From: Lachlan Riehl
To: Abraham Zebian; Paul Morton
Cc: PublicOnlyCouncilEmail
Subject: Halfway River - Information Re Flooding and Erosion Risks
Date: November 19, 2024 9:38:48 AM
Attachments: 2021-2022 Halfway River Habitat Assessment Report February 2022.pdf
Halfway River Habaitat Assessment Report November 2018.pdf

Good morning,

On November 14, 2024 CBC news published the article “N.S. government, railway company settle lengthy legal battle over Hantsport aboiteau” https://www.cbc.ca/news/canada/nova-scotia/hantsport-halfway-river-aboiteau-1.7382213

A statement from Mayor Zebian was included in the article: "I trust that the province of [Nova Scotia] will continue to ensure the aboiteau operates accordingly to its design to prevent any future flooding to the community that was experienced when it originally failed," said Zebian said in an email Wednesday.

Given this statement, I wish to bring forward information that Mayor Zebian may not be aware of. Please be advised that CBWES was hired by the province to carry out monitoring on the Halfway River after the previous structure failed in 2017. Several reports have been published on this situation and include valuable information that I encourage the Municipality to review.

The reports of most relevance are attached:
-2018 report “A River in Transition – the Restoration of the Halfway River and its Tidal Wetlands”
-2022 report “Halfway River Tidal Wetland Habitat Assessment 2021”

Information the municipality should be aware of:

2018 report pg 15-16:
-Erosion concerns from tidal flow were unfounded and observed erosion that was occurring predated the failure of the structure in 2017 meaning it wasn’t due to tidal flow.
-A recommended mitigation measure by CBWES to prevent further erosion at this site is to cut down any dead or dying trees in the area before they naturally fall and potentially take a part of the slope with them and further expose and destabilize the bank. This was recommended in 2018 has yet to be actioned by any agency.
-Sections of Highway 1 near the mouth of the river, the Highway 101 Exit 8 on/off ramps, and a low-lying section of Schurman Rd., are vulnerable to flooding during peak spring tides and storm surge events without a tidal barrier in place. However, the report outlined that NSTIR

(province) was aware of these areas of vulnerability and were prepared to take the necessary actions to upgrade their infrastructure to alleviate the risk. Agricultural lands in the area were also purchased among other actions to mitigate impacts to residents.

In the end, the province decided to construct a new tidal barrier at this site.

2022 report pg x:
-"Flooding of the high marsh platform (48.5 ha) is now limited to irregular extreme rainfall events. Events which are expected to increase in frequency and severity in the future due to climate change. While the new structure has reduced the risk of flooding from tidal events, the risk remains, particularly from significant rainfall or freshet events. Improvement of highway infrastructure above the 2055 High High Water Large Tide (HHWLT) level would provide a more robust solution to both tidal and freshwater events and would eliminate the perceived need for the causeway-culvert at the mouth of the river".
-"Improvement of highway infrastructure above the 2055 HHWLT level would be a more effective flood risk management approach than continuing to rely on the downstream causeway-culvert to provide flood protection".

Takeaways:
-Dead trees should be removed from the banks and slopes before they fall over to mitigate those erosion risks.
-The new structure is reported to still have a flood risk – from freshwater – and the recommended course of action with or without the structure is to upgrade the vulnerable road and bridge infrastructure that is vulnerable in either situation. You currently have a flood risk on the Halfway River with or without the structure.

Thank you,
Lachlan Riehl

Halfway River Tidal Wetland Habitat Assessment 2021

Prepared for:
The Confederacy of Mainland Mi'kmaq

Prepared by:
CBWES Inc.

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Executive Summary

The failure of the Halfway River causeway-aboiteau in November 2017 resulted in the re-establishment of the natural hydrological regime to the river and reconnected the watershed to the broader Minas Basin and Bay of Fundy ecosystem. The re-establishment of tidal flow initiated the recovery of approximately 75 ha of provincially significant salt marsh habitat.

In 2019, the Province of Nova Scotia made the decision to rebuild the causeway and replace the failed aboiteau with similarly-sized concrete culverts in order to protect upstream infrastructure, secure access to Hantsport, and accommodate fish passage. This work was subsequently approved and authorized by the NS Environment (NSECC Approval 2019-2534602) and Fisheries and Oceans Canada (*Fisheries Act* Emergency Authorizations 19-HMAR-00017, 19-HMAR-00526 & 20-HMAR-00098). As part of a larger study started in 2019 by the Confederacy of Mainland Mi'kmaq (CMM), CBWES developed and implemented a multi-year monitoring program to study the changing hydrological and wetland habitat conditions on the Halfway River following the restoration of tidal flow to the system and during and following the construction of the new tidal barrier.

The first year of the study (2019) focused on the naturally restoring tidal wetland habitat (salt marsh) throughout the tidal portion of the system and documented the area, extent, and condition of the re-establishing wetland habitat. The second year of monitoring (2020) captured the systems response to the prolonged period of tidal blockage that was required to facilitate construction of the new structure. With all construction activities having been completed in 2020, the third year of the study (2021), represented the first full year of wetland habitat monitoring under the new [restricted] tidal regime. This report draws upon all three years of data collection and field observations in order to describe the evolution of habitat conditions over the course of the study and to extend that trajectory into the future. The results are summarized below.

Geospatial Attributes

Elevations on the former high marsh (floodplain) have decreased from the pre-restoration condition but changed only nominally from 2019 to 2021. This may be due to root collapse of the former agricultural surface, though Lidar errors due to dense vegetation may also play a role. Elevations in the low marsh terrace have increased from the pre-restoration period, with seasonal increases observed in the fall of 2020 reflecting sedimentation patterns in the Bay of Fundy (May to November); however, seasonal analysis was not able to be completed in 2021 due to high water levels during the fall flight. The main Halfway River channel has shown no change in morphology. The armour stone associated with the new causeway-culvert structure has resulted in measurable scour immediately upstream of the structure.

Habitat mapping showed that the spatial distribution of vegetation communities has continued to evolve along the pathways identified in 2019, with distinct communities mapped on the former high marsh (marsh platform or floodplain habitat) and low marsh (terrace). Bare ground on the platform has been reduced from nearly 100% in the initial stages of wetland re-establishment to 4% in 2021. In 2020, over 50% of the *Spartina alterniflora* cover (3.7 ha of 7.5 ha) in the low marsh experienced a rapid dieback event. During the 2021 growing season, total area of *S. alterniflora* increased to 4.7 ha; with 3.8 ha in good condition and 0.9 ha growing sparsely (but not in poor condition). Areas of dieback near the mouth of the river were generally converted to bare ground

with new sparse growth emanating from healthy stands that did not dieback. Areas farther from the mouth retained sparse growth with total patch size expanding beyond 2018 levels.

Hydrology

Tide Signal and Flood Mapping:

The causeway-culvert has reduced the maximum high tide by ~ 2.3 m from 7.4 to 5.1 m CVGD2013 and reduced flood extent from the 2019 post-breach maximum of 75 ha to 26.5 ha during normal tidal flow. This has resulted in the elimination of tidal flooding of the floodplain (former high marsh platform). Conversely, the hydroperiod and mean inundation time for the low marsh terrace has increased by 15% compared to the 2019 unrestricted conditions. In the fall of 2021 an intense rainfall event (storm) lead to flooding of 80% of the marshland during a neap tide cycle, with water levels inside the site higher than high tide outside the site. A similar, and potentially greater, flood event was observed in February 2022.

Suspended Sediment Concentrations, and Velocity:

Sampling carried out in 2019 and 2020 showed high suspended sediment concentrations (SSC) about 3 hours before high tide, as the tide was coming in, then concentrations decreasing until high tide, followed by another increase in concentration as the tide was on its way out, peaking again about 3 hours after high tide. Differences in SSC values were observed between years due to rainfall events during or prior to sampling. Suspended sediment concentrations were consistent with values recorded in other tidal systems in the Upper Bay but lower than values reported in rivers with fluid mud such as the Salmon River or portions of the Avon River. The concentrations are sufficient to cause the sedimentation observed on the marsh platform with highest values closest to the River. Turbidity was higher in October 2020 than July 2019, with higher tides and colder temperatures also recorded during the 2020 deployment.

Velocity patterns from the ADCP show fast flow of water on the initial flood tide and on the end of the ebb tide. At these extremities of the inundation period at this site, water speeds are around 1.0 $m \cdot s^{-1}$. As the site fills with water, velocities decrease, slowing down consistently to a minimum of about 0.25 $m \cdot s^{-1}$. Values between 2019, 2020 and 2021 were similar.

Salinity and temperature were also similar across years. Salinity peaked at 27 to 29 PSU, and dropped to values between 7 and 20 PSU at the end of the tidal cycle. Temperatures showed seasonal variability, with 2019 and 2020 around 18 degrees Celsius (summer) and 13-14 degrees Celsius (Fall) at high tide.

Tidal Discharge:

Discharge, measured ~90 m above Highway 1 bridge, across all three years was consistent, with discharge at approximately 5 $m^3 \cdot s^{-1}$ at the beginning of the incoming tide, growing as the tide increased and water passed through a larger cross-sectional area. Maximum discharge on the incoming tide ranged from 34 - 35 $m^3 \cdot s^{-1}$ (water coming into the river), and 36 - 39 $m^3 \cdot s^{-1}$ on the ebb tide (water flowing out of the river).

Soils and Sediments

Sediment Accretion and Elevation:

Marked differences were recorded in surface elevation change at the RSETs, which are located on the low marsh terrace and continue to be flooded by tidal waters, however all were positive vertical changes in elevation. In 2019-2020 the greatest annual change in surface elevation occurred closest to the river mouth, and therefore to the incoming sediment laden tidal waters. In 2020-21, however, the patterns of highest and lowest changes in surface elevation were reversed with the highest rates of change recorded at SET-03. The majority of the positive (upward) change in surface elevation can be attributed to sediment deposition. However, subtraction of the RSET and marker horizon data indicate that negative (sinking) processes within the root zone were occurring at SET-01 in 2020-21, SET-02 in 2019-2020 and SET-03 in both time periods. This may either be due to compaction or decay of former vegetation platform.

Sediment Characteristics:

In 2019, the majority of cores exhibited differences between bottom and top of the core reflecting tidal inundation after the culvert structure failed. All samples are classified as mud for their textural group and sediment names ranged from fine silt to very coarse silt. Most samples were classified with a sediment name of coarse silt. All grain size distributions were poorly sorted in all years. Skewness varied from fine skewed to symmetrical. The mean of all mean grain sizes for all samples on site increased from 10.3 to 12.1 µm between 2019 and 2020 and returned to 10.4 µm in 2021. In general, coarser material was also found closest to the river itself and finer sediments located at the head of creek systems. Highest water contents were found closest to the river where they would be more frequently inundated and have moderate to low organic matter content. Between 2020 and 2021, nine out of twelve stations recorded a positive change in organic matter content. The majority of samples have a bulk density greater than 1.1 $g \cdot cm^{-3}$ which is similar to values recorded at the St. Croix restoration site in the first-year post-restoration. Higher bulk densities are also typically associated with agricultural soils.

In 2019, there was no consistent pattern of the grain size curve for all of the samples collected. Between 2019 and 2020, some of the grain size curves had marked changes. Both stations on Transect 1 had different grain size distributions shapes between 2019 and 2020. T1S2 became finer and changes from a bimodal appearance to a single mode appearance and a rapid drop of the curve. T1S3 became much coarser, and the fine end of the curve changed to be much lower, representing that more grains were deposited in single grain form at T1S3 in 2020 than in 2019. At Transects 6 and 7, there is much less change in the shape of the grain size distribution in that same 1-year time span. In 2021 T2S1 and T4S1 got much finer, while T4S2 saw a rapid drop of the curve indicating coarser material. The remaining stations remained consistent with 2020 results.

Vegetation

Halfway River (HWR) vegetation plots contain a range of brackish and salt marsh vegetation types, overlapping with reference site species composition and abundance except that there is no representation of high salt marsh vegetation in the Halfway River plots. HWR floodplain plots have shown a consistent shift in plant community composition and abundance, from early successional salt marsh communities dominated by native annuals in 2019/2020 to a weedy "wet meadow" community with a high abundance of non-native species in 2021, reflecting the exclusion of tidal waters from the floodplain. Consistent with the shift from early successional salt marsh flora to wet meadow, the average number of plant species in floodplain plots has increased steadily from

2019-2021. The number and cover of halophytic species peaked in 2020 but declined in 2021. Unvegetated area was high in 2019 but has declined to almost zero by 2021 in the monitoring plots.

In the low marsh area, most plots have been consistently dominated by *S. alterniflora* across all three years, and there are no indications of any consistent shift towards different vegetation types between 2019-2021. Unvegetated areas covered approximately 25% of plot areas in 2019, declined substantially in 2020 but returned to 2019 levels in 2021, reflecting the loss of poor condition vegetation detected in a sudden dieback event which occurred late in 2020.

Structured Winter Walk

The winter of 2021/22 was characterized by variable temperatures and significant snow and rainfall events. As a result of the fluctuating temperatures (stretches above zero, followed by days below zero) the marsh routinely went through periods of freezing and thawing. Approximately 50 cm of snow was present consistently on the entire site surface on February 9, 2022. The main river was mostly filled with ice blocks from the causeway to the Hwy 1 bridge while directly upstream of the bridge had areas of ice blocks as well as open water. Further south, the river was generally covered with ice (single ice layer rather than separate blocks), and very little open water was visible.

Fish

Overall, eight different species were observed from the fish surveys in HWR in 2020 and 2021: Atlantic Silverside (*Menidia menidia*), American Eel (*Anguilla rostrata*), Green Crab (*Carcinus maenas*), Mummichog (*Fundulus heteroclitus*), and Tomcod (*Microgadus tomcod*) were caught in all years. In 2020 Four Spine Stickleback (*Apeltes quadracus*) and Sand Shrimp (*Crangon sp*.) were also caught, and in 2021 Striped Bass (*Marone saxatilils*) were caught. Fish surveys in 2020 and 2021 were both carried out in the Fall, and the 2020 surveys had higher catches (both in absolute and CPUE measurements). Mummichogs (*F. heteroclitus*) comprised the greatest portion of the catch in both years, with absolute numbers higher in 2020 than 2021 but percent catch comparable at 76% and 73% respectively.

Summary

The Halfway River flood plain continues to change in response to the significant alterations to the hydrology that have occurred over the past 4 years. Examination of geospatial attributes, hydrology, soils and sediments, vegetation, and winter conditions annually from 2019 to 2022, several key patterns were observed.

The failure of the original causeway-aboiteau structure in 2017 resulted in the re-establishment of unrestricted tidal flow to the river and the restoration of the 75 ha flood plain to tidal wetland (salt marsh).

The new causeway-culvert structure, constructed in 2019/2020, is a significant tidal restriction and has caused the loss of nearly 50 ha of salt marsh habitat that had started to recover in 2018 following the 2017 washout of old railway structure. The new structure has caused an increase in hydroperiod at elevations below 3 m (CGVD2013) and a decrease in hydroperiod above that elevation. This limiting, or cutting of the tide, results in both the reduced height and reach of the tide. Tidal flow is now limited to 26.5 ha (7.1 ha main river channel; 19.4 ha low salt marsh terrace). The remaining 48.5 ha of previously re-establishing salt marsh, representing a majority of the high salt marsh platform, is now beyond the reach of the tide. In the absence of regular tidal influence, the halophytic vegetation that had been re-establishing throughout the 48.5 ha are being replaced by terrestrial species and the associated wetland functions are being lost.

Between 2019 and 2021 vegetation cover has increased throughout the high (salt) marsh platform, to 96%. However, the 2021 vegetation survey confirmed the decrease in halophytes and in an increase in weedy terrestrial species. This reflects the loss of tidal influence above ~5.2 m (CGVD2013) and represents the transition back to a freshwater and terrestrial system.

Flooding of the high marsh platform (48.5 ha) is now limited to irregular extreme rainfall events. Events which are expected to increase in frequency and severity in the future due to climate change. While the new structure has reduced the risk of flooding from tidal events, the risk remains, particularly from significant rainfall or freshet events. Improvement of highway infrastructure above the 2055 High High Water Large Tide (HHWLT) level would provide a more robust solution to both tidal and freshwater events and would eliminate the perceived need for the causeway-culvert at the mouth of the river.

There has been little change in the morphology of the primary channel, except immediately upstream and down of the causeway, where the placement of armour rock and the resulting erosion/scour over the past year has resulted in direct habitat loss and elevation changes. Both velocity and discharge remain similar to the 2019 measurements (made prior to the additional construction activities to re-enforce the structure) with a slight flood dominance.

In 2020, an unexplained and sudden vegetation dieback (SVD) of approximately 3.7 ha of *S. alterniflora* was observed, representing 50% of the existing 7.5 ha of vegetated low marsh habitat. Based on the available data and our understanding of the site, it was possible that the change in hydrology and sediment patterns caused by the new structure could have been responsible for poor condition and loss the vegetation. However, there was limited evidence that they alone were the causal agents for the spatial pattern of the dieback. In 2021, *S. alterniflora* coverage totaled 4.7 ha, with 3.8 ha in good condition and 0.9 ha growing sparsely (but not in poor condition). Areas that experienced dieback near the mouth of the system (Transects 1-5) have generally not recovered and remain bare ground. However, areas of low marsh farther from tidal flow (T6+) have retained sparse vegetation in the location of the dieback and have in fact experienced an increase in *S. alterniflora* coverage compared to 2018 levels. The spatial pattern of dieback persisting closer to the river mouth and dissipating with distance upstream, points more towards a contaminants issue. It is likely not a single variable that has resulted in the changes to the low marsh vegetation community observed – but rather the cumulative effects of several stressors. The pattern of dieback, as well as the pattern of recovery, does support contaminants as a primary driver. However, sedimentation and hydroperiod are also considered contributing factors as the change in the environment could also be expected to impact the health of established vegetation, reducing their resilience to other stressors.

Considering the results of three years of study, the following conclusions and recommendations are made:

1) Changes in hydrology (reduction of tide height and increased hydroperiod) from the new causeway-culvert, have resulted in the conversion of the re-establishing high salt marsh habitat to a predominantly weedy wet meadow/terrestrial condition, and a degradation of form and function of the remaining 26.5 ha. Tidal wetlands (salt marshes) are designated as Wetlands of Special Significance (WSS) in Nova Scotia (NS Wetland Policy[1]) and are protected federally as important fish habitat (*Fisheries Act*[2]). The new causeway-culvert is a significant hydrological barrier and removal of the structure would result in the re-establishment of the natural tidal regime to the system, restoring 48.5 ha of salt marsh and improving the function of the remaining 26.5 ha of tidal river and low marsh habitat.
2) The nature and source of pollutants entering the system should be identified and eliminated in order to prevent further degradation and loss of habitat and to allow for the recovery of what has already been impacted.
3) The Halfway River system has experienced significant changes to the physical (i.e., hydrology, sediment) and biological (i.e., vegetation) since 2017, and has yet to reach any sort of dynamic equilibrium. Given this, and the SVD-contaminants issue, it is recommended that the monitoring of habitat conditions be continued for at least another two years in order to determine longer-term trends and the ecological/habitat condition of the site.
4) Improvement of highway infrastructure above the 2055 HHWLT level would be a more effective flood risk management approach than continuing to rely on the downstream causeway-culvert to provide flood protection.

[1] https://novascotia.ca/nse/wetland/conservation.policy.asp
[2] https://laws-lois.justice.gc.ca/eng/AnnualStatutes/2019_14/

Introduction

Halfway River historically, and naturally, was a free-flowing tidal river with extensive salt marshes that comprised the lower reaches of the river's flood plain and transitioned upstream into brackish and tidal fresh wetlands. As with many salt marshes and tidal rivers throughout the Bay of Fundy, the tidal aspects of Halfway River were lost due to the construction of barriers (e.g., dykes & aboiteau, causeways) to tidal flow and fish passage. Following a period of previous collapse and partial tidal flow, the complete failure of the Halfway River causeway-aboiteau in November 2017 resulted in the re-establishment of the natural hydrological regime to the river and reconnected the watershed to the broader Minas Basin and Bay of Fundy ecosystem (Bowron et al., 2018). The re-establishment of tidal flow initiated the recovery of approximately 75 ha of provincially significant salt marsh habitat.

In 2019, the Province of Nova Scotia made the decision to rebuild the causeway and replace the failed aboiteau with similarly sized concrete culverts in order to protect upstream infrastructure, secure access to Hantsport, and accommodate fish passage. This work was subsequently approved and authorized by the NS Environment (NSECC Approval 2019-2534602) and Fisheries and Oceans Canada (*Fisheries Act* Emergency Authorizations 19-HMAR-00017, 19-HMAR-00526 & 20-HMAR-00098). CBWES Inc. was commissioned by the Confederacy of Mainland Mi'kmaq (CMM) in June 2019 to develop and implement a three-year tidal wetland monitoring program as part of a larger study being led by the CMM looking at fish and fish habitat in three major rivers in the Southern Bight of the Minas Basin – Halfway River, Avon River and Cogmagun River (reference system). The intention of the CBWES study was to document the hydrological and habitat conditions on the Halfway River following one year of restored tidal flow and the subsequent restriction of tidal flow by the installation of the new causeway-culvert structure.

The purpose of the study was to document the changes in the river and tidal wetland habitat as a result of the failure of the original tidal barrier, its eventual replacement, and the extended period of tidal restriction required to facilitate efforts to repair and stabilize the replacement infrastructure. The first year of the study (2019) focused on the naturally restoring tidal wetland habitat (salt marsh) throughout the tidal portion of the system and sought to document the area, extent, and condition of the re-establishing wetland habitat. The second year of monitoring (2020) captured the systems response to the prolonged period of tidal blockage that was required to facilitate construction of the new structure, and the subsequent re-introduction of limited tidal flow. With all construction activities having been completed in 2020, the third year of the study (2021), represented the first full year of wetland habitat monitoring under the new [restricted] tidal regime. This report draws upon all three years of data collection and field observations in order to describe the evolution of habitat conditions over the course of the study and to extend that trajectory into the future.

Study Area

Halfway River in Hantsport, NS, flows into the Avon River, which is part of the Southern Bight of the Minas Basin, Bay of Fundy (FIGURE 1, FIGURE 2). Tidal flow to the former macrotidal river was eliminated by the historical construction and operation of a privately-owned railway causeway across the mouth of the river. Freshwater drainage was primarily facilitated by the presence of a large wooden aboiteau structure within the base of the causeway and a smaller secondary multi-barreled metal aboiteau structure set high in the causeway to serve as relief valve during high water events. Lack of adequate maintenance of the causeway and aboiteau structure in recent decades contributed to its deterioration and the re-introduction of limited tidal flow to the river. Full tidal flow returned to the river in November 2017 with the complete failure of the causeway and aboiteau (FIGURE 3, FIGURE 4).

In response to public pressure, work to repair the causeway and to replace the aboiteau with concrete culverts commenced in Spring 2019 (FIGURE 6). The new causeway has a larger footprint and is more heavily armoured than the original structure. The additional work required to ensure the stability of the new structure involved the use of a considerable amount of rock and steel sheet pile which extended the footprint of the structure both upstream and narrowed the channel (FIGURE 5). The new culvert is a concrete double box culvert and it is our understanding that the intention was to replicate the capacity of the original structure and to return the system to pre-2017 failure condition in order to protect upstream infrastructure, secure continuing access to the community of Hantsport, and allow for fish passage.

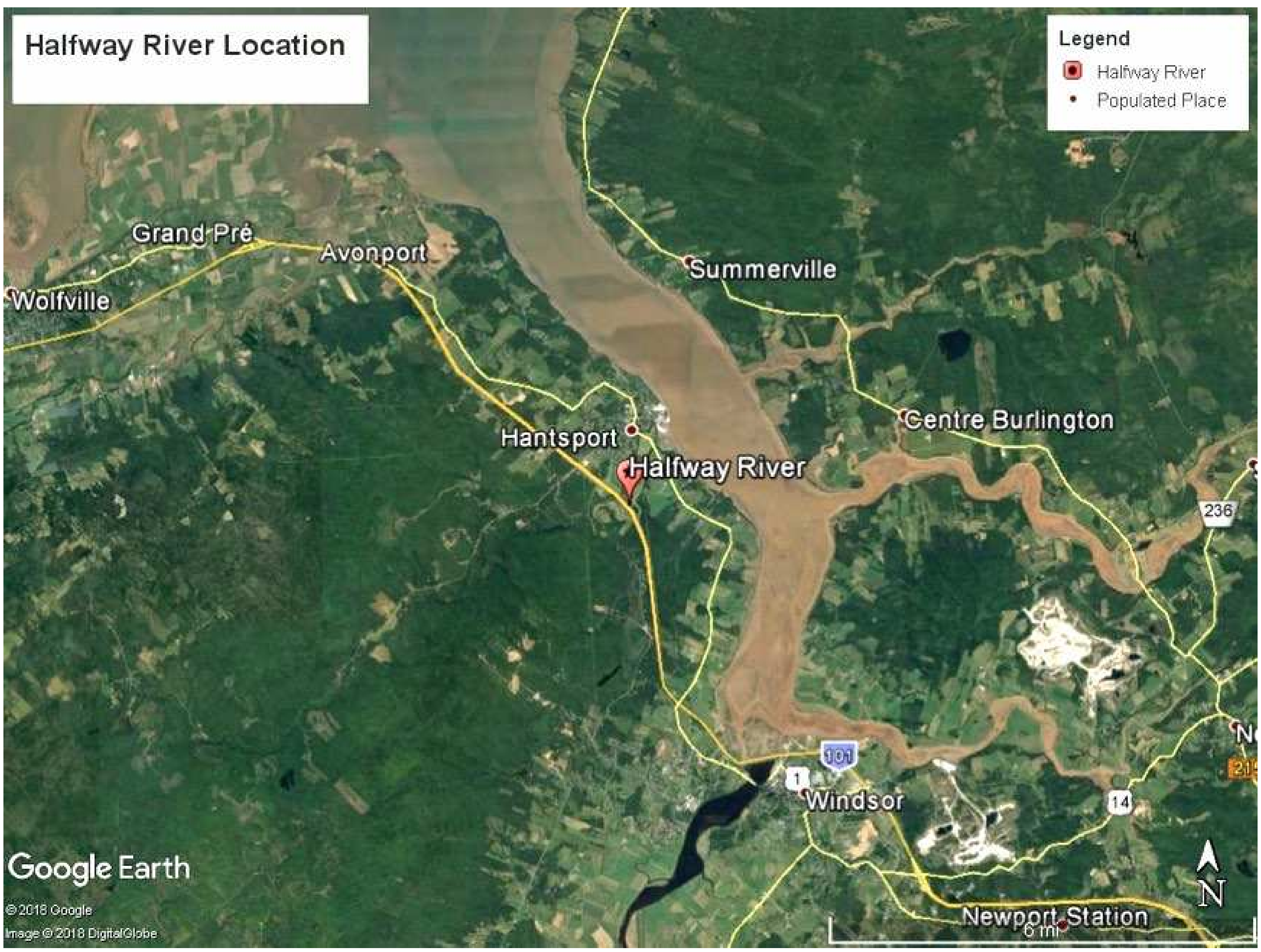


Figure 1: Location of Halfway River near Hantsport, NS.

Figure 2: Run of the river looking upstream with Highway 1 in the foreground. Aerial photograph was taken at high (spring) tide on July 7, 2020. Drone Imagery CBWES Inc.

Figure 3: Mouth of HWR post-failure with aboiteau, construction material and rail line remaining within the crossing (breach) location. Photograph by CBWES Inc 2018.

Figure 4: Aerial photograph of mouth of the Halfway River and breach site. Photograph was taken at high (neap) tide on September 5, 2018. The secondary, overflow, aboiteau is to the left of the main opening. Drone imagery by CBWES 2020.

Figure 5: Causeway at high spring tide (July 7, 2020), tidal ingress occurring through main culvert, evidenced by upwelling, and through the overflow culverts.. Drone Imagery by CBWES 2020.

Figure 6: The causeway and double box culvert from upstream at low tide August 11, 2021 (Top); Discharge on falling tide downstream of structure with white water conditions for 50+ m (Bottom Right); Eddy upstream on falling tide (Bottom Left) both from May 20, 2020. All photos by CBWES Inc.

Establishment of Tidal Wetland (Summary of 2018 Findings)

In 2018 CBWES Inc. was contracted by the Nova Scotia Department of Public Works (NSPW) (Transportation and Infrastructure Renewal (NSTIR) at the time) to begin the process of documenting the area, extent, and condition of the recovering Halfway River (HWR) tidal wetlands (Bowron et al, 2018). The study found that the recovery of a significant amount of salt marsh and tidal wetlands had been initiated with the re-establishment of a more natural hydrological regime to the system, via the failure and breaching of the railway causeway in 2017. Heavy sedimentation and saline water brought in by high spring tides had resulted in the loss of agricultural and freshwater plant species which dominated the site prior to the breach. Initial colonization of the resulting mudflat by a range of salt marsh and tidal wetland plant species was observed in 2018. The hypsometric curve for the system indicated that the flood plain was flooding in a typical salt marsh pattern, though the presence of low salt marsh terraces did lead to early and more frequent flooding of the low marsh, and the prior extended period of eliminated tidal flow and agricultural use had resulted in a subsided platform.

To determine the extent of the die off of agricultural and freshwater species, UAS imagery was captured September 10, 2018 and die off was manually delineated to be at least 65 ha. However, due to flight constraints (access to properties for ground control, regulated buffer zones to infrastructure) the furthest upstream reaches and some areas east of the Hantsport Connector were not captured in the orthomosaic and not delineated. In addition to manual delineation, predicted flood extents were generated from LiDAR. Flood extents matched well with delineated die off where they overlapped, and when areas outside the orthomosaic were considered an additional 15 ha were flooded. Thus, the extent of the establishing salt marsh was predicted to be between 65 and 80 ha.

The 2018 CBWES report recommended that consideration be given to the removal of the remaining causeway and aboiteau infrastructure from the breach area, the stabilization/restoration of the mouth of the river, and the protection of upstream infrastructure where necessary (e.g., upgrades to transportation network). The clean-up and restoration of the mouth of river would have eliminated the continued influence of the structure on tidal flow and fish passage, allowed for the fully naturalized movement of water and species into and out of the system, improved public safety and re-established safe navigation. This would have also reduced the velocity of water moving through the opening which would likewise reduce the risk of erosion, particularly to vulnerable areas immediately up- and downstream. It was noted that if the infrastructure was repaired and the breach closed, the upstream habitats would not immediately return to their pre-breach condition. The marine sediments which had already been deposited would need to dewater, and time would be required for the salt to leach from the soil before the terrestrial vegetation could begin to recolonize.

Monitoring Program

To understand the current and future condition of the Halfway River floodplain which began transitioning to salt marsh following the failure of the causeway-aboiteau, a modified version of the regional monitoring program used by CBWES for monitoring tidal wetland restoration projects was used. The monitoring program was developed based on previous monitoring and research experience with recovering and intact tidal wetlands in the region (Neckles et al., 2002; van Proosdij et al., 2010; NSTIR, 2017). The program is intended to: document the changing habitat conditions following the breach and construction of the new causeway; evaluate the impacts of the new structure on the hydrology and wetland habitat within the site; identify if additional interventions are required and their nature; and to determine the ecological impacts of the causeway on the developing tidal wetland habitat.

The monitoring program utilizes a suite of wetland indicators and data collection methods tailored to this project to characterize a broader range of ecosystem components. These indicators represent key measures of tidal wetland structure and function and collectively provide information on ecosystem status. The physical and biological parameters within each of these indicator categories and the timeline and frequency for the monitoring activities are identified in TABLE 1. Station and equipment locations are shown in FIGURE 7.

Table 1: Monitoring Program, including core and additional ecological indicators, methodologies, and sampling frequency (X - completed sampling; I – Equipment Installed; Y – scheduled future sampling).

Category	Parameters	Sampling Method	Sampling Frequency	2019	2020	2021
Geospatial	Landscape	UAS Orthomosaic; Digital Surface Model (DSM); GNSS RTK survey	Aerial survey – minimum 3 times per year; annual elevation survey	X	X	X
	Marsh surface elevation	Digital Elevation Model (DEM); G8 GNSS RTK surveying unit (or equivalent)	Annually	X	X	X
	Habitat map	Low-altitude aerial photography; Vegetation data	Annually	X	X	X
Hydrology	Tidal signal	Automated water level recorders (5-minute intervals)	Minimum 29 day period	X	X	X
	Discharge/velocity	Sontek M9 River Surveyor; Nortek ADCP	Annually	X	X	X
	Flood Map	DEM; Tide Signal	Annually	X	X	X
Soils & Sediments	Sediment elevation & accretion	G8 GNSS RTK survey; Rod Surface Elevation Tables (RSET); Marker Horizons	Annually	X	X	X
	Sediment characteristics	bulk density, organic matter content, sediment type, water content	Annually	X	X	X
	Suspended Sediment Concentrations	RBR turbidity logger; ISCO automated water sampler (2019)	Annually	X	X	X
	Soil Test Report (NSDA)	Soil parameters (nutrients, minerals, pH, OM, Salt, etc.)	Annually	X	X	X
Vegetation	Composition Abundance Height	Transect based, Point Intercept Method (1 m^2 plots)	Annually	X	X	X
Structured Winter Walk	Visual assessment of winter conditions	Structured winter walk & photo-documentation	Annually	X	X	X

Fish	Composition; abundance; size; location	Fyke nets; minnow traps	Minimum of 2 sampling events per year		X	X

2019 Monitoring Summary

The habitat within the tidally influenced portion of the HWR continued to evolve in response to the alteration of hydrology, from unrestricted to restricted, to partially restricted within the span of a little over a year (Graham et al., 2020). Comparison of 2018 and 2019 flood extents and die off delineation refined the calculation of establishing salt marsh area – resulting in the identification of ~ 75 ha of early successional salt marsh. Changes in surface cover and elevation varied seasonally and annually. During the growing season surface cover of halophyte vegetation increased on the former agricultural surface, dominated by early successional salt marsh species, while surface cover in the low marsh (*S. alterniflora*[3]) decreased relative to 2018 in some locations. A general trend of stability on the platform and elevation gain in the low marsh since the breach was observed, with seasonal decrease in elevation in the low marsh over the fall (following gate installation). The tide signal was altered by the causeway construction, leading to decreased flooding overall, but not uniformly in space or time. Lower elevations flooded for longer periods or more frequently than expected due to both the modified tidal period and the heightened sensitivity of the system to freshwater influence leading to a recorded high water which exceeded those observed for the partially restricted condition.

2020 Monitoring Program Summary

Tidal flooding is limited to 26.5 ha (main river channel, unvegetated channel banks and low marsh platform), with the remaining 48.5 ha of the floodplain (initially recovering salt marsh) now excluded from tidal flooding. In 2020 vegetation cover increased on the tidal floodplain, primarily dominated by early successional salt marsh annuals and accompanied by increases in halophytic abundance, species diversity, and weedy terrestrial species. Overall the amount of bare ground throughout the site decreased, however, it increased in the low marsh due to sudden dieback of *S. alterniflora*. The rapid dieback of approximately 3.7 ha (50% of low marsh area) of *S. alterniflora* was particularly concerning, and analysis indicated that increased deposition, hydroperiod, and mean inundation time could have played a role in some areas but were not spatially consistent with the observed dieback areas. In addition, numerous reports of oil were made to the coast guard reporting line 1 (800) 565-1633 and officers did respond. This may present an additional stressor to the system. There has been little change in the morphology of the primary channel, except around the causeway where the additional rock armoring and scouring has resulted in changes in bottom elevation and channel width. Velocity and discharge remain similar to 2019 measurements, and display a slight flood dominance. Sediment characteristics strongly reflect both the agricultural past and recent flooding of the site, with both sediment size and water content related to proximity to the river channel. While geospatial data showed both a loss of

[3]*S. alterniflora* has been reclassified as *Sporobolus alterniflorus. Spartina* nomenclature is used in this document to maintain consistency with past reports.

elevation or little change in the system, all three RSET stations showed a gain in elevation through increased sedimentation.

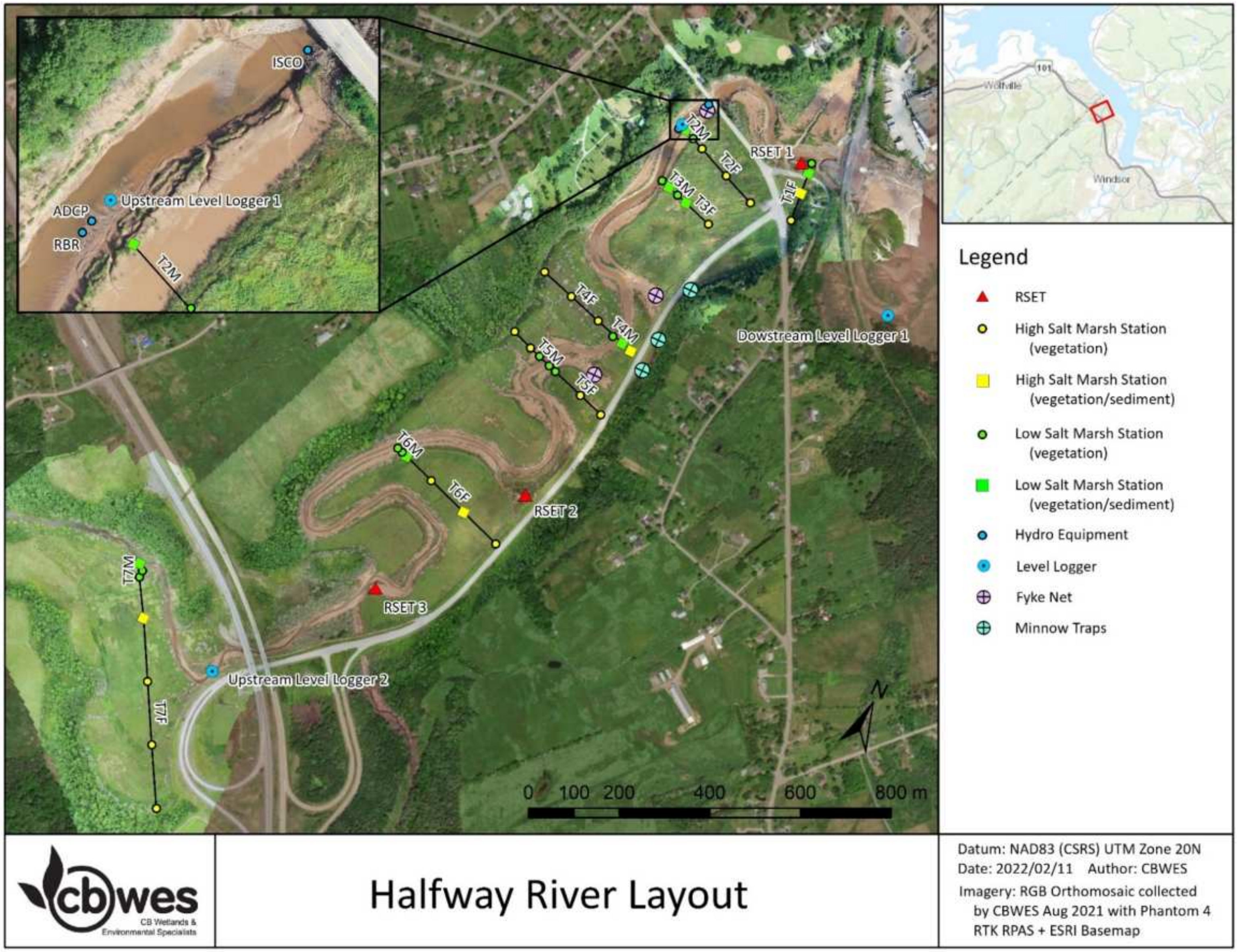


Figure 7: Monitoring program sampling layout.

Geospatial Attributes

Geospatial attributes are important in understanding the form and function of rivers, floodplains and salt marshes and serve as the basis for many other analyses. Geospatial data are monitored using five primary data sources: georeferenced low-altitude aerial photography, Digital Surface Models (DSM), Digital Elevation Models (DEM), GNSS elevation surveys, and derived surface cover and habitat maps.

Methods

Georeferenced low-altitude aerial photography was collected for HWR during three separate flights using the CBWES-Saint Mary's University (SMU) DJI Phantom 4 RTK Remotely Piloted Aircraft System (RPAS) (May 17, August 11, and December 1, 2021). These were intended to capture conditions throughout the season (spring, summer and fall) to document the changing vegetation communities, topography and site morphology. Tidal conditions during the month of August necessitated two flights in order to capture the full site during low water conditions. The two August flights captured summer conditions across the site with the first flight imaging the front of the site and the second imaging the rear. Orthophoto mosaics were generated using Agisoft Metashape software and were used as base imagery throughout all mapping tasks (e.g., habitat mapping, DEM analysis; geomorphic and anthropogenic feature identification). DSMs were generated concurrently with mosaics using standard structure from motion algorithms. The use of Ground Control Points (GCPs) surveyed with RTK GNSS ensured the horizontal and vertical accuracy of both orthophotos and DSMs. DSMs were validated using RTK GNSS points collected in bare ground areas on the same date as the RPAS surveys. Elevation values from the DSMs were subtracted from the GNSS orthometric heights (CGVD2013) at each point location, and the differences between values were summarized to estimate accuracy of bare ground areas throughout the DSMs. Accuracy assessments for each surface are provided in TABLE 2.

Surface difference rasters, also referred to as DEMs of Difference (DoDs), were created for annual elevation change by subtracting bare ground areas of the August 2020 DSM from the August 2021 DSM. A seasonal DoD was not constructed for the 2021 season due to high water levels during the fall 2021 RPAS survey which obscured the majority of bare ground areas. Bare ground areas were isolated by classifying the Aug 2021 RPAS imagery, converting the classification to a shapefile, and then manually cleaning the results to create a shapefile of bare ground coverage only. This mask was then combined with the Aug 2020 bare ground mask to isolate areas of bare ground that were present in both datasets.

It is important to note that the DSM captures the top of the vegetation canopy and bare ground only where it is visible. To understand changes in marsh topography, a bare earth, or DEM, is needed. To this end, two LiDAR DEMs were obtained from the province of Nova Scotia Geonova server. The data was collected in 2019 by Leading Edge Geomatics (NVA RMSEz = 6.6 cm, 13.0 cm at 95% C.I; tested using 464 RTK checkpoints) and in 2013 (NVA RMSEz = 6.3 cm, +/- 12.4 cm at a 95% C.I.; tested using 225 RTK checkpoints). In addition to LiDAR surfaces, elevation data was collected at the site using a Leica GNSS RTK survey unit between May 17-20, 2021. To understand change along vegetation transects elevation profiles were extracted from the 2019 LiDAR DEM, the May 2020, May 2021 and August 2021 RPAS DSMs, and GNSS survey data were plotted along with the extracted elevation data. An additional survey was undertaken on November 10, 2021 to capture elevations (bathymetry) within the main river channel in line with the marsh surface transects.

Habitat maps (also known as surface cover maps) document vegetation community structure and other important habitat features at the landscape scale (e.g., channels, culverts, beaver dams). A habitat map was created for the site using vegetation survey plot data, RTK survey data and low-altitude aerial photography. Habitat community classes were identified by using vegetation analysis results to first identify larger community types (i.e., Wet Meadow, Low marsh, etc.), and then using plot-level data (training points) to digitize surface cover classes from low-altitude imagery on smaller scales. Habitat community classes were delineated following distinct surface appearances by interpreting spectral reflectance, surface texture, and site photos. Image classification shapefiles to identify spectrally distinct features such as bare ground and water were incorporated into the manual delineation where appropriate.

Table 2: Accuracy Assessment for 2021 DSM.

	MAY 17	AUGUST 11	DECEMBER 1
# OF VALIDATION POINTS (N):	50	19	37
MEAN ABSOLUTE ERROR:	0.020 m	0.024 m	0.034
STANDARD DEVIATION:	0.020 m	0.026 m	0.038
ROOT MEAN SQUARED ERROR:	0.024 m	0.033 m	0.042

Results

Landscape Changes (Seasonal Orthophotos)

Aerial imagery shows the continued evolution of the site from summer 2019 through Fall 2021 under different seasonal and hydrological conditions (FIGURE 8, FIGURE 9, FIGURE 10, FIGURE 11, FIGURE 12). During the Spring (May) 2021 flight, vegetation growth has not yet begun, and bare ground area is still in line with that observed at the height of the 2020 growing season. August 2021 imagery, used for habitat mapping, shows very little bare ground remaining, with vegetation appearing dense and vibrant. Fall 2021 imagery showed higher water levels in the river, with the foreshore partly flooded, and vegetation that has become dormant for the winter season. White water can be observed on the downstream side of the causeway in all imagery (indicating high velocity flow at the outlet).

In 2019, limited decreases in the extent of *S. alterniflora* on the low marsh terrace were noted at some locations, with decreases located primarily at the edge of the vegetation stands. During August 2020 field work and imagery capture *S. alterniflora* was noted to be in poor condition throughout much of the low marsh, with sudden and unusual dieback no longer limited to the edges of the habitat (FIGURE 13, FIGURE 14). In 2021 much of the low marsh, particularly towards the mouth of the river, is bare with *S. alterniflora* limited to the edge of the marsh.

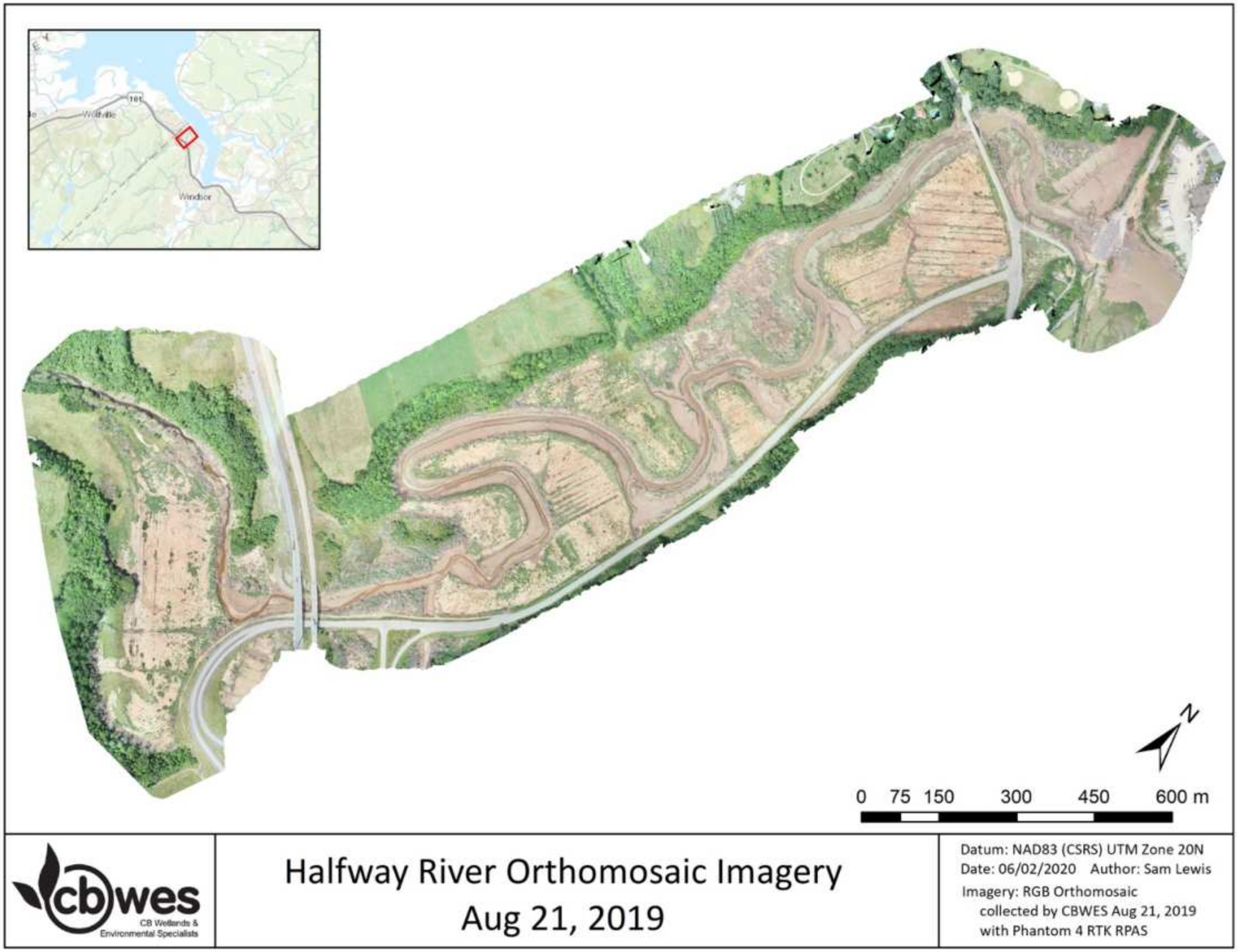


Figure 8: Summer 2019 Orthomosaic.

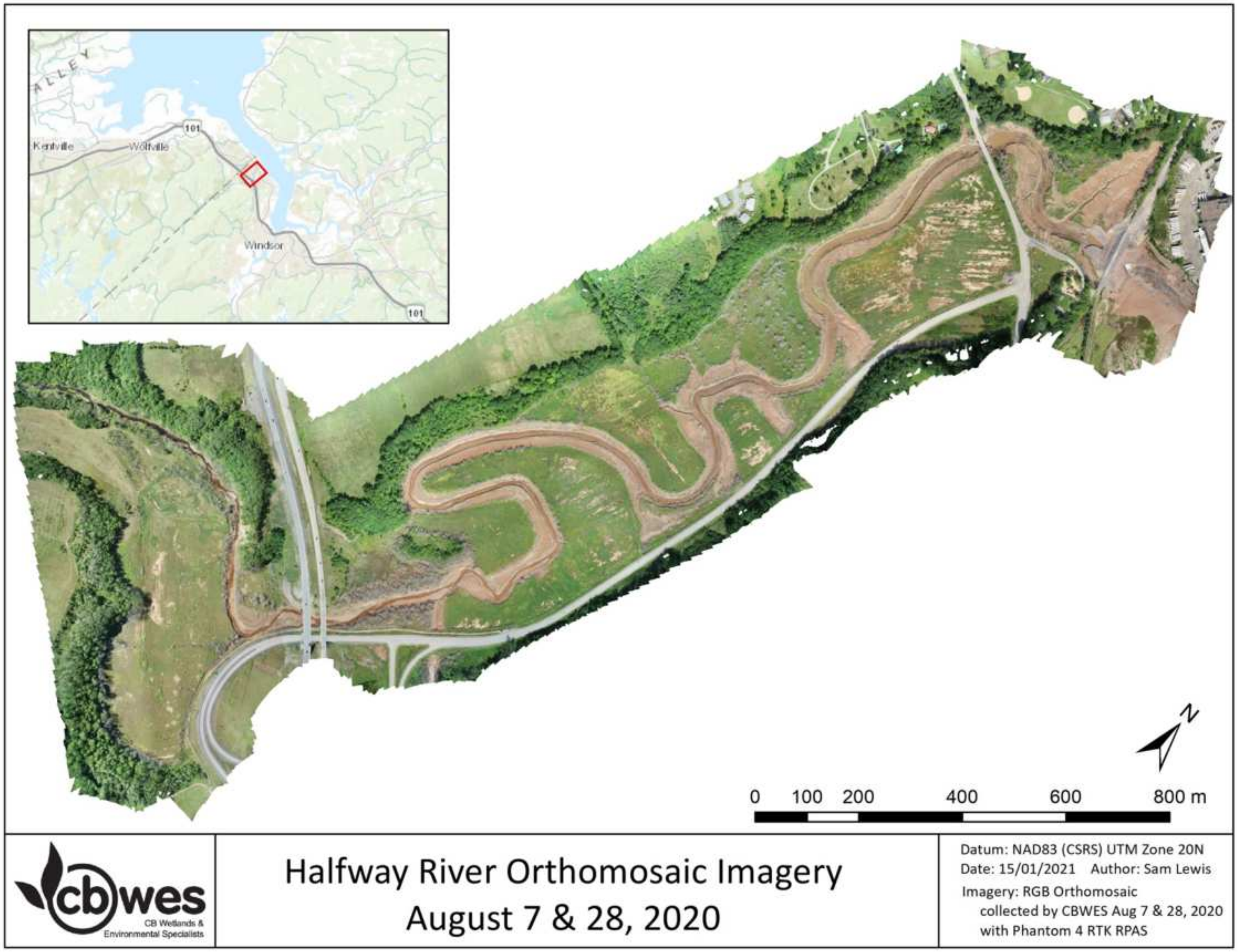


Figure 9: Summer Orthomosaic 2020.

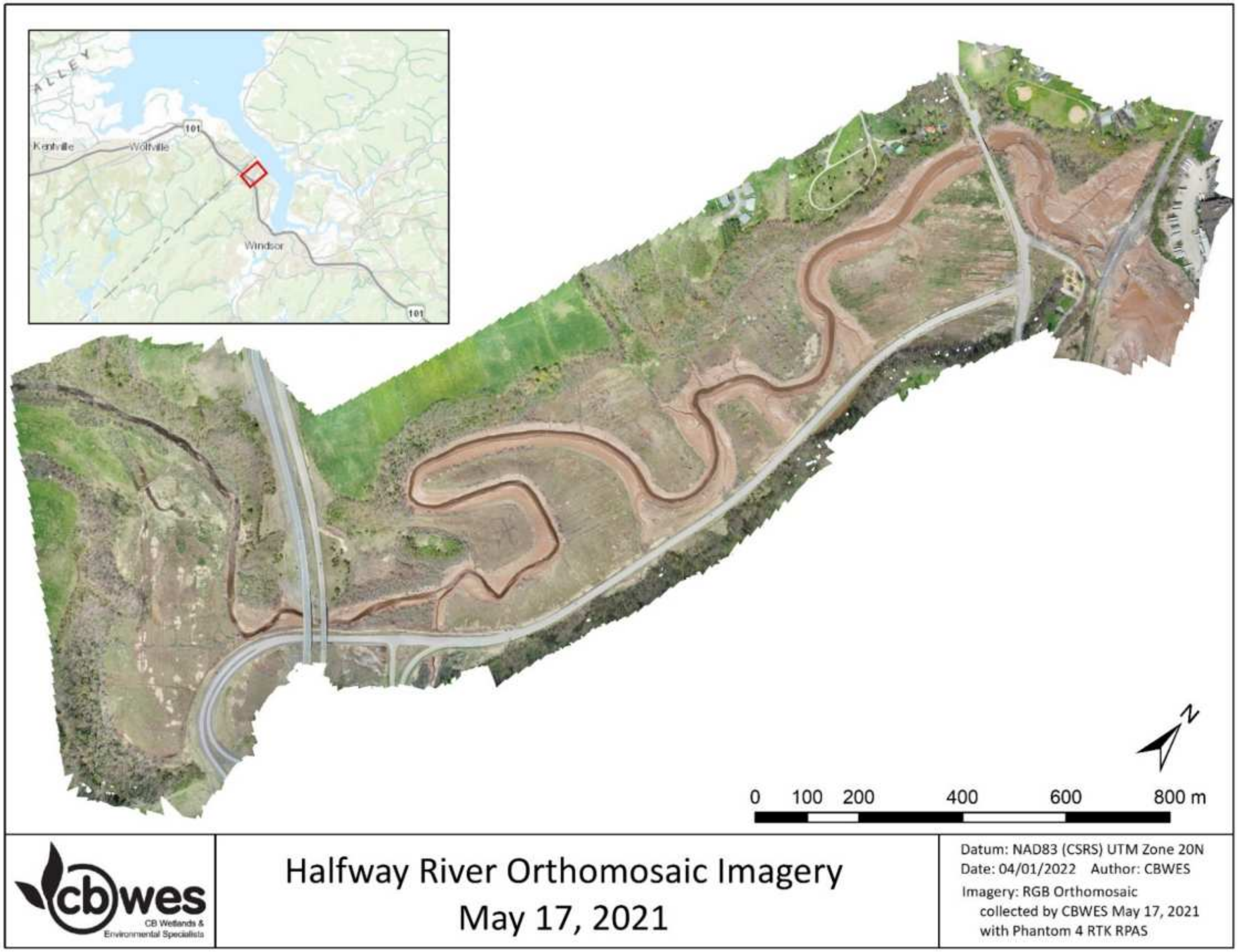


Figure 10: Spring Orthomosaic 2021.

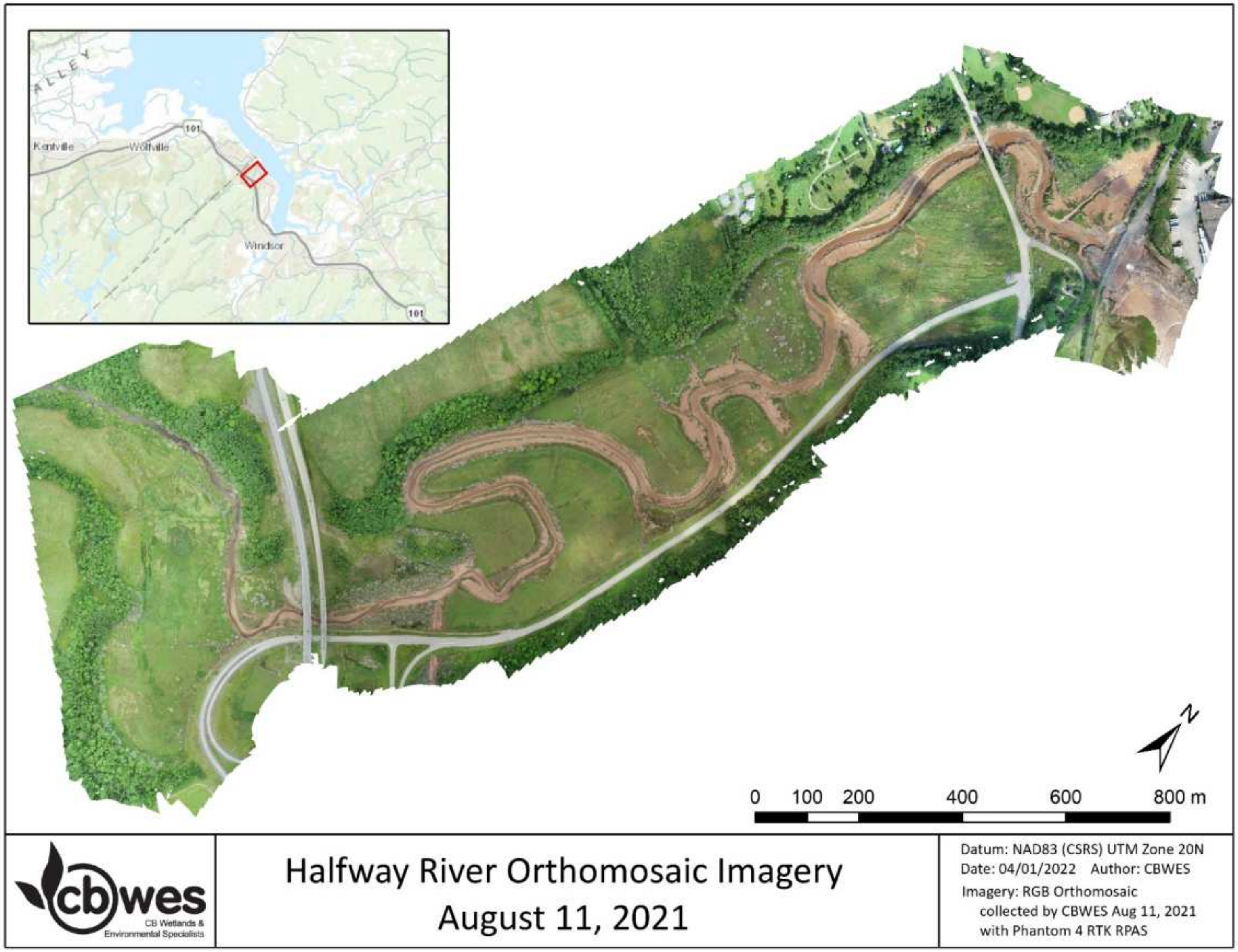


Figure 11: Summer Orthomosaic 2021.

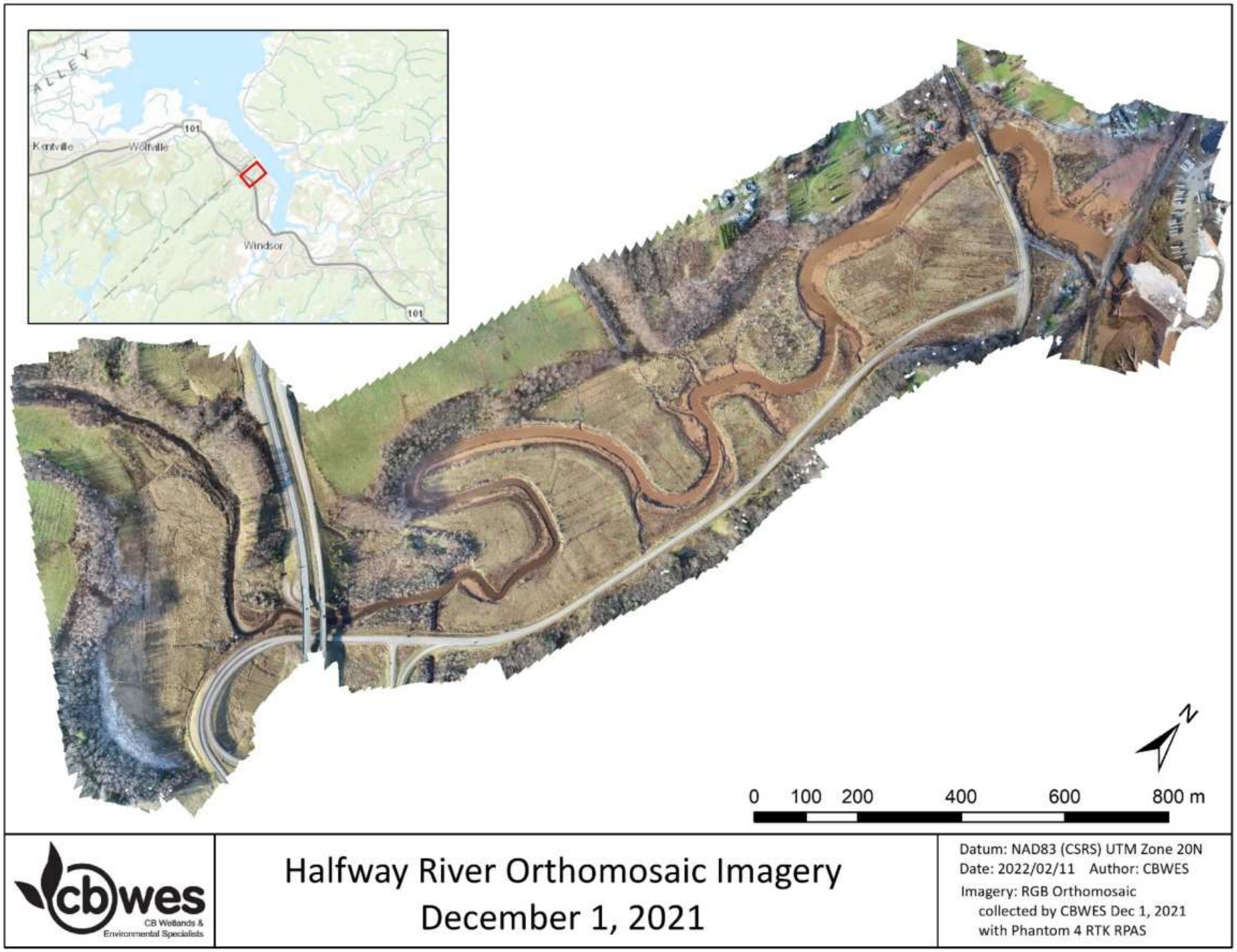


Figure 12: Fall Orthomosaic 2021.

Figure 13: Unusual dieback of S. alterniflora on the low marsh platform A) August 2020 aerial, B) August 10, 2020, C) Oct 8, 2020, D) May 17, 2021 E) August 11, 2021.

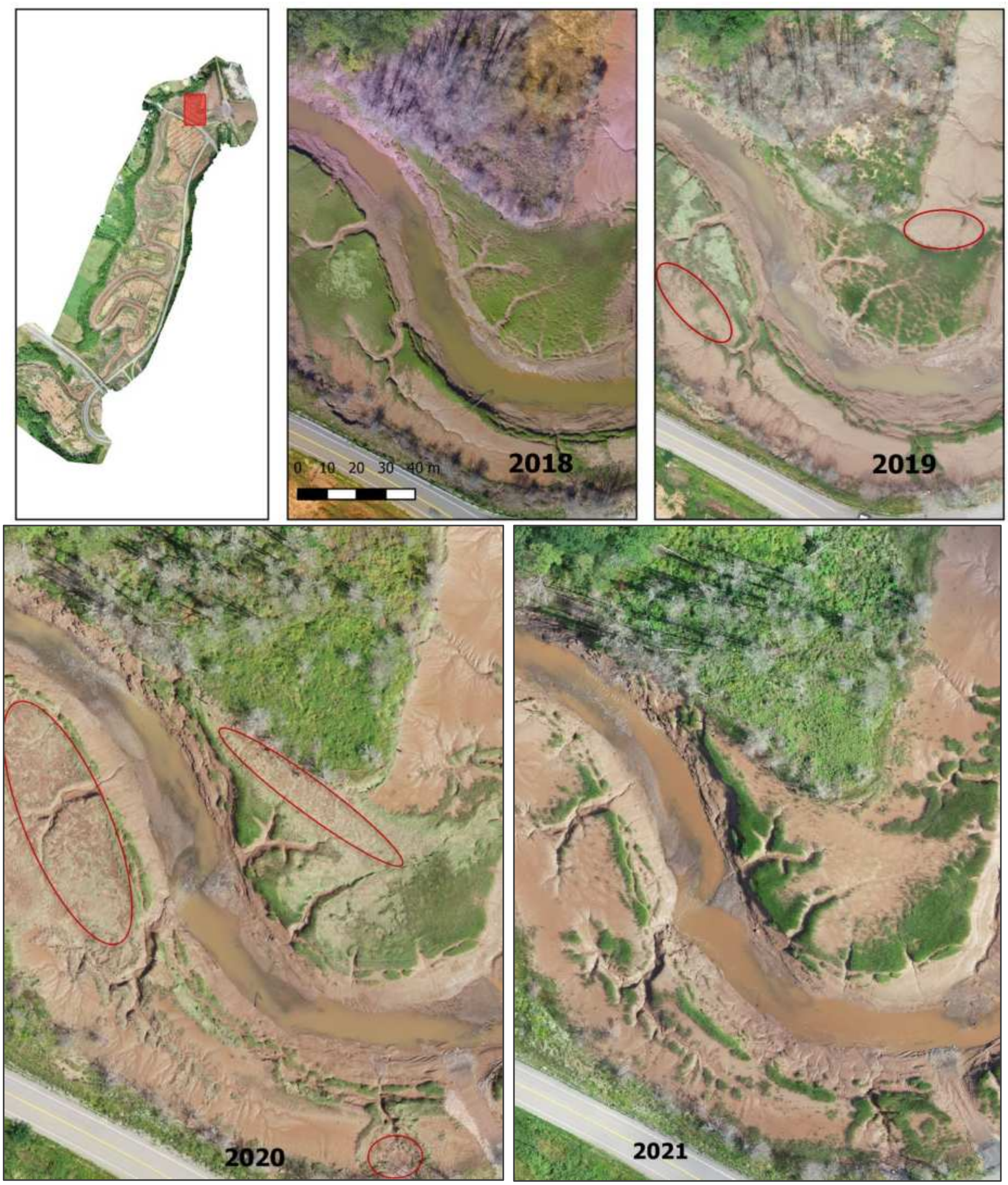


Figure 14: Change in low marsh extent 2018-2021.

Elevation Change

Annual and seasonal changes in the elevation of the marsh and river channel were analysed using survey data, DSM and DEM identified previously. Summary statistics for topographic datasets are shown in TABLE 3. Bathymetric elevation profiles showed very little change between 2020 and 2021 from the mouth of the river to the head of tide (FIGURE 15), although no transects were completed directly adjacent to the causeway due to safety concerns (where the greatest changes might be expected).

2021 elevation profiles (FIGURE 16) support trends observed in 2020, with a generally stable marsh surface. The 2019 Lidar generally lies below the RPAS DSM surfaces, suggesting an elevation increase from 2019-2021, but this difference may be explained by vegetation coverage in the DSM surfaces. The summer 2021 DSM surface values highlight vegetation height compared to surface elevation.

Survey data showed a slight elevation increase between 2020 and 2021 vegetation stations on the high marsh platform (0.033 ± 0.039 m). Elevation has increased in the low marsh from pre-restoration to current conditions, however, the mean surface elevation change between 2020 and 2021 at vegetation stations in the low marsh was negligible (0.006 ± 0.173 m), and elevation change at these stations varied significantly (-0.681 – 0.159 m). The annual DoD of bare ground areas showed a trend of increasing or stable surface elevation on most mud flats, with values generally ranging from 0-30 cm. Channel banks were more variable, with areas of surface elevation increase, decrease and stability throughout the site (FIGURE 17).

Table 3: Summary statistics for toporaphic datasets in m CGVD2013.

STATISTIC	2021 DEM (CLIPPED TO MAX FLOOD EXTENT WITHIN SITE BOUNDARIES)	2021 GNSS TOPOGRAPHIC SURVEY	2021 GNSS BATHYMETRIC SURVEY
Minimum	-1.859	-0.135	-1.312
Maximum	8.418	7.671	4.389
Mean	4.633	4.958	0.327
Standard Deviation	1.802	1.220	1.513

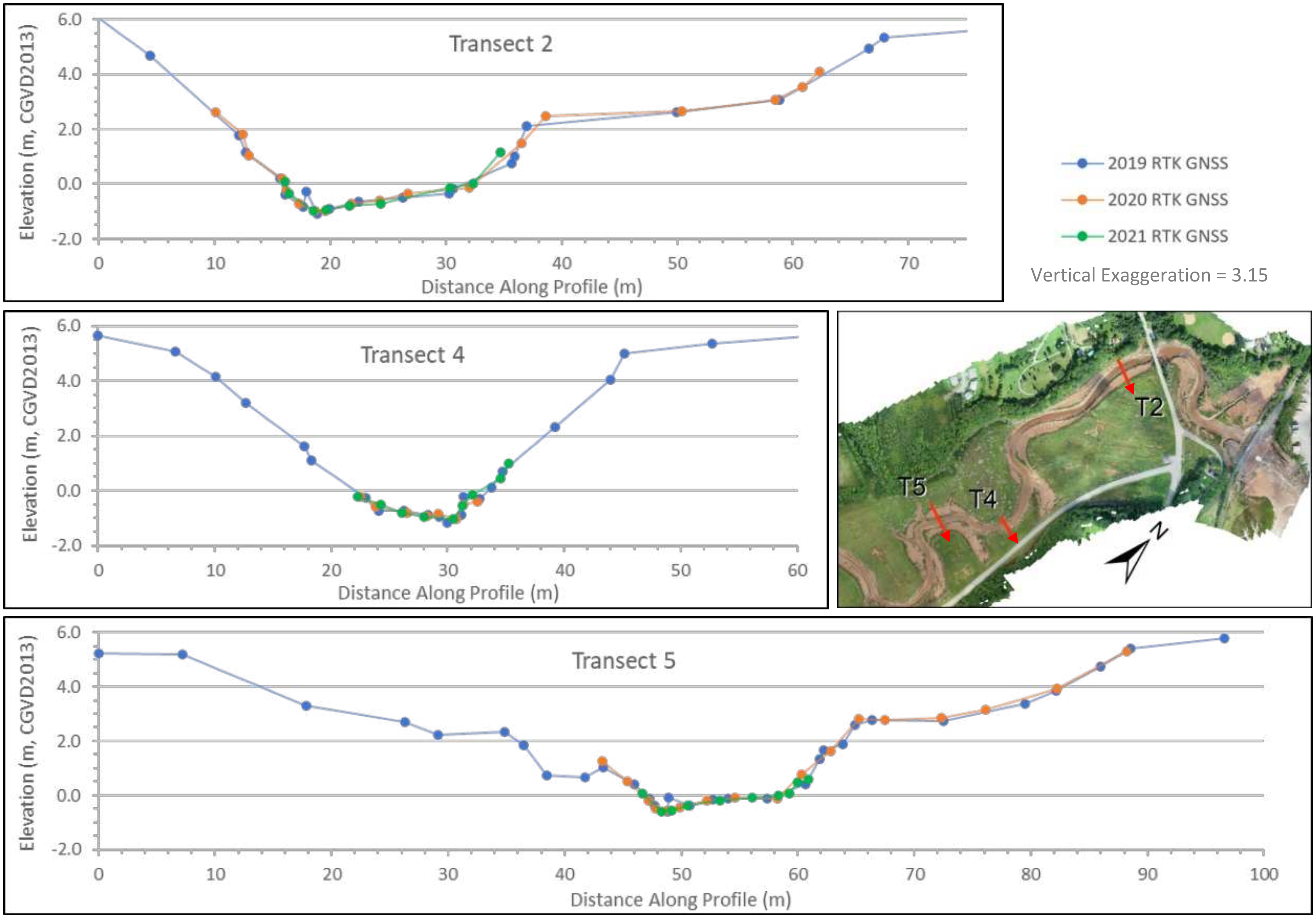


Figure 15: Cross-sectional profiles of river channel for select surveyed transects (T2, T4, T6, T7).

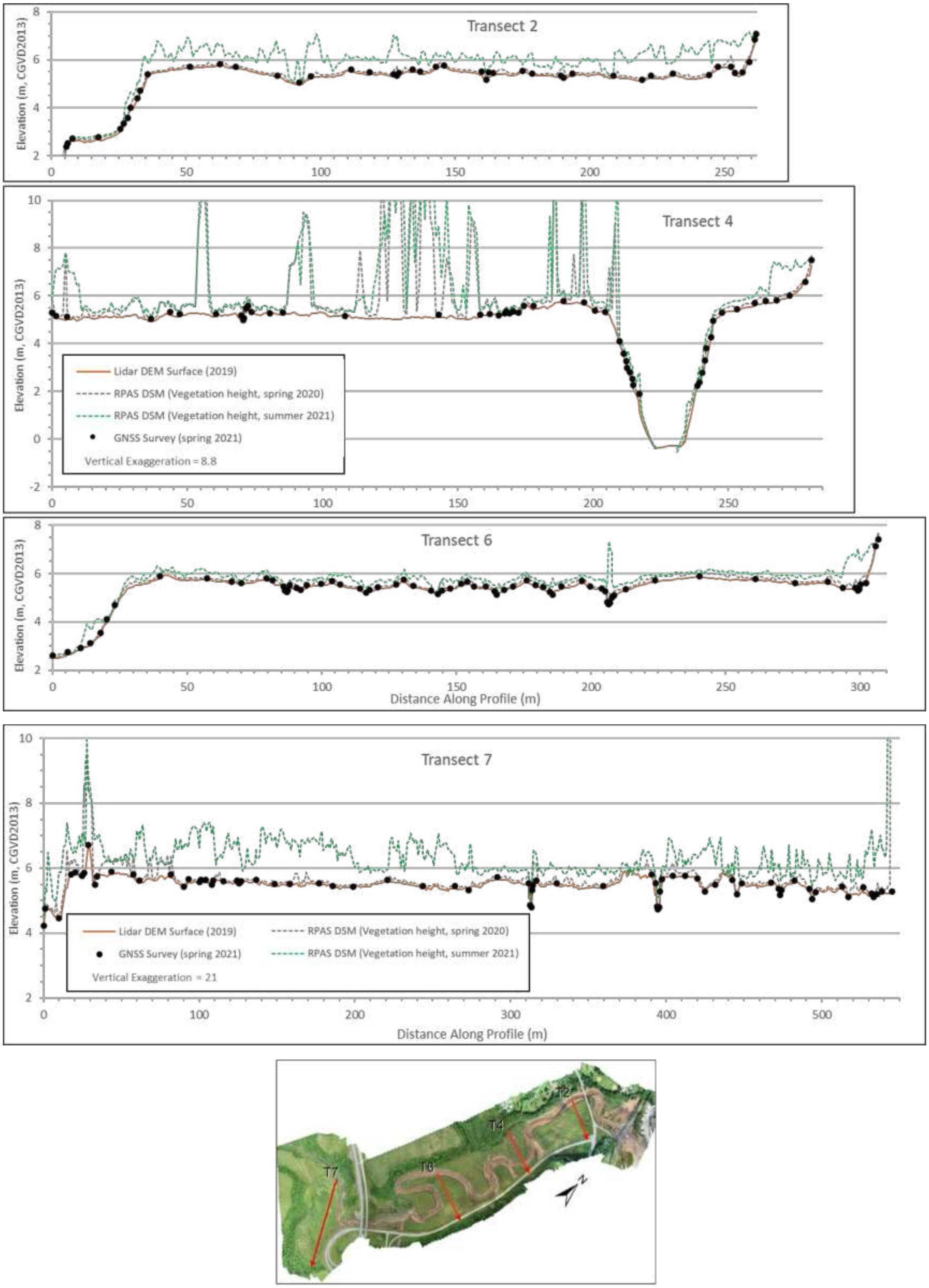


Figure 16: Cross-sectional elevation profiles along a subset of sampling transects. Note that RPAS DSM show vegetation canopy rather than bare ground. (T2, T4, T6, T7).

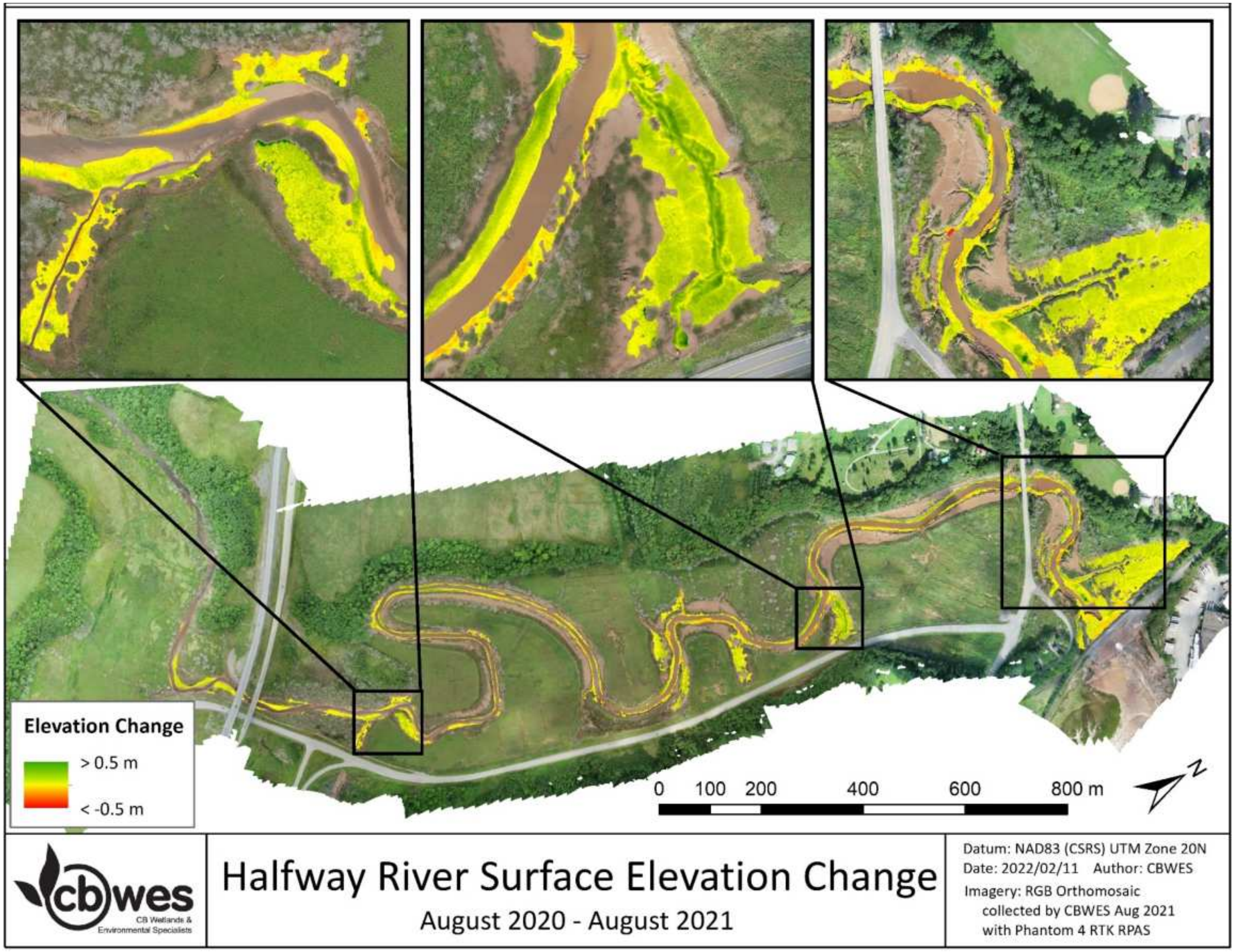


Figure 17: Changes in elevation at HWR between August 2020 and August 2021.

Habitat Map

Several habitat community classes were identified in 2021 based on the vegetation analysis, on site observations, and aerial imagery. A summary of class characteristics is shown in TABLE 4, and the extent and distribution of vegetation communities for 2019-2021 are mapped in FIGURE 18 and FIGURE 19, and examples of plots are shown in FIGURE 20. The site is now nearly entirely vegetated within the former high marsh (floodplain) footprint, with several communities indicating wet meadow conditions in various stages of progression. Halophytic early colonizers observed in 2019 and 2020 cover a lower proportion of the site and are giving way to wet meadow species. Bare ground now accounts for only 4% of the floodplain and 43 % of the low marsh, and standing dead wood still accounts for ~3% of the marshland, though it is considerably less dense than it was initially and provides ecological benefits such as perch habitat for birds.

In 2020 rapid dieback was observed in much of the low marsh. One-way ANOVA Analysis preformed found that no significant differences were found between the dieback zone, mud and live *S. alterniflora* patches for elevation or hydroperiod (Inundation Ratio, Mean Inundation Time, Inundation Frequency). However, dieback areas had lower slope than both other cover types ($F(2,463)=3.27$; $p=0.039$), and were observed to occur mostly in flat areas where water was expected to pool and sedimentation could be higher. Numerous reports of oil were made to the coast guard reporting line and officers did respond. The presence of hydrocarbons, or oil spills, are known to have both acute and long-term impacts on salt marshes – effecting leaves, soils, and root systems (Culbertson et al., 2008; Anderson et al, 2010).

In 2020, 7.7 ha of *S. alterniflora* were delineated, of which 3.7 ha was in poor condition due to rapid die back. In 2021, *S. alterniflora* coverage in the low marsh totaled 4.7 ha, with 3.8 ha in good condition and 0.9 ha sparse. Poor condition and dying *S. alterniflora* were not observed in 2021. Along Transects 1- 5 (nearer to causeway) most areas where poor condition *S. alterniflora* was observed have transitioned to bare ground, with poor condition plants buried and new growth radiating from established edge patches which didn't die back in 2020 (FIGURE 21). Beyond transect 5 (further from the causeway) poor condition *S. alterniflora is* recovering (sparse alterniflora), and vegetative extent in the low marsh has in fact exceeded that observed in 2018 (FIGURE 22).

Table 4: Habiat Community Classes used in image classificaton.

HABITAT CLASS	YEAR	DESCRIPTION	DOMINANT SPECIES
WATER	All	Open water, either river or standing	--
BARE GROUND	All	--	--
ROCK/GRAVEL	All	Armor rock, placed around culvert and bridges, in channel.	--
DEAD VEGETATION (WOODY)	All	Standing dead woody vegetation - Trees and brush	--
DENSE *S. ALTERNIFLORA*	All	Robust monotypic low salt marsh community dominated by *S. alterniflora*	*S. alterniflora*

POOR CONDITION *S. ALTERNIFLORA* (DIEING)	2020	Sudden Dieback of *S. alterniflora*	*S. alterniflora*
SPARSE *S. ALTERNIFLORA*	2021	Developing or rebounding monotypic low saltmarsh community dominated by *S. alterniflora*	*S. alterniflora*
EARLY COLONIZER COMMUNITY	2019 2020	Halophytic annual species, generally first species to appear on recovering floodplain habitat.	*Atriplex sp., Suaeda sp., Salicornia depressa, Spergularia salina*
WEEDY WET MEADOW	2021	Wet Meadow dominated by terrestrial and halophytic weedy species with very few grasses present.	*Atriplex sp., Taraxacum officinalis, Suaeda maritima, Cirsium vulgare, Epilobium ciliatum*
MIXED WET MEADOW	2021	Diverse wet meadow with an even mix of weedy species, graminoids, and annual early colonizers. Species may be mixed or in distinct clumps	*Epilobium ciliatum, Alopecurus pratensis, Euthamia graminifolia, Poa palustris, Lactuca canadensis*
BRACKISH GRASSES AND SEDGES	2020 2021	Stands of brackish affiliated grasses and sedges, sometimes in mixed stands but often monotypic, with few or no weedy species intermixed	*S. pectinata*[4]*, Elymus repens, Phalaris arundinacea*
***TYPHA LATIFOLIA* WETLAND**	2021	Wetland dominated by *Typha latifolia* with grasses and flower species intermittently mixed.	*Typha latifolia, S. pectinata*

[4] Renamed to *Sporobolus michauxiana*, synonym used for consistency with past reports.

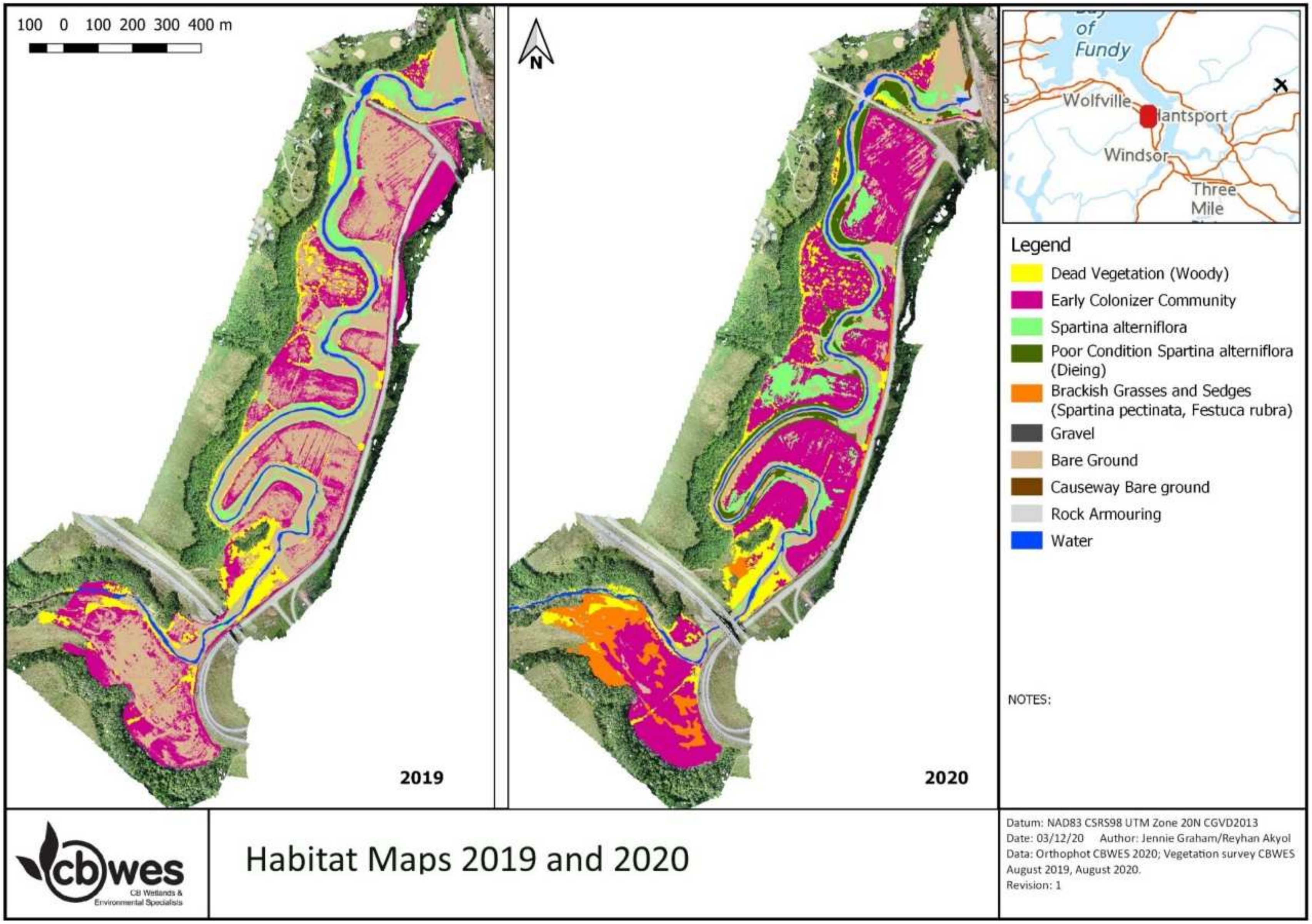


Figure 18: Habitat map for Halfway River showing vegetation communities for 2019 and 2020.

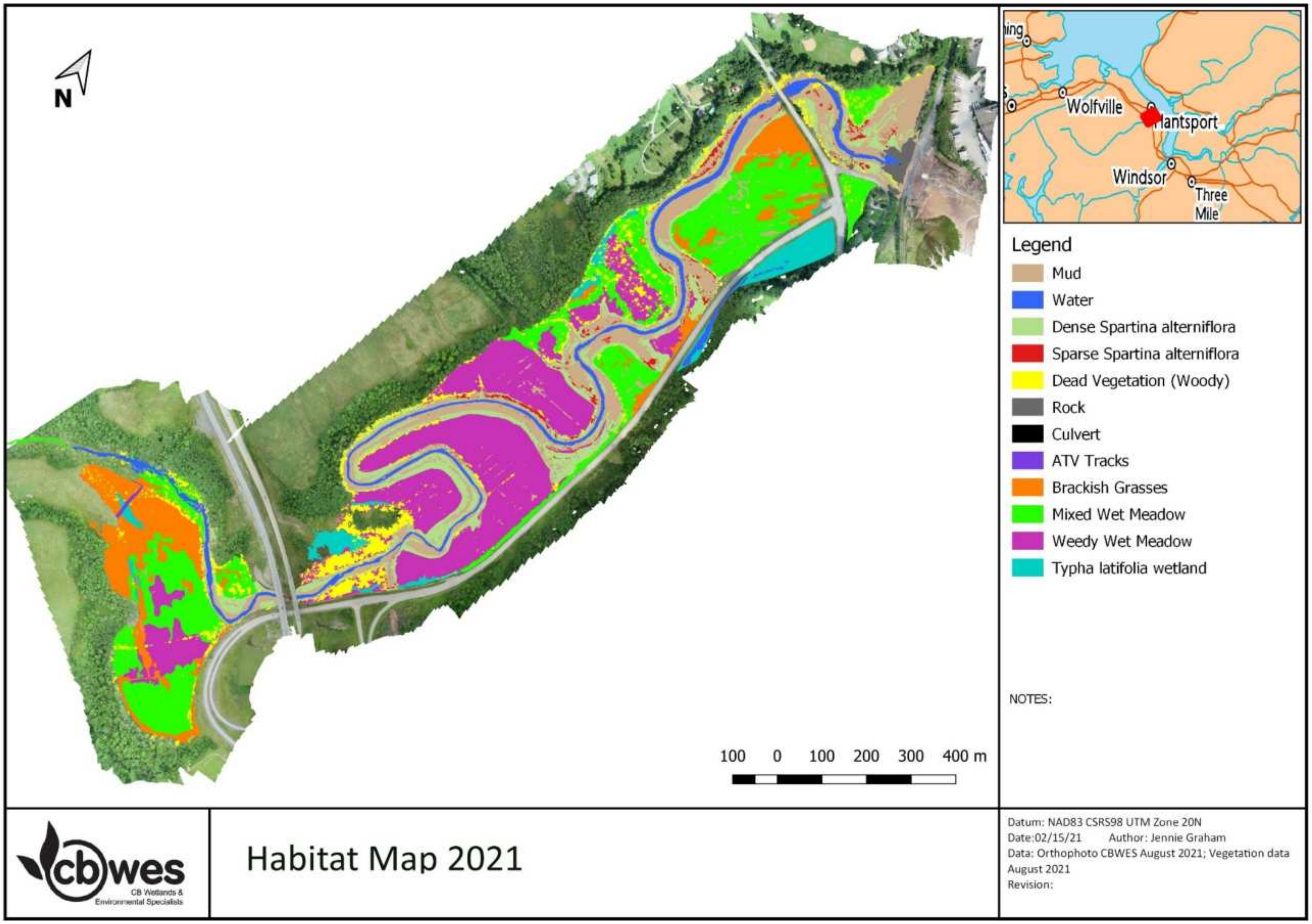


Figure 19: Habitat map for Halfway River showing vegetation communities for 2021.

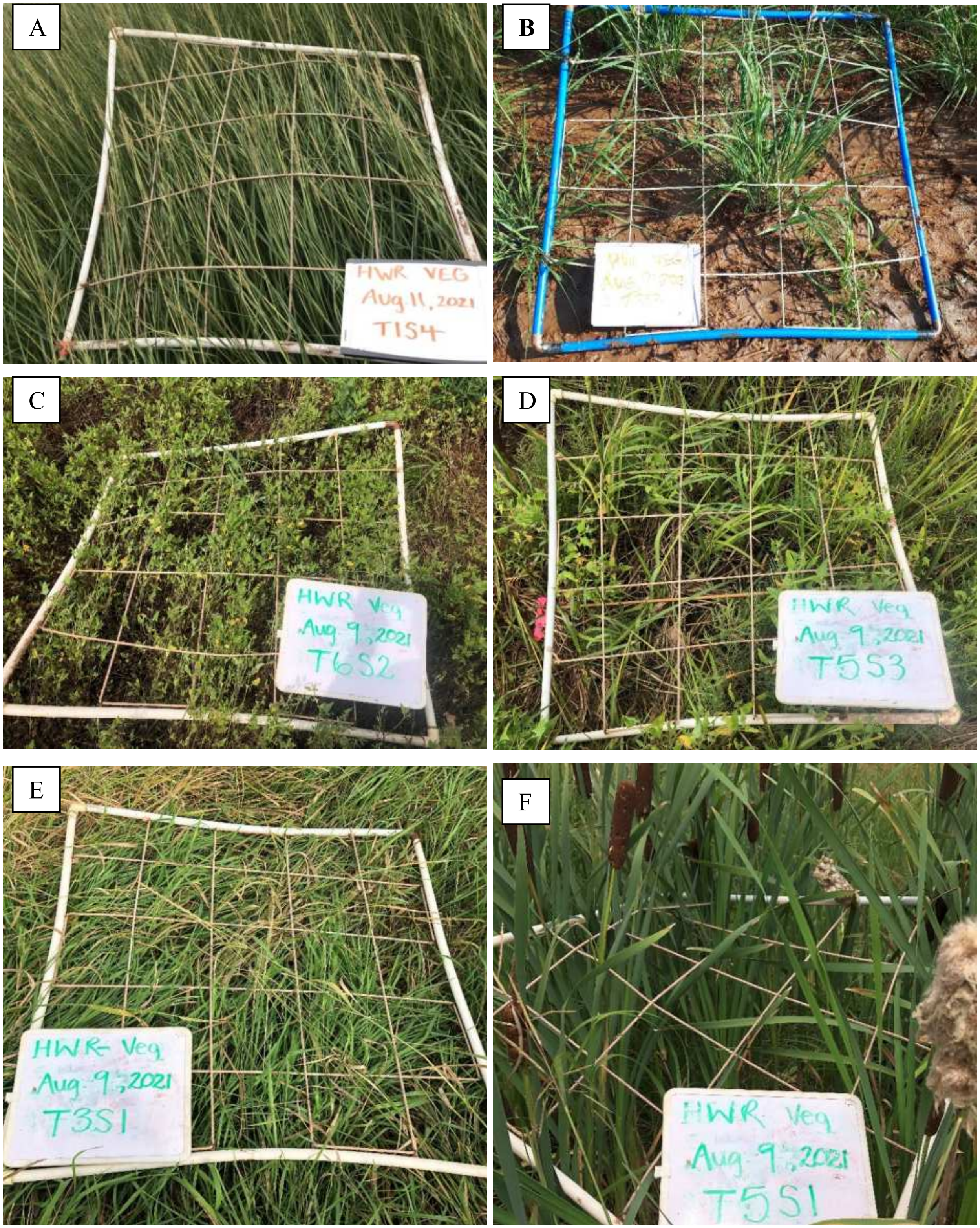


Figure 20: A) Healthy S. alterniflora on low salt marsh terrace. B) Sparse S. alterniflora on low salt marsh terrace. C) Early colonizer community – monotypic stand of Atriplex species. D) Mixed community weedy ruderals (Suaeda maritima, Rorippa palustris and Salicornia depressa) and grasses. E) Brackish grasses – monotypic Elymus repens stand. F) Typha latifolia stand.

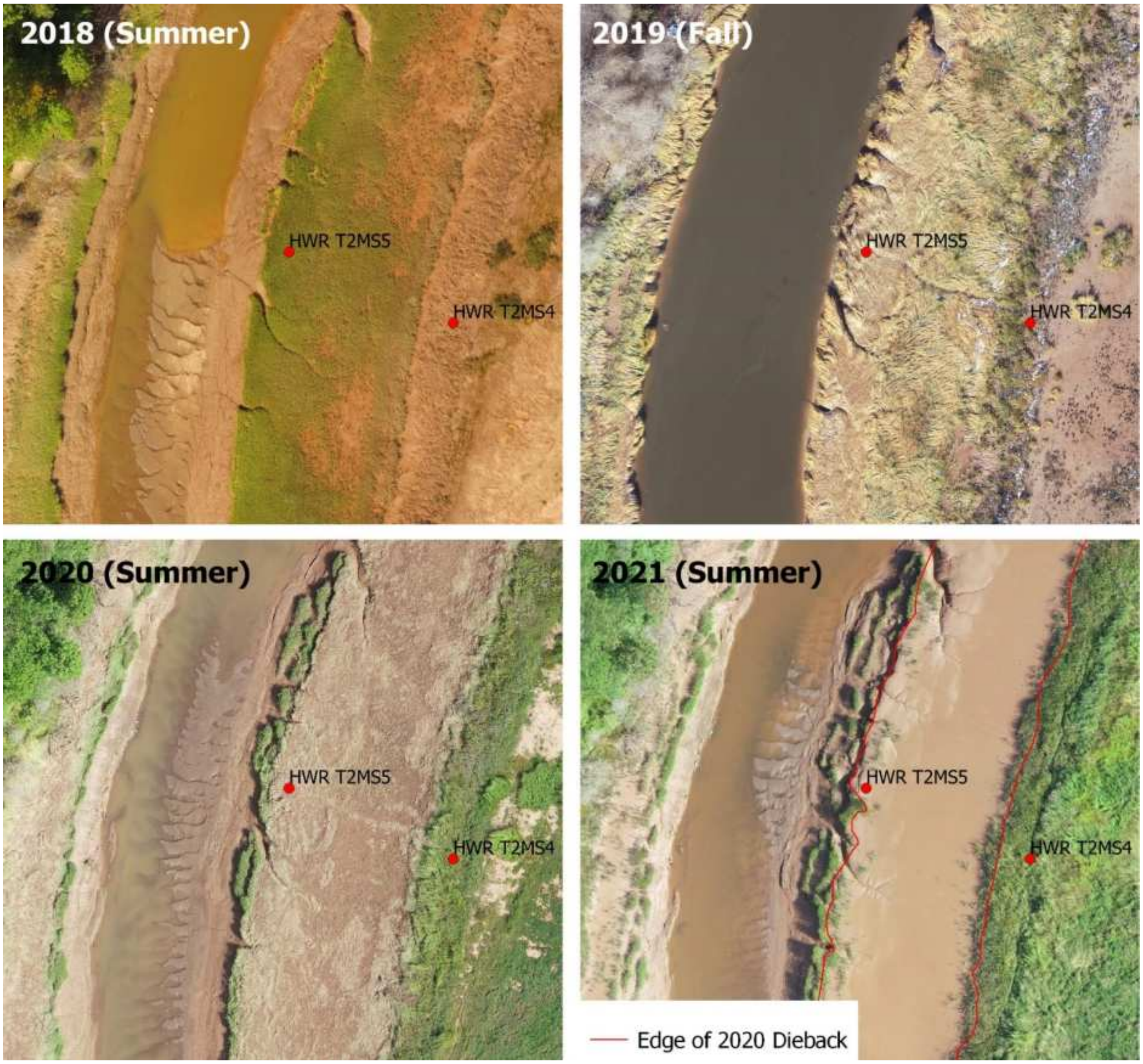


Figure 21: Impact of sudden dieback of low marsh along T1 2018-2021.

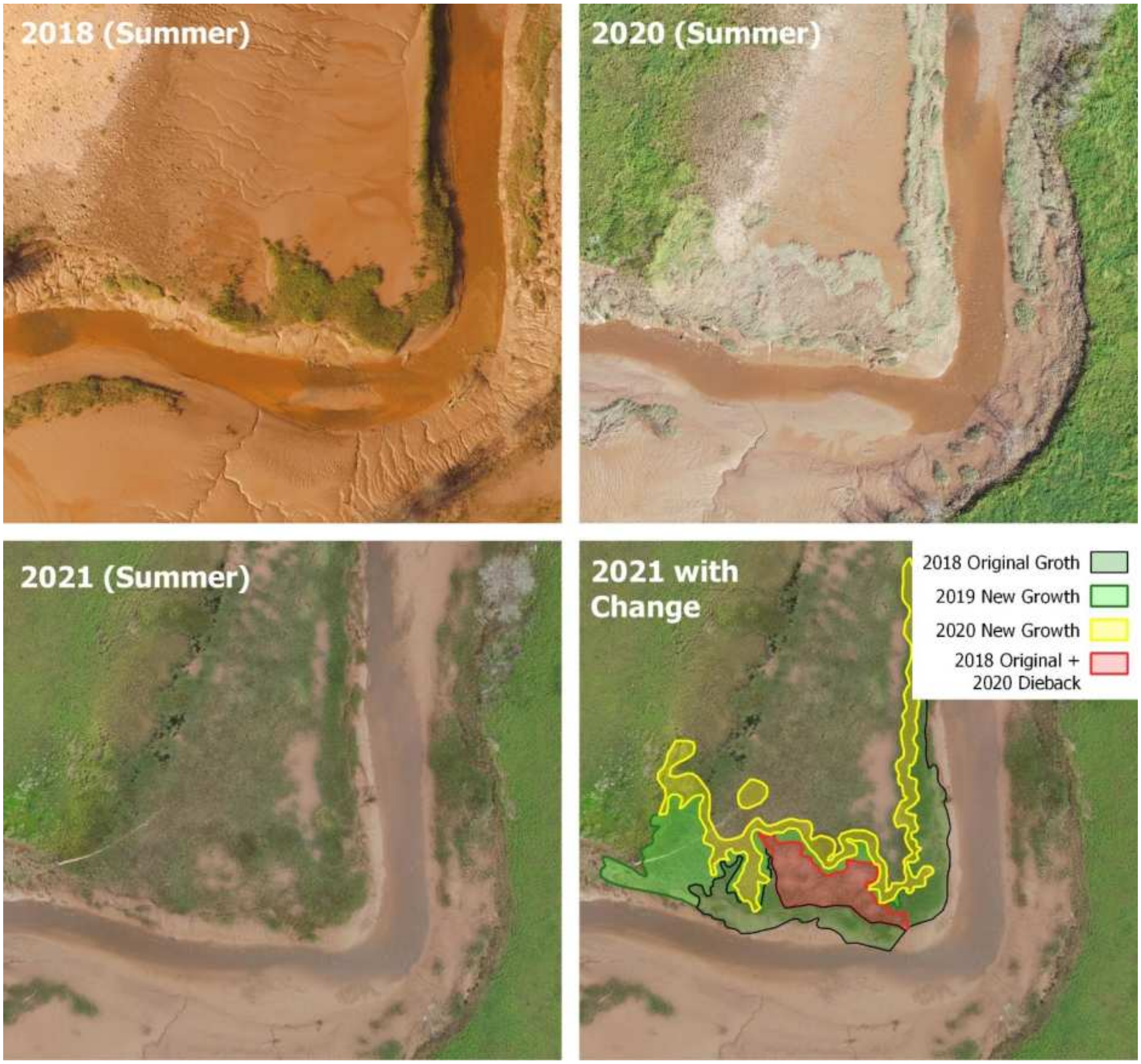


Figure 22: Impact of sudden dieback of low marsh along T6 2018-2021.

Hydrology

Hydrology is the study of water on and beneath the earth's surface, including its movement in relation to living (biotic) and material (abiotic) components of the environment (Bales, 2015). Because the fundamental control on the structure and function of tidal wetlands is salt-water flooding (Mitsch and Gosselink 1986; Neckles and Dionne 2000), changes in the tidal signal at HWR have a direct impact on the habitat within the site. Hydroperiod (frequency and duration of tidal flooding) play a crucial role in processes such as sedimentation, soil development, vegetation zonation, and carbon sequestration. The hydroperiod is determined by the tidal signal (pattern of water level change with respect to a reference point) and marsh surface elevation.

Methods

To assess water levels in the river, automated water level recorders (Onset HOBO data recorders, Figure 23) were deployed in still wells during the period of late spring to fall (May 2021 to December 2021). Loggers were placed on both sides of the causeway and at the rear of the system beneath the Highway 101 overpass. The results were graphed in excel and critical water levels and descriptive statistics were extracted. The water levels were analyzed to better understand hydroperiod and inundation frequency (flood statistics) and flood extents (flood mapping). In addition, water levels identified by earth-water Concepts Inc.'s hydraulic analysis (Gagne and Casey, 2018) and Saint Mary's University (van Proosdij, 2018) were considered as per the results of the 2018 study.

In addition to water levels, a better understanding of flow in the river under restricted conditions was needed. To characterize the flow of the HWR, discharge measurements were taken on June 29, 2021. Discharge is the volume of water passing through a channel at a certain time. Discharge was collected with the Sontek M9 Riversurveyor[5], which is an acoustic Doppler profiler that is mounted on a Hydroboard[6]. For this survey, the Hydroboard was towed behind a kayak, and was transported back and forth across the river along the same cross section, approximately 90 m upstream of the Highway 1 bridge, to obtain discharge throughout the targeted high tide cycle.

Suspended sediment concentrations (SSC) and velocities were recorded in the main channel in 2019 and again in 2020. An RBR turbidity logger[7] was deployed to measure turbidity levels, salinity, and temperature of the water. For velocities, a Nortek ADCP[8] was installed on the bottom of the channel looking up. In 2019, an ISCO automated water sampler[9] was setup on site immediately upstream of the road crossing the river as an additional instrument (Figure 24). This instrument was programmed to take one water sample every 30 minutes during the duration of two tides, from July 18 to July 19, 2019.

Figure 23: Stillwell (left) and HOBO automated water level recorder (right).

[5] www.sontek.com/riversurveyor-s5-m9
[6] www.sontek.com/media/pdfs/hydroboard-web.pdf
[7] https://rbr-global.com/products/compact-loggers
[8] http://195.62.126.26/en/products/current-profilers/profilers
[9] https://www.teledyneisco.com/en-us/water-and-wastewater/portable-samplers

Figure 24: Aerial view of location of instruments deployed to measure SSC, velocity, water levels, turbidity and salinity, during July 2019 deployment. Similar sampling locations were used in 2020.

Results

Tidal Signal and Hypsometric Curve

The data loggers upstream of Highway 1 and downstream of the causeway were deployed for a period of 194 days in 2021, while the logger upstream of Highway 101 was deployed for a shorter period of 148 days. A large snag caught and dislodged the logger well upstream of highway 101 during the early fall, preventing re-deployment in November. FIGURE 25 shows the tidal signals with precipitation data from the Kentville weather station. Though restriction is greater on spring tides than neap tides, peak tide upstream of the structure is lower than downstream levels across all tides recorded (FIGURE 26). When the downstream high tide was plotted against the observed upstream water a clear linear relationship was observed, with greater tide heights resulting greater restriction (FIGURE 27). A significant time lag was also observed, with upstream water levels peaking an average 75 minutes and up to 145 minutes (2 hours and 25 minuets) after high tide and not dropping until the downstream water levels have fallen below those upstream. Further, ebb tide is delayed with water levels returning to base flow up to ~ 5 hours after water levels have peaked. While the largest precipitation event during the recording occurred on Sept 2, it did not result in appreciably higher water levels in the river. An intense rainstorm on November 23, which led to flooding in many low-lying areas of the province, resulted in the highest water levels in the river observed in any recording period since gate installation and which flooded ~80% of the site (FIGURE 26). The intensity of the rainfall resulted in two consecutive days of water levels behind the causeway which exceeded the downstream high tide.

Table 3 shows critical water levels, with the flooded area derived from the 2021 hypsometric curve (**Figure 28**). In 2019, prior to the completion of the causeway (~June 23), equivalent high tide water levels were recorded at all three locations. The loggers were deployed (downstream of the causeway, immediately upstream of the causeway, and near the limit of tidal flow near Highway 101 at the rear of the system), indicating full tidal flow. In the same year, the causeway was completed, and the gates were installed, which resulted in a significant tidal restriction upstream. In comparison to the downstream loggers, the upstream loggers indicated a reduction in the maximum high tide height of up to 1.84 m.

In 2020, the maximum high tide height recorded upstream (immediately upstream of the Highway 1 bridge) was 2.31 m lower than the maximum high tide downstream. The logger placed upstream closer to head of tide (upstream of the Highway 101 bridge), had similar values as the Highway 1 logger, apart from mean water levels. Due to the difference in deployment lengths, the maximum high tide recorded for the logger upstream of Highway 1 and Highway 101 occurred on different dates. Mean water levels for the upstream Highway 1 logger differed from the downstream logger by 0.47 m. The mean high tide of the upstream loggers was approximately 1.26 m lower than the downstream logger, which indicates that the causeway structure significantly restricts tidal flow by cutting off the head of the tide flowing into the system. The tidal restriction greatly reduces the upstream reach of the tide; resulting in lower high tides levels throughout the site and consequently does not allow for water levels to flood the high salt marsh platform (floodplain habitat).

In the hypsometric curve (FIGURE 28), the high salt marsh platform (floodplain) and low salt marsh terrace are evident as a steep increase in flooding, with all high tide levels flooding the low marsh terrace but the high marsh flooding only on unrestricted tides or under storm conditions (predominantly freshwater flow) (as shown in FIGURE 29). Because the restricted tidal regime does not flood the high marsh platform except during storm events, the curve does not closely resemble that of a natural salt marsh.

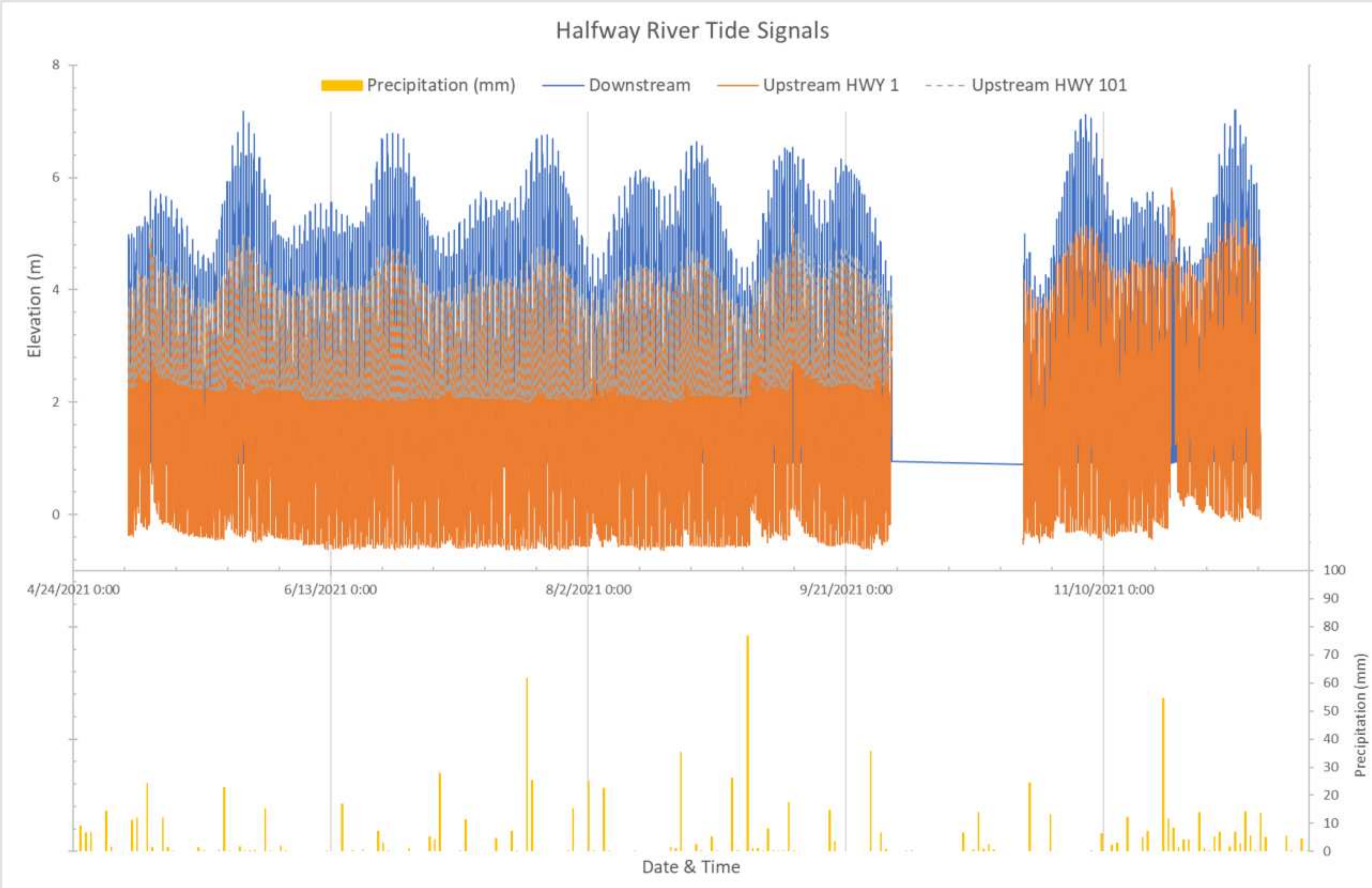


Figure 25: Tide signal for Halfway River with precipitation (mm) from the Kentville weather station.

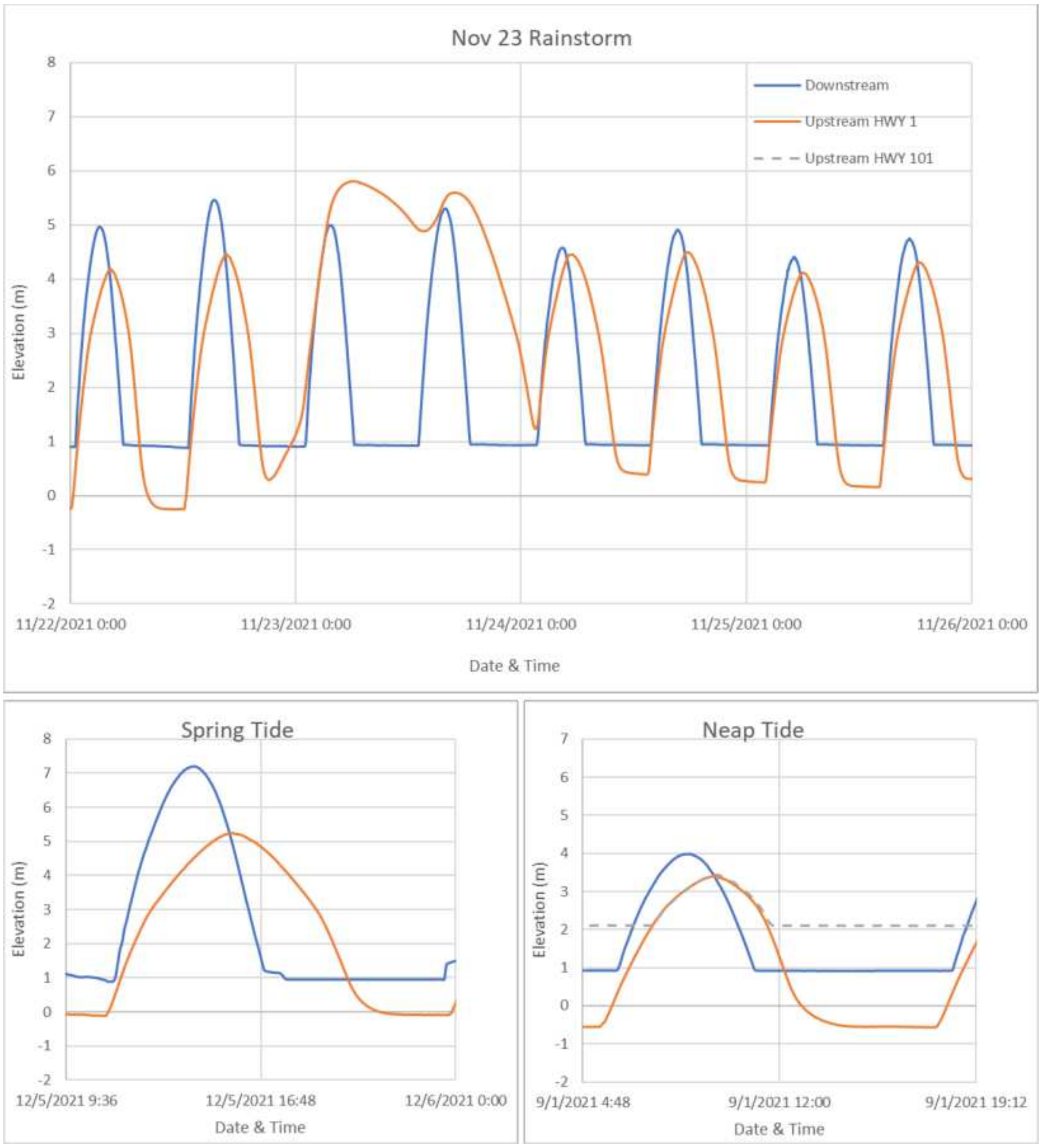


Figure 26: Intense Rain Event (Top) and Spring and Neap Tides (Bottom) for the Halfway River.

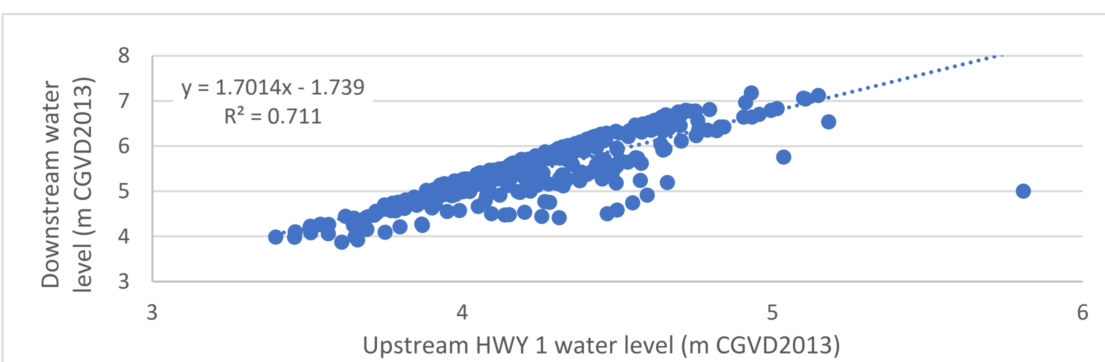


Figure 27: Waterlevels at high tide upstream and downstream of the causeway, demonstrating tidal restriction

Table 5: Critical tide heights recorded at HWR over the monitoring period.

		Upstream HWY 1 (m CGVD13)	Upstream HWY 101 (m CGVD13)	Downstream (m CGVD13)	Area (ha) Upstream for HWY 1 Water Level
Maximum potential upstream area (7.4 m tide, unrestricted)					75
2019 (Pre-Causeway - Spring)	*Days Deployed*	*30*	*30*	*30*	—
	Max High Tide	6.71	6.71	6.70	71
	Mean High Tide	5.85	5.85	5.84	43
	Mean water level	1.99	3.21	2.36	10
	Min High Tide	4.66	4.66	4.65	19
	Min water level	logger exposed	logger exposed	logger exposed	—
2019 (Post Causeway - Summer)	*Days Deployed*	*52*	*52*	*52*	
	Max High Tide	5.24	5.23	7.23	31
	Mean High Tide	4.88	4.88	5.83	24
	Mean water level	2.02	3.02	2.40	7
	Min High Tide	4.12	4.11	4.82	20
	Min water level	logger exposed	logger exposed	logger exposed	—
2019 (Gated Fall)	*Days Deployed*	*75*	*75*	*75*	—
	Max High Tide	5.51	—	7.34	45
	Mean High Tide	1.84	—	5.71	7
	Mean water level	0.63	—	2.26	4
	Min High Tide	0.60	—	4.47	4
	Min water level	logger exposed	logger exposed	logger exposed	—
2020	*Days Deployed*	*76*	*76*	*76*	—
	Max High Tide	5.08	5.07	7.39	26
	Mean High Tide	4.23	4.23	5.54	20
	Mean water level	1.64	2.78	2.29	6
	Min High Tide	3.45	3.45	3.33	17
	Min water level	-1.52	1.07	logger exposed	—
2021	*Days Deployed*	*194*	*148*	*194*	—
	Max High Tide	5.81	5.43	7.20	62
	Mean High Tide	4.23	4.24	5.49	20
	Mean water level	1.71	2.78	2.18	6
	Min High Tide	3.4	3.44	3.87	17
	Min water level	-0.64	2.00	logger exposed	—
All Years (Upstream Post-causeway only)	*Total Days*	*352*	*381*	*427*	—
	Max High Tide	5.81	5.43	7.39	62
	Mean High Tide	4.45	4.45	5.64	21
	Mean water level	1.79	2.86	2.28	7
	Min High Tide	3.40	3.44	3.33	17
	Min water level	-1.52	1.07	logger exposed	—

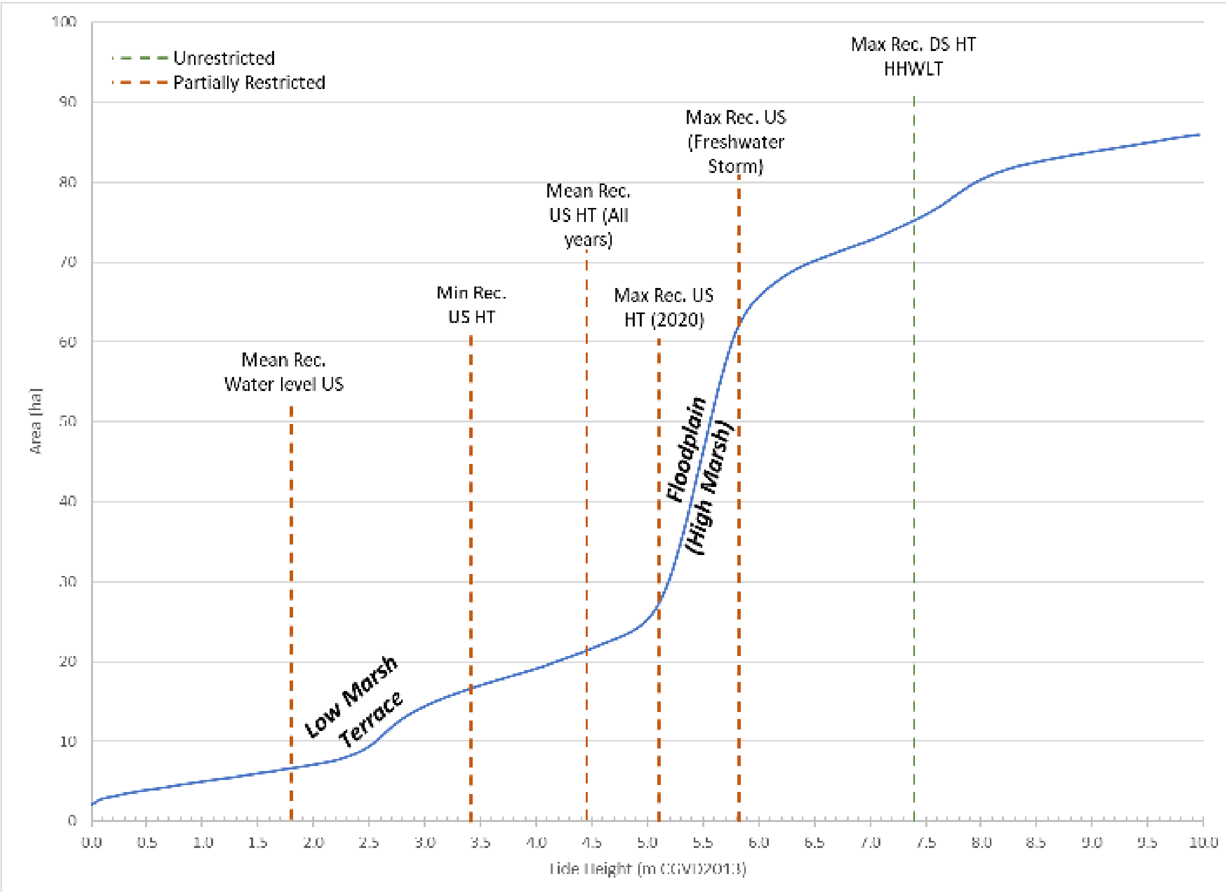


Figure 28: 2021 hypsometric curve for Halfway River generated from the 2019 LiDAR with critical tides heights noted. US = upstream, DS = downstream, HT = high tide

Flood Maps and Hydroperiod

The flood map and hydroperiod statistics (Inundation Ratio (IR), Inundation Frequency(IF), and Mean Inundation Time (MIT)) are shown in Figure 29 and Table 6. As noted above, the Nov 23 rainstorm led to significant flooding throughout the site (water level 1.4 m below downstream HHWLT and flooded 80% of site area) and resulted in slightly higher flood metrics in 2021 than 2020. Flood metrics showed little change from 2020 and 2019 ungated tide signals. As described in previous years, only 26 of 75 ha are flooded by normal high tides. Inundation statistics show that when compared to unrestricted conditions, flooding is more frequent and longer in duration below ~ 3 m CGVD2013 and shorter and less frequent above that elevation. The delay in drainage caused by the culvert results in water being held in the site and increased inundation at low elevations, while flooding is decreased or eliminated at higher elevations.

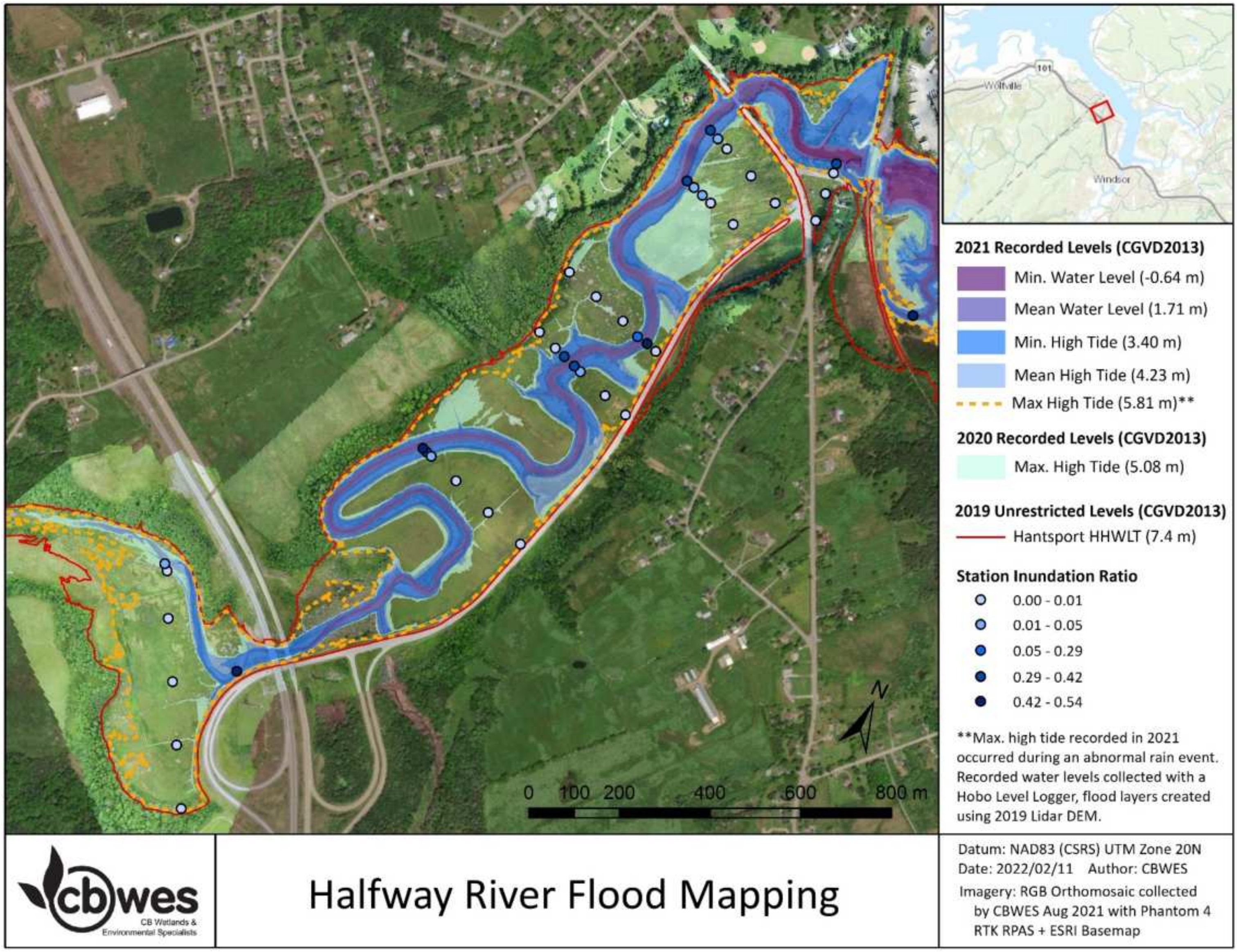


Figure 29: HWR flood map showing extent of tidal flooding based on recorded tide data during unrestriced tidal flow.

Table 6: Hydroperiod metrics: Inundation Ratio, Inundation Frequency and Mean Inundation Time for elevation classes 2- 7 meters. A = Unrestricted Tidal Flow 2019; B = Partially Restricted Tidal Flow 2019; C = Gated 2019; D = Partially Restricted Tidal Flow 2020; E = Partially Restricted Tidal Flow 2021; F = Partially Restricted Tidal Flow Average All Years.

Elevation (m CGVD2013)	**Inundation Ratio (IR)**						
	A	*B*	*C*	*D*	*E*	*F*	**Restricted – Unrestricted (F-A)**
2	0.41	0.49	0.09	0.46	0.47	0.47	0.06
2.5	0.37	0.44	0.05	0.41	0.42	0.42	0.05
3	**0.33**	**0.37**	**0.03**	**0.33**	**0.34**	**0.35**	**0.02**
3.5	0.29	0.29	0.02	0.23	0.24	0.25	-0.04
4	0.25	0.19	0.01	0.11	0.12	0.14	-0.11
4.5	0.2	0.08	0.01	0.02	0.03	0.04	-0.16
5	0.14	0.01	0	0.001	0.01	0.01	-0.13
5.5	0.09	0	0	0	0.002	0.001	-0.09
6	0.03	0	0	0	0	0	-0.03
6.5	0.004	0	0	0	0	0	0.00
7	0	0	0	0	0	0	0.00
	Inundation Frequency (%) (IF)						
	A	*B*	*C*	*D*	*E*	*F*	**Restricted – Unrestricted (F-A)**
2	100	100	35.1	100	100	100	0.00
2.5	100	100	17.2	100	100	100	0.00
3	**100**	**100**	**9.3**	**100**	**100**	**100**	**0.00**
3.5	100	100	4	99.3	99.2	100	-0.50
4	100	96.6	2.6	73.2	74.1	81.3	-18.69
4.5	100	55.7	2	18.8	22.1	32.2	-67.79
5	84.1	15.9	0.7	2	3.5	7.1	-76.98
5.5	73	0	0.7	0	0.3	0.09	-72.91
6	30.2	0	0	0	0	0	-30.20
6.5	6.3	0	0	0	0	0	-6.30
7	0	0	0	0	0	0	0.00
	Mean Inundation time (min) (MIT)						
	A	*B*	*C*	*D*	*E*	*F*	**Restricted – Unrestricted (F-A)**
2	291	349	179	334	351	345	53.77
2.5	269	315	208	296	311	307	38.44
3	**241**	**269**	**218**	**241**	**255**	**255**	**14.16**
3.5	210	210	318	170	182	187	-22.51
4	178	141	286	110	120	124	-54.35
4.5	142	103	202	96	100	100	-42.33
5	119	58	310	28	127	71	-47.90
5.5	85	0	40	0	470	157	71.67
6	62	0	0	0	0	0	-62.00
6.5	41	0	0	0	0	0	-41.00
7	0	0	0	0	0	0	0.00

Suspended Sediment Concentrations and Velocities

In 2019, during the first tide of the ISCO deployment, on July 18, concentrations ranged from a minimum of 61 $mg \cdot L^{-1}$ at the beginning of the tide to a maximum of 243 $mg \cdot L^{-1}$ 3 hours before high tide. During the second tide, on July 19, concentrations lacked as high of a peak, ranging from 70 $mg \cdot L^{-1}$ to 162 $mg \cdot L^{-1}$. Temporal patterns during the tidal cycle were very different between these two tides. The concentrations are consistent with values recorded in other tidal systems in the Upper Bay (e.g. Poirier et al., 2017; O'Laughlin et al., 2014; van Proosdij et al., 2004) but lower than values reported in rivers with fluid mud such as the Salmon River or portions of the Avon River (van Proosdij et al., 2020). The concentrations are sufficient to cause the sedimentation observed on the marsh platform with highest values closest to the banks consistent with Poirier et al. (2017). These values will, however, likely display seasonal variability.

The ISCO was deployed again from June 28-30th, 2021, which in terms of seasonality was within a month of the 2019 sampling so differences between these two deployments were not expected due to seasonality. Suspended sediment concentrations in 2021 were similar in tidal pattern to 2019 but were lower in values. Both sampling periods showed high suspended sediment concentrations about 3 hours before high tide, as the tide was coming in, then concentrations decreasing until high tide, followed by another increase in concentration as the tide was on its way out, peaking again about 3 hours after high tide. Interestingly, in 2019 the highest concentrations were on the incoming tide, and in 2021 the highest concentrations were on the outgoing tide suggesting re-suspension of material (FIGURE 30). The Kentville weather station recorded 1.3 mm and 0.4 mm of rain on June 28 and 30 respectively for one hour which may have contributed to increased concentrations. Incoming concentrations peaked at 243 $mg \cdot L^{-1}$ in 2019 and peaked at 123 $mg \cdot L^{-1}$ in 2021, while the outgoing concentrations peaked at 151 $mg \cdot L^{-1}$ in 2019 and 143 $mg \cdot L^{-1}$ in 2021, showing that the water coming in had less sediment in 2021 than in 2019, but the water leaving the site had the same amount of sediment during both sampling periods.

The RBR XR-420 instrument measured turbidity, salinity, and temperatures in 2019, 2020, and 2021. Results for turbidity and salinity are shown in FIGURE 31. Salinity values in 2019 peaked at 27 PSU during high tide, while salinity values in 2020 peaked at 29 PSU during high tide. Trends during the tide were very similar in both collection periods. Water levels were also higher during the 2020 measurement period. In 2021, salinities again peaked at 29 PSU, very similarly to 2020. One notable change was that in 2021 the water leaving the site at the end of the tidal cycle was still around 20 PSU, while in the other two sampling periods, water leaving the site went down in salinity to values between 7 and 17 PSU (FIGURE 31).

Temperatures were colder during 2020 as these RBR data were collected in October 2020 and in July 2019. In July 2019 water temperatures were 17-18 degrees Celsius at high tide, and temperatures decreased with the incoming tide and increased with the outgoing tide. In October 2020 water temperatures were 13-14 degrees Celsius at high tide, and temperatures increased on the incoming tide and decreased on the outgoing tide. In late June 2021, temperatures were again around 18 degrees Celsius at high tide.

In terms of turbidity from the RBR, values were higher in October 2020 than July 2019. In July 2019, the incoming tide has turbidity values of approximately 150-200 NTU, with the high tide having values around 50 NTU. On the outgoing tide, values were around 100 NTU with the exception of the first tide that saw a peak of 360 NTU (FIGURE 32). In October 2020, the incoming tide turbidity values were 250-350 NTU, high tide turbidity values were around 60 NTU, and outgoing values around 150-220 NTU (FIGURE 32). There are large peaks in these turbidity readings, and these could possibly be due to sediment transport but could also be due to vegetation debris getting caught in the sensor. In June 2021, turbidity values were similar to the July 2019 values, with a peak during the incoming tide around 100-120 NTU, a high tide settling to about 40 NTU, and outgoing tide of about 90 to 115 NTU.

Velocity patterns from the ADCP show fast flow of water on the initial flood tide and on the end of the ebb tide (FIGURE 33). These figures show a time series of speed above the ADCP, which is in the main channel, over several tidal cycles. At these extremities of the inundation period at this site, water speeds are around 1.0 $m \cdot s^{-1}$. As the site fills with water velocities decrease, slowing down consistently to a minimum of about 0.25 $m \cdot s^{-1}$. Values for 2019, 2020, and 2021 were quite similar (FIGURE 33). The first sampling period, 2019, had speeds consistently at 1.0 $m \cdot s^{-1}$ a little longer on both the very first part of the tide and the very last part of the tide (FIGURE 33a), though differences between years were quite small.

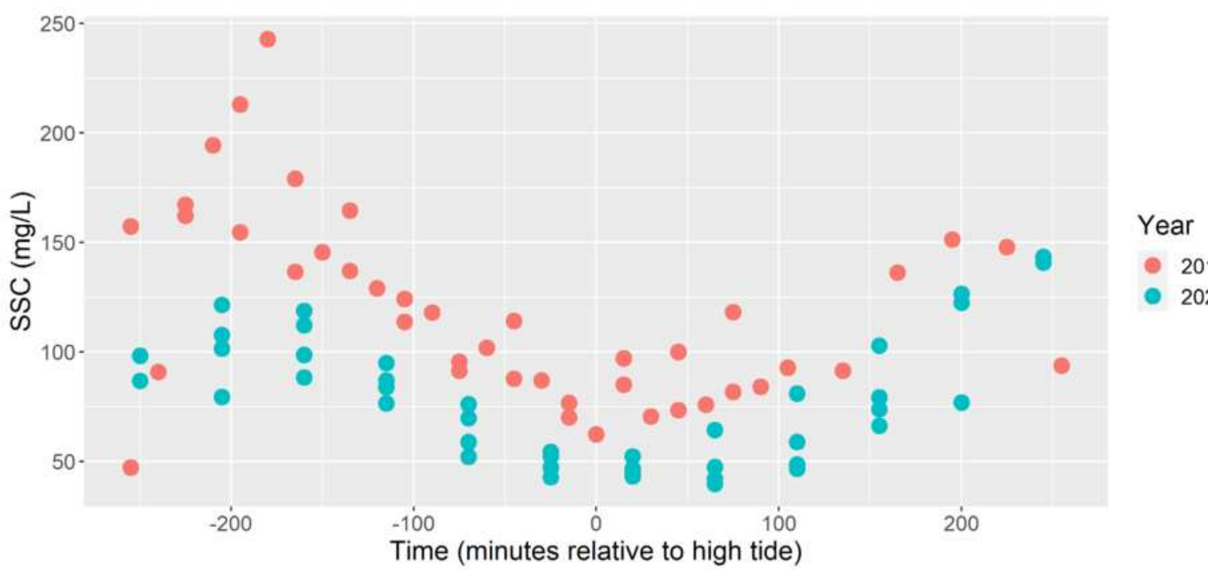


Figure 30: Suspended sediment concentration ($mg \cdot L^{-1}$) measured by the ISCO water sampler, over 2 tides for July 2019 and 4 tides for June 2021 relative to high tide measured at the ADCP.

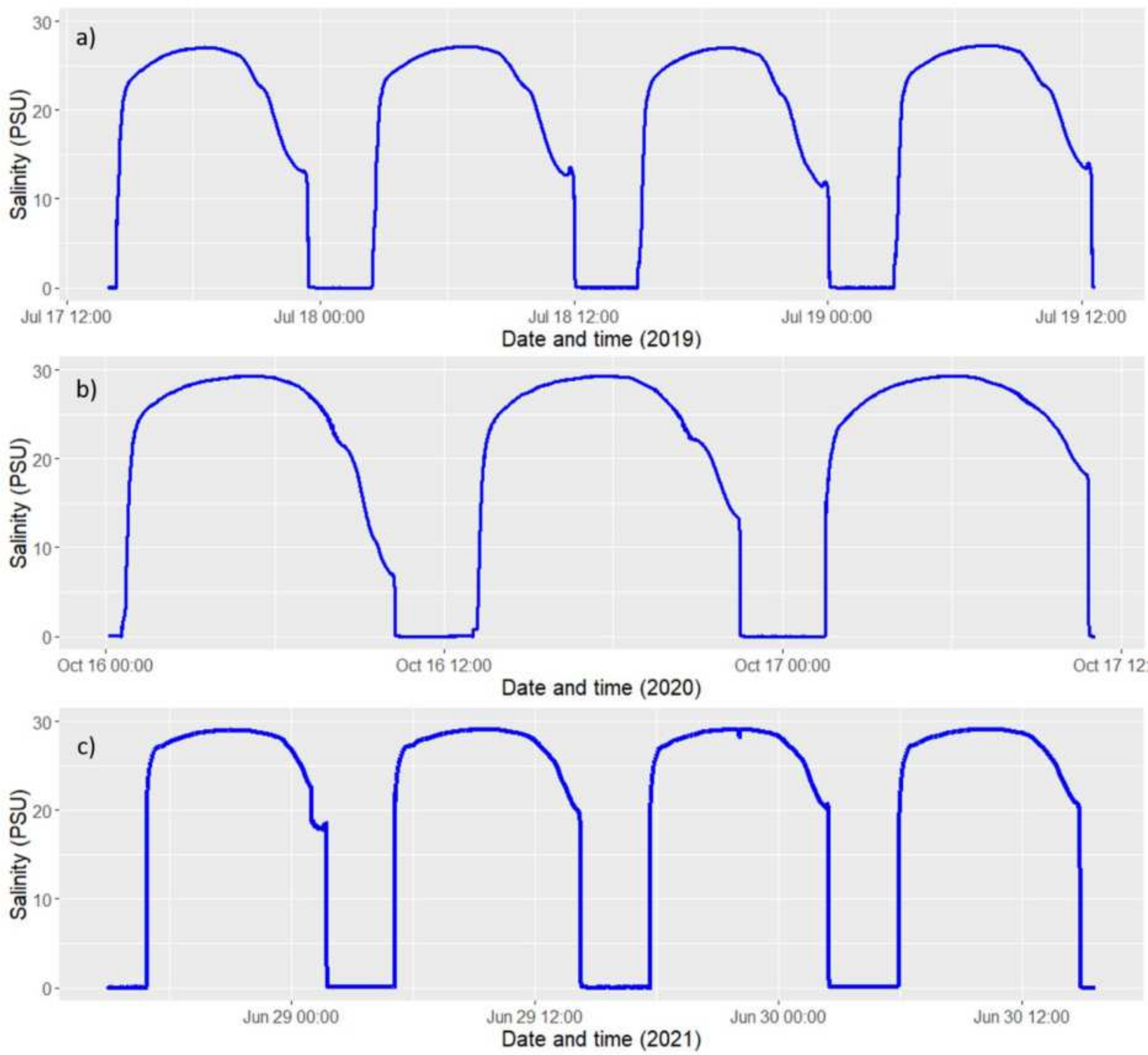


Figure 31: Salinity results from RBR XR-420 in July 2019, Oct 2020, and June 2021.

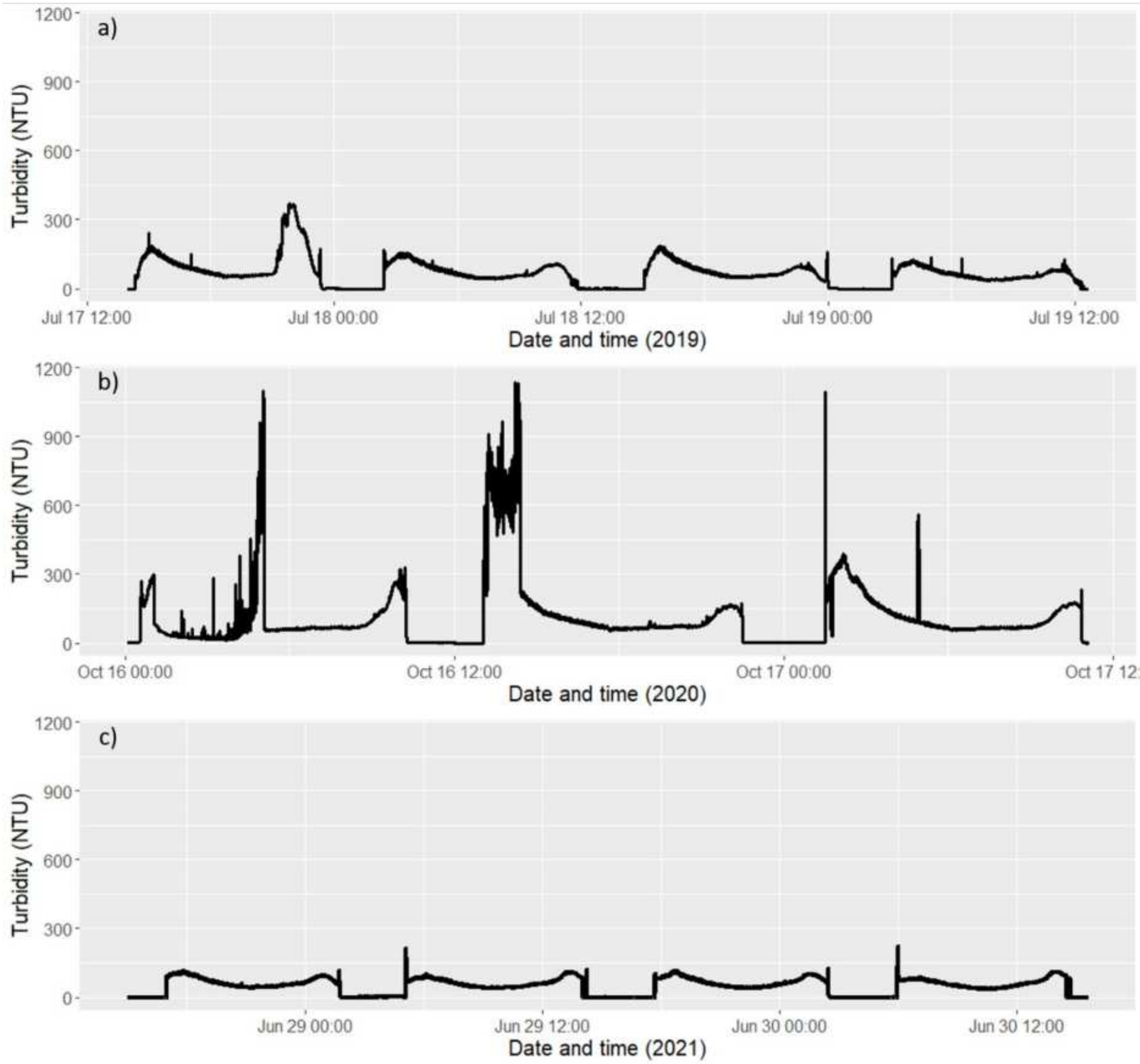


Figure 32: Turbidity results from RBR from Turbidity results from RBR XR-420 in July 2019, Oct 2020, and June 2021.

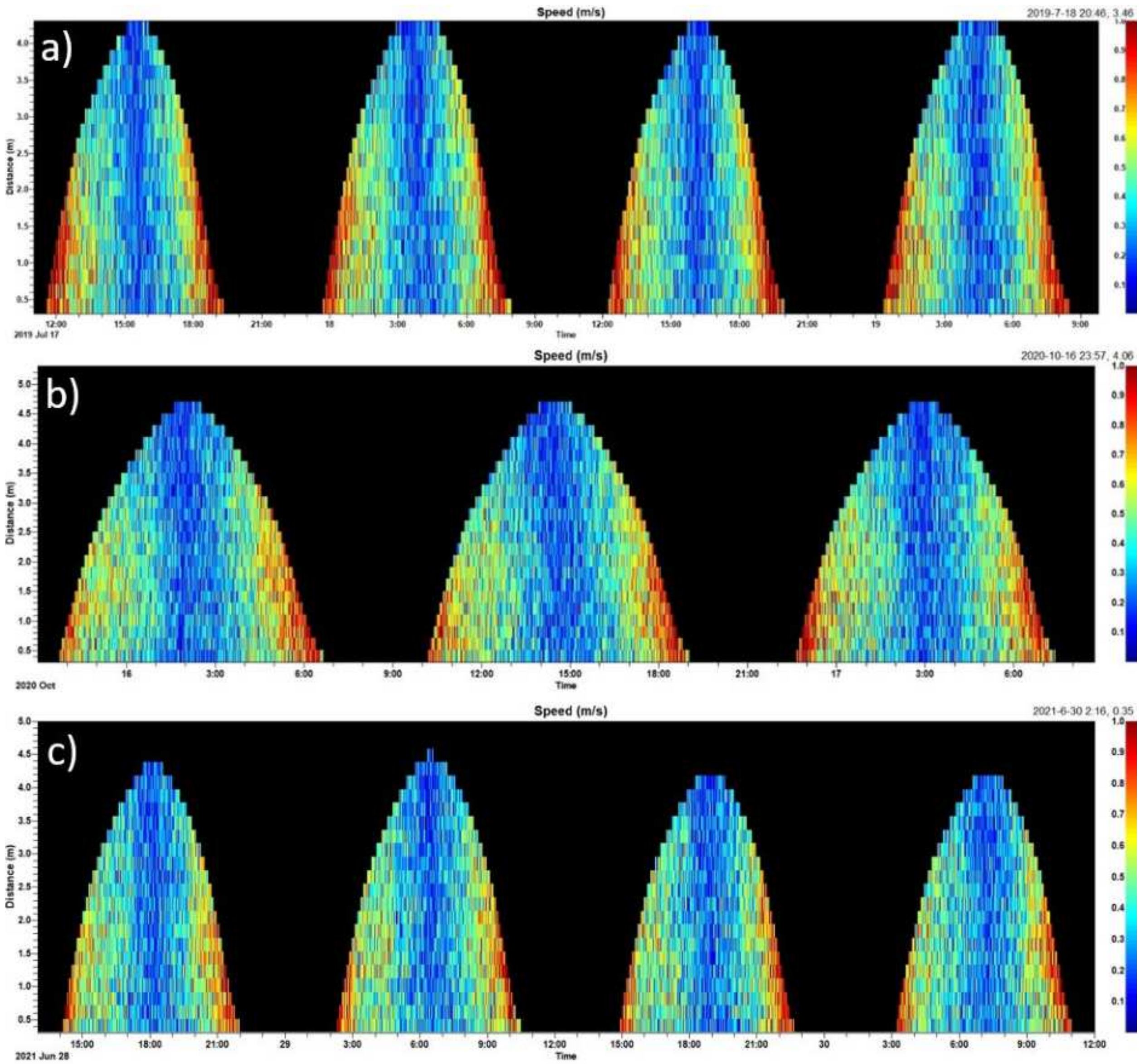


Figure 33: ADCP speeds for 4 tides during July 17-19, 2019; three tides during October 15-17, 2020; and 4 tides during June 28-30, 2021. Scale is 0 - 1 $m \cdot s^{-1}$ with higher velocities in red.

Tidal Discharge

Freshwater rivers would have relatively constant discharge outside of rainfall, seasonal changes and ice thaw events, but tidal rivers have a changing discharge throughout the tidal cycle. For the Halfway River, in July 2019, during the period of partial restriction, discharge started at approximately 5 $m^3 \cdot s^{-1}$ at the beginning of the incoming tide and grew as the tide increased and water passed through a larger cross-sectional area (FIGURE 34). At maximum discharge on the incoming tide, 34 $m^3 \cdot s^{-1}$ of water was coming into the river. The reason the points bounce back and forth (and appear as there are two lines rather than one) is because one set of points is going from left bank to right, and the other set of points is going from right bank to left bank. The same discharge survey was repeated on October 15, 2020 (FIGURE 35). One year later, the discharge showed a very similar pattern as the first survey. In the 2019 survey more of the beginning of the tide was captured while in the 2020 survey more of the latter part of the tide was captured, but the portions that are at the same time relative to high tide are very similar. High tide corresponds to the point when the flow changes direction and discharge becomes positive (FIGURE 34, FIGURE 35). In 2020, the maximum discharge on the flood tide was 35 $m^3 \cdot s^{-1}$ of water coming into the river, and the maximum discharge on the ebb tide was 39 $m^3 \cdot s^{-1}$ of water flowing out of the river. The survey was repeated a third time in 2021, and the results show that the discharge of the river remained fairly similar to previous years, with incoming discharge values peaking around 35 $m^3 \cdot s^{-1}$ and outgoing discharge values peaking at 36 $m^3 \cdot s^{-1}$. A small difference is observed on the outgoing tide with more water leaving the river in October 2020 than June 2021 (peak of 39 $m^3 \cdot s^{-1}$ vs peak of 36 $m^3 \cdot s^{-1}$). This may be attributed to a rainfall event the day prior to the 2020 survey in which the Kentville weather station recorded 11.5 mm of rain whereas only 1.3 mm of rain was recorded on June 28, 2021.

Discharge can also be visualized with the water speed plotted throughout the cross section. Four cross sections are displayed as such: 25 minutes before high tide—which shows the fastest water in the center of the channel, at high tide, 7 minutes after high tide, and 28 minutes after high tide for the 2019 survey (FIGURE 38). Flow speeds in these example transects are highest on the flood tide, increasing to between 0.3 and 0.4 $m \cdot s^{-1}$ within the deepest part of the channel. Not unexpectedly, the S. alterniflora canopy reduced flow velocities to less than 0.1 $m \cdot s^{-1}$ throughout the entire tide. Flow speeds at 28 minutes after high tide are less than 0.2 $m \cdot s^{-1}$ in the main channel. Water speed plotted throughout the cross section for similar times relative to high tide in 2020 (FIGURE 39) compare with values from 2019. When discharge values are at their highest around 3:30 pm on October 15, 2020 speeds are around 0.5 $m \cdot s^{-1}$ in the channel. As was seen in the ADCP data section, flow speeds are highest as the very beginning and at the very end of the tide, when they reach 1 $m \cdot s^{-1}$. Interestingly it appears that the degraded *S. alterniflora* canopy may have not been as effective at reducing velocities on the ebb tide compared to the healthy vegetation in 2019 seen in panel c (FIGURE 39, FIGURE 40).

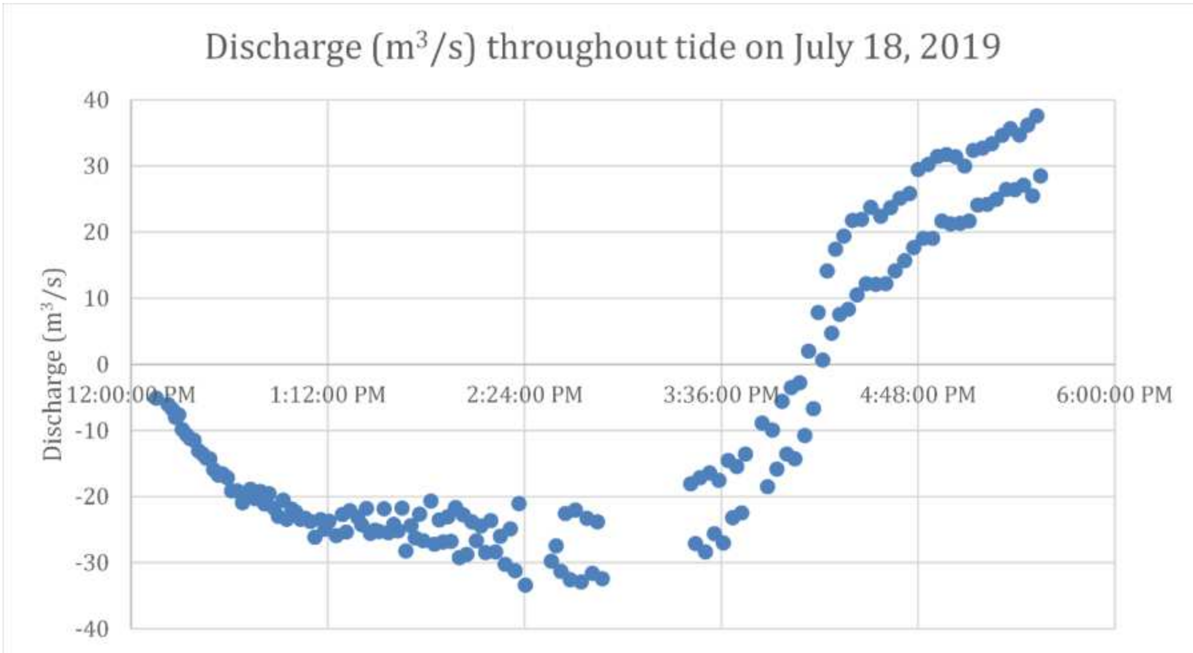


Figure 34: Discharge of the Halfway River throughout the high tide cycle on July 18, 2019. Each dots represents one transect across the river. Negative values indicate incoming flow (flood tide) and positive values indicate outgoing flow (ebb tide).

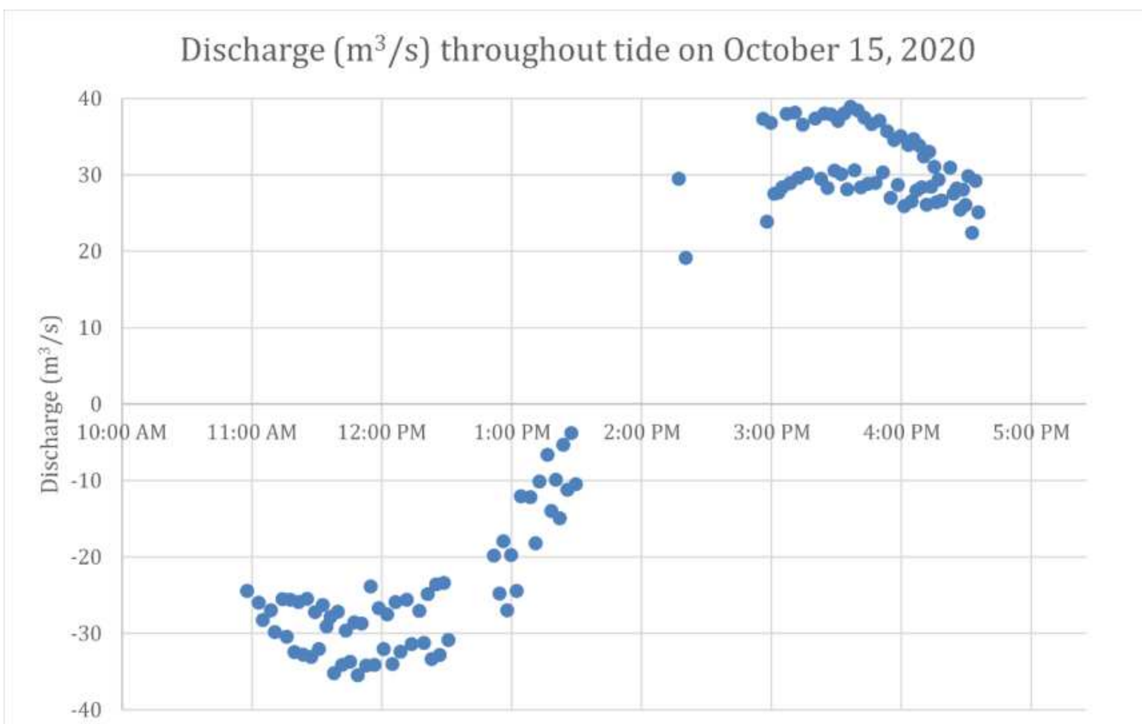


Figure 35: Discharge of the Halfway River throughout the high tide on October 15, 2020. Each dot represents one transect across the river. Negative values indicate incoming flow (flood tide) and positive values indicate outgoing flow (ebb tide).

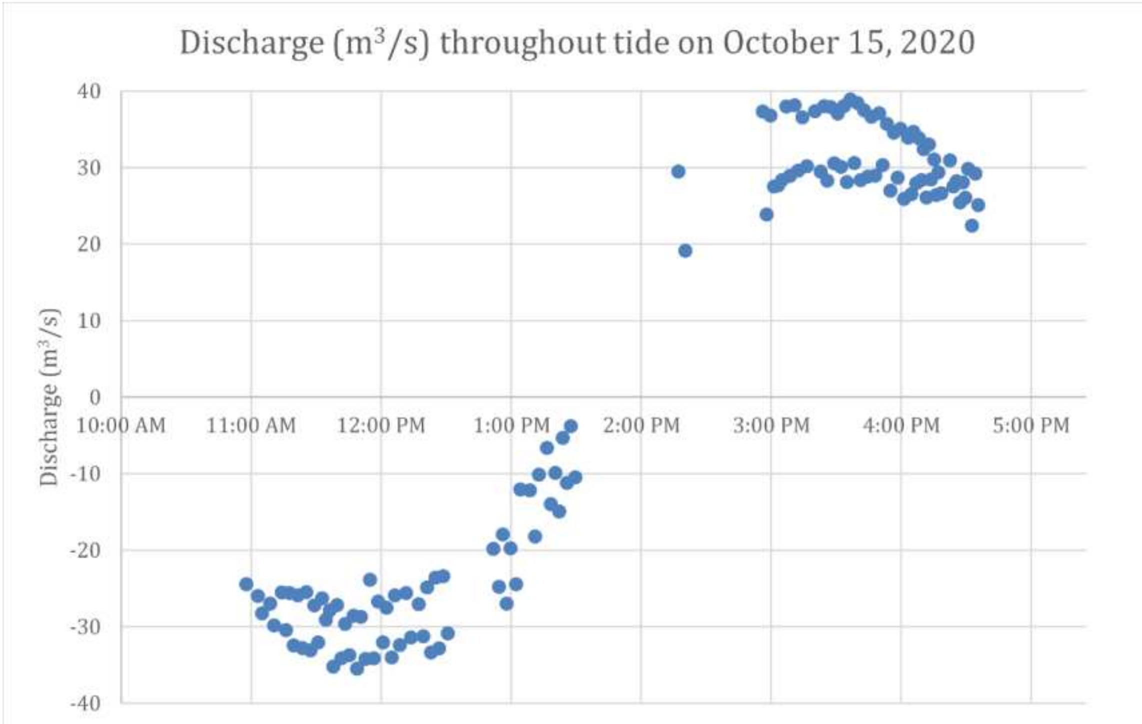


Figure 36: Discharge of the Halfway River throughout the high tide on October 15, 2020. Each dot represents one transect across the river. Negative values indicate incoming flow (flood tide) and positive values indicate outgoing flow (ebb tide).

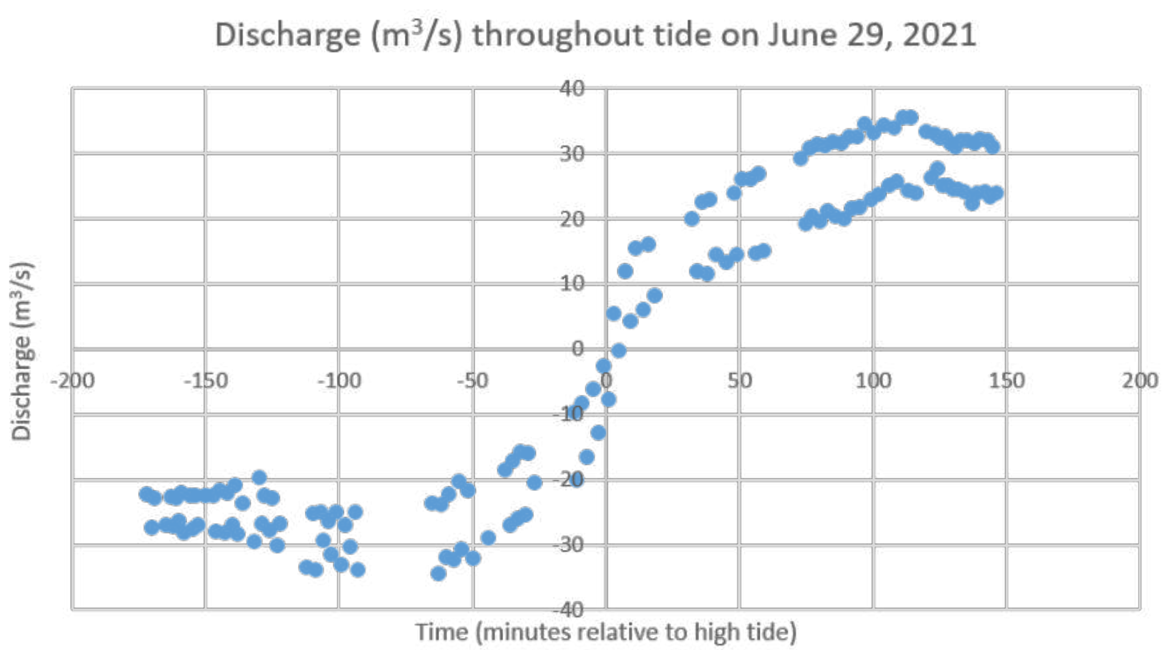


Figure 37: Discharge of the Halfway River throughout the tide on June 29, 2021. Each dot represents one transect across the river. Negative values indicate incoming flow (flood tide) and positive values indicate outgoing flow (ebb tide).

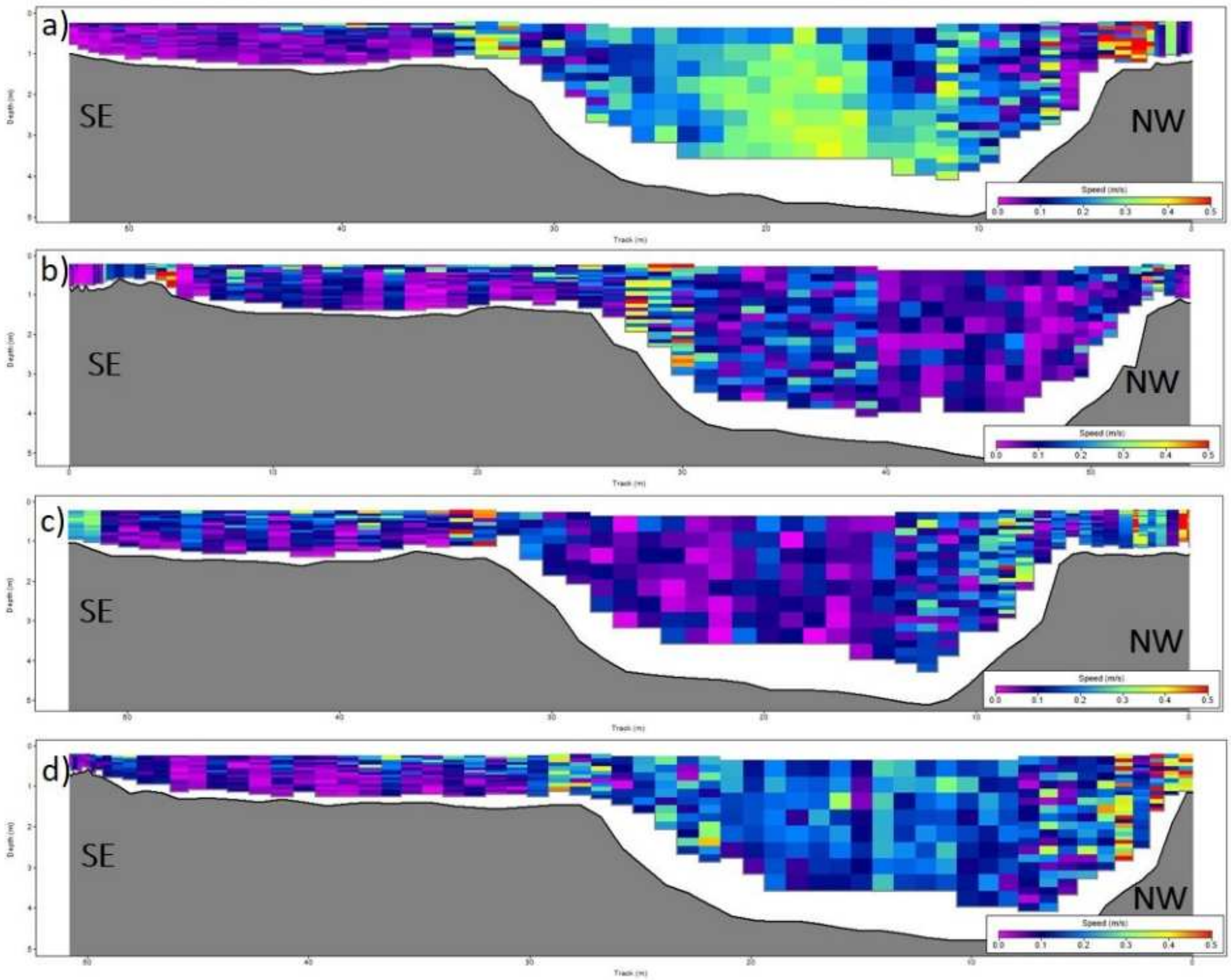


Figure 38: Speed (m/s) through a cross section of the river on July 18, 2019. Scale is from 0 to 0.5 m/s with red values indicating higher velocities. a) 25 minutes before high tide, b) at high tide, c) 7 minutes after high tide, and d) 28 minutes after high tide.

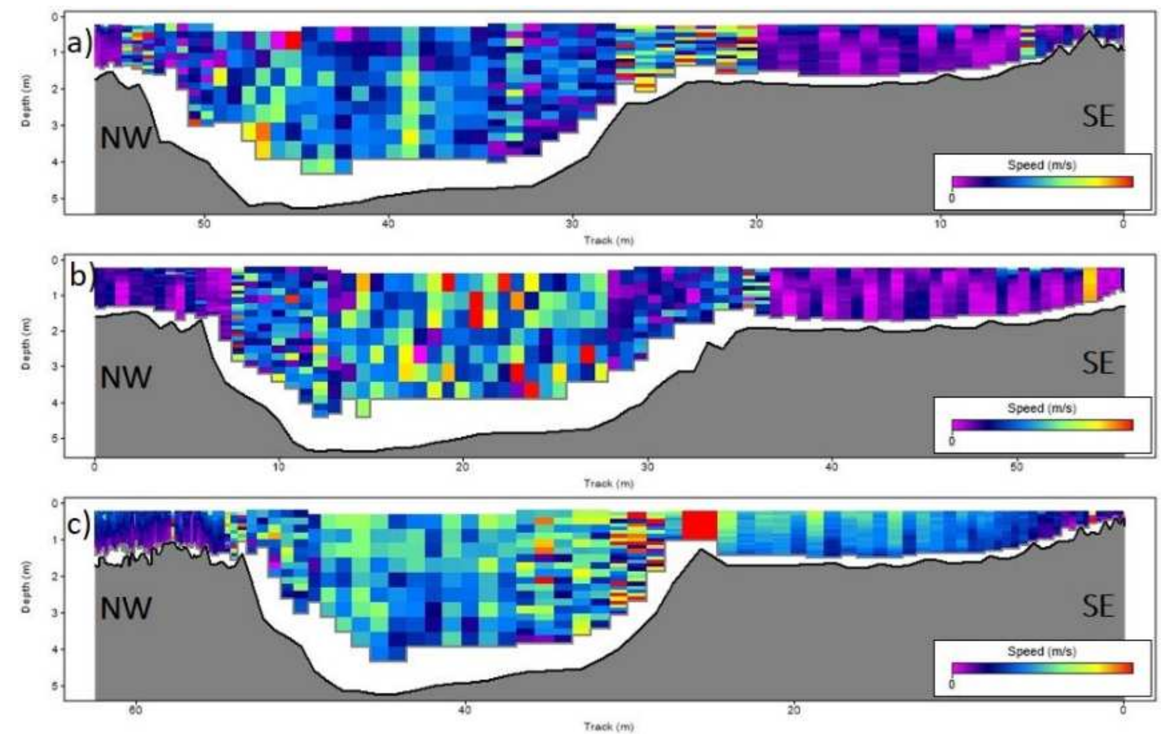


Figure 39: Speed (m/s) through a cross section of the river on October 15, 2020. Scale is 0 to 0.5 m/s. a) 29 minutes before high tide, b) 8 minutes before high tide, and c) 45 minutes after high tide

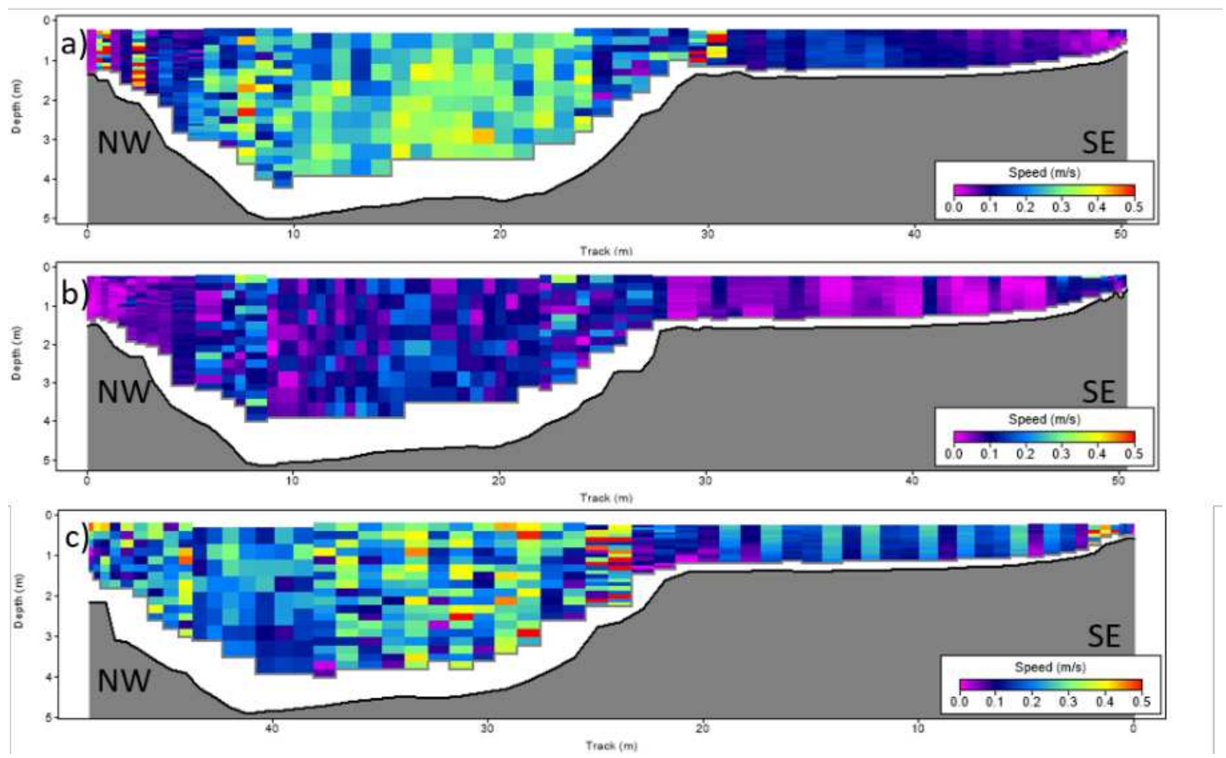


Figure 40: Speed (m/s) through a cross section of the river on June 29, 2021. Scale is 0 to 0.5 m/s. a) 29 minutes before high tide, b) 2 minutes after high tide, and c) 41 minutes after high tide.

Soils and Sediments

Monitoring marsh surface elevation, sediment accretion rates, and soil characteristics provides insight into the processes controlling vegetation type, cover and productivity and the vertical growth of marsh following restoration (Neckles and Dionne, 2000). Monitoring soil and sediment conditions before and after restoration can reveal insights regarding pre-restoration conditions of the marsh (subsidence due to oxidation of organic matter in sediments) and the process of recovery following restoration.

Accretion of inorganic and organic material deposited onto the marsh surface by flood waters and vegetation is one of the main processes that allow marshes to build vertically over time, offsetting increased tidal flooding resulting from restoration activities and/or sea level rise. Failure to keep pace with increased flooding could result in the loss of tidal wetland features and functions (i.e., loss of productivity and extent of habitat). The GPAC Protocol recommends the use of Rod Surface Elevation Tables (RSET) and Marker Horizons (MH) (mm resolution) in combination to monitor/explain processes behind marsh elevation changes (i.e., sedimentation, subsidence) (Lynch et al., 2015; Neckles et al., 2002) (FIGURE 41). These methods have been used on a number of tidal wetland restoration projects in the region and have provided valuable information on the response of the systems to restoration activities. Other sediment monitoring methods (i.e., RTK, sediment pins) provide information on sediment gain or loss (change in elevation) (cm resolution), but not actual sedimentation rates, or processes operating in the zone of shallow subsidence such as changes in below ground biomass (Lynch et al., 2015).

Marsh soil characteristics are determined by the sediment source and tidal current patterns (Mitsch and Gosselink, 1986). As tidal waters flow over the marsh surface, increasing elevation and vegetation slows the water allowing coarse-grained sediment to drop out of suspension close to the main channel edge while finer sediments drop further inland (Redfield, 1972; Mitsch and Gosselink, 1986). Sediment type and particle size greatly influences soil aeration and drainage (Packham and Willis, 1997). Silt, clay, and sand are the different soil textures typical of salt marshes. Silt and clay materials tend to retain more salt than sand, and clay is the most absorptive (Mitsch and Gosselink, 1986). Clay and silt are expected to dominate high salt marsh soils, while the low salt marsh is expected to have a higher proportion of sand (Packham and Willis, 1997), however, this will vary depending on the source material. Bulk density is a measure of soil compaction and reflects the soil's ability to function for structural support, movement of water and solutes, and soil aeration. All of these components will influence the ability of plant roots to access nutrients and minerals as well as the composition and health of microbial communities and chemical processes within the soil matrix. Changes in soil color and composition can be used to indicate biochemical processes that may have negative impacts (e.g., sulfide production) and affect the recovery of the marsh system.

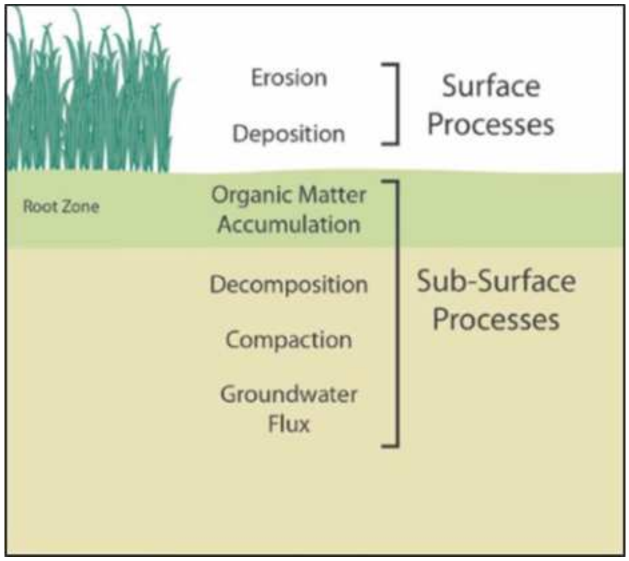


Figure 41: Surface and sub-surface processes measured by the RSET – MH method that determine elevation change in a wetland (from Lynch et al., 2015).

Sediment Accretion and Elevation

Methods

Sediment deposition monitoring was conducted at HWR using a combination of the RTK elevation surveys (DEM, previously discussed), elevation difference surfaces using repeat RPAS flights, and RSET with MH. In the absence of a local unaltered tidal wetland, the Cogmagun restoration site (Bowron et al., 2015) was selected as the reference site for Halfway River given similarities in position within the estuary, sediment composition and proximity.

Three MH plots were established with each RSET. The MH were established according to the methods developed by Cahoon and Lynch (USGS, 2005). Vertical accretion at each marker was measured using a Cryogenic Corer using standard protocols for stations situated on unconsolidated, water saturated soils (Cahoon et al., 1996; Lynch et al., 2015). For stations at shallow, consolidated soils a manual core was collected using a knife. See Lynch et al., 2015 for a comprehensive guidance document and standard protocols on the placement, installation, measurements, and analysis of RSET/MH stations. Three RSET stations and associated MH were installed and measured in November 27, 2019 (FIGURE 42) and were re-measured on November 18, 2020 and September 13, 2021 (TABLE 7). Repeat elevation surveys indicate slight (~1.5 cm) difference in vertical elevation at the RSET receiver indicating minimal impacts of frost heave over the year. Given the relative magnitude of surface elevation change the results can therefore be interpreted with confidence.

Figure 42: Installation of RSET 2 at HWR on Novemeber 27, 2019.

Table 7: Coordinates and elevations of RSET stations, MH and slight differences in elevation between years. Vertical elevation differences approximately 1 cm.

RSET Code	***Coordinates***			***Annual Survey diff***			***Error (root sum of squares) (2019-2021)***		
	X	**Y**	**Elev CGVD2013**	**Δx**	**Δy**	**Δz**	**Stdev x**	**Stdev y**	**Stdev z**
HWR SET-01 19	407506.163	4990583.052	3.166						
HWR SET-02 19	407263.854	4989661.394	3.966						
HWR SET-03 19	407050.481	4989335.785	2.837						
HWR SET-01 20	407506.163	4990583.060	3.183	0.000	0.008	**0.017**	0.006	0.009	**0.011**
HWR SET-02 20	407263.856	4989661.415	3.947	0.002	0.021	**-0.019**	0.007	0.010	**0.011**
HWR SET-03 20	407050.485	4989335.784	2.819	0.004	-0.001	**-0.018**	0.007	0.012	**0.012**
HWR SET-01 21	407506.163	4990583.100	3.150	0.000	0.040	**-0.016**	0.006	0.010	**0.008**
HWR SET-02 21	407263.834	4989661.423	3.967	-0.022	0.008	**0.001**	0.007	0.010	**0.009**
HWR SET-03 21	407050.441	4989335.880	2.822	-0.044	0.096	**-0.015**	0.008	0.013	**0.010**

Marker Horizon Station	**Easting**	**Northing**	**Elev 2019 (m)**	**Elev 2020 (m)**	**Elev 2021 (m)**	**Δ Elev. 2019-2020**	**Δ Elev. 2020-2021**	**Δ Elev. 2019-2021**	***Error (root sum of squares)(m) 2019-2021***
HWR SET-01 MHA	407508.045	4990583.601	2.925	3.005	3.004	0.080	-0.001	0.079	0.013
HWR SET-01 MHB	407505.712	4990585.108	2.942	3.007	3.001	0.065	-0.006	0.059	0.012
HWR SET-01 MHC	407504.633	4990582.485	3.081	3.138	3.091	0.057	-0.047	0.010	0.013
HWR SET-02 MHA	407264.620	4989662.677	3.808	3.827	3.872	0.019	0.045	0.064	0.012
HWR SET-02 MHB	407262.606	4989662.094	3.757	3.772	3.801	0.015	0.029	0.044	0.013
HWR SET-02 MHC	407263.186	4989659.852	3.715	3.768	3.757	0.053	-0.011	0.042	0.027
HWR SET-03 MHA	407051.498	4989336.557	2.540	--	2.550			0.010	0.011
HWR SET-03 MHB	407050.022	4989337.107	2.454	--	2.516			0.062	0.010
HWR SET-03 MHC	407049.573	4989334.846	2.531	--	2.556			0.025	0.011

Results

During the 2019-2020 reporting period, marked differences were recorded in surface elevation change at the HWR RSETs, however, all were positive vertical changes in elevation. The greatest annual change in surface elevation (HWR SET-01, 5.22 cm) (TABLE 8) was recorded on the pre-existing foreshore marsh closest to the river mouth, therefore, closest to the incoming sediment laden tidal waters. The lowest change was recorded at HWR SET-02 (0.99 cm) (TABLE 8) which is situated approximately 0.8 m higher in elevation than the other two RSETs, therefore would be flooding less frequently (TABLE 7). The RSET furthest up the river and at the lowest elevation had a recorded 1.30 cm of surface elevation change (TABLE 8). The majority of the positive (upward) change in surface elevation can be attributed to sediment deposition (TABLE 9, FIGURE 43). This is supported by visual observations (FIGURE 44, FIGURE 45) and repeat UAS surveys. Just under 5 cm of sediment was deposited at HWR SET-01 (FIGURE 43) with 1.88 and 3.49 cm at stations 2 and 3 respectively (TABLE 10). However, subtraction of the RSET and MH data indicate that HWR SET-02 and HWR SET-03 are both experiencing negative (sinking) processes within the root zone of -0.88 cm and -2.19 cm respectively (TABLE 10). This may either be due to compaction or the beginning of decay of former vegetation platform.

In 2020-21, however, the patterns of highest and lowest changes in surface elevation were reversed. HWR SET-01 on the foreshore marsh recorded only 1.86 cm with mean accretion of 2.69 cm (FIGURE 43, TABLE 8) resulting in net deficit in subsurface processes (-0.83 cm) (TABLE 9). The change in surface elevation at HWR SET-02 was almost 2.5 times greater than in the previous year (TABLE 8) with higher sediment accretion (2.61 cm) as well and overall net positive below ground contribution (TABLE 9). Significantly higher sediment accretion was recorded at the station furthest upriver. HWR SET-03 recorded 11.7 cm of deposition and was highly bioturbated and only one viable core was used for the analysis (TABLE 9, TABLE 10). However, this only contributed to a 6.19 cm change in surface elevation (TABLE 9, FIGURE 43) reflecting a loss of 5.5 cm in root production or compaction (TABLE 10).

Sedimentation is directly influenced by the number of tides that flood each station (inundation frequency) and how long sediment laden tidal waters are on site (inundation time). Based on the 2021 record, HWR SET-03 is flooded on all tides with a mean inundation time of 283 min and 1.41 m of water at max tide compared to HWR SET-02 which is flooded by 86.7% of the tides for 151 min by a maximum of 0.25 m of water (TABLE 6). This likely explains the higher sedimentation at HWR SET-03. All sites exhibited visible growth of halophytic vegetation (FIGURE 44).

The annual change in surface elevation recorded by the RSETs at HWR is more than double than values previously recorded at the Cogmagun reference site (TABLE 10, FIGURE 43). The reference site also recorded negative decay of below ground material which is typical of formally impounded sites as the site transitions from freshwater to brackish or salt tolerant species.

Table 8: RSET results for 2019-2021.

Halfway River				net change in elevation between sampling periods (cm)								
HWR SET-01		Position	Bearing	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8	Pin 9
2019-20		1	110	5.5	5.3	5.2	5.2	5.2	4.6	4.5	4.6	4.9
mean (cm)	5.22	3	200	5.2	5.2	5.2	5	5	4.2	4.3	4.1	4.2
stdev	0.84	5	290	4.7	6.6	6.5	7.1	5.9	6.8	6.4	6.8	6.5
SE	0.14	7	20	5.7	4.7	4.5	4.6	5.4	4.9	4.9	4.2	4.4
2020-21		1	108	1.2	1.7	1.7	1.8	1.8	2	2.2	2.3	2
mean (cm)	1.86	3	197	2.1	2	2.5	3.1	2.9	2.8	2.9	2.9	3.3
stdev	0.81	5	289	3.5	1.7	2.1	1.6	2	1.2	1.9	0.1	1.2
SE	0.14	7	17	0.2	1.3	1.2	1.2	0.3	1.1	1.3	1.9	1.8
HWR SET-02		Position	Bearing	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8	Pin 9
2019-20		1	110	1.4	1.6	1.2	1.5	1.9	1.7	1.2	0.9	0.7
mean (cm)	0.99	3	200	0.7	0.7	0.7	0.7	1.2	1.4	2	0.9	1.4
stdev	0.50	5	290	0.5	0.8	1.4	0.2	0.4	0.7	1	1	1.3
SE	0.08	7	20	1	0.9	0.9	0.9	1.1	1	1	0.6	-0.7
2020-21		1	210	3.6	3.6	4.4	3.7	2.9	1.7	1.4	0.8	0.5
mean (cm)	2.74	3	298	3.2	2.8	4.1	4.9	4.1	3.7	3.1	2.2	-0.3
stdev	1.33	5	21	2.4	2.2	2.2	2.3	1.5	1.6	0.9	1.2	1
SE	0.22	7	107	2.8	3.1	3.3	4	2.8	3.5	3.5	4.2	5.6
HWR SET-03		Position	Bearing	Pin 1	Pin 2	Pin 3	Pin 4	Pin 5	Pin 6	Pin 7	Pin 8	Pin 9
2019-20		1	110	0.6	1	1.2	1.2	1.2	1.6	1.3	1.3	1.7
mean (cm)	1.30	3	200	0.9	1.1	1.2	1	1.8	1.4	1.1	1.1	1.1
stdev	0.51	5	290	0	0.4	0.4	0.8	0.6	1.2	1.7	1.5	1.2
SE	0.09	7	20	1.9	2	1.8	1.7	2.1	1.9	2.1	1.7	1.9
2020-21		1	95.5	5	4.8	4.9	4.9	5.2	5.2	5.9	5.5	5.4
mean (cm)	6.19	3	182.5	5.2	5.1	5	5	4.9	5	4.6	4.6	4.7
stdev	1.74	5	281.5	6	5.6	5.8	5.7	6.1	5.7	5.5	5.6	5.6
SE	0.29	7	2.5	7.4	7.5	8	8.6	9.3	9.4	9.4	10.2	10.6

Marker Horizon Station	**Easting (m)**	**Northing (m)**	**2019 Elevation (m)**	**2020 Elevation (m)**	**2021 elevtion (m)**	**2019-20 accretion (cm)**	**Core Quality**	**2019-21 accretion (cm)**	**2020-21 net accretion (cm)**	**Core Quality**
HWR SET-01 MHA	407508.045	4990583.601	2.925	3.005	3.004	5.0	excellent	8.2	3.3	Okay
HWR SET-01 MHB	407505.712	4990585.108	2.942	3.007	3.001	5.7	excellent	9.1	3.3	Great
HWR SET-01 MHC	407504.633	4990582.485	3.081	3.138	3.091	3.0	excellent	4.5	1.5	Good
HWR SET-02 MHA	407264.620	4989662.677	3.808	3.827	3.872	1.5	excellent	6.1	4.6	Poor
HWR SET-02 MHB	407262.606	4989662.094	3.757	3.772	3.801	1.7	excellent	5.5	3.8	Okay
HWR SET-02 MHC	407263.186	4989659.852	3.715	3.768	3.757	2.5	excellent	3.5	1.0	Almost gre
HWR SET-03 MHA	407051.498	4989336.557	2.54	--	2.55	10.3	poor	11.7	1.4	Poor
HWR SET-03 MHB	407050.022	4989337.107	2.454	--	2.516	3.5	fair	15.2	11.7	Okay
HWR SET-03 MHC	407049.573	4989334.846	2.531	--	2.556	3.5	fair/poor	11.5	8.0	Poor

* Marker horizons in grey were significantly bioturbated and excluded from calculation of mean

Table 9: Mean change in elevation measured by RSET, accretion measured by MH and integrated to calculate net subsurface processes.

2019-2020	**mean change in surface elevation (cm)**	**mean accretion (cm)**	**net subsurface processes (cm)**
HWR SET-01	5.22 (±0.8)	4.77 (±1.4)	0.66
HWR SET-02	0.99 (±0.5)	1.88 (±0.5)	-0.88
HWR SET-03	1.30 (±0.5)	3.49 (±0.02)	-2.19
2020-21			
HWR SET-01	1.86 (±0.8)	2.69 (±2.4)	-0.83
HWR SET-02	2.74 (±1.3)	2.61 (±1.43)	0.13
HWR SET-03	6.19 (±1.7)	11.7 (±0.00)	-5.52

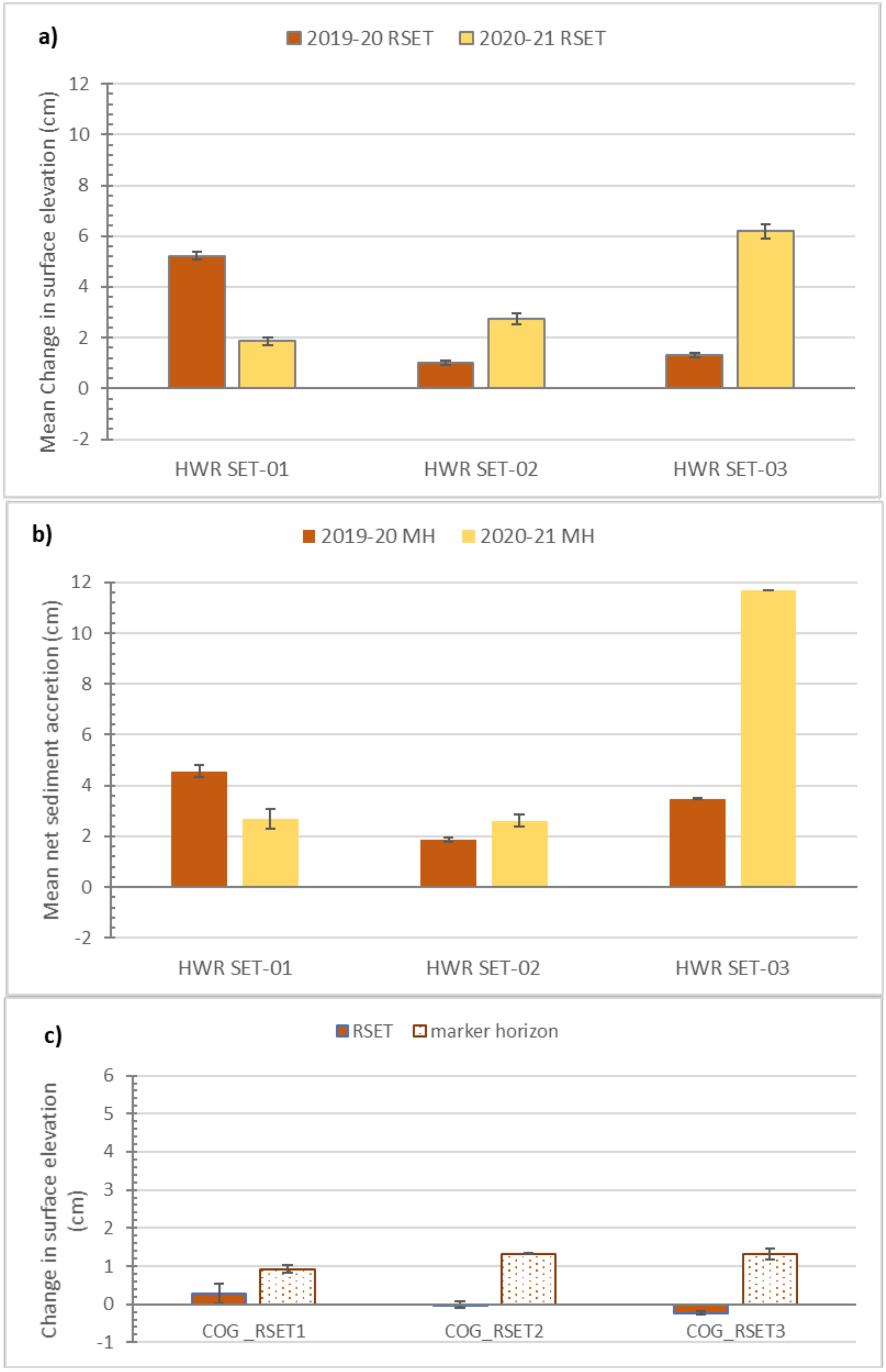


Figure 43: Comparison of RSET and MH measurements at a) HWR and b) reference site COG.

Table 10: Changes in surface elevation measured with the RSET, net accretion from MH and calculated sub-surface processes at the Cogmagun restoration site which was used as a reference site for HWR.

Surface elev change (cm)	2009-10	2010-11	2011-12	2012-13
COG _RSET1	-2.06	1.07	0.83	1.29
COG_RSET2	-0.13	0.09	-0.62	0.63
COG_RSET3	-0.52	-0.08	-0.32	0.00
Net Accretion (cm)	**2009-10**	**2010-11**	**2011-12**	**2012-13**
COG _RSET1	0.00	1.13	1.17	1.38
COG_RSET2	1.43	1.31	1.14	1.43
COG_RSET3	0.79	1.75	0.41	2.28
Sub-surface processes (cm)	**2009-10**	**2010-11**	**2011-12**	**2012-13**
COG _RSET1	-2.06	-0.06	-0.34	-0.09
COG_RSET2	-1.55	-1.22	-1.76	-0.81
COG_RSET3	-1.31	-1.84	-0.73	-2.28

Figure 44: One year and two year post photos at HWR RSET sites.

Figure 45: Example of a MH core (mudscicle) paired with RSET-01.

Soil Characteristics

Methods

Soil characteristics at each sample location are highly influenced by the site's elevation within the tidal frame, distance from the mouth of the estuary and distance from the creek bank. Bulk density, water content and organic matter content are influenced primarily by the sediment characteristics of the underlying substrate, presence or absence of vegetation and agricultural history. Grain size spectra are controlled by the source material and current velocity (Kranck and Milligan, 1985).

Sediment cores were collected from HWR on November 10, 2021. Twelve, 10 cm cores were collected (Figure 44) and processed at the In_CoaST research lab at Saint Mary's University for bulk density, water, and organic matter content using standard procedures. In 2019, the top 2 cm and bottom 2 cm were analyzed separately to potentially isolate the conditions of the agricultural surface. In some cores, a distinct difference between upper and lower portions were visible, while in others it was not. In 2020, only the top 2 cm were analyzed, to represent any new sediment being deposited in the last year. The process was repeated in 2021. Grain size was determined using a Multisizer 3 Coulter Counter in which both 30 µm and 200 µm aperture tubes were used and merged in Matlab. Samples were digested with 30% H_2O_2 prior to processing through the Coulter Counter and therefore results are of disaggregated inorganic sediments. For full details on determining particle size with electroresistance, see Milligan and Kranck (1991). The results of the Coulter Counter and the sieving were normalized, and run through Gradistat for grain size statistics, using the Folk and Ward method (Blott and Pye, 2001). Full Gradistat results are provided in Appendix B.

Results

In the first round of sampling, in 2019, the majority of cores exhibit differences between bottom and top of the core reflecting tidal inundation following the failure of the causeway-culvert. All samples are classified as mud for their textural group and sediment names ranged from fine silt to very coarse silt. Most samples were classified with a sediment name of coarse silt. All grain size distributions were poorly sorted, both in 2019, 2020 and 2021. Skewness varied from fine skewed to symmetrical.

In 2020, several stations had mean grain sizes several micrometers larger than in 2019 (TABLE 11). These include T1S3, T3S2, T4S1, T4S2, and T6S2. These represent a range of conditions including T1S3 which is closest to the culvert, T4S1 and T6S2 which are closer to the road on the East side of the channel, T3S2 which is in a wet secondary drainage channel, and T4S2 which is on the bank of channel. T2S5 had a decrease in mean grain size from 11.2 to 8.4 µm. T2S5 is the station immediately on the upstream side of the Highway 1 bridge. Overall, the mean of all mean grain sizes for all samples on site increased from 10.3 to 12.1 µm between 2019 and 2020 before dropping back to 10.4 µm in 2021.

Highest water contents were found closest to the river where they would be more frequently inundated and have moderate to low organic matter content. In general, coarser material was also found closest to the river itself and finer sediments located at the head of creek systems. The exception was T4S2 which had the highest water content but smaller grain size. Bulk density is a measure of the relative pore space available in a sample. In general soils with coarser material or lots of roots have lower bulk density as bulk density tends to be inversely proportional with organic matter content. Higher bulk densities are also typically associated with agricultural soils. The majority of samples have a bulk density greater than 1.1 $g{\cdot}cm^{-3}$ which is similar to values recorded at the St. Croix restoration site in the first year of post restoration (Bowron et al., 2011). T2S1 and T6S2, however, had lower values of 0.7 and 0.9 $g{\cdot}cm^{-3}$, respectively. T2S1 had a high organic matter content and finer material than T6S2 which contained coarse silt and had the lowest water content.

In 2021, T6S5/T6S4 had the highest water content, increased from 23% in 2020 to 56% in 2021. However, this station also had the lowest recorded dry bulk density, at 0.5 $g{\cdot}cm^{-3}$. Other stations that experienced significant increases in water content include T2S1 (for 13%), and T3S4 (10%), with the latter located closer to the river where they would be more frequently inundated. On the other hand, despite experiencing a slight increase of 3%, T6S2 still had the lowest water content for the third consecutive year at 26%. While the station's organic matter and bulk density did not increase significantly, its mean grain size dropped from 15.6 to 12.9 µm.

Between 2019 and 2020, one sample, T3S2, experienced a much larger change in both water content and organic matter than all other samples. Water content went from 23% on the top in 2019 to 49% in 2020. Organic matter went from 4.3% on the top in 2019 to 20.6% in 2020, which is greater than 12% higher than any other organic matter value at this site (TABLE 11). The reason for this is likely the proximity of T3S2 to a drainage channel (FIGURE 47). In the same time interval, dry bulk density stayed the same at T3S2, with a value of 1.3 $g{\cdot}cm^{-3}$ during both years. T1S3, which is the sediment station closest to the culvert structure, increased in water content, from 24% to

36%, and decreased in organic matter, from 8.4% to 4.2%. The dry bulk density at this station also stayed similar, decreasing only 0.1 g·cm^{-3} from 1.1 g·cm^{-3} to 1.0 g·cm^{-3}.

Between 2020 and 2021, nine out of twelve stations recorded a positive change in organic matter content. While the increases were minimum for some samples (T6S2 and T4S2), significant rises were recorded for T1S3 (for 4.2%), T6S5/T6S4 (3%), and especially T4S1 with a 9.8% rise from 4.2% in 2020 to 13.5% in 2021, making it the station with the highest organic matter content (TABLE 11). T4S1 also had the second highest increase in water content of 21%, while its mean grain size dropped from 17.8 µm (highest in 2020) to 7.5 µm. In dry bulk density, the station recorded a 0.9 g·cm^{-3}, a 0.2 g·cm^{-3} rise from 2020. Lying closer to the road on the East side of the channel, T4S1 is higher in elevation compared to T4S2, which is on the bank of the river (FIGURE 47). With almost no changes in organic matter content, T4S2 increased the most in dry bulk density with 0.5 g·cm^{-3}, along with T1S3, while recorded the lowest in mean grain size among all the stations at 6.6 µm.

There was a range of changes in bulk density values between 2019 and 2020. T6S2 and T7S4, which had the smaller bulk density values in 2019 with 0.7 g·cm^{-3}, both had a marked increase in bulk density values with T6S2 increasing to 1.2 g·cm^{-3} and T7S4 increasing to 1.1 g·cm^{-3} (TABLE 11). On the other hand, T1S2, T2S5, T4S1, and T4S2 all had a marked decrease in bulk density values, going from 1.1-1.2 g·cm^{-3} in 2019 to 0.7-0.8 g·cm^{-3} in 2020. T2S5 and T4S2 are of lower elevation on the bank of the channel, and T4S1 is higher elevation but in an area where the channel development seems to be restricted by the road (FIGURE 47). T1S2 is in a unique situation on the other side of the road from the culvert, surrounded by road on all sides. T3S2, T6S5/T6S4, and T7S7 were the three stations that remained constant with bulk density values generally high compared to other stations on site (TABLE 11).

In 2021, the two stations furthest away from the culvert, T7S4 and T7S7, showed almost identical results for all four indicators. Closer to the culvert, most stations had a dry bulk density higher than 1.1 g·cm^{-3}, except for T1S2 and T2S1 which are located close to the intersection to the north of the study area. While both stations underwent an increase in water content and organic matter content, T2S1's mean grain size dropped from 13.0µm to 7.3µm when sediments at T1S2 became coarser. Among the rest of the stations, T2S5, T3S2, and T3S4 shared similar results for dry bulk density while varied in other categories, a pattern also observed in previous years. Of all the stations, T3S2 also had the highest mean grain size at 18.3µm, 3.6µm higher than the record at T1S3 – the station with the highest bulk density at 1.5 g·cm^{-3}. Despite being closest to the culvert, T1S3 recorded among the lowest in water content at 31%, while upheld a significantly higher organic matter content than most of the northern stations.

A significant advantage of the Coulter Multisizer is the ability to perform disaggregated grain size analysis and plot grain size versus normalized volumetric concentration. The shape of the curve is an indication of both source material and transport mechanism (Kranck and Milligan, 1985), specifically transport as single grains or as flocs. Flocculation is the development of an aggregate of fine particles, which assembles to fabricate a porous bunch of sediment larger than equivalent individual grain sizes. Sedimentation is greatly dependent on the flocculation of particles in both a matter of how much deposits and also where on the marsh it deposits. A floc contains particles of all grain sizes which would have a smaller settling rate if it were in single form. The settling rate of small particles which are included in flocs can be several orders of magnitude greater than it would be individually (Milligan et al., 2007). After flocs deposit, they are an amalgamation of both the flocculated flux and the single grain flux when consolidated on the bed. They cannot be distinguished from the single grains as both forms are now together on the bed.

In 2019, there was no consistent pattern of the grain size curve for all of the samples collected. However, the sample at T3S4 appears to have a distinct coarse peak and T6S5 may exhibit some bimodality. Samples from stations T3S4, T1S2, T6S5 and T7S4 appear to have a different source tail as indicated by the intersection of the curve with the Y-axis in FIGURE 48. Most of these are located closest to the Halfway River. Between 2019 and 2020, some of the grain size curves had marked changes (FIGURE 48). Both stations on Transect 1 have different grain size distributions shapes between 2019 and 2020 (FIGURE 48). T1S2 became finer and changes from a bimodal appearance to a single mode appearance and a rapid drop of the curve. T1S3 became much coarser, and the fine end of the curve changed to be much lower, representing that more grains were deposited in single grain form at T1S3 in 2020 than in 2019. By transects 6 and 7, there is much less change in the shape of the grain size distribution in that same 1-year time span (FIGURE 48). In 2021, some of the grain size curves remained relatively close to the shape of the data from 2020 (FIGURE 48). These include T1S2, T1S3, T7S4, and T7S7. On the other hand, T2S1 and T4S1 got much finer, while T4S2 saw a rapid drop of the curve indicating coarser material.

Table 11: Sediment characteristics of Halfway River cores collected on June 20, 2019 October 8, 2020, and and October 11, 2021. T= Top; B= Bottom

Sample ID	Water Content (%)				Organic Matter (%)				Dry Bulk Density (g·cm3)			Mean Grain Size (um)			
	2019		2020	2021	2019		2020	2021	2019	2020	2021	2019		2020	2021
	T	B	T	T	T	B	T	T				T	B	T	T
T1S2	26	28	29	37	5.6	7.9	5.8	6.5	1.1	0.8	0.9	8.1	12.6	6.8	8.6
T1S3	24	16	36	31	8.4	4.5	4.2	8.4	1.1	1.0	1.5	6.7	10.8	13.2	14.7
T2S1	31	40	32	45	5.8	9.1	5.2	6.6	0.9	0.9	0.6	10.9	9.9	13.0	7.3
T2S5	38	22	47	37	4.3	1.8	6.0	4.3	1.2	0.8	1.1	11.2	8.1	8.4	10.6
T3S2	23	29	49	33	4.3	8.1	20.6	4.8	1.3	1.3	1.1	8.4	10.9	12.0	18.3
T3S4	30	37	24	34	4.1	4.3	3.0	5.8	1.1	1.3	1.1	17.2	15.5	16.3	9.7
T4S1	25	28	27	48	2.2	3.7	4.2	13.5	1.1	0.7	0.9	10.6	10.7	17.8	7.5
T4S2	42	25	42	31	5.5	2.1	4.9	4.9	1.1	0.7	1.2	9.3	10.2	11.3	6.6
T6S2	20	24	23	26	4.3	7.0	4.7	5.0	0.7	1.2	1.3	11.7	10.2	15.6	12.9
T6S5/ T6S4	31	34	24	56	3.0	3.0	3.9	6.9	1.2	1.2	0.5	13.4	8.7	12.5	8.2
T7S4	28	32	24	33	6.7	9.4	5.0	6.2	0.7	1.1	0.8	9.9	9.6	9.2	10.2
T7S7	28	28	28	33	4.3	6.3	5.3	6.1	1.1	1.1	0.9	9.7	9	9.1	10.3

Figure 46: Photos of split cores from Halfway River, collected October 11, 2021.

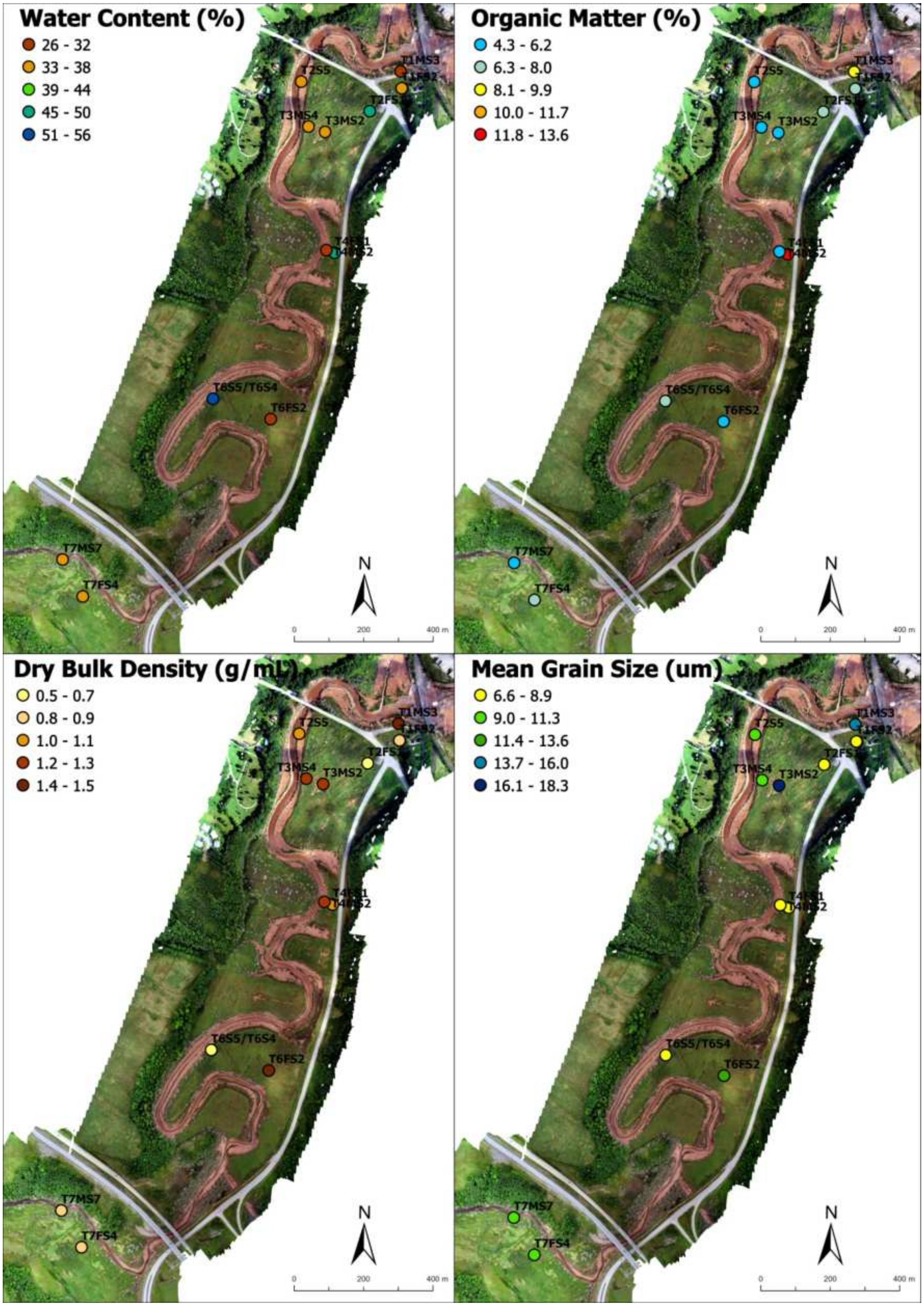


Figure 47: Sediment characteristics for top 2 cm of cores collected in 2021.

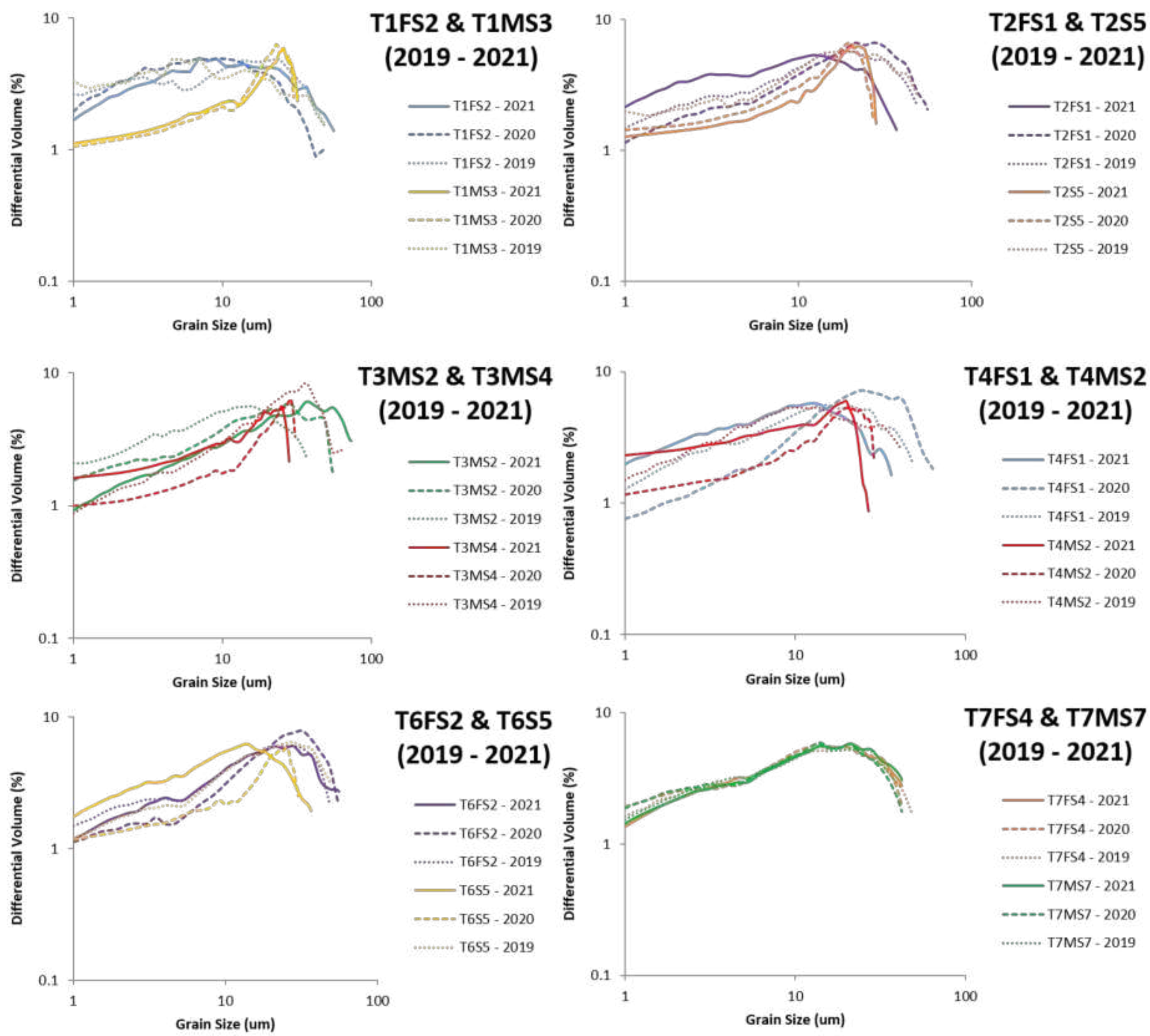


Figure 48: Grain size distributions 2019, 2020 and 2021 sediment core tops, by transect.

Vegetation

In 2018 CBWES documented the establishment of halophytic (salt marsh) vegetation throughout the floodplain of the Halfway River following the restoration of unrestricted tidal flow to the system. A species inventory was developed, and vegetation extent was established qualitatively. In 2019, 2020 and 2021 quantitative statistical analysis of vegetation communities and mapping of habitats were undertaken. The 2021 results are compared to 2019, 2020 and reference condition data to better understand the trajectory of the site under partially restricted conditions.

Methods

Vegetation surveys were undertaken at HWR on August 9, August 11 and August 12, 2021 using a modified point intercept method (Roman et al., 2002). The point intercept method utilizes permanent 1 m^2 plots positioned at intervals along each transect. Landscape photographs were taken along each transect, as well as close-up photographs of each plot.

Plant species richness, halophytic species and abundance, and unvegetated area in 1 m^2 plots were assessed at Halfway River floodplain (formerly high marsh) and Halfway River low marsh sites (20 plots in each zone). Plant species abundances in plots were assessed as the number of pins contacted by leaves/stems/flowers out of a total of 25 pins in a 5 x 5 grid of 20 cm squares; total number of contacts per species was multiplied by four to yield a percent cover estimate (x/25 * 100). Halophytic species abundance was estimated as the total number of contact points by halophytic species per plot to a maximum of 25. The species encountered at these sites that were classified as halophytes are: *Atriplex glabrisculata*, *Atriplex patula*, *Atriplex sp.*, *Carex paleacea, Distichlis spicata*, *Juncus gerardii*, *Limonium carolinianum*, *Plantago maritima*, *Puccinellia maritima*, *Bolboschoenus maritimus* (*Scirpus maritimus*), S*olidago sempervirens,* (*S. alterniflora*), *S. pumilus, S. michauxianus, Spergularia salina, Sueda maritima, Salicornia depressa*, and *Triglochin maritima*. Non-metric multidimensional scaling ordination was used to compare species composition and abundance between plots. Due to the large number of species that only occurred in a single plot each, we removed any such species prior to ordination analysis; full species composition results appear in TABLE 12. For all variables, we compared the Halfway River zones with salt marsh reference sites including Cogmagun restoration site (2011 and 2014 plot data), Cogmagun reference site (2014 data) and Windsor (2017 data). Data on dead plant material and trees as well as bare (unvegetated) areas were also collected in the plots.

Results

Halfway River vegetation plots contain a range of brackish and salt marsh vegetation types, overlapping with reference site species composition and abundance except that there is no representation of high marsh vegetation in the Halfway River plots (FIGURE 49a; upper right section of plot), and the weedy meadow communities common on the HWR floodplain are not represented in the reference plots (FIGURE 49a; lower left section of plot).

HWR floodplain plots have shown a consistent shift in plant community composition and abundance from 2019 to 2021 (FIGURE 49b), from early successional salt marsh communities dominated by native annuals to a weedy "wet meadow" community with a high abundance of non-native species, reflecting the exclusion of tidal waters from the floodplain. Floodplain communities were dominated by salt marsh annual halophytes such as Salicornia maritima and *Suaeda maritim*a in 2019, but by 2021 there was lower cover and frequency of these species (FIGURE 49). In 2021 the floodplain vegetation contains a large area of weedy wet meadow species such as *Epilobium ciliatum, Alopecurus pratensis*, and *Elymus repens*, but native species typical of similar habitats like *Euthamia graminifolia, Poa palustris* and *Galium palustre* are also now common. The abundance of these species indicates that the site is somewhat wet but with less influence of salt compared with 2019. The floodplain also contains areas dominated by brackish marsh species like *Sporobolus michauxiana*, which now occurs in 50% of the floodplain plots, and *Typha latifolia. Rosa multiflora*, an invasive species, showed up in 2021. This species is found throughout the region, outside of the study area, including both floodplain and upland areas farther upstream. Consistent with the shift from early successional salt marsh flora to wet meadow, the average number of plant species in floodplain plots has increased steadily from 2019-2021 (FIGURE 50a). The number and cover of halophytic species both peaked in 2020 but declined in 2021 (FIGURE 50b,c). Unvegetated area was high in 2019 but has declined to almost zero by 2021 in the monitoring plots (FIGURE 50d).

In the low marsh area, most plots have been consistently dominated by *Sporobolus alterniflorus* across all three years (TABLE 12). The low marsh area is also increasingly being colonized by weedy species (e.g. *Elymus repens, Rumex crispus*) and some halophytic annuals considered to be early salt marsh colonizers (e.g. *Suaeda maritima*) (TABLE 12). There are no indications of any consistent shift towards different vegetation types in the low marsh between 2019-2021 (FIGURE 49c) but the relative abundance of ruderal species suggests high levels of disturbance. Total species and halophyte richness, and halophyte abundance have shown modest increases from 2019-2021 (FIGURE 50a,b,c). Unvegetated areas covered approximately 25% of plot areas in 2019, declined substantially in 2020 but returned to 2019 levels in 2021 (FIGURE 50d), reflecting the loss of poor condition vegetation detected in a sudden dieback event which occurred late in 2020.

Table 12: Plot average cover and frequency of vegetation for Halfway River high marsh (HWR-HM) and low marsh (HWR-L) zones in 2019, 2020 and 2021. Cogmagun reference site (COR-14), Cogmagun restoration site (COG-11, COG-14), and Windsor (WIN-17) plot data included as Reference Condition.

		HWR-Floodplain						HWR-Low Marsh						Reference Condition	
		2019		2020		2021		2019		2020		2021			
Species	code	% cover	no. plots	% cover	no. plots	% cover	no. plots	% cover	no. plots	% cover	no. plots	% cover	no. plots	% cover	no. plots
Agrostis sp.	Agr.sp	0	0	0	0	1.25	2	0	0	0	0	0.63	1	0	0
Agrostis stolonifera	Agr.sto	0	0	0	0	0	0	0.4	1	0.8	1	1.26	1	1.37	6
Alopecurus pratensis	Alo.pra	0	0	0	0	5.8	3	0	0	0	0	0	0	0	0
Ambrosia artemisiifolia	Amb.art	0	0	0.21	1	0	0	0	0	0	0	0	0	0	0
Angelica sp.	Ang.sp	0	0	0	0	0.05	1	0	0	0	0	0	0	0	0
Anthoxanthum nitens	Hie.odo	0	0	0	0	0	0	0	0	0	0	0	0	1.08	4
Anthoxanthum odoratum	Ant.odo	0	0	0	0	1.4	1	0	0	0	0	0	0	0	0
Atriplex glabrisculata	Atr.gla	0	0	29.53	9	28.2	10	0	0	5.85	4	4.26	4	2.74	19
Atriplex patula	Atr.pat	0	0	27.37	8	0	0	0	0	2.2	1	0	0	0	0
Atriplex sp.	Atr.sp	1.4	2	5.05	1	1.65	3	0	0	0.05	1	6.74	3	0	0
Bidens cernua	Bid.cern	0	0	0	0	0.2	1	0	0	0	0	0	0	0	0
Bidens frondosa	Bid.fro	0	0	0	0	0.2	1	0	0	0.4	1	2.11	2	0	0
Bulboschoenus maritimus	Sci.mar	0	0	0	0	0	0	0	0	0	0	0	0	0.78	2
Calamagrostis canadensis	Cal.can	0.05	1	0	0	0	0	0	0	0	0	0	0	0.31	2
Calystegia sepia	Cal.sep	0	0	0	0	0	0	1	1	3	1	3.37	1	0	0
Carex lurida	Car.lur	0	0	0	0	1.4	1	0	0	0	0	0.05	1	0	0
Carex paleacea	Car.pal	0	0	0.05	1	0	0	0	0	0.4	1	0	0	5.17	12
Carex sp.	Car.sp	0	0	0	0	3.5	4	0	0	0	0	0	0	0	0
Chenopodium album	Che.alb	0.8	1	0	0	0	0	0	0	0	0	0	0	0	0
Cirsium vulgare	Cir.vul	0	0	0	0	2.6	3	0	0	0	0	0.42	1	0	0
Dactylis glomerata	Dac.glo	0	0	0	0	0	0	0	0	5	1	0	0	0	0
Daucus carota	Dau.car	0	0	0.84	1	4.6	1	0	0	0.05	1	0.47	2	0	0
Distichlis spicata	Dis.spi	0	0	0	0	0	0	0	0	0	0	0	0	8.31	21
Echinochloa crus-galli	Ech.crus	0	0	0	0	0.4	1	0	0	0	0	0	0	0	0
Elymus repens	Ely.rep	0	0	4.53	5	29.2	9	2.2	1	3.6	1	8.21	3	1.08	3
Epilobium ciliatum	Epi.cil	0	0	0.11	2	9.35	10	0	0	0	0	0.47	3	0	0
Epilobium strictum	Epi.str	0	0	0	0	0.2	1	0	0	0	0	0	0	0	0
Equisetum arvense	equi.arv	0	0	0	0	0	0	2.6	1	1.4	1	0	0	0	0
Erechtites hieraciifolius	Ere.hie	0	0	0	0	0.2	1	0	0	0.05	1	0	0	0	0
Euthamia graminifolia	Eut.gra	0	0	0	0	10.85	8	0.2	1	2.4	1	2.32	2	0	0

Fern	Fer.sp	0	0	0	0	0.05	1	0	0	0	0	0	0	0	0
Festuca rubra	Fes.rub	0	0	3.47	3	0	0	0	0	0	0	0	0	0.7	2
Galium palustre	Gal.pal	0	0	0	0	1.6	3	0.4	1	1.05	2	0	0	0	0
Hordeum jubatum	Hor.jub	0	0	0	0	0	0	0	0	0	0	0	0	0.03	1
Iris versicolor	Iri.ver	0	0	0	0	0	0	0	0	0	0	0	0	0.03	1
Juncus brevicaudatus	Jun.bre	0	0	0	0	1	1	0	0	0	0	0	0	0	0
Juncus bufonius	Jun.buf	0	0	0	0	1.2	1	0	0	0	0	0	0	0	0
Juncus effusus	Jun.eff	0	0	0	0	2.2	2	0	0	0	0	1.68	1	0	0
Juncus gerardii	Jun.ger	0	0	0	0	0	0	0	0	0	0	0	0	20.33	32
Juncus sp.	Jun.sp	0	0	0.21	1	0.4	2	0.05	1	1.2	1	0	0	0	0
Juncus tenuis	Jun.ten	0	0	0	0	0	0	0	0	0	0	0.21	1	0	0
Lactuca canadensis	Lac.can	0	0	0	0	3.05	6	0	0	0	0	0.42	1	0	0
Leersia oryzoides	Lee.ory	0	0	0	0	1.4	2	0	0	0	0	0	0	0	0
Limonium carolinianum	Lim.nas	0	0	0	0	0	0	0	0	0	0	0	0	0.15	5
Linaria vulgaris	Lin.vul	0	0	0	0	0.8	1	0	0	0	0	0	0	0	0
Matteuccia struthiopteris	Mat.str	0	0	0	0	0	0	0	0	0	0	0.21	1	0	0
Medicago lupulina	Med.lup	0	0	0	0	0	0	0	0	0.05	1	0	0	0	0
Muhlenbergia glomerata	Muh.glo	0	0	0	0	0	0	0.6	1	0	0	0	0	0	0
Oenothera biennis	Oen.bie	0	0	0	0	0	0	0	0	0.05	1	0	0	0	0
Onoclea sensibilis	Ono.sen	0	0	0	0	0	0	0	0	0	0	1.05	1	0	0
Oxalis sp.	Oxa.sp	0	0	0	0	0	0	0	0	0.6	1	0.05	1	0	0
Oxybasis glauca	Che.gla	0.05	1	0	0	0	0	0	0	0	0	0	0	0	0
Panicum dichotomiflorum	Pan.dic	0	0	0	0	0	0	0.8	2	0	0	0	0	0	0
Parathelypteris noveboracensis	Par.nov	0	0	0	0	0	0	0	0	0.05	1	0	0	0	0
Persicaria hydropiper	Per.hyd	0	0	0	0	0	0	0	0	0.6	1	0	0	0	0
Persicaria lapathifolia	Per.lap	0	0	0	0	0.05	1	0	0	0	0	0	0	0	0
Persicaria pensylvanica	Per.pen	0	0	0	0	0.05	1	0	0	0	0	0	0	0	0
Persicaria sagittata	Per.sag	0	0	0	0	3	3	0	0	0	0	0	0	0	0
Persicaria sp.	Per.sp	0	0	0	0	0.05	1	0	0	0	0	0	0	0	0
Phalaris arundinacea	Pha.aru	0	0	0	0	5	1	0	0	0	0	0	0	0	0
Phleum pratense	Phl.pra	0	0	0	0	0	0	0	0	0.2	1	0	0	0	0
Phragmites australis	Phr.aus	0	0	0	0	0	0	0	0	0	0	0	0	0.42	1
Plantago major	Pla.maj	0	0	0.21	1	0.1	2	0.4	1	0.4	1	0.21	1	0	0
Plantago maritima	Pla.mar	0	0	0	0	0.05	1	0	0	0	0	0.42	1	0	0
Poa palustris	Poa.pal	0	0	0	0	13.4	5	0	0	1.6	1	0.21	1	0.67	2
Poa pratense	Poa.pra	0	0	0	0	0.8	1	0	0	0	0	2.53	1	0	0
Potentilla anserina	Pot.ans	0	0	0	0	0	0	0	0	0	0	0	0	0.03	1

Puccinellia maritima	Puc.mar	0	0	0	0	0	0	0	0	0	0	0	0	0.11	1
Ranunculus repens	Ran.rep	0	0	0	0	0	0	0	0	0.05	1	0.42	2	0	0
Rorippa palustris	Ror.pal	0	0	0.84	1	0	0	0	0	0	0	0	0	0	0
Rosa multiflora	Ros.mul	0	0	0	0	0.2	1	0	0	2.4	1	0	0	0	0
Rosa palustris	Ros.pal	0	0	0	0	0	0	0	0	0	0	0.05	1	0	0
Rumex crispus	Rum.cri	0	0	0	0	0	0	0	0	0	0	0.21	1	0	0
Salix bebbiana	Sal.beb	0	0	0	0	0	0	0	0	0	0	0.21	1	0	0
Salicornia maritima	Sal.dep	5.2	10	27.42	12	7.4	5	0.65	2	5	4	13.68	6	3.72	20
Scorzoneroides autumnalis	Leo.aut	0	0	0.21	1	0	0	0	0	0	0	0	0	0	0
Solidago canadensis	Sol.can	0	0	0	0	1.25	3	0	0	0	0	0	0	0	0
Solidago rugosa	Sol.rug	0	0	0	0	0.35	4	0	0	0.05	1	0	0	0	0
Solidago sempervirens	Sol.sem	0	0	0	0	0	0	0	0	0	0	0	0	1.12	7
Solidago sp.	Sol.sp	0	0	0	0	0	0	0	0	0	0	0.68	2	0	0
Sonchus arvensis	Son.arv	0	0	0.21	1	3.65	2	0	0	6.4	2	3	2	0	0
Sonchus asper	Son.asp	0	0	0	0	0.05	1	0	0	0	0	0	0	0	0
Sonchus sp.	Son.sp	0	0	0	0	0.05	1	0	0	0	0	0	0	0	0
Sporobolus alterniflorus	Spa.alt	4.8	2	6.74	2	0.05	1	51.6	12	44.25	13	33.32	12	61.35	106
Sporobolus pumilus	Spa.pat	0	0	0	0	0	0	0	0	0	0	0	0	11.29	28
Sporobolus michauxianus	Spa.pec	3.8	2	17.95	8	34.45	10	5	1	5	1	6.53	2	5.92	13
Spergularia salina	Spe.sal	0	0	3.26	3	6.2	3	0	0	0	0	2.11	1	0	0
Suaeda maritima	Sua.mar	24.65	13	42.84	16	4.7	7	5.05	3	15.8	4	17.47	7	2.89	23
Symphyotrichum cordifolium	Sym.cor	0	0	0	0	1.4	2	0	0	0	0	0	0	0	0
Symphyotrichum lanceolatus	Sym.lan	0	0	0	0	0	0	0	0	0	0	0	0	0.06	1
Symphyotrichum lateriflorum	Sym.lat	0	0	0	0	4.4	5	0	0	0.2	1	1.89	2	0	0
Symphyotrichum novi-belgii	Sym.nov	0	0	0.11	2	5.7	6	0	0	0	0	0.21	1	0.44	2
Symphyotrichum sp.	Ast.sp	0	0	0	0	0	0	0	0	0	0	0.26	2	0	0
Taraxacum officinalis	Tar.off	0.05	1	0	0	4.25	6	0	0	0.2	1	1.89	2	0.19	1
Tragopogan pratensis	Tra.pra	0	0	0	0	0.2	1	0	0	0	0	0	0	0	0
Triglochin maritima	Tri.mar	0	0	0	0	0	0	0	0	0	0	0	0	0.08	3
Tussilago farfara	Tus.far	0	0	0	0	0	0	0.4	1	0	0	0	0	0	0
Typha angustifolia	Typ.Ang	0	0	0	0	0	0	0	0	0	0	0	0	1.78	3
Typha latifolia	Typ.lat	0	0	0.42	1	9	2	0	0	0	0	0	0	1	2
Typha sp.	Typ.sp	0	0	0	0	0.05	1	0	0	0	0	0	0	0.87	3
Vicia sp.	Vic.sp	0	0	0.32	3	12.7	8	0	0	0	0	0.42	1	0	0
Wrack		0	0	0	0	0	0	0	0	0	0	2.95	1	0	0
Bare Ground		52.2	16	7.16	5	3.4	3	23.05	10	2.2	3	41.26	13	3.95	12
Dead Plant Material		18.9	11	18.53	8	11.85	5	17.6	5	13.25	8	9.05	4	1.67	5

Debris		0	0	0	0	0	0	0	0	0	0	0	0	1.45	6
Moss		0	0	0	0	4.45	5	0	0	0	0	1.47	1	0	0
Mud		0	0	0	0	0	0	0	0	11.6	3	0	0	0	0
Unvegetated area		61.6	18	3.79	3	2	2	25.6	10	6.2	4	23.37	10	2.33	11
Unknown grass		0	0	5.32	2	0	0	0	0	0.2	1	0	0	0	0
Unknown seedling		0	0	0	0	0.85	3	0	0	0	0	0.26	2	0	0
Water		0	0	0	0	0	0	0	0	5	1	0	0	0	0
Wood Debris		0	0	0	0	0	0	0	0	0	0	2.32	1	0.03	1
Spartina dieback		0	0	0	0	0	0	0	0	12.6	3	0	0	0	0
Dead Spruce		5	1	0	0	0	0	10	2	0	0	0	0	0.17	1

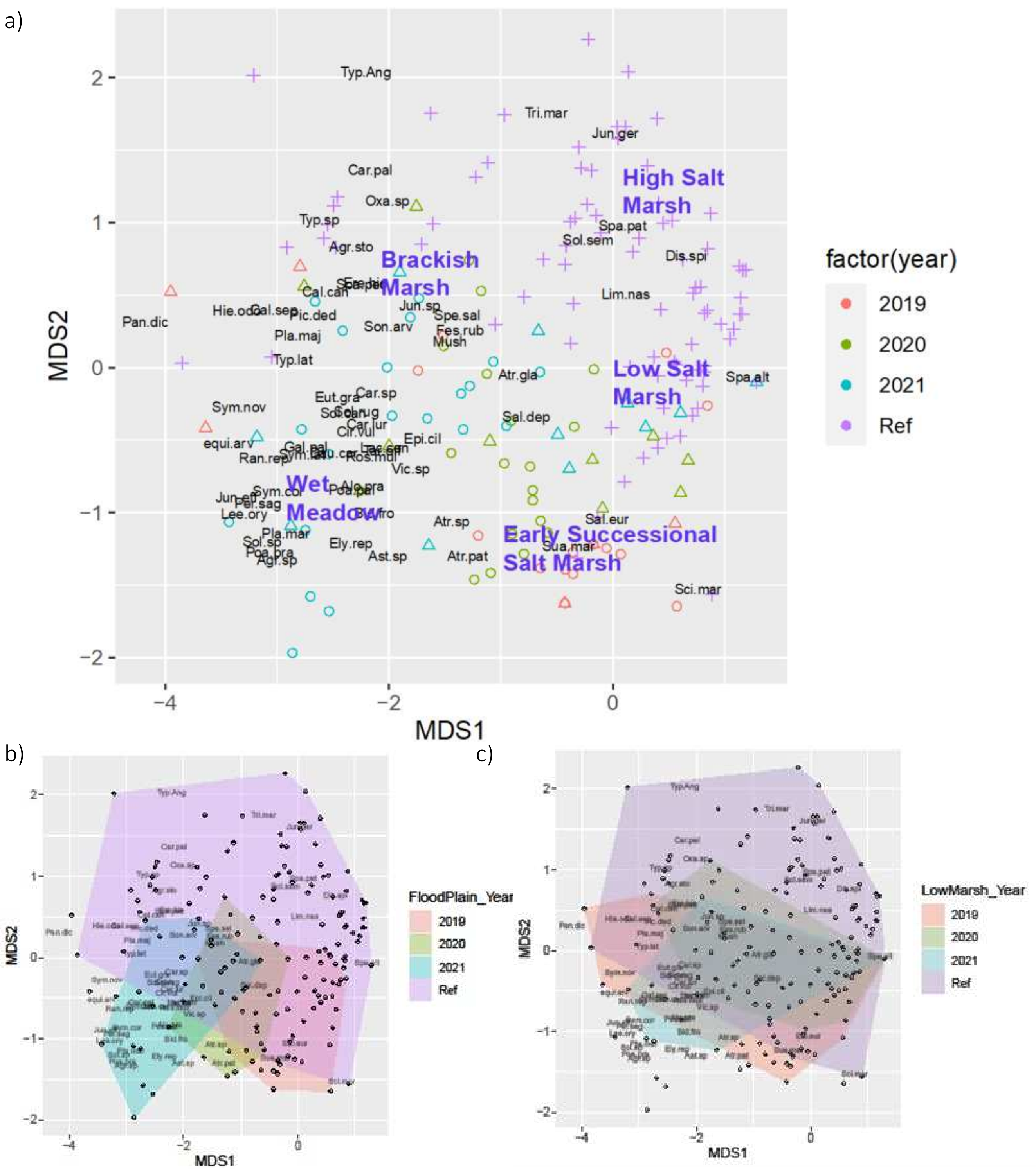
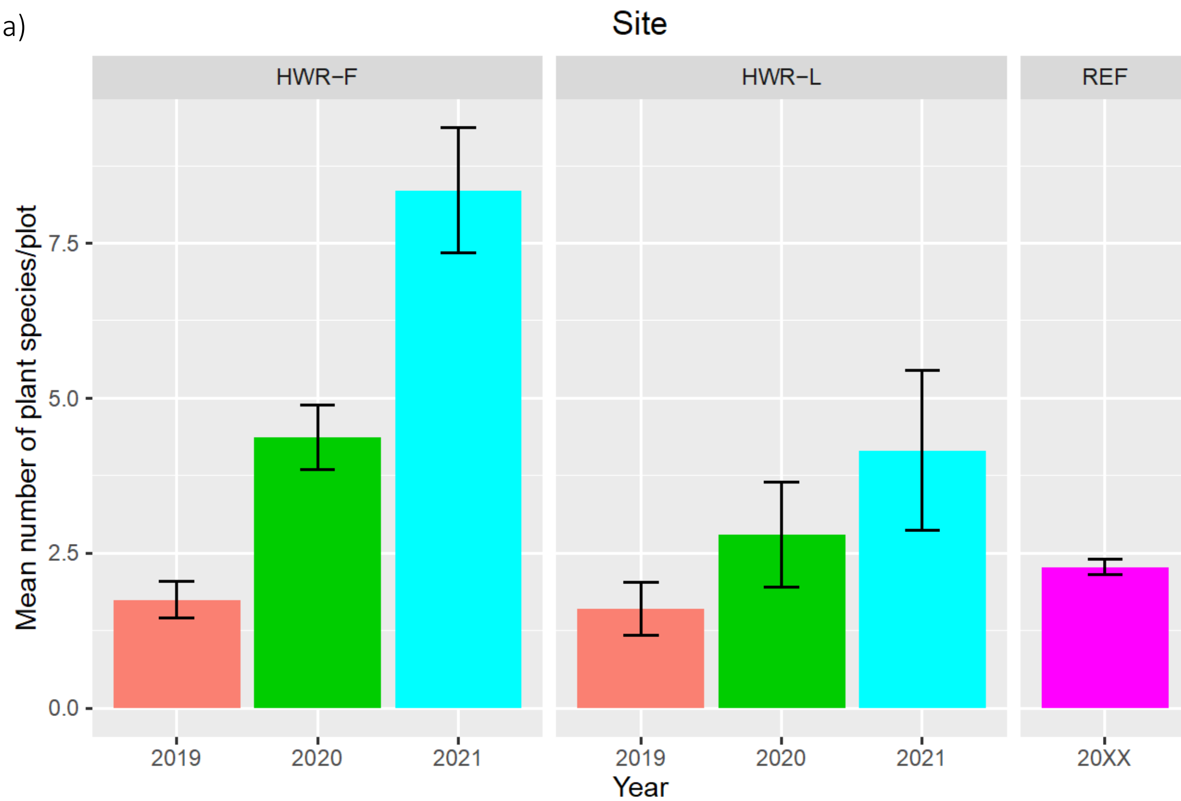
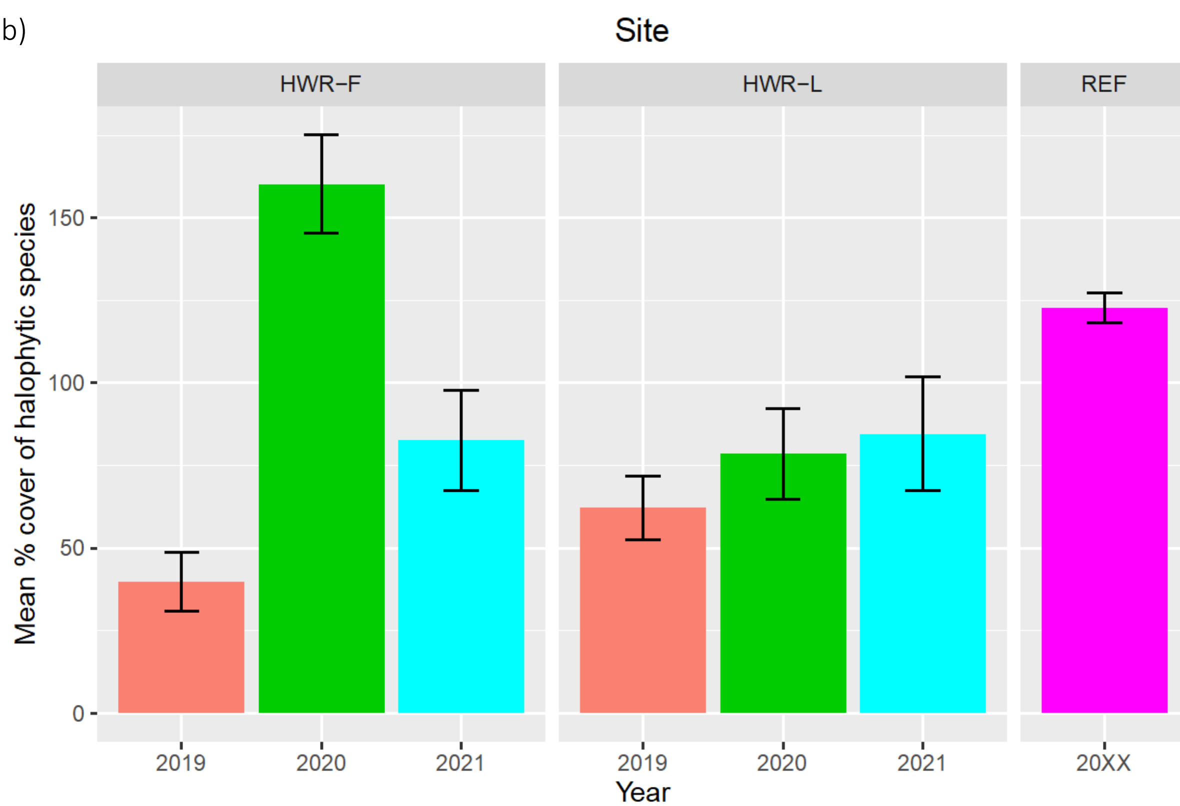


Figure 49: Non-metric multidimensional scaling ordination of plant species composition in vegetation monitoring plots at Halfway River floodplain and low marsh (two dimensions; stress=0.10). Reference site plots are taking from equivalent elevations at three other salt marsh sites in the Minas Basin. a) vegetation types; b) convex hulls outlining floodplain and reference site plots; c) convex hulls outlining low marsh and reference site plots.

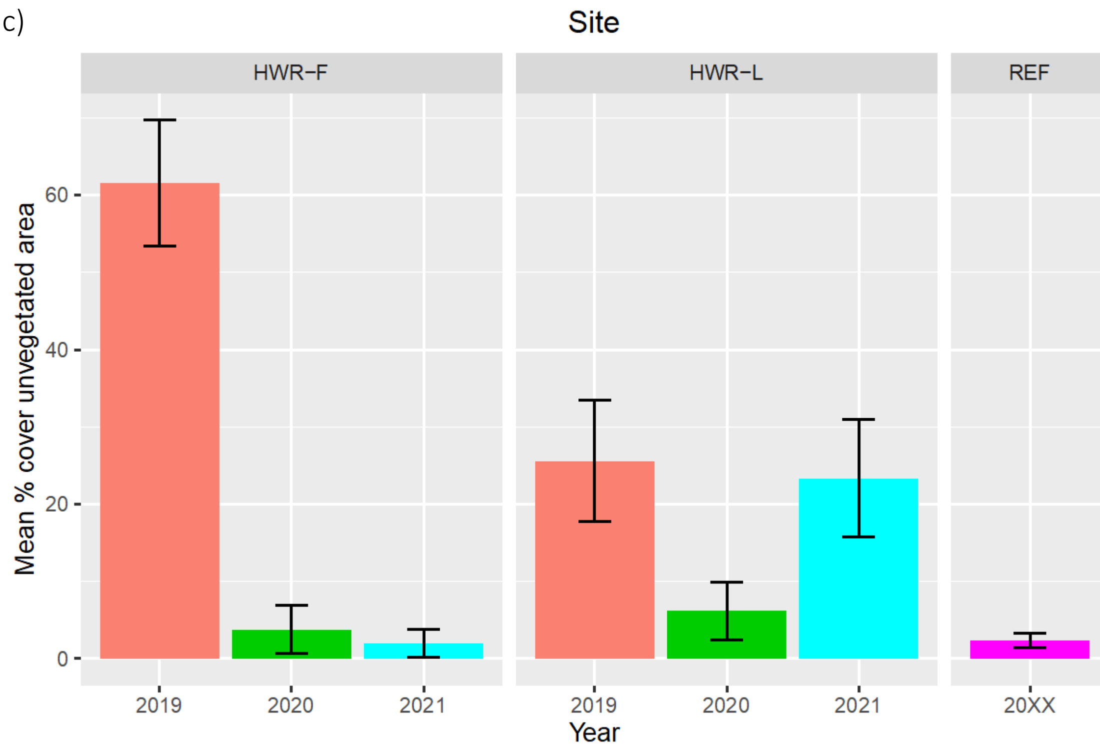
a)


Site
HWR−F
HWR−L
REF
Mean number of plant species/plot
0.0
2.5
5.0
7.5
2019
2020
2021
2019
2020
2021
20XX
Year

b)


Site
HWR−F
HWR−L
REF
Mean % cover of halophytic species
0
50
100
150
2019
2020
2021
2019
2020
2021
20XX
Year

c)



d)

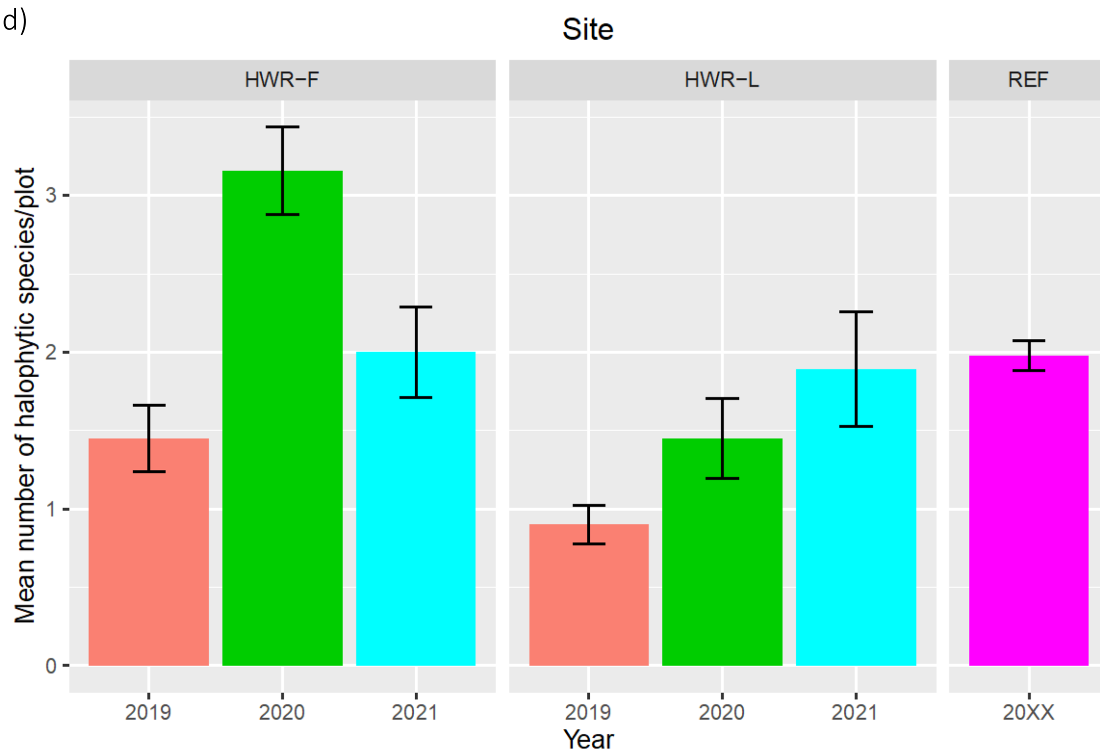


Figure 50: Vegetation plot results for HWR high salt marsh/floodplain (HWR-f), low salt marsh (HWR-lm), and reference plots. a) plant species richness; b) halophytic species richness; c) halophyte cover (note that % cover can exceed 100 due to overlapping plant species); d) unvegetated cover.

Fish

Salt marshes support a wide range and abundance of organisms that swim, collectively referred to as nekton, which include fish and many types of invertebrates. Fish and macrocrustaceans are an important ecological link between the primary producers of the marsh (plants and algae) and near shore fisheries (Neckles and Dionne, 2000). Their position in the upper levels of the coastal food webs and their dependence on a wide range of food and habitat resources serve to integrate ecosystem elements, processes and productivity (Kwak and Zedler, 1997).

Methods

Fyke nets are used to sample a variety of species and size ranges of fish, that use the marsh surface, following a design and methodology adapted from Dionne et al. (1999), and the Global Programme of Action Coalition for the Gulf of Maine (1999). The fyke net requires a spring tide to ensure adequate depth (depth of water on marsh surface > 1 m) and duration (approximately 3 hours) of tidal water on the marsh surface. The fyke net is set at low tide and retrieved following high tide once the water level drops low enough to approach the net while ensuring that the bottom of the funnel throats and cod-end remains submerged. Smaller species accessing the salt pannes and smaller channels were sampled using baited minnow traps. Traps are deployed in advance of high tide and retrieved once the tide level drops (approximately 3.5 hours).

Typically, fish sampling results are compared to the CBWES database of results of previous fish sampling. In 2020, a student research project (which had a duration of one sampling season) allowed for fish surveys and analysis of the unrestricted foreshore marsh directly adjacent to the box culverts at HWR. This single sampling season of data has been included in this section to provide additional comparison and is referred to as HWR-Reference (HWR-R). It should be noted that 2020 was the first year that CBWES conducted fish surveys at HWR.

Fish surveys were carried out on; August 20 & 21, 2020 at HWR-R, September 21 & October 16, 2020 at HWR, and October 5 & November 3, 2021 at HWR. During all sampling events, two fyke nets were set at HWR-R and HWR sites during low tide and retrieved following high tide. One minnow trap was set at HWR-R, and five were set during all sampling days at HWR. All captured individuals were held in buckets, identified to species using identification guides (Audubon Society, 1993; Graff and Middleton, 2002; Scott and Scott, 1988), counted, and measured for length (15 individuals per species). Green crabs were counted because they are an invasive species and hence a species of interest, but not measured. Sand shrimp (crustaceans) were also counted but not measured. Photographs, if necessary, of unknown species were taken for identification purposes, and all individuals were returned (alive) to the site of capture.

Results

Overall, eight different species were observed from the fish surveys in HWR in 2020 and 2021: Atlantic Silverside (*Menidia menidia*), American Eel (*Anguilla rostrata*), Green Crab (*Carcinus maenas*), Mummichog (*Fundulus heteroclitus*), and Tomcod (*Microgadus tomcod)* were caught in all years (FIGURE 51, TABLE 14). In 2020 Four Spine Stickleback (*Apeltes quadracus*) and Sand Shrimp *(Crangon sp*) were also caught, and in 2021 Striped Bass (*Marone saxatilils*) were caught. Fish surveys in 2020 and 2021 were both carried out in the Fall, and the 2020 surveys had higher catches (both in absolute and CPUE measuments).

Mummichogs (F. heteroclitus) comprised the greatest portion of the catch in both years, with absolute numbers higher in 2020 than 2021 but percent catch comparable at 76% and 73% respectivley (FIGURE 51, FIGURE 52). Atlantic Silversides (M. menidia) were the second most frequently observed species representing 13% of the catch in 2020, but were only 3% of the catch in 2021. Mummichogs tend to be a resident species, while Silversides move into and out coastal marshes with the tide. The next most abundant species in 2021 was Tomcod (12%), followed by green crab (8%) which represented less than 1% of the catch in 2020. For 2020 and 2021, the average length of fish measured by species were generally similar, except for Tomcod which appeared to be larger across both min, mean and max measurements in 2021 (TABLE 14). Fish were generally observed to be in good condition, except for mummichogs caught in the a minnow trap deployed on the east side of the Hantsport Connector on October 5th, where a large catch (181) led to a number of stunned and dead fish.

Table 13: Total Catch at Halfway River in 2020 and 2021.

	Species	Catch by Net		Total Catch	Total Catch (%)	Catch Per Unit Effort (CPUE by number of nets)
		Fyke	*Minnow Trap*			
2021	*Anguilla rostrata*	3	1	4	1%	1.3
	Carcinus maenas	23	15	38	8%	7.6
	Fundulus heteroclitus	84	258	342	76%	48.9
	Menidia menidia	10	3	13	3%	6.5
	Microgadus tomcod	10	42	52	12%	13.0
	Morone saxatilis	1	2	3	1%	1.5
	Total Catch			452	100%	64.6
2020	*Anguilla rostrata*	5	11	16	3%	8.0
	Apeltes quadracus		1	1	0.2%	1.0
	Carcinus maenas		2	2	0.3%	2.0
	Crangon sp	1		1	0.2%	58.1
	Fundulus heteroclitus	160	305	465	73%	1.0
	Menidia menidia	29	55	84	13%	12.0
	Microgadus tomcod	63	1	64	10%	21.3
	Total Catch			633	100%	90.4

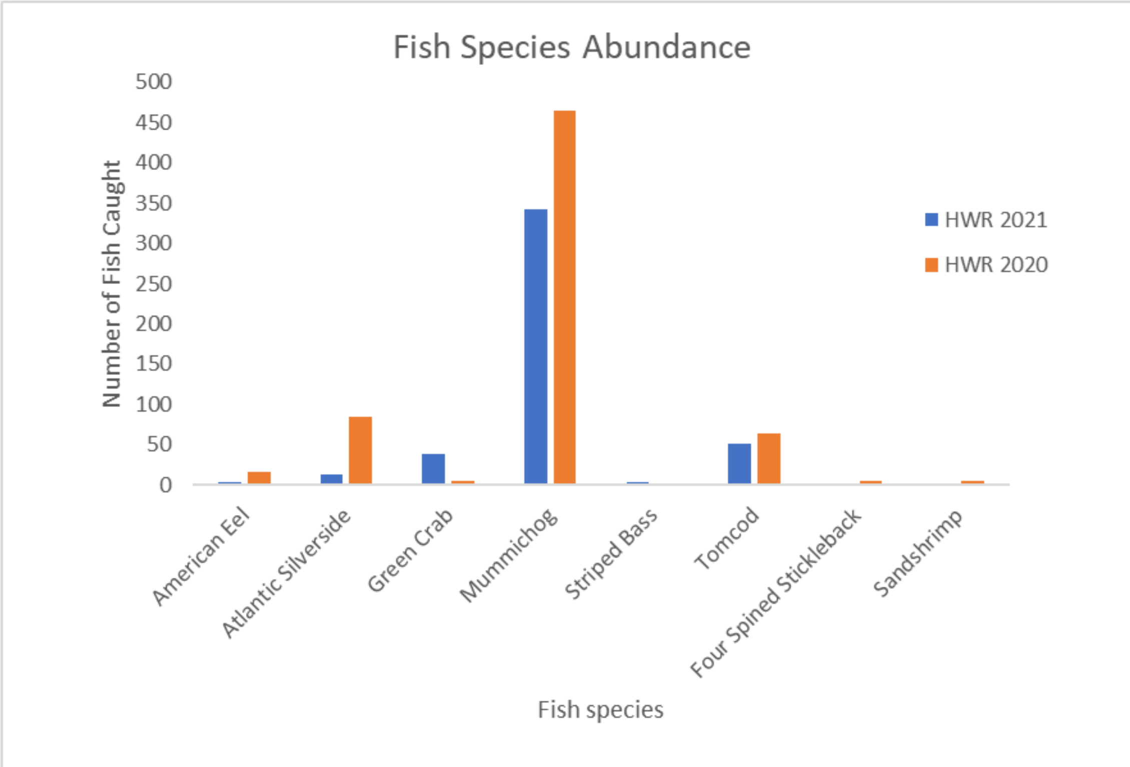


Figure 51: Comparison of fish abundance and species richness between 2020 and 2021 at HWR.

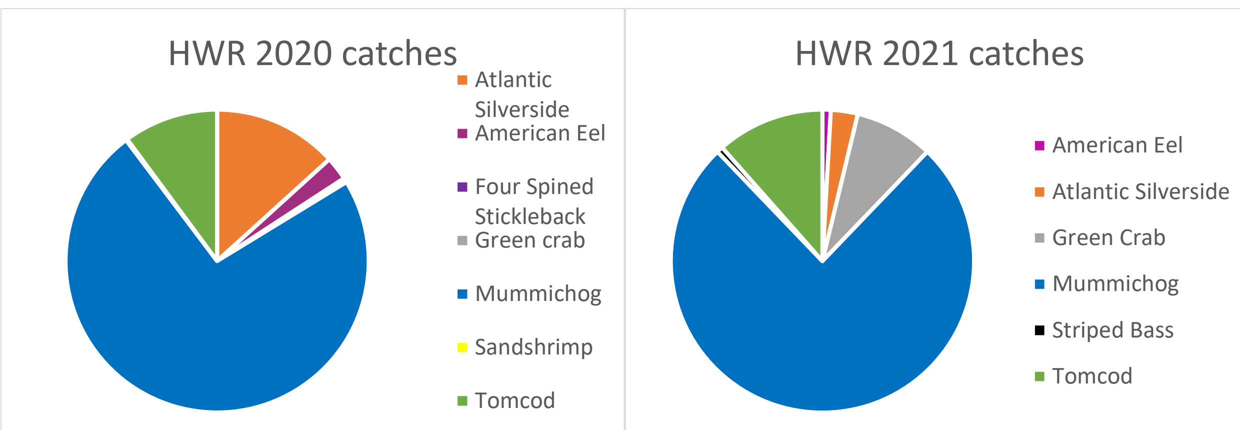


Figure 52: Proportion of each species of the overall catch at HWR in 2020 (n=632) and 2021 (n=452).

Table 14: Comparison of the mean, max, and min length (cm) of fish species surveyed at HWR and HWR-R.

Scientific name	Common name	HWR 2020				HWR 2021			
		MEAN LENGTH	MAX LENGTH	MIN LENGTH	N	MEAN LENGTH	MAX LENGTH	MIN LENGTH	N
Menidia menidia	Atlantic Silverside	7.8	9.5	6.0	84	8.7	10.5	7.0	13
Anguilla rostrata	American Eel	30.3	72.0	19.0	16	29.1	50.8	4.0	4
Carcinus maenas	Green Crab	-	-	-	2	2.8	6.0	1.0	38

Scientific name	Common name	HWR 2020				HWR 2021			
		MEAN LENGTH	MAX LENGTH	MIN LENGTH	N	MEAN LENGTH	MAX LENGTH	MIN LENGTH	N
Fundulus heteroclitus	Mummichog	7.3	10.5	3.4	465	6.9	10.5	4.0	342
Apeltes quadracus	Fourspine Stickleback	4.5	4.5	4.5	1	-	-	-	-
Microgadus tomcod	Tomcod	15.0	19.5	11.5	64	18.1	22.0	14.0	52
Morone saxatilis	Striped Bass	-	-	-	-	13.3	15.0	11.0	3

Structured Winter Walk

The winter of 2021/22 was characterized by variable temperatures and significant snow and rainfall events. As a result of the fluctuating temperatures (stretches above zero, followed by days below zero) the marsh routinely went through periods of freezing and thawing. Approximately 50 cm of snow was present consistently on the entire site surface on the day of the winter walk, February 9, 2022. The main river was mostly filled with ice blocks from the causeway to the Hwy 1 bridge (FIGURE 53a)), while directly upstream of the bridge had areas of ice blocks as well as open water. Further south, the river was generally covered with ice (single ice layer rather than separate blocks), and very little open water was visible (FIGURE 53, FIGURE 52b).

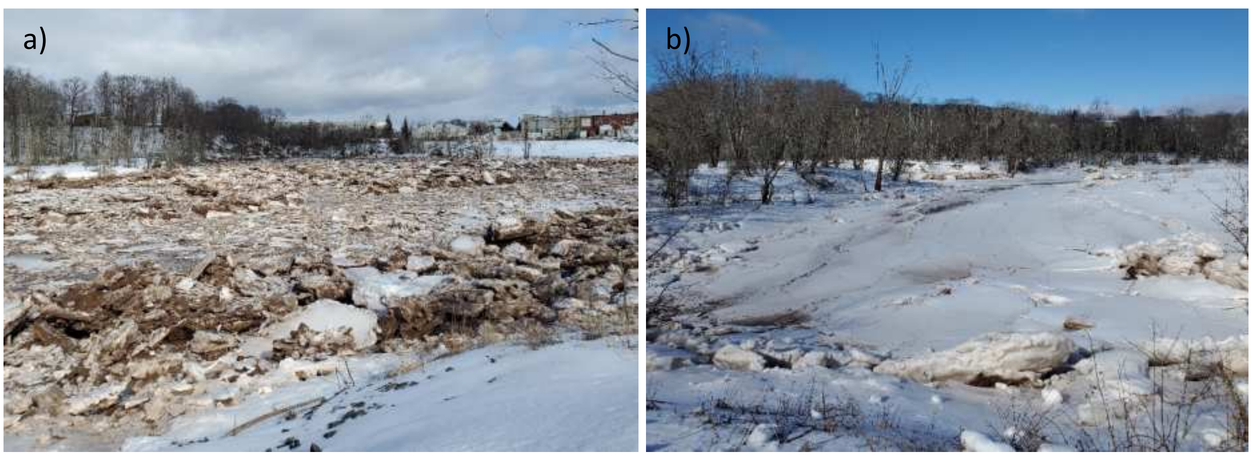


Figure 53: a) Ice blocks located between the causeway and the Hwy 1, and b) ice coverage of the river towards head of tide (just north of the Hwy 101). Photographs were collected on February 9, 2022.

Summary and Recommendations

The Halfway River floodplain continues to change in response to the significant alterations to the hydrology that have occurred over the past 4 years. Examination of geospatial attributes, hydrology, soils and sediments, vegetation, and winter conditions annually from 2019 to 2022, several key patterns were observed.

The failure of the original causeway-aboiteau structure resulted in the re-establishment of unrestricted tidal flow to the river and the initiation of restoration of the 75 ha floodplain to tidal wetland (salt marsh).

The new causeway-culvert structure, constructed in 2019/2020, is a significant tidal restriction and has caused the loss nearly 50 ha of recovering salt marsh habitat. The new structure has caused an increase in hydroperiod at elevations below 3 m (CGVD2013) and a decrease in hydroperiod above that elevation. This limiting, or cutting of the tide, results in both the reduced height and reach of the tide. Tidal flow is now limited to 26.5 ha (7.1 ha main river channel; 19.4 ha low salt marsh terrace). The remaining 48.5 ha of previously re-establishing salt marsh, representing a majority of the high salt marsh platform, is now beyond the reach of the tide. In the absence of regular tidal influence, the halophytic vegetation that had been re-establishing throughout the 48.5 ha are being replaced by terrestrial species and the associated wetland functions are being lost.

Between 2019 and 2021 vegetation cover has increased throughout the high (salt) marsh platform, to 96%. However, the 2021 vegetation survey confirmed the decrease in halophytes and in an increase in weedy terrestrial species. This reflects the loss of tidal influence above ~5.2 m (CGVD2013) and represents the transition back to a freshwater and terrestrial system.

Flooding of the high marsh platform (48.5 ha) is now limited to irregular extreme rainfall events. Events which are expected to increase in frequency and severity in the future due to climate change. While the new structure has reduced the risk of flooding from tidal events, the risk remains, particularly from rainfall and freshet events. Improvement of highway infrastructure above the 2055 High High Water Large Tide (HHWLT) level would provide a more robust solution to both tidal and freshwater events and would eliminate the perceived need for the causeway-culvert at the mouth of the river.

There has been little change in the morphology of the primary channel, except immediately upstream and down of the causeway, where the placement of armour rock and the resulting erosion/scour over the past year has resulted in direct habitat loss and elevation changes. Both velocity and discharge remain similar to the 2019 measurements (made prior to the additional construction activities to re-enforce the structure) with a slight flood dominance.

In 2020, an unexplained and sudden vegetation dieback (SVD) of at least 3.7 ha of *S. alterniflora* was observed, representing 50% of the existing 7.5 ha of low marsh habitat. Based on the available data (hydroperiod, DEM, sediment) and our understanding of the site, the altered hydrology and sediment supply were assessed to be contributing factors to the poor condition of the vegetation. However, there was limited evidence that they alone were the causal agents for the spatial pattern of the dieback – with only slope and standard deviation of elevation showing a statistically significant correlation, as dieback was primarily located in flat areas of low slope where water might be expected to pool. In 2021, *S. alterniflora* coverage totaled 4.7 ha, with 3.8 ha in good condition and 0.9 ha growing sparsely (but not in poor condition). Areas that experienced dieback near the mouth of the system (Transects 1-5) have generally not recovered and remain bare ground. However, areas of low marsh farther from tidal flow (T6 and back) have retained sparse vegetation in the location of the dieback and have in fact experienced an increase in *S. alterniflora* coverage compared to 2018 conditions. While in 2020 sedimentation was highest at RSET-1 (located on T1), in 2021 it was highest at RSET-3 (located at T6). This further reduces the likelihood that sedimentation is the primary driver of plant loss, as heavy sedimentation in 2021 should have reduced the capacity of stands at T6 to recover.

Dieback persistent closer to the river mouth may point to point source pollution, with impacts dissipating with distance from the pollutant source. Numerous reports of oil were made to the coast guard reporting line by CMM researchers working on the fish study at the site in 2020. It is our understanding that officers did respond and that an investigation was initiated. The presence of hydrocarbons, or oil spills, are known to have both acute and long-term impacts on salt marshes – affecting leaves, soils, and root systems (Culbertson et al., 2008; Anderson et al, 2010). The intensity, duration, and extent of impacts will depend on the type of oil (5 categories are recognized), type and density of fouling (leaves versus soil), the season when impacts take place (more severe in growing season), and the type of marsh impacted (Pezeshki et al., 2000). Several authors have also identified thresholds of fouling above which plants face mortality, while lower levels may have only short term or negligible impacts from which plants can recover (Silliman et al., 2012; Silliman et al., 2016). Li et al. (1990) also found that vegetation biomass had a non-linear response to a 2-year hydrocarbon treatment – with low doses stimulating plant processes (biomass, microbial activity, respiration) and high doses inhibiting it.

In the South and North-Eastern United States cases of SVD, also called “brown marsh”, have been observed since the 1990’s. These diebacks were characterized by their rapid progression (on the scale of months) and the death of rhizomes resulting in no new growth. In most cases SVD could not be traced to a single cause but was postulated to be a result of multiple stresses. These could include drought, changes in soil chemistry, fungal pathogens, herbivory/grazing and nematodes among other things (Alber et al., 2008; Elmer and Marra, 2011; Elmer et al., 2013; Marsh et al, 2016). Other causes of stress to *S. alterniflora* include prolonged inundation time combined with heavy metal toxicity. A recent study by Sun et al. (2018) showed that that long period of high inundation (60 days, 12 hours per day) together with heavy metal treatments had a deleterious effect on *S. alterniflora*, reducing photosynthetic rate and antioxidative enzymes. However, the same study showed no or very limited effects of low to medium inundation/heavy metal treatments.

In any case, it is likely not a single variable that has resulted in the changes to the low marsh observed – but rather the cumulative effects of several stressors. The pattern of dieback, as well as the pattern of recovery, does support contaminants as a primary driver. However, sedimentation and hydroperiod are also considered contributing factors as the change in the environment could also be expected to impact the health of established vegetation, reducing their resilience to other stressors.

Considering the results of the three years of study, the following conclusions and recommendations are made:

1) Changes in hydrology (reduction of tide height and increased hydroperiod) from the new causeway-culvert, have resulted in the conversion of the re-establishing high salt marsh habitat to a predominantly weedy wet meadow/terrestrial condition, and a degradation of form and function of the remaining 26.5 ha. Tidal wetlands (salt marshes) are designated as Wetlands of Special Significance (WSS) in Nova Scotia (NS Wetland Policy[10]) and are

[10] https://novascotia.ca/nse/wetland/conservation.policy.asp

protected federally as important fish habitat (*Fisheries Act*[11]). The new causeway-culvert is a significant hydrological barrier and removal of the structure would result in the re-establishment of the natural tidal regime to the system, restoring 48.5 ha of salt marsh and improving the function of the remaining 26.5 ha of tidal river and low marsh habitat.

2) The nature and source of pollutants entering the system should be identified and eliminated in order to prevent further degradation and loss of habitat and to allow for the recovery of what has already been impacted.
3) The Halfway River system has experienced significant changes to the physical (i.e., hydrology, sediment) and biological (i.e., vegetation) since 2017, and has yet to reach any sort of dynamic equilibrium. Given this, and the SVD-contaminants issue, it is recommended that the monitoring of habitat conditions be continued for at least another two years in order to determine longer-term trends and the ecological/habitat condition of the site.
4) Improvement of highway infrastructure above the 2055 HHWLT level would be a more effective flood risk management approach than continuing to rely on the downstream causeway-culvert to provide flood protection.

[11] https://laws-lois.justice.gc.ca/eng/AnnualStatutes/2019_14/

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Appendix A – Structured Winter Walk

STRUCTURED