee Category of Invasiveness D protocol.

Table 1. Specifications of acoustic tags (VEMCO V16-1L) surgically implanted in Striped bass and Atlantic sturgeon including transmission frequency (kHz), dimensions (mm), weight in water/air (g), and battery life.

Tag	Frequency (kHz)	Diameter (mm)	Length (mm)	Weight in Air (g)	Weight in Water (g)	Est. Tag Life (days)
V16-1L	69	16	68	24	10.3	3650

3. Results

3.1 Beach Seines

Beach seines were conducted at 13 sites in the Annapolis River, 3 sites in Bear River, and 1 site in Allain's Creek. From July to November 2022, a total of 80 beach seine surveys were conducted. A total of 4 juvenile striped bass were found in mid-October at the Allain's Creek site The full tables of abundance data sorted by site, are available in Appendix A and full morphometric data are available in Appendix B.

A total of 53502 individuals were recorded, belonging to 31 species. Sand shrimp, the most abundant species, accounted for 50.8% of all observations. Removing sand shrimp observations, the total count dropped to 29300 individuals, and the relative abundance of each species is illustrated in Figure 8. The most common fish species was Atlantic silverside, totalling 13667 individuals (Table 2). Some of the less common species collected included windowpane flounder, smallmouth bass, sculpin, Atlantic butterfish, and Atlantic mackerel, each with only 1 individual observed. Striped bass, Atlantic tomcod, creek chub, lefteye flounder and ninespine stickleback were also among the less common species. Herring (Clupeidae) could only be identified to the family level.

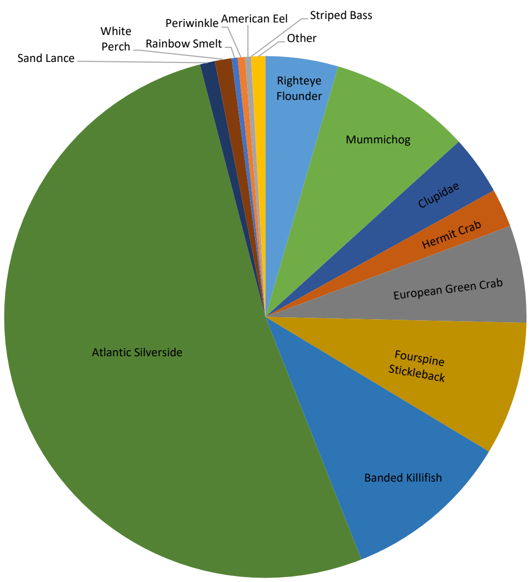

Figure 8. Cumulative results from all beach seine surveys showing relative species composition. "Other" includes windowpane flounder, lefteye flounder, Northern pipefish, ninespine stickleback, three-spined stickleback, white sucker, silver hake, creek chub, Atlantic tomcod, smallmouth bass, sculpin, Atlantic mackerel, Atlantic butterfish, Atlantic rock crab, and Jonah crab.

On average, striped bass, windowpane flounder and Atlantic mackerel displayed the greatest total length of any species observed, although sample sizes for all three species are relatively low. Sticklebacks, both fourspine and three-spined, as well as Atlantic butterfish displayed the smallest average lengths. Average, maximum and minimum total length for each species is reported in Table 3.

The greatest species richness was observed at site AR3, recording 15 species. Site AR5 recorded the greatest abundance of individuals (*n*= 7128; Table 4), and AR1 recorded the greatest diversity of species (Shannon's Diversity Index H = 1.57, E = 0.598; Table 3). Contrarily, BR3, AR8, and AR10 all reported the lowest diversity scores ($H = 0.71$, $H = 0.67$, H = 0.42, respectively). Sand shrimp are of particular importance in the diet of juvenile striped bass less than 50mm in length (Robichaud et al. 1997), and therefore could be an indicator of suitable habitat. Of the 17 sites, sand shrimp were observed at 16. The highest abundance of sand shrimp was observed at AR5, AR8, AR9, AR10, and AR13, and may indicate likely areas for juvenile striped bass habitat (Figure 9).

Table 2. Total count of each species collected. Data includes all beach seine surveys across Allain's Creek, Annapolis River, and Bear River sites.

Species	*n*	Species	*n*
American Eel	97	Northern Pipefish	62
Atlantic Butterfish	1	Periwinkle	119

Atlantic Mackerel	1	Rainbow Smelt	98
Atlantic Rock Crab	24	Righteye Flounder	1183
Atlantic Silverside	13667	Sand Lance	243
Atlantic Tomcod	20	Sand Shrimp	27202
Banded Killifish	2727	Sculpin	1
Clupeidae spp.	966	Silver Hake	20
Creek Chub	3	Smallmouth Bass	1
European Green Crab	1585	Striped Bass	4
Fourspine Stickleback	2176	Squid	6
Hermit Crab	628	Three-spined Stickleback	19
Jonah Crab	3	White Perch	272
Lefteye Flounder	6	White Sucker	49
Mummichog	2307	Windowpane Flounder	1
Ninespine Stickleback	10	**Grand Total**	**53502**

Table 3. Length data grouped by species. Data come from the duplicate seine survey conducted during each beach seine sampling event (see methods).

Species	Average Total Length (cm)	Max Total Length (cm)	Min Total Length (cm)
American Eel	10.73	71.00	6.20
Atlantic Butterfish	4.10	4.10	4.10
Atlantic Mackerel	29.00	29.00	29.00
Atlantic Silverside	7.54	17.00	1.90
Atlantic Tomcod	12.84	14.40	9.60
Banded Killifish	4.88	10.00	1.80
Clupeidae spp.	6.68	48.00	3.10
Creek Chub	7.73	13.40	4.30
Fourspine Stickleback	3.61	6.10	1.40
Lefteye Flounder	17.35	32.00	5.50
Mummichog	4.53	13.40	1.70
Ninespine Stickleback	4.83	5.80	3.80
Northern Pipefish	12.93	18.5	2.2
Rainbow Smelt	6.39	14.8	3.6
Righteye Flounder	5.15	15.30	2.00
Sand Lance	8.66	14.00	4.50
Sculpin	9.50	9.50	9.50
Silver Hake	5.93	8.00	3.00
Smallmouth Bass	17.10	17.10	17.10
Striped Bass	33.68	34.50	32.60
Three-spined Stickleback	4.25	5.30	3.00
White Perch	10.24	29.5	2.40
White Sucker	8.67	24.00	4.00
Windowpane Flounder	30.80	30.80	30.80

Table 4. Measures of community composition at the 17 beach seine sampling sites. Abundance is the total number of individuals, richness is the total number of species, and diversity and evenness are measures of composition that account for relative abundance of each species at a site. Shannon's index was used to calculate diversity and evenness scores. Higher Shannon's diversity index scores indicate greater diversity of species, and an evenness score closer to 1 indicates that species abundance is similar across all species, with a value of 1 indicating that all species are present in equal proportions.

Site	Abundance (*n*)	Richness	Diversity (H)	Evenness (E)
AC1	2350	12	1.002640	0.403492
AR1	3770	14	1.579884	0.598654
AR2	4250	10	1.301022	0.565026
AR3	2039	15	1.426868	0.526898
AR4	3492	11	0.823762	0.343535
AR5	7128	12	0.873786	0.351637
AR6	3450	10	0.823441	0.357615
AR7	717	11	1.041399	0.434297
AR8	6157	13	0.673927	0.262745
AR9	4943	12	1.025626	0.412742
AR10	6586	9	0.428223	0.194893
AR11	1640	9	1.451931	0.660802
AR12	1535	8	1.393572	0.670166
AR13	4313	13	0.918775	0.358204
BR1	661	9	1.330727	0.605640
BR3	346	4	0.711977	0.513583
BR4	609	8	1.006163	0.483862

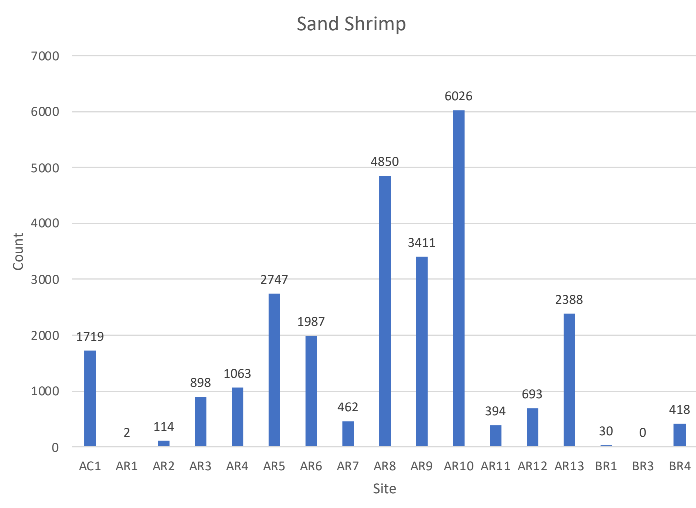

Figure 9. Abundance of sand shrimp: a possible habitat suitability indicator for juvenile striped bass.

3.2 Water Quality Monitoring

3.2.1 Estuary Water Quality Sampling

Fourteen water quality sampling events took place bi-weekly from May to November 2022. Initial examination of the data collected over the sampling period has yielded insight into the structure and extent of the stratified portion of the estuary, as well as observations on the timing and extent of oxygen depletion below the halocline. These observations are summarized below in Table 5, which presents observations on a site-by-site basis.

Table 5. Water quality sampling results summarized by site.

Site Number	Description
AR84	• Little to no stratification • Halocline present between 0.5m and 2.0m • No oxygen depletion observed
AR86	• Little to no stratification • Halocline present between 0.5m and 2.0m • No oxygen depletion observed
AR83	• Little to no stratification • Halocline present between 0.5m and 2.0m • No oxygen depletion observed
AR82	• Little to no stratification • Halocline present between 0.5m and 2.0m • No oxygen depletion observed
AR81	• Stratified throughout sampling until October 11th • Halocline present between 0.5m and 2.0m • No oxygen depletion observed
AR75	• Highly variable, often weak stratification • No oxygen depletion observed
AR71	• Strong stratification • Halocline present between 0.5m and 2.0m • No oxygen depletion observed
AR67	• Strong stratification • Halocline present between 0.6m and 2.5m • Oxygen depletion was present between July 7th and September 8th • Lowest recorded D.O. on August 22nd (3.35mg/L)
AR64	• Strong stratification • Halocline present between 0.5m and 3.0m • Oxygen depletion was present between July 7th and September 8th • Lowest recorded D.O. on August 23rd (2.63mg/L)
AR60	• Strong stratification • Halocline present between 0.5m and 2.0m • Oxygen depletion was present between July 7th and September 8th • Lowest recorded D.O. on August 22nd (1.19mg/L)
AR53	• Strong stratification • Halocline present between 1.0m and 2.5m • Oxygen depletion was present between June 7th and September 8th • Lowest recorded D.O. on August 22nd (2.63mg/L)
AR50	• Strong but variable stratification

	• Halocline present between 1.0m and 5.0m • Oxygen depletion was present, but some data was unavailable • Lowest recorded D.O. on August 23rd (0.79mg/L)
AR85	• Intermittent stratification • Halocline between 1.5m and 1.7m • Oxygen depletion was present between August 22nd and September 8th • Lowest recorded D.O. was on September 8th (2.8mg/L)
AR49	• Stratified for 2/14 events • Halocline present at 1.7m and 2.0m.

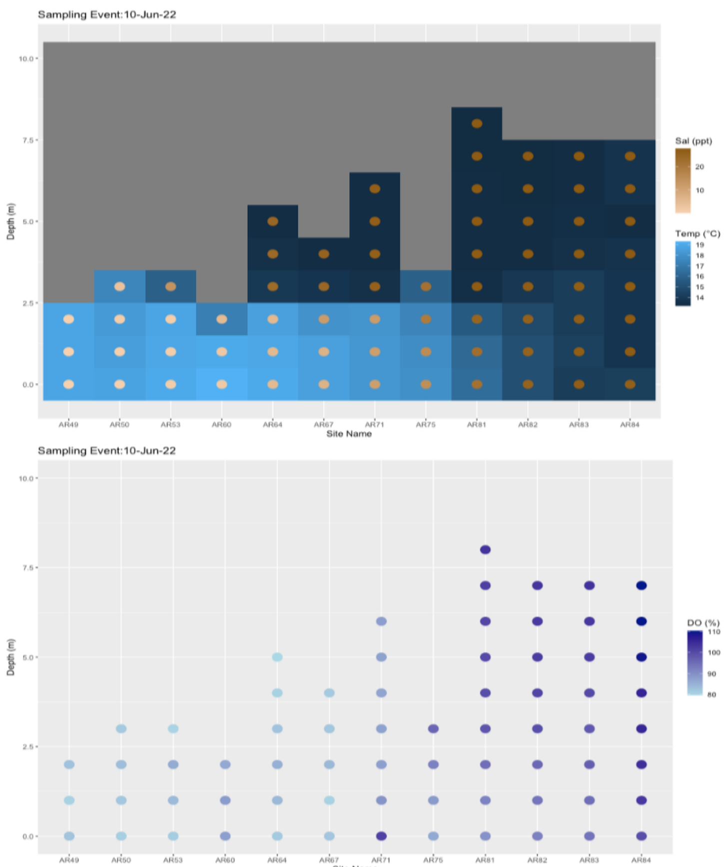

Figure 10. Results from one of the first estuary water quality sampling surveys conducted one June 10th, 2022. The top panel depicts salinity and temperature at each sampling point: the parameters used to identify halocline and thermocline profiles. The lower panel depicts dissolved oxygen saturation. All data points are plotted by depth and ordered to reflect direction of river flow (left to right).

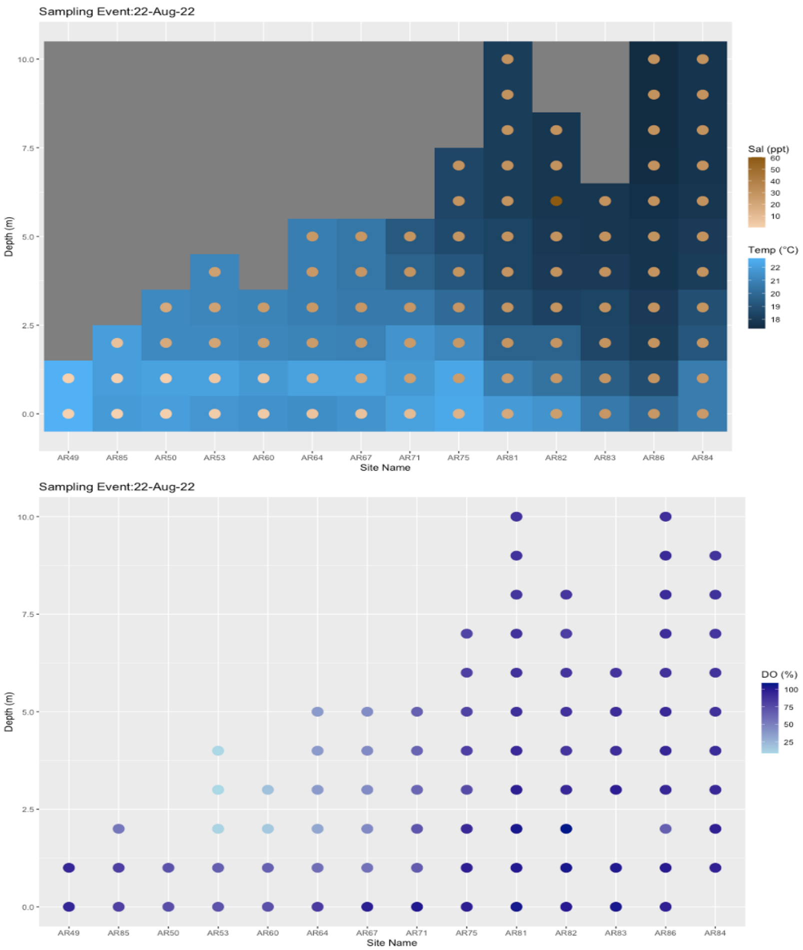

Figure 11. Results from an estuary water quality sampling survey conducted on August 22nd, 2022, approximately halfway through the monitoring season. Lowest recorded dissolved oxygen levels occurred for multiple sites either on or after this sampling date. The top panel depicts salinity and temperature at each sampling point: the parameters used to identify halocline and thermocline profiles. The lower panel depicts dissolved oxygen saturation. All data points are plotted by depth and ordered to reflect direction of river flow (left to right).

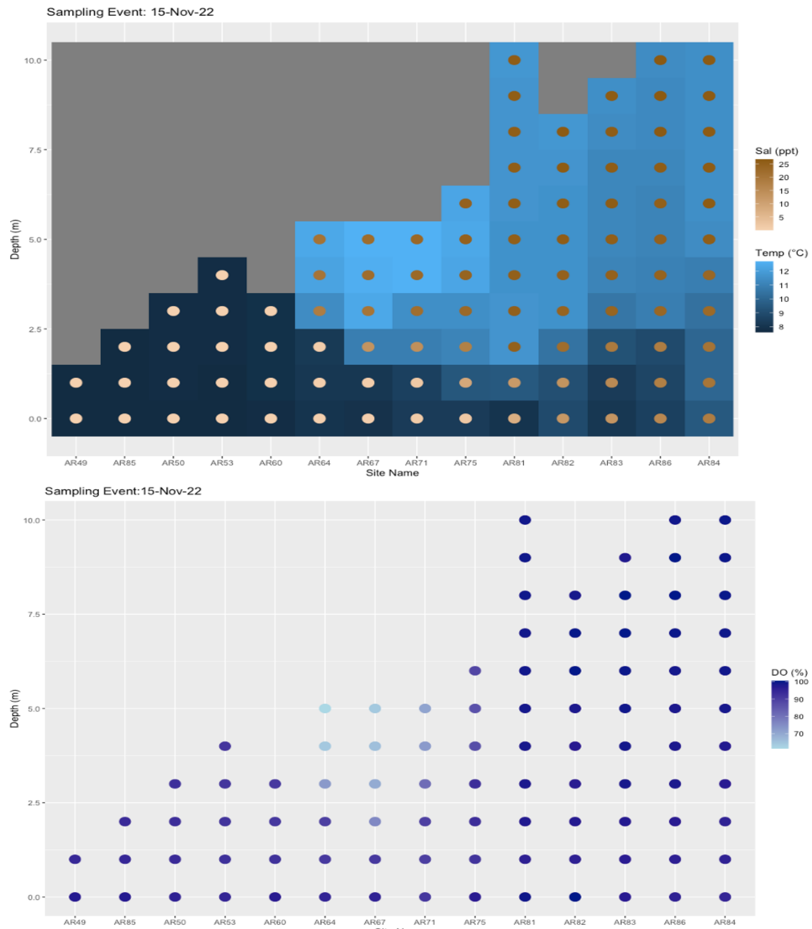

Figure 12. Results from the fifteenth and final estuary water quality sampling survey conducted on November 15th, 2022. The top panel depicts salinity and temperature at each sampling point: the parameters used to identify halocline and thermocline profiles. The lower panel depicts dissolved oxygen saturation. All data points are plotted by depth and ordered to reflect direction of river flow (left to right).

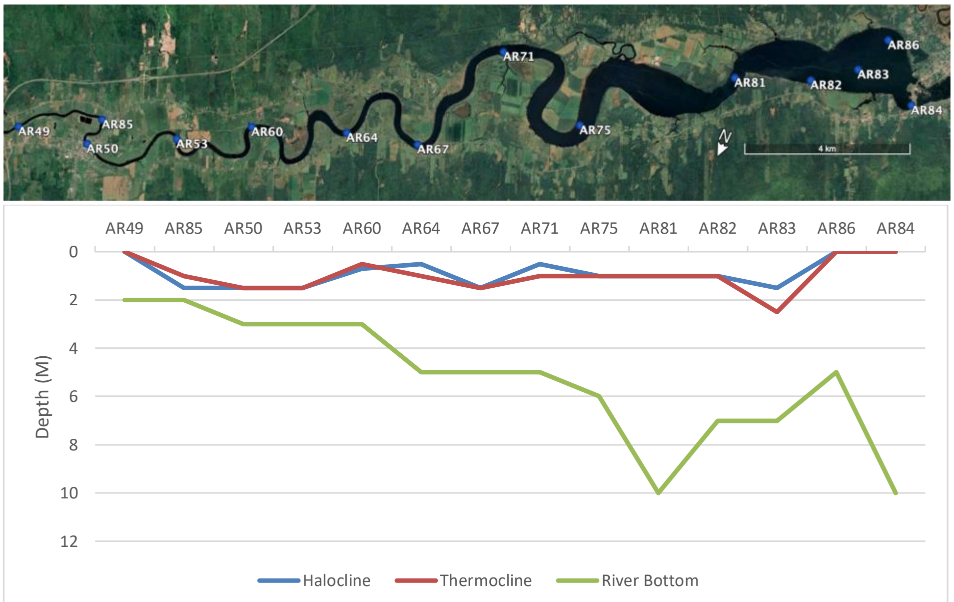

Figure 13. Profile of the salt wedge as observed at 14 sampling sites between Bridgetown and Annapolis Royal, on August 23rd, 2022. The area below the halocline and thermocline represents the salt water, and the area above represents freshwater. Maximum depth was measured using a weighted measuring tape, and salinity and temperature gradients were detected using a YSI multiparameter sonde. Boundaries shown on the map span from upstream at Bridgetown (left boundary) to downstream at Annapolis Royal (right boundary).

In early Spring sites AR82, AR83, AR84, and AR86 were not completed in the first sampling round due to safety concerns resulting from high winds and wave action. In late Fall, AR83 was not sampled due to the same concerns. Site AR49 was not sampled on October 27th as abundant organic matter in the river was binding the propeller and causing the motor to stall, preventing access to the site.

Dissolved oxygen values were not recorded for some sites on certain dates, leading to some minor data gaps. This was due to challenges achieving stability with the YSI multiparameter sonde, potentially resultant from varying salinity levels interfering with the electrolytic D.O. probe.

3.2.2 Temperature Sensor Arrays

Upon initial examination of the data collected by the temperature loggers, a daily pattern of temperature fluctuation can be observed for the locations at Paradise, Daniels Brook, and Bridgetown (Appendix D). The minimum temperatures coincide with early morning and night-time hours, while the highs correspond to mid-afternoon: as would be expected for waters influenced primarily by atmospheric conditions. Due to shallow depths in this portion of the estuary, atmospheric influence is highly likely.

The data collected from the array in Belleisle only represents September 14th to October 31st, rather than the entire sampling period (September to November). This is due to vandalization and loss of equipment earlier in the season. Data for September 14th show distinct temperature differences between the sensors placed at various depths (Figure 14). Thermal stratification patterns begin to change rapidly in the following days with thermal strata become inverted and less distinct, likely resultant from seasonal changes in air temperature and atmospheric conditions.

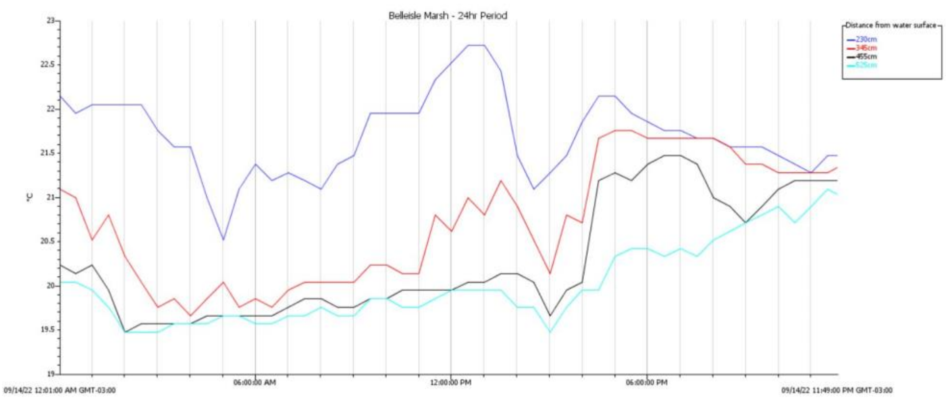

Figure 14. Data from Belleisle Marsh showing the temperature at varying depths on September 24th.

When the arrays were deployed, each setup was labelled with a tag indicating it was scientific equipment. Even with this precaution, the arrays in Bloody Creek and Belleisle Marsh were stolen in August creating a data gap for the months of July and August. To prevent this issue from occurring with the new arrays, they were deployed such that the buoys would be 1m below the water surface at low tide to keep them out of sight. Only a limited number of loggers were available for replacements, resulting in a consistent 1m spacing between temperature sensors on the replacement arrays, rather than spacing the sensors between the buoy and the thermocline at 0.5m intervals.

The temperature data logger array at Moschelle was not retrieved successfully due to wave action limiting visibility under the surface. This array was left for the winter season and will be retrieved in the Spring of 2023.

3.3 Acoustic Monitoring

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To date, 35 striped bass have been externally tagged (FLOY TAGS) in the Annapolis River; 10 of which have also been equipped with an acoustic tag (Table 6). Only fish that met the size requirements for possible sexual maturity were tagged with acoustics (>55 cm).

Table 6. Tagging details for striped bass captured in the Annapolis River.

Tag ID	Serial #	Fork Length (cm)	Total Length (cm)	Weight (kg)	Age (y)
31311	1500783	52.00	55.50	2.06	5
31312	1500784	59.00	63.30	2.92	6
31313	1500785	58.50	63.50	3.24	6

31314	1500786	55.50	58.00	2.48	6
31315	1500787	52.00	56.00	1.84	5
31318	1500790	51.00	55.00	1.82	5
31316	1500788	55.00	59.50	1.95	6
31319	1500791	56.00	60.00	2.20	6
31320	1500792	53.00	57.00	1.92	6

Additionally, 21 Atlantic sturgeon were caught and tagged externally (FLOY TAGS) in the Annapolis River; 10 of which were tagged with acoustic transmitters (Table 3). Originally, sexually mature individuals were intended to be tagged (>150 cm), however, only two met this requirement (tag id: 31301, 31306), which resulted in 8 of the largest sturgeon also receiving acoustic tags (Colton 2022).

Table 7. Tagging details for Atlantic sturgeon captured in the Annapolis River.

Tag ID	Serial #	Fork Length (cm)	Total Length (cm)	Weight (kg)
31308	1500780	95.00	110.00	5.79
31309	1500781	92.50	104.90	5.30
31307	1500779	108.30	124.20	8.22
31306	1500778	144.00	159.00	N/A
31304	1500776	106.50	125.50	8.56
31303	1500775	97.00	111.00	N/A
31301	1500773	184.50	212.50	N/A
31300	1500772	99.00	112.00	N/A
31302	1500774	96.00	107.50	6.02
31305	1500777	92.00	106.00	N/A

4. Discussion

In the summer of 2022, the Clean Annapolis River Project conducted estuary monitoring activities and data collection in the form of beach seines, acoustic monitoring, and water quality sampling. This work was conducted as part of a larger project focused on restoring the health of the Annapolis River estuary and restoring populations of anadromous species at risk in the watershed. This marked the second consecutive year that CARP conducted surveys targeting striped bass populations in the Annapolis River and its tributaries since the ATGS ceased operation in 2019. Consistent with results from previous years, no evidence of spawning striped bass was observed during the 2022 field season.

4.1 Beach Seine

The availability of food sources is thought to be a key determinant of year-class strength, as well as survival to the juvenile stage. Primary food sources, however, shift in accordance with developmental stage: larvae and small juveniles feed primarily on copepods and other zooplankton, but once striped bass reach 50mm in length, sand shrimp become the principal prey source (Robichaud et al. 1997). Most beach seine sites in the survey exhibited large populations of sand shrimp, and a variety of juvenile fish species: conditions which, in theory, could support various developmental stages of striped bass. Sand shrimp were present at nearly all beach seine sites (Figure 9), suggesting an abundant food source for larger juveniles. Considering its importance for early life development in striped bass, quantifying zooplankton abundance could also prove valuable for identifying suitable striped bass habitat in the Annapolis River. In contrast, some beach seines presented a very low abundance and diversity of species (Table 4), namely AR7, BR1, BR3, and BR4. It is important to note that that the Bear River sites were only sampled seasonally, whereas the Annapolis River sites were sampled bi-weekly. As a result, the Bear River sites may not representative.

In addition to food availability, habitat suitability is another factor that could contribute to striped bass survival beyond the larval stage. Larvae and juvenile striped bass often occupy habitat in shallow warm water that offers refuge from predators. These types of habitats are associated with wetlands, streams, and vegetated shorelines, with eelgrass reported as being of particular importance (*Weldon et al. 2007, 2009*). Sample sites in 2022 included vegetated shorelines as well as intertidal mudflats along the steep shorelines of the upper river. Juvenile striped bass can tolerate a greater range of temperature and chemical conditions than the larval or egg stages (Bain and Bain 1982). All dissolved oxygen levels recorded were between 50%-193%, water temperatures were in the range of 10°C -25°C, and 14 of the 16 observations (87.5%), showed pH readings between 6.5-8.5: the range often observed in estuarine environments. It is thus unlikely that these physiochemical parameters explain the absence of juvenile striped bass. Green crabs were observed throughout the estuary and their presence is likely to cause decline in habitat for striped bass as a result of depleted eel grass. The impact of predation, however, is not quantified and could be an additional factor contributing to the patterns that were observed.

During the 2021 sampling season, beach seines were conducted following an irregular schedule. The period separating the first and second sampling events varied from days to months, meaning that some sites captured greater seasonal variation than others. To correct this, in 2022, all Annapolis River sites were sampled on a bi-weekly basis and the sites at Allain's Creek and Bear River were sampled seasonally. Increased sampling efforts in Allain's Creek are recommended in the future to follow up on the 2022 observations of juvenile striped bass at the site.

Due to site-specific differences in community composition, as well as seasonal variation, it is difficult to draw any conclusions regarding size trends without conducting more rigorous statistical testing. In the future, it could be of interest to determine whether larger individuals are more commonly found in certain areas of the river, possibly indicating areas of greater food availability, or increased competition for resources.

4.2 Water Quality Monitoring

Monitoring and assessing water quality conditions in the Annapolis River can help to identify suitable habitat for striped bass and other anadromous species at risk, to determine candidate sites for habitat restoration and enhancement, and to inform management decisions. By conducting sampling at sites upstream of the ATGS, as well as sites below, a direct comparison can be drawn between flow regimes and the resulting differences in water quality.

Analyses of the physical and chemical features of the Annapolis River estuary were conducted in the mid 1970s before the establishment of the tidal generating station, but no such data exist prior to the construction of the causeway in 1960. Data from 1975 therefore provides the reference point closest to historic conditions in the area.

4.2.1 Estuary Water Quality Sampling

The results provide a baseline description of the thermal and saline stratification present in the portion of the Annapolis River above the Annapolis Tidal Generating Station. The salt wedge, as observed on June 24th and September 8th, 2022, extends as far as Bridgetown, reflecting the reduced tidal exchange upstream. Prior to the construction of the dam in 1960, the Annapolis estuary was vertically homogenous (Daborn 1979), but since at least 1975, the water column has been strongly stratified as far upstream as Bridgetown (Jessop 1976, Daborn 1979). This change in physiochemical composition can pose challenges for species that were previously adapted to a mixed estuary system, and could have implications that extend to habitat use, trophic structure, and migration patterns. In the context of striped bass, a species that relies on freshwater habitat for spawning, overwintering, and incubation, the presence of the salt wedge may disrupt these processes.

As discussed earlier, dense saline waters could threaten egg viability in striped bass; a study in the Miramichi River found that 94.3% of post yolk-sac larvae occurred in freshwater (Robichaud et al. 1996). For a life stage that depends heavily on freshwater conditions, the presence of the salt wedge in historically freshwater spawning locations could potentially disrupt the developmental process. Furthermore, zooplankton are most abundant in the surface freshwaters where stratification is most stable, but in contrast, zooplankton abundance is lowest in the mixed waters downstream (Redden et al. 1982). This could have implications for striped bass movements during early development, which are driven by prey distribution (Robichaud et al. 1997). Increased surface water temperatures resulting from stratification could drive spawning to take place earlier in the season, or drive species to seek more suitable habitat, potentially introducing new challenges like increased competition or predation risks.

The physiochemical differences observed between waters above and below the pycnocline are striking. A range of 80%-120% dissolved oxygen saturation is considered healthy, and in the surveys conducted in 2022, 39.6% of all DOSAT readings fell below this threshold. These results are higher than those produced in 2021, where 26.5% of readings fell below the threshold. This increase in results is thought to be caused by equipment failure of the YSI multiparameter sonde. The lowest DOSAT readings were observed below the halocline at corresponding salinities upwards of 10ppt, which is consistent with the fact that saline waters have a decreased capacity to hold oxygen compared to freshwater. Surveys conducted in the 1970s in the Annapolis River found that the underlying salt layer reached oxygen saturation levels as low as 44% (Daborn 1979), which if persistent, can have serious ecological implications. Even more extreme levels of oxygen depression were observed between 2004 and 2006, when CARP conducted surveys to investigate the patterns of low dissolved oxygen in the Annapolis River. Oxygen-depleted saltwater extended over 20km in the lower estuary: below the halocline, DO levels averaged 3.52mg/L in 2005, and dropped progressively throughout the season to a low of 1.5mg/L in October 2006 (Sharpe 2007).

It is worth noting that the description of the halocline that is presented illustrates monitoring events conducted over a limited period of time. Sampling conducted over seasons with varying conditions, or at different points in the tide cycle could yield varying results. In the Fraser River, for example, the flood tide produces a salt wedge that extends further up the estuary, while the ebb tide erodes the structure (Geyer and Farmer 1989). Rainfall and freshwater discharge into estuary systems is also a strong determinant of stratification, and these parameters can show significant seasonal and annual fluctuation. The 2022 results demonstrate this, showing notable differences between early and late season sampling with respect to salinity gradients, surface water temperatures, and dissolved oxygen saturation. It is for these reasons that the continued monitoring of this system is important. Conducting surveys at different points in the seasonal and tidal cycles will produce a more comprehensive profile of the salt wedge in the Annapolis estuary and aid in understanding how the salt wedge changes relative to the seasonal movements and habitat use by anadromous species.

4.2.2 Temperature Sensor Arrays

There appears to be a notable drop in temperatures between the first and second sensors in the Belleisle array: a pattern that may provide further support for the presence of the salt wedge. In addition, temperatures at the deep end of the array appear to peak and fall twice throughout the day, coinciding with tidal patterns of the underlying salt wedge. Contrarily, the upper sensors show only one rise and fall each day, corresponding more closely with solar patterns affecting the surface freshwater. These observations would require further investigation before drawing firm conclusions, however, similar research conducted at Dalhousie University found that the temperature regime in the upstream portions of the Annapolis River is solar-dominated, whereas the downstream portions are tide-dominated (Bonnington 2021).

Some instances occur in which the surface water temperatures fall below those of the deeper sensors, and these patterns may be explained by coinciding weather events or seasonal temperature changes. For example, the inverted pattern observed around September 24th - 28th could be a result of Hurricane Fiona which occurred in Nova Scotia on September 24th, 2022. Similarly, this pattern can be seen again on October 3rd – 5th when extreme rainfall occurred as remnants of Hurricane Ian (Figure 15).

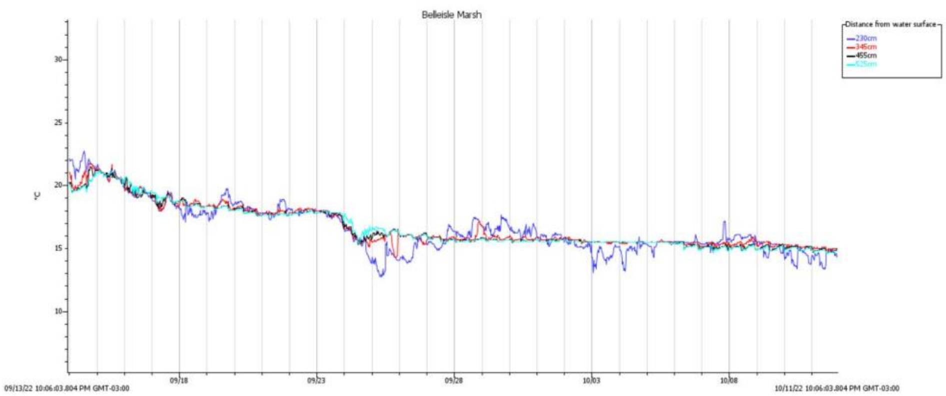

Figure 15. Data from Belleisle Marsh where the inverted pattern can be observed.

With the data gathered this year, recommendations can be made on sampling design and direction for the project moving forward. For example, future sampling efforts should be focused around Bridgetown, where the head of the salt wedge is predicted to be. Future arrays should also be constructed such that distances between sensors are consistent (positioned at 0.5m intervals up the water column), so that the thermocline can be identified and tracked accordingly.

4.3 Acoustic Monitoring

Due to the range in size and age of sexually mature striped bass, it is possible that some of the tagged individuals (<60cm) were not of sexual maturity. If any number of the tagged striped bass did not spawn in the spring of 2022, it is likely that if they were to return or overwinter in the Annapolis River they would spawn during the spring of 2023. As the project moves forward, additional striped bass are projected to be equipped with acoustic tags to gain further understanding of habitat use in the Annapolis River system.

Atlantic sturgeon detections showed no signs of upstream movement associated with spawning behaviour among the two potentially sexually mature individuals. If no spawning behaviour is observed in the river over the duration of the project it is likely due to sexual immaturity outlasting the 10-year life span of the acoustic tags, or the presence of sturgeon in the system is strictly due to seasonal feeding habits. Recurring detections of tagged sturgeon in future years could provide more insight into the use of the Annapolis estuary for feeding purposes. To gain further insight into potential spawning of Atlantic sturgeon in the Annapolis River, smaller gill nets will be used to attempt capture of younger age class individuals, as the presence of juveniles (age 3-5 years, <45 cm) in a system is an indicator of previous spawning (Dadswell 2006; Stewart 2014). Additionally, only Atlantic sturgeon of potential sexual maturity (>150 cm) will receive acoustic tagging for the duration of this project.

5. Additional Activities

In addition to the work completed during the 2022 field season, several ongoing projects are also underway, with results to come.

5.1 Stationary Plankton Nets

In May 2022, stationary plankton nets were deployed in an attempt to collect striped bass eggs in the Annapolis River. No striped bass eggs were collected over the duration of the sampling period. These results are consistent with surveys conducted in the past two decades (Douglas et al. 2003, CARP 2010, Labenski 2011, CARP 2015), and support the hypothesis that no successful spawning population persists in the river. Like the predictions made by DFO (DFO 2014), the observations of adult striped bass in this system suggests that the Annapolis River may still serve as foraging or overwintering grounds (reports by community and recreational anglers as part of CARP's volunteer angler program).

Striped bass are documented to begin spawning in water temperatures above 10°C, to an upper limit of 19°C, although optimal temperatures vary among populations. In the Shubenacadie River, for example, surveys for striped bass eggs were most successful in water temperatures between 18-19.9°C (Rulifson & Tull 1999), whereas in the Annapolis River, historic surveys report greatest egg abundance at surface temperatures between 19-24.4°C (Williams et al. 1984). Collectively, the Bay of Fundy populations tend to spawn in late May or early June, at temperatures around 15°C (COSEWIC 2012).

Egg collection surveys in 2022 were conducted at temperatures above 15°C and at observed dissolved oxygen levels that reflect suitable spawning conditions (8mg/L-10.9mg/L; Rulifson & Tull 1999). Two plankton nets were deployed on May 12, 2022, and checked inconsistently until June 2, 2022. A third net was deployed on May 24, 2022, to increase sampling efforts. The nets were secured in the water column with rebar. Upon sample collection, the plankton nets were rinsed with a squirt bottle and observed for the presence of striped bass eggs. Samples were flushed into a 500mL glass jar and preserved in a cooler for further identification.

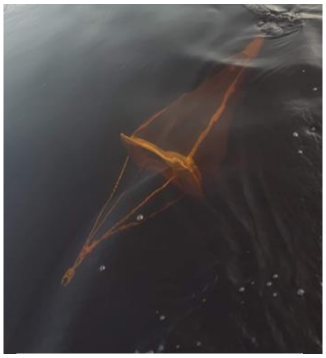

Figure 16. Stationary plankton net deployed in the Annapolis River to collect striped bass eggs.

Earlier surveys conducted between 1994-1996 identified a strong USA genetic component (Wirgin et al. 2020), but notable differences in life-history, ecology, and physiology have been documented between USA and Canadian stocks (Rulifson and Dadswell 1995). More recent analyses have determined that Annapolis River fish appear to be of Shubenacadie origin (O'Halloran 2021). In the Shubenacadie River, surveys for striped bass eggs were most successful in water temperatures between 18-19.9°C, and dissolved oxygen values of 8-10.9mg/L (Rulifson & Tull 1999). Most CARP surveys fall within this DO range, and above the minimum dissolved oxygen requirement for most organisms, defined as 5mg/L (Bain & Bain 1982). However only 21% of observations fall within this temperature range; an overwhelming majority of sampling events occurring in waters over 20°C and up to a maximum of 25.3°C. This temperature range extends well above the threshold of 23°C, at which

American populations begin to show a decline in egg viability (Morgan et al. 1987), however no such threshold has been documented for the Annapolis River population.

Striped bass eggs have a slight buoyancy in low salinities, and with a moderate current will remain suspended in the water column during the 2-3 day incubation period. In the Miramichi system, eggs were not found in any places where bottom salinities exceeded 3ppt (Robichaud et al. 1996). Early-stage larvae were found in low salinity environments, and mid-stage larvae were found to tolerate slightly higher salinities, but 94% of post-yolk-sac larvae occurred in freshwater (Robichaud et al. 1996). Egg tow surveys conducted in the Annapolis River in 1984 acknowledge the strong vertical stratification in the river upstream of the Annapolis tidal dam, and spawning was observed only in freshwater, at salinities below 0.1% (Williams et al. 1984).

5.2 Volunteer Angler Program

The volunteer angler program was established in 2019 as part of CARP's invasive species work and was adopted for the striped bass work in 2021, to broaden the scope of the research. This was accomplished by collecting observations, catch data, and scale samples from knowledgeable and skilled anglers utilizing the Annapolis River. In the 2022 season, the volunteer angler participant list included 13 individuals. In partnership with the Striped Bass Research Team, angler kits consisting of logbooks, scale sample envelopes and instructions printed on rite-in-the-rain paper were distributed to all participants. Upon catching a striped bass, anglers were instructed to record date, time, location, fork and total length, weight, gear used, and fishing effort. Additionally, CARP encouraged volunteers to submit data through MyCatch: a mobile application used to facilitate virtual angling tournaments and citizen science data collection.

Figure 17. Scale drop-off box.

Anglers were provided with rite-in-the-rain envelopes to collect a sample of 3-4 scales and record additional information on species, age, and sex. A drop-off box was installed at the Annapolis Royal causeway boat launch in August 2021, to advertise the project and encourage data return. The drop-off box was relocated in June 2022 to a popular striped bass angling location at the end of Wharf Road in Round Hill. A total of 8 scale samples were collected and submitted through CARP's volunteer angling program. All data sheets and scale samples were shipped to the Striped Bass Research Team at Acadia University for genetic analysis. The scale samples will also be used to determine whether individuals in the river constitute a local population or represent migrant individuals from neighboring populations. These genetic analyses will be performed by collaborators at the Striped Bass Research Team.

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Appendix A. Average, maximum and minimum total length of each species collected during the second seine of beach seine surveys, sorted by site.

Note: BR4 is omitted, because no fish were collected during the duplicate seine.

AC1				
Species	**n**	**Average Total Length (cm)**	**Max Total Length (cm)**	**Min Total Length (cm)**
Atlantic Silverside	60	6.89	10.40	4.00
Clupeidae	2	7.15	8.60	5.70
Mummichog	22	4.08	5.30	2.90
Rainbow Smelt	2	9.65	14.80	4.50
Righteye Flounder	35	5.39	15.30	2.90
Striped Bass	4	33.68	34.5	32.60
Three-spined Stickleback	1	4.20	4.20	4.20
Grand Total	**126**	**10.15**	**34.50**	**2.90**

AR1				
Species	**n**	**Average Total Length (cm)**	**Max Total Length (cm)**	**Min Total Length (cm)**
American Eel	8	9.80	22.70	6.20
Atlantic Silverside	53	4.86	9.00	2.50
Atlantic Tomcod	2	12.05	14.50	9.60
Banded Killifish	81	4.98	10.00	1.80
Clupeidae	29	5.61	7.50	3.10
Creek Chub	3	7.73	13.40	4.30
Mummichog	85	4.72	9.20	1.70
Ninespine Stickleback	10	4.83	5.80	3.80
Smallmouth Bass	1	17.10	17.10	17.10
Three-spined Stickleback	11	4.20	5.30	3.00
White Perch	25	10.08	29.50	2.40
White Sucker	23	8.00	20.90	4.00
Grand Total	**331**	**7.83**	**29.50**	**1.70**

AR2				
Species	**n**	**Average Total Length (cm)**	**Max Total Length (cm)**	**Min Total Length (cm)**
American Eel	10	13.64	54.00	6.90
Atlantic Silverside	53	6.57	11.00	2.90
Banded Killifish	83	4.82	10.00	2.20
Clupeidae	2	4.55	4.90	4.20
Fourspine Stickleback	74	3.64	6.10	1.90
Mummichog	82	4.73	13.40	2.30
Three-spined Stickleback	1	4.90	4.90	4.90
Grand Total	**305**	**6.12**	**54.00**	**1.90**

AR3				
Species	**n**	**Average Total Length (cm)**	**Max Total Length (cm)**	**Min Total Length (cm)**
American Eel	10	8.31	9.40	8.00
Atlantic Silverside	62	6.02	12.20	3.00
Atlantic Tomcod	2	13.30	13.50	13.10
Banded Killifish	1	2.30	2.30	2.30
Clupeidae	60	6.11	8.00	3.30
Fourspine Stickleback	61	3.88	5.80	2.90
Lefteye Flounder	5	14.42	28.10	5.50
Mummichog	3	3.97	5.10	2.20
Northern Pipefish	5	14.50	17.00	10.00
Rainbow Smelt	6	5.92	7.40	4.60
Righteye Flounder	13	7.72	10.80	4.50
White Perch	2	12.35	12.60	12.10
White Sucker	1	24.00	24.00	24.00
Grand Total	**231**	**9.45**	**28.10**	**2.20**

AR4				
Species	**n**	**Average Total Length (cm)**	**Max Total Length (cm)**	**Min Total Length (cm)**
American Eel	20	11.68	71.00	7.00
Atlantic Silverside	100	6.72	14.10	2.60
Clupeidae	20	5.66	8.80	4.20
Fourspine Stickleback	8	6.69	4.50	3.30
Northern Pipefish	7	10.27	15.60	2.20
Righteye Flounder	10	8.09	10.60	6.90
Grand Total	**165**	**8.18**	**71.00**	**2.20**

AR5				
Species	**n**	**Average Total Length (cm)**	**Max Total Length (cm)**	**Min Total Length (cm)**
American Eel	12	9.88	15.50	7.60
Atlantic Silverside	86	6.83	12.60	2.80
Clupeidae	6	13.30	7.50	5.20
Fourspine Stickleback	16	3.63	5.00	2.00
Lefteye Flounder	1	32.00	32.00	32.00
Northern Pipefish	12	13.24	17.50	10.70
Rainbow Smelt	1	4.90	4.90	4.90
Righteye Flounder	8	5.83	12.00	3.20
Windowpane Flounder	1	30.80	30.80	30.80
Grand Total	**143**	**13.38**	**32.00**	**2.00**

AR6

Species	n	Average Total Length (cm)	Max Total Length (cm)	Min Total Length (cm)
American Eel	1	7.80	7.80	7.80
Atlantic Silverside	100	7.48	12.90	4.40
Clupeidae	5	7.06	7.90	5.60
Fourspine Stickleback	6	4.02	4.50	3.10
Mummichog	1	2.50	2.50	2.50
Northern Pipefish	2	13.70	14.00	13.40
Rainbow Smelt	5	4.40	4.90	3.60
Righteye Flounder	4	8.33	11.00	6.70
Grand Total	**124**	**6.91**	**14.00**	**2.50**

AR7

Species	n	Average Total Length (cm)	Max Total Length (cm)	Min Total Length (cm)
Atlantic Butterfish	1	4.10	4.10	4.10
Atlantic Silverside	44	7.66	13.70	3.70
Clupeidae	1	5.20	5.20	5.20
Fourspine Stickleback	1	1.90	1.90	1.90
Rainbow Smelt	2	3.90	4.10	3.70
Righteye Flounder	2	9.55	12.00	7.10
Silver Hake	1	3.60	3.60	3.60
Grand Total	**52**	**5.13**	**13.70**	**1.90**

AR8

Species	n	Average Total Length (cm)	Max Total Length (cm)	Min Total Length (cm)
Atlantic Silverside	53	5.52	10.70	1.90
Clupeidae	12	7.87	8.60	6.00
Fourspine Stickleback	1	1.40	1.40	1.40
Rainbow Smelt	1	3.60	3.60	3.60
Righteye Flounder	26	6.15	10.30	2.60
Silver Hake	1	4.60	4.60	4.60
Grand Total	**94**	**4.86**	**10.70**	**1.40**

AR9

Species	n	Average Total Length (cm)	Max Total Length (cm)	Min Total Length (cm)
American Eel	1	7.40	7.40	7.40
Atlantic Silverside	107	9.27	14.00	5.50
Clupeidae	5	8.56	10.20	6.50
Rainbow Smelt	1	4.30	4.30	4.30
Righteye Flounder	30	5.85	12.30	3.10
Silver Hake	2	3.60	4.20	3.00
Grand Total	**146**	**6.50**	**14.00**	**3.00**

AR10				
Species	**n**	**Average Total Length (cm)**	**Max Total Length (cm)**	**Min Total Length (cm)**
Atlantic Silverside	50	8.66	14.00	4.50
Clupeidae	1	10.14	14.00	8.00
Rainbow Smelt	1	9.80	9.80	9.80
Righteye Flounder	28	4.20	4.40	4.00
Sand Lance	43	3.79	6.80	2.00
Grand Total	**123**	**7.32**	**14.00**	**2.00**

AR11				
Species	**n**	**Average Total Length (cm)**	**Max Total Length (cm)**	**Min Total Length (cm)**
Atlantic Silverside	69	10.82	17.00	8.50
Clupeidae	3	10.57	11.00	10.00
Mummichog	3	5.53	6.40	4.40
Rainbow Smelt	1	12.30	12.30	12.30
Righteye Flounder	50	4.61	9.00	3.40
Grand Total	**126**	**8.77**	**17.00**	**3.40**

AR12				
Species	**n**	**Average Total Length (cm)**	**Max Total Length (cm)**	**Min Total Length (cm)**
Atlantic Silverside	22	8.77	10.60	5.70
Clupeidae	3	9.70	10.70	8.90
Fourspine Stickleback	4	3.35	4.20	2.60
Righteye Flounder	41	4.21	5.40	2.90
Grand Total	**70**	**6.51**	**10.70**	**2.60**

AR13				
Species	**n**	**Average Total Length (cm)**	**Max Total Length (cm)**	**Min Total Length (cm)**
Atlantic Mackerel	1	29.00	29.00	29.00
Atlantic Silverside	120	7.68	13.10	4.10
Clupeidae	4	4.55	5.00	4.30
Northern Pipefish	1	18.50	18.50	18.50
Righteye Flounder	19	5.76	9.50	3.40
Sculpin	1	9.50	9.50	9.50
Silver Hake	8	6.96	8.00	5.00
Grand Total	**154**	**11.71**	**29.00**	**3.40**

BR1				
Species	**n**	**Average Total Length (cm)**	**Max Total Length (cm)**	**Min Total Length (cm)**
Atlantic Silverside	4	2.98	3.60	2.50
Clupeidae	4	9.28	9.90	8.60
Mummichog	20	3.01	3.50	2.50
Rainbow Smelt	3	11.73	13.20	9.30
Righteye Flounder	20	4.83	6.40	3.40
Grand Total	**51**	**6.38**	**13.20**	**2.50**

BR3				
Species	**n**	**Average Total Length (cm)**	**Max Total Length (cm)**	**Min Total Length (cm)**
Atlantic Silverside	4	10.90	11.70	10.00
Righteye Flounder	21	4.22	6.40	3.00
Grand Total	**25**	**7.56**	**11.70**	**3.00**

Appendix B. Count data collected from beach seine surveys, sorted by site.

AC1	*n*
Atlantic Rock Crab	9
Atlantic Silverside	188
Clupeidae	5
European Green Crab	245
Hermit Crab	67
Mummichog	26
Periwinkle	8
Rainbow Smelt	2
Righteye Flounder	76
Sand Shrimp	1719
Striped Bass	4
Three-spined Stickleback	1
Grand Total	**2350**

AR2	*n*
American Eel	12
Atlantic Silverside	94
Banded Killifish	1170
Clupeidae	15
Fourspine Stickleback	1104
Mummichog	1734
Periwinkle	2
Rainbow Smelt	1
Sand Shrimp	114
Three-spined Stickleback	4
Grand Total	**4250**

AR4	*n*
American Eel	31
Atlantic Silverside	2303
Atlantic Tomcod	9
Clupeidae	25
European Green Crab	4
Fourspine Stickleback	28
Mummichog	1
Northern Pipefish	10
Rainbow Smelt	2
Righteye Flounder	16
Sand Shrimp	1063
Grand Total	**3492**

AR1	*n*
American Eel	14
Atlantic Silverside	308
Atlantic Tomcod	2
Banded Killifish	1555
Clupeidae	103
Creek Chub	3
Fourspine Stickleback	1036
Mummichog	406
Ninespine Stickleback	10
Sand Shrimp	2
Smallmouth Bass	1
Three-spined Stickleback	14
White Perch	268
White Sucker	48
Grand Total	**3770**

AR3	*n*
American Eel	16
Atlantic Silverside	558
Atlantic Tomcod	9
Banded Killifish	2
Clupeidae	367
European Green Crab	2
Fourspine Stickleback	125
Lefteye Flounder	5
Mummichog	6
Northern Pipefish	21
Rainbow Smelt	6
Righteye Flounder	19
Sand Shrimp	898
White Perch	4
White Sucker	1
Grand Total	**2039**

AR6	*n*
American Eel	1
Atlantic Silverside	1369
Clupeidae	40
European Green Crab	27
Fourspine Stickleback	12
Mummichog	1
Northern Pipefish	2
Rainbow Smelt	6
Righteye Flounder	5
Sand Shrimp	1987
Grand Total	**3450**

AR8	*n*
American Eel	2
Atlantic Silverside	1035
Clupeidae	16
European Green Crab	182
Fourspine Stickleback	1
Hermit Crab	6
Jonah Crab	2
Northern Pipefish	1
Rainbow Smelt	5
Righteye Flounder	53
Sand Shrimp	4850
Sliver Hake	3
Squid	1
Grand Total	**6157**

AR10	*n*
Atlantic Silverside	142
Clupeidae	2
European Green Crab	103
Hermit Crab	9
Periwinkle	27
Rainbow Smelt	5
Righteye Flounder	158
Sand Lance	114
Sand Shrimp	6026
Grand Total	**6586**

AR5	*n*
American Eel	20
Atlantic Silverside	4118
Clupeidae	85
European Green Crab	46
Fourspine Stickleback	46
Hermit Crab	10
Lefteye Flounder	1
Northern Pipefish	27
Rainbow Smelt	2
Righteye Flounder	25
Sand Shrimp	2747
Windowpane Flounder	1
Grand Total	**7128**

AR7	*n*
Atlantic Butterfish	1
Atlantic Silverside	174
European Green Crab	38
Fourspine Stickleback	1
Hermit Crab	20
Periwinkle	11
Rainbow Smelt	2
Righteye Flounder	5
Sand Shrimp	462
Sliver Hake	2
Squid	1
Grand Total	**717**

AR9	*n*
American Eel	1
Atlantic Silverside	568
Clupeidae	6
European Green Crab	74
Hermit Crab	514
Periwinkle	13
Rainbow Smelt	2
Righteye Flounder	350
Sand Lance	1
Sand Shrimp	3411
Silver Hake	2
Squid	1
Grand Total	**4943**

AR12	*n*
Atlantic Silverside	406
Clupeidae	10
European Green Crab	139
Fourspine Stickleback	6
Mummichog	7
Periwinkle	44
Righteye Flounder	230
Sand Shrimp	693
Grand Total	**1535**

BR1	*n*
Atlantic Rock Crab	3
Atlantic Silverside	4
Clupeidae	4
European Green Crab	193
Mummichog	38
Rainbow Smelt	62
Righteye Flounder	326
Sand Shrimp	30
Squid	1
Grand Total	**661**

BR4	n
Atlantic Rock Crab	12
Atlantic Silverside	2
Clupeidae	1
European Green Crab	84
Mummichog	75
Rainbow Smelt	2
Righteye Flounder	15
Sand Shrimp	418
Grand Total	**609**

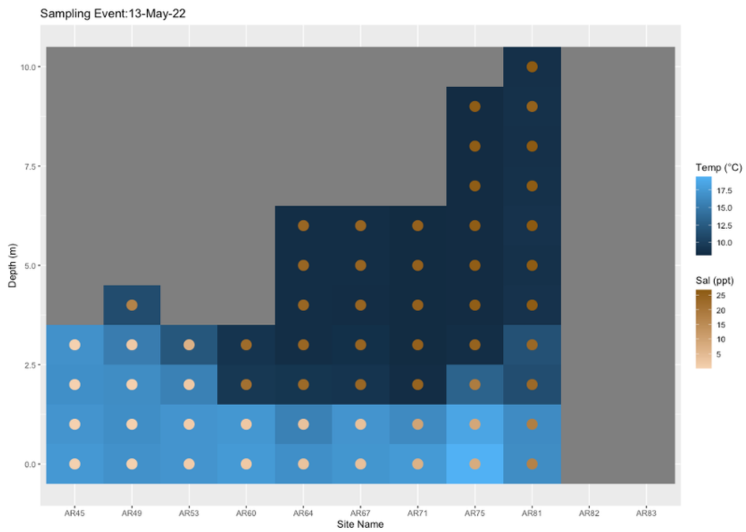
AR11	*n*
Atlantic Silverside	705
Clupeidae	3
European Green Crab	272
Mummichog	6
Periwinkle	4
Rainbow Smelt	1
Righteye Flounder	127
Sand Lance	128
Sand Shrimp	394
Grand Total	**1640**

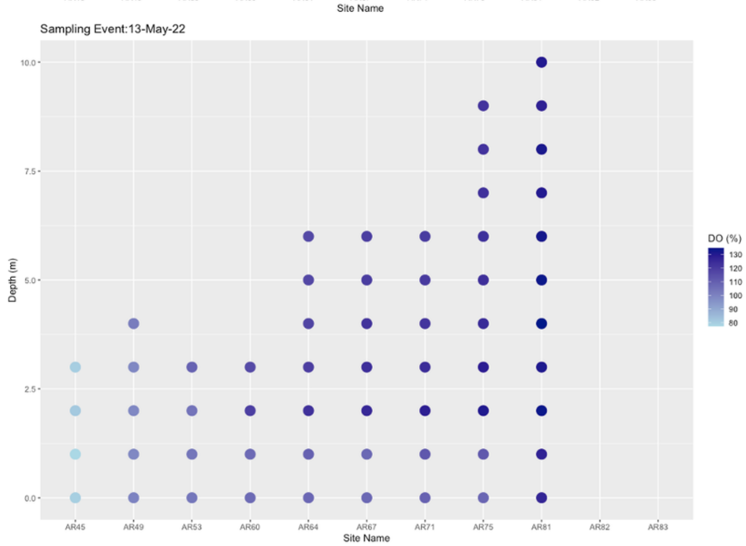
AR13	*n*
Atlantic Mackerel	1
Atlantic Silverside	1689
Clupeidae	19
European Green Crab	159
Hermit Crab	3
Jonah Crab	1
Northern Pipefish	1
Periwinkle	10
Righteye Flounder	26
Sand Shrimp	2388
Sculpin	1
Silver Hake	13
Squid	2
Grand Total	**4313**

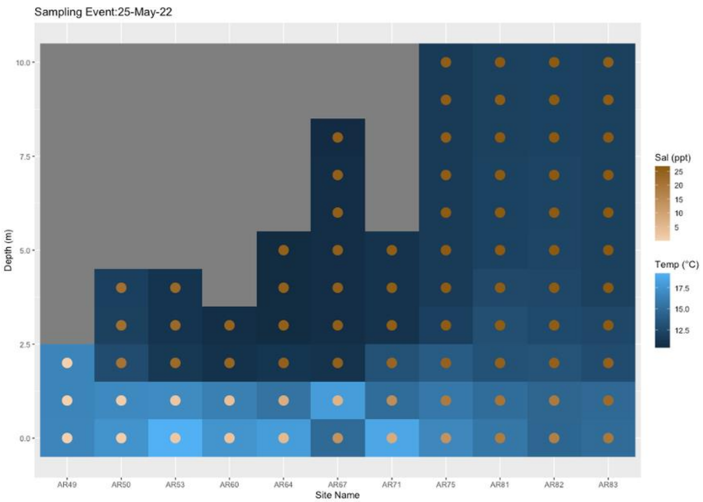
BR3	*n*
Atlantic Silverside	4
Clupeidae	264
European Green Crab	17
Righteye Flounder	61
Grand Total	**346**

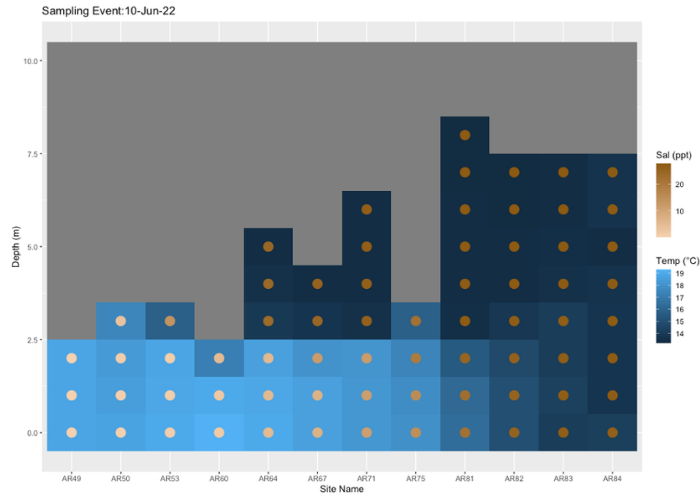
Appendix C. Salinity, temperature and dissolved oxygen data collected during water quality monitoring, sorted by date.

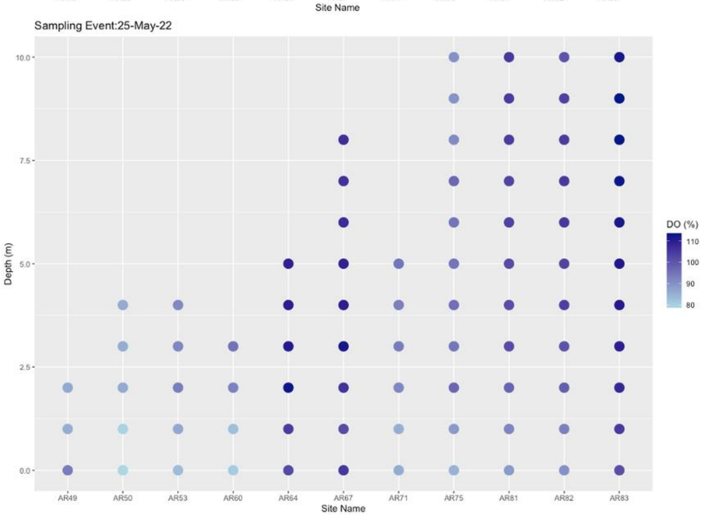
Note: The top panel of each chart depicts salinity and temperature at each sampling point: the parameters used to identify halocline and thermocline profiles. The lower panel depicts dissolved oxygen saturation. All data points are plotted by depth and ordered to reflect direction of river flow (left to right).

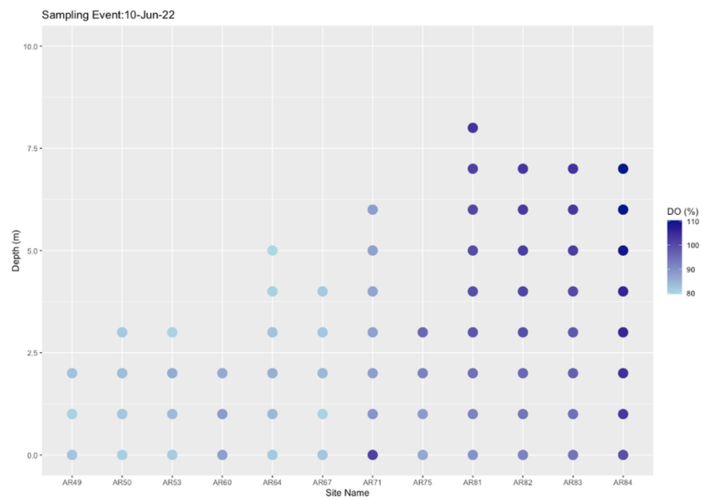


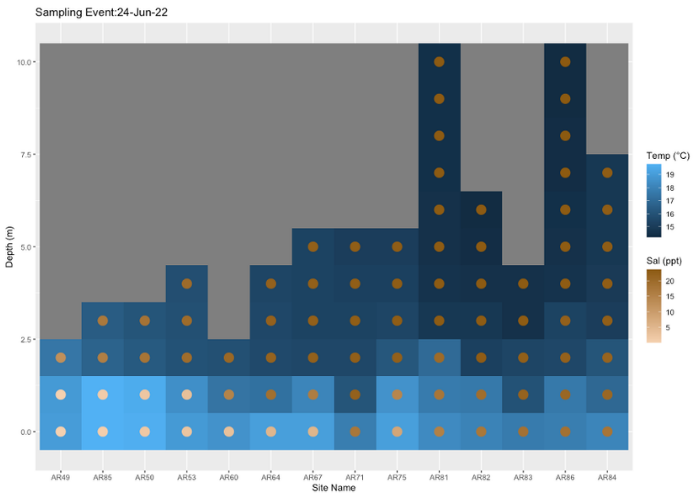


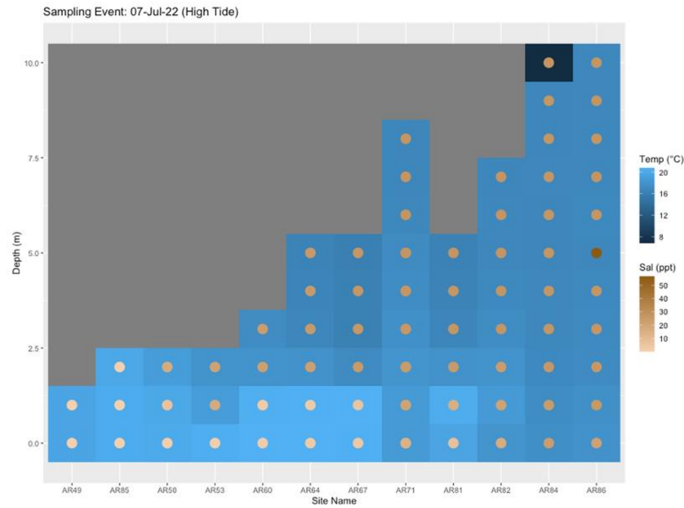

Sampling Event:25-May-22
Depth (m)
Site Name
Sal (ppt)
Temp (°C)

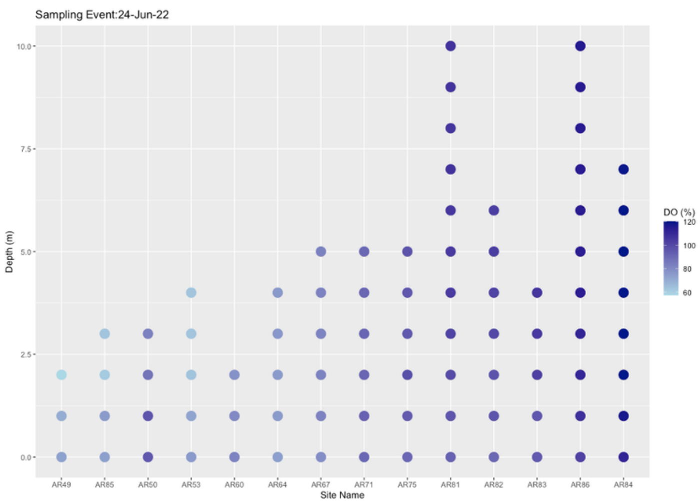

Sampling Event:10-Jun-22
Depth (m)
Site Name
Sal (ppt)
Temp (°C)

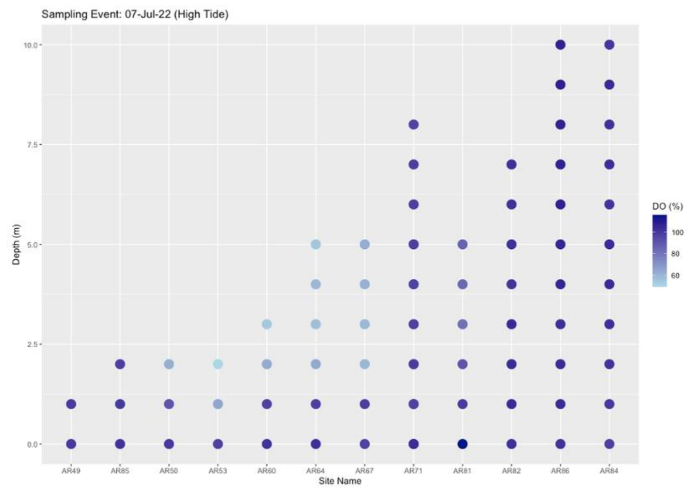

Sampling Event:25-May-22
Depth (m)
Site Name
DO (%)

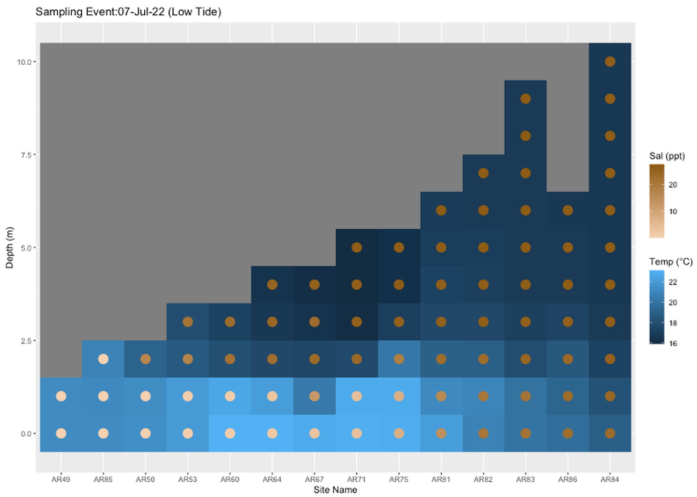

Sampling Event:10-Jun-22
Depth (m)
Site Name
DO (%)

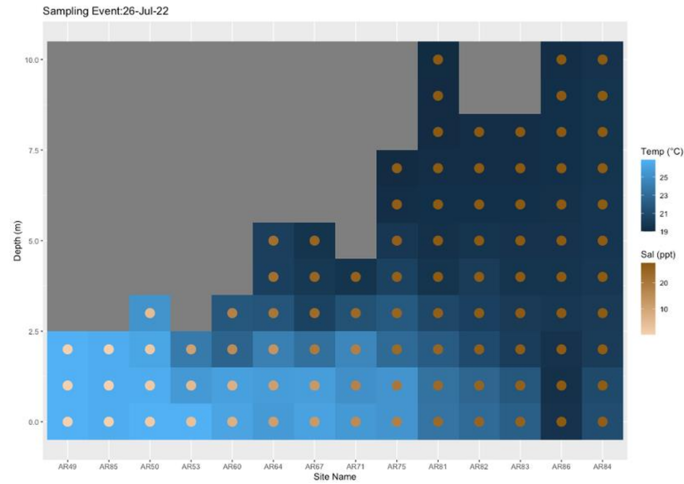

Sampling Event:24-Jun-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
Temp (°C)
Sal (ppt)

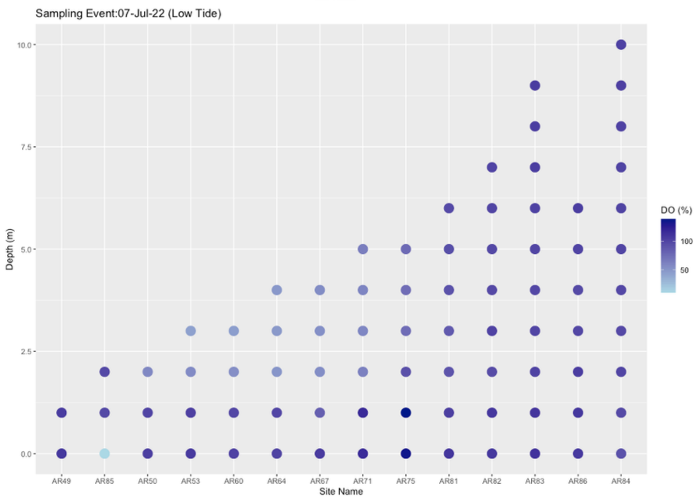

Sampling Event: 07-Jul-22 (High Tide)
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR81 AR82 AR84 AR86
Temp (°C)
Sal (ppt)

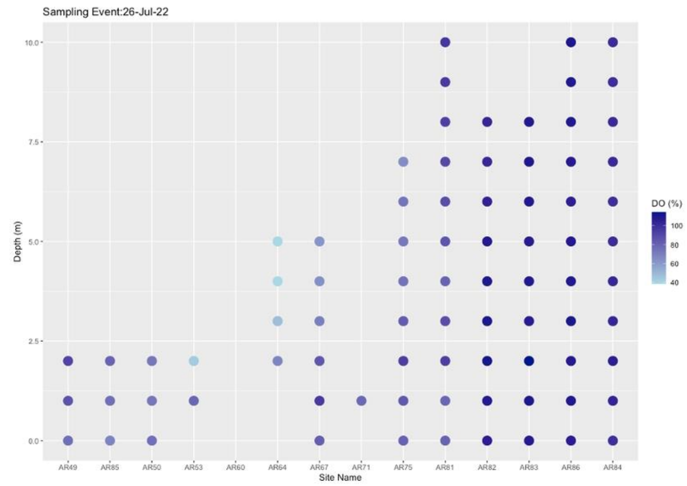

Sampling Event:24-Jun-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
DO (%)

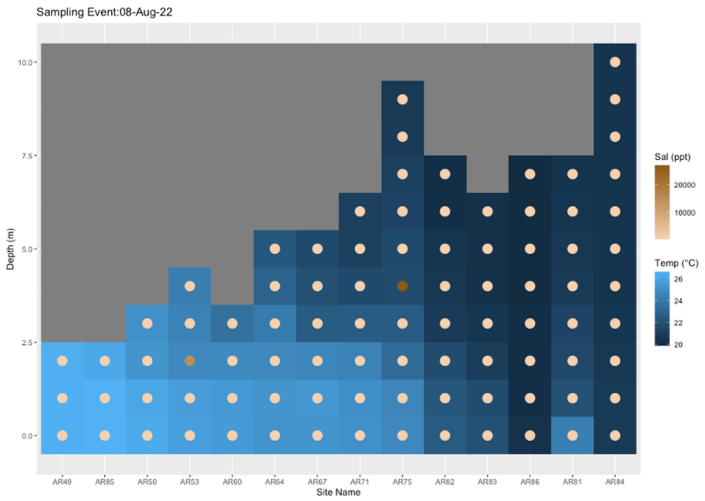

Sampling Event: 07-Jul-22 (High Tide)
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR81 AR82 AR86 AR84
DO (%)

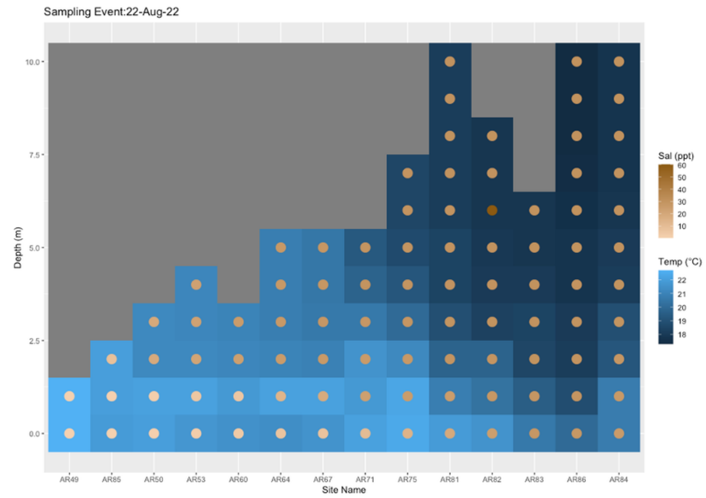

Sampling Event:07-Jul-22 (Low Tide)
Depth (m)
10.0
7.5
5.0
2.5
0.0
Sal (ppt)
20
10
Temp (°C)
22
20
18
16
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
Site Name

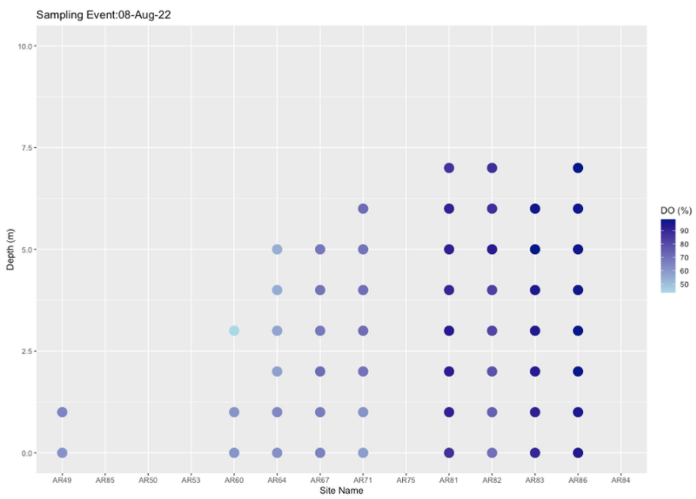

Sampling Event:26-Jul-22
Depth (m)
10.0
7.5
5.0
2.5
0.0
Temp (°C)
25
23
21
19
Sal (ppt)
20
10
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
Site Name

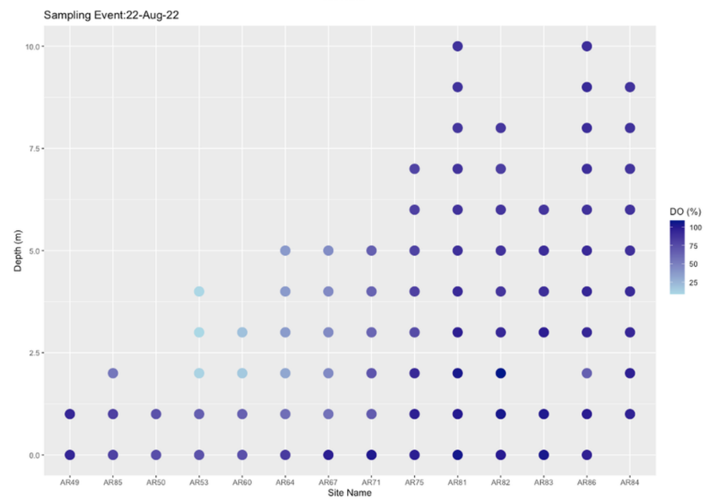

Sampling Event:07-Jul-22 (Low Tide)
Depth (m)
10.0
7.5
5.0
2.5
0.0
DO (%)
100
50
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
Site Name

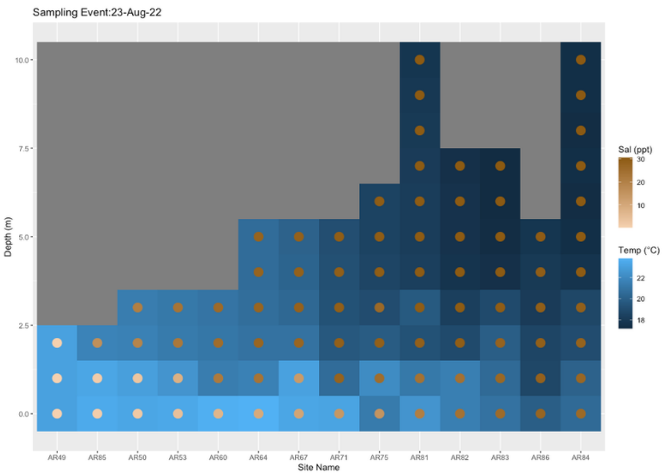

Sampling Event:26-Jul-22
Depth (m)
10.0
7.5
5.0
2.5
0.0
DO (%)
100
80
60
40
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
Site Name

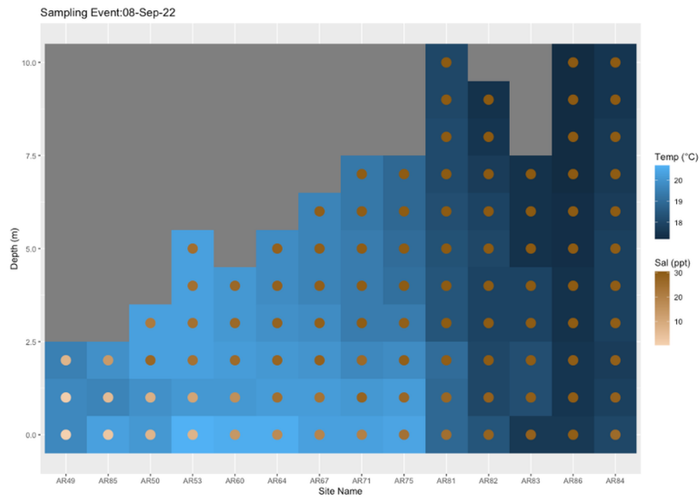

Sampling Event:08-Aug-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR82 AR83 AR86 AR81 AR84
Sal (ppt)
20000
10000
Temp (°C)
26
24
22
20

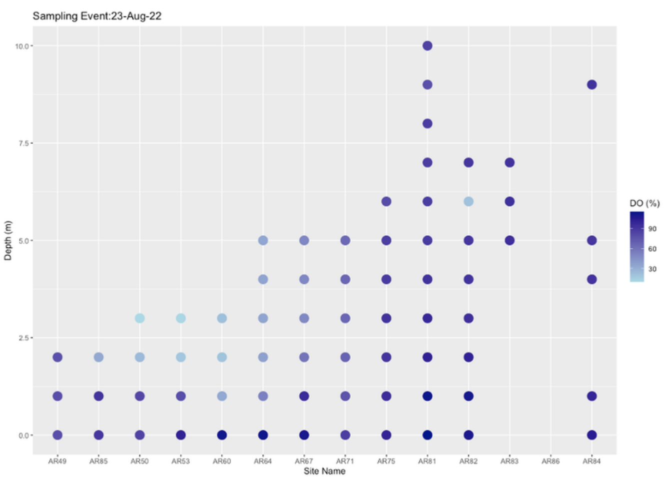

Sampling Event:22-Aug-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
Sal (ppt)
60
50
40
30
20
10
Temp (°C)
22
21
20
19
18

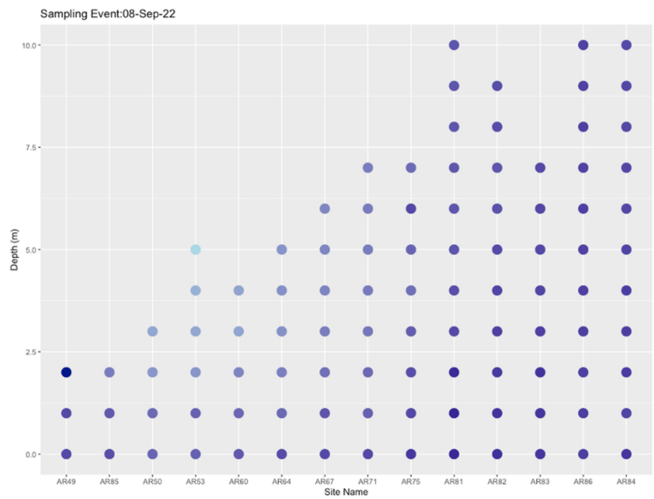

Sampling Event:08-Aug-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
DO (%)
90
80
70
60
50

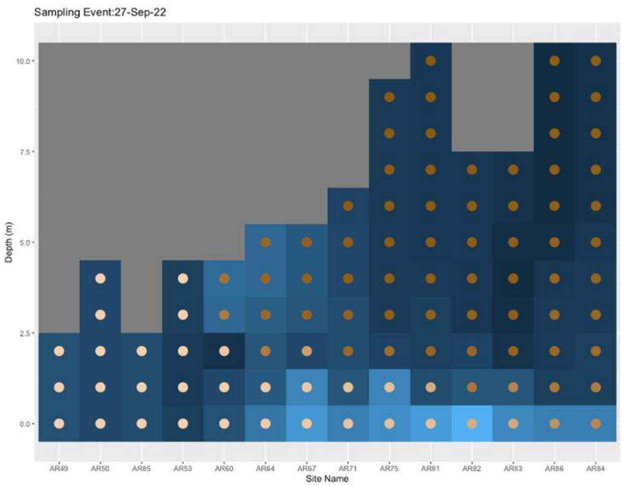

Sampling Event:22-Aug-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
DO (%)
100
75
50
25

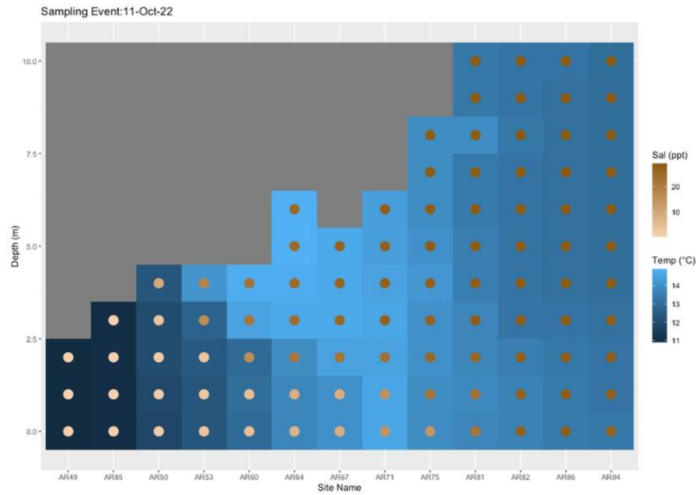

Sampling Event:23-Aug-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
Sal (ppt)
Temp (°C)

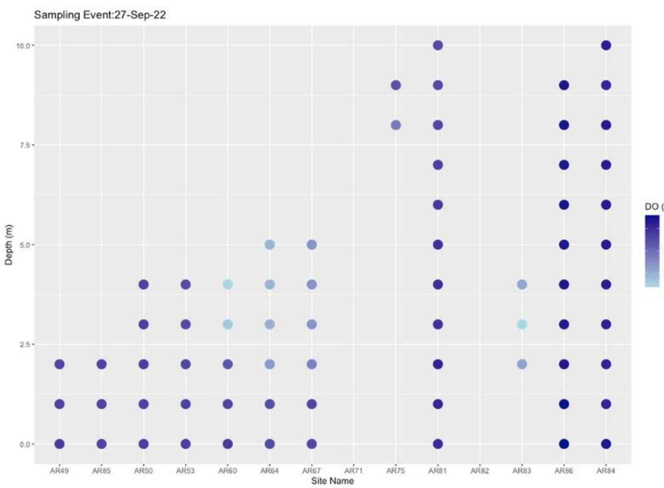

Sampling Event:08-Sep-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
Temp (°C)
Sal (ppt)

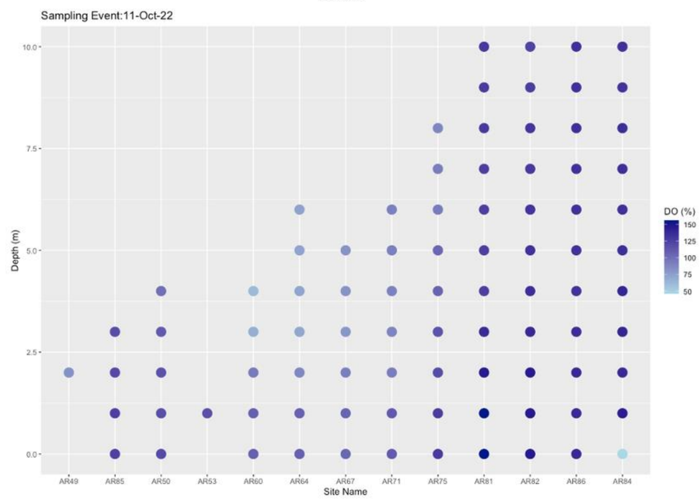

Sampling Event:23-Aug-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
DO (%)


Sampling Event:08-Sep-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
DO (%)

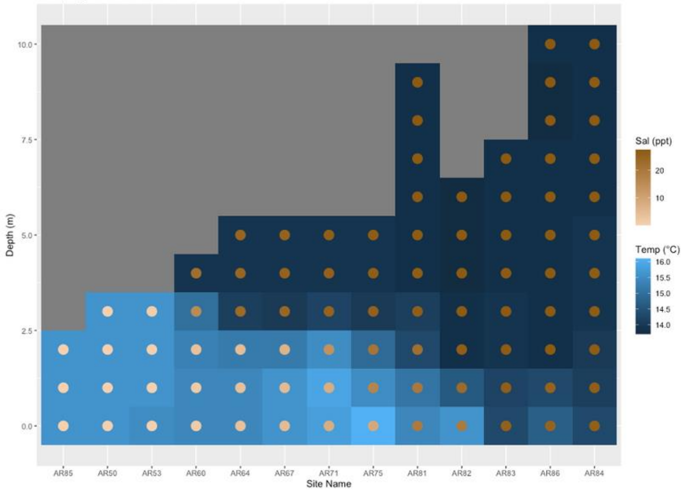

Sampling Event:27-Sep-22
Depth (m)
Site Name
AR49 AR50 AR85 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
Sal (ppt)
Temp (°C)


Sampling Event:11-Oct-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR86 AR84
Sal (ppt)
Temp (°C)

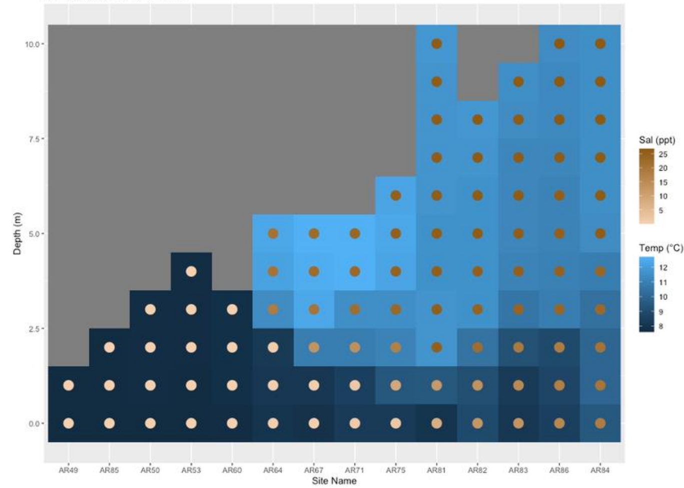

Sampling Event:27-Sep-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR83 AR86 AR84
DO (%)


Sampling Event:11-Oct-22
Depth (m)
Site Name
AR49 AR85 AR50 AR53 AR60 AR64 AR67 AR71 AR75 AR81 AR82 AR86 AR84
DO (%)

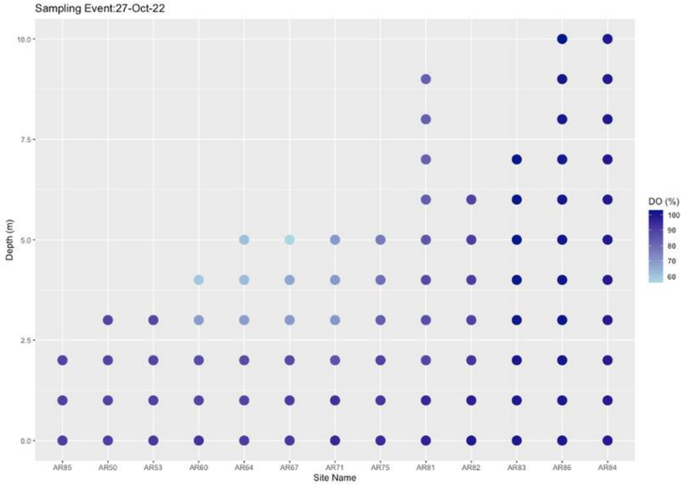
Sampling Event: 27-Oct-22



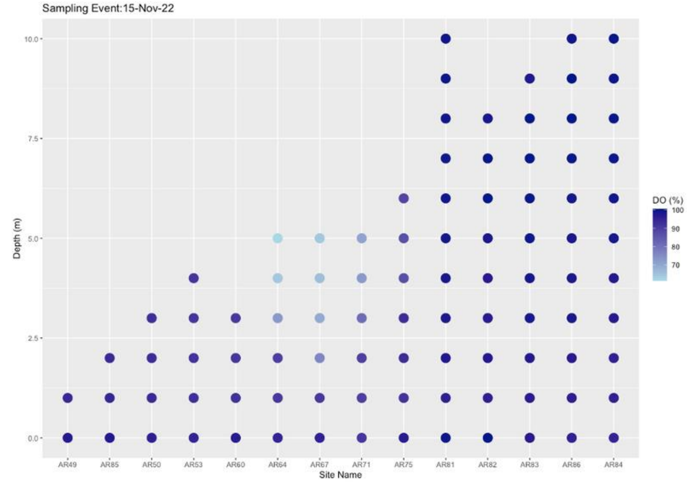
Sampling Event: 15-Nov-22



Sampling Event:27-Oct-22

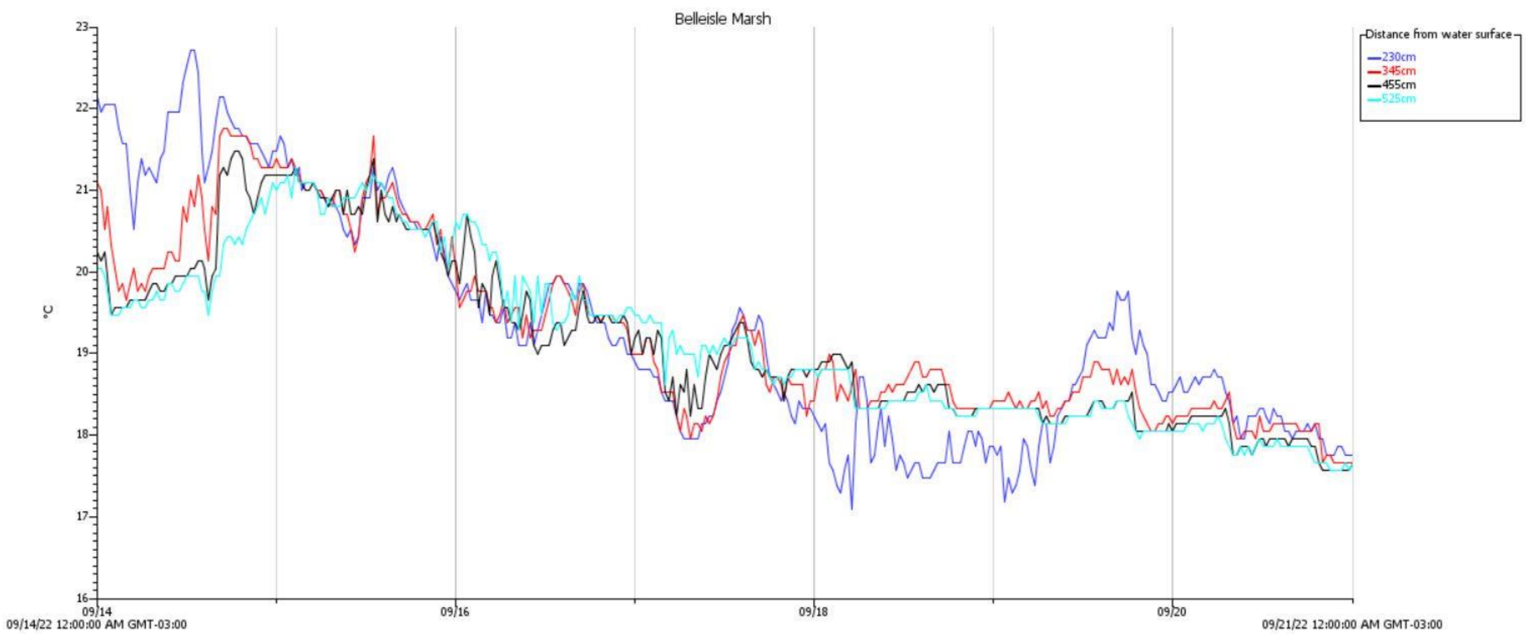


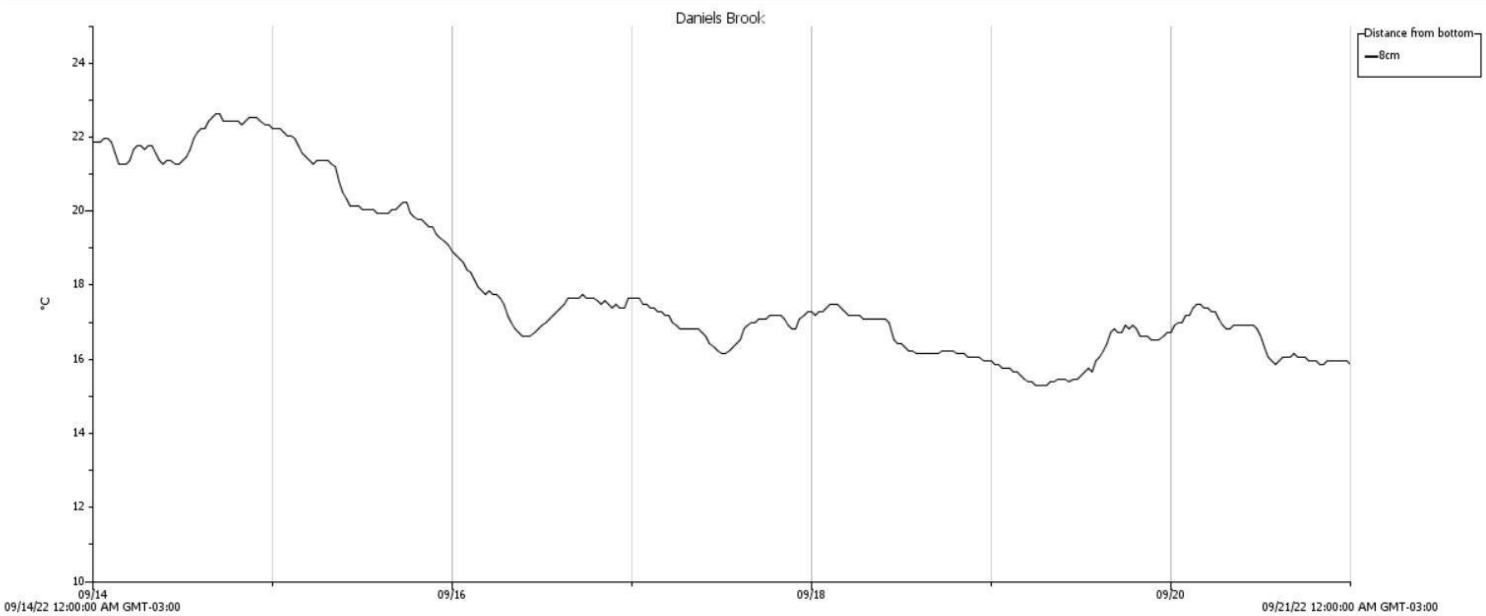
Sampling Event:15-Nov-22

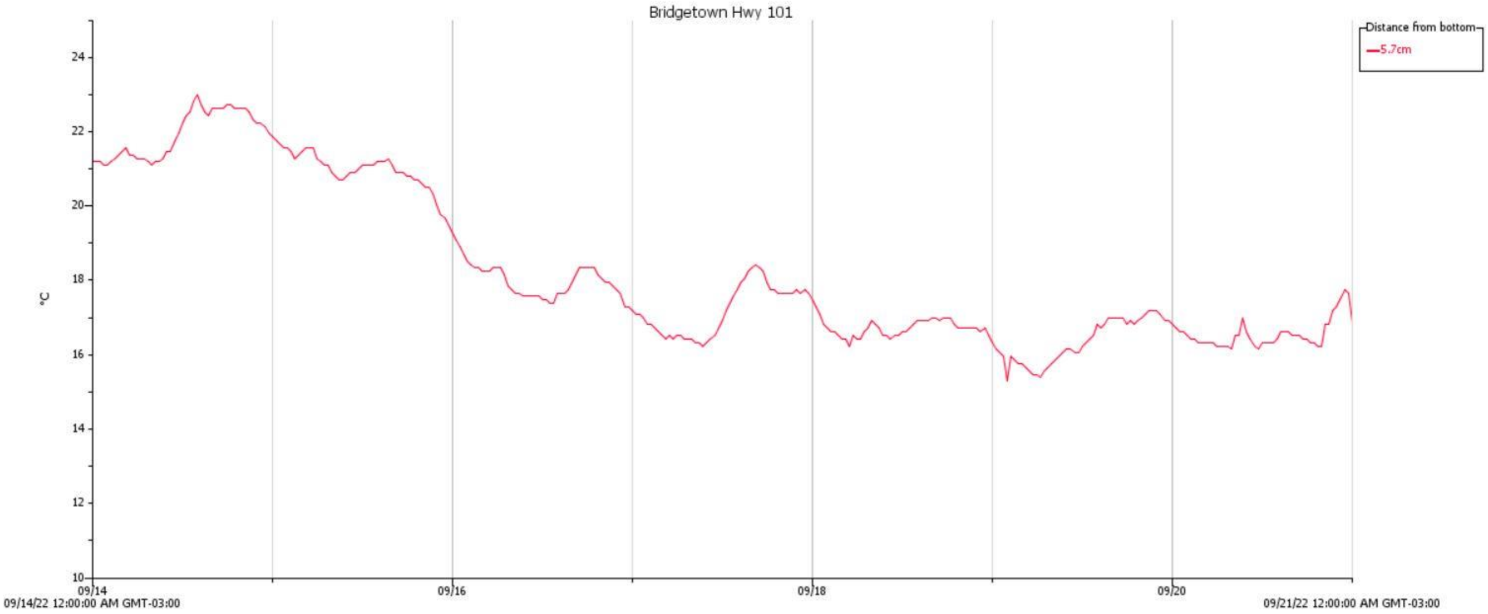


Appendix D. Temperature sensor data, sorted by site.

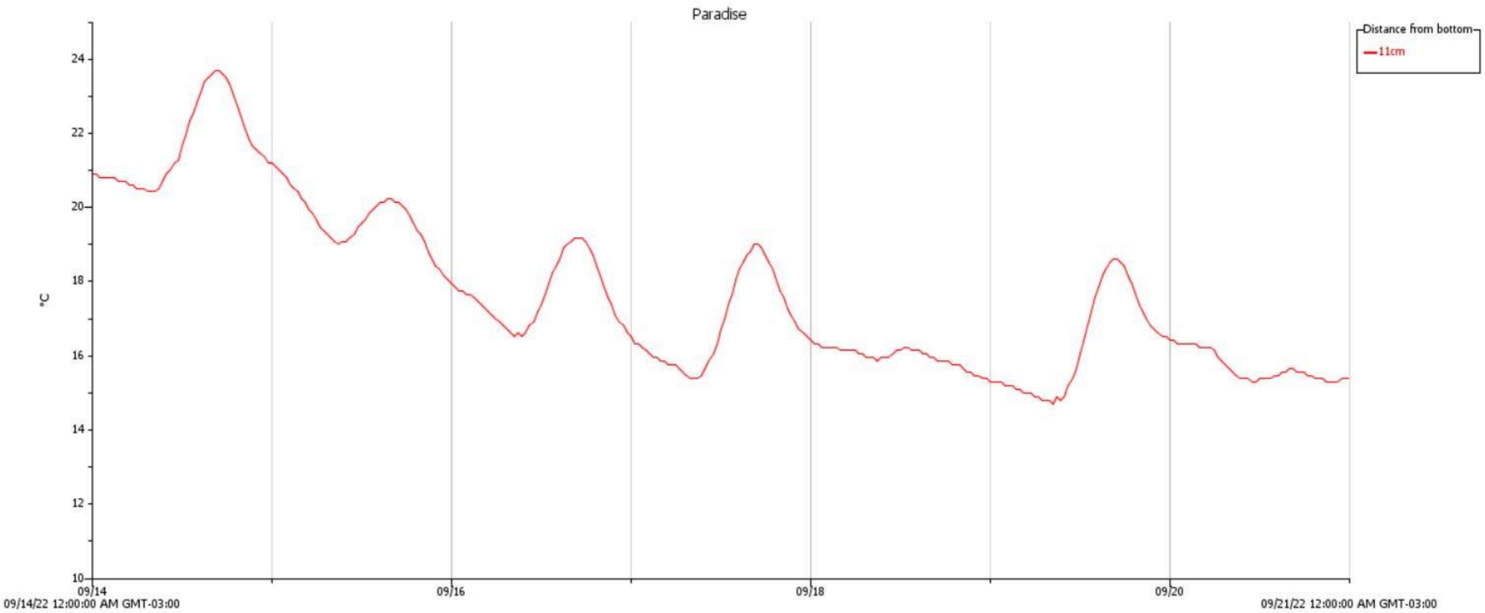
Note: Results are zoomed in to show temperature fluctuations over a week period, from September 14 – 21, 2022.




Daniels Brook
Distance from bottom
8cm
°C
24
22
20
18
16
14
12
10
09/14
09/14/22 12:00:00 AM GMT-03:00
09/16
09/18
09/20
09/21/22 12:00:00 AM GMT-03:00



Bridgetown Hwy 101
Distance from bottom
5.7cm
°C
24
22
20
18
16
14
12
10
09/14
09/14/22 12:00:00 AM GMT-03:00
09/16
09/18
09/20
09/21/22 12:00:00 AM GMT-03:00


Paradise
Distance from bottom
11cm
°C
24
22
20
18
16
14
12
10
09/14
09/14/22 12:00:00 AM GMT-03:00
09/16
09/18
09/20
09/21/22 12:00:00 AM GMT-03:00

Appendix E. Stationary plankton net results

Date	Observations
May 12, 2022	2 plankton nets deployed in the Annapolis River
May 16, 2022	Nets checked at 12:30pm. No eggs collected
May 18, 2022	Nets checked at 1:45pm. No eggs collected
May 20, 2022	Nets checked at 11:00am. No eggs collected
May 24, 2022	Nets checked at 7:00pm. No eggs collected
May 25, 2022	Nets checked at 6:00pm. No eggs collected
May 26, 2022	Nets checked at 6:15pm. No eggs collected
June 1, 2022	Nets checked at 12:30pm. No eggs collected
June 2, 2022	Nets retrieved. No eggs collected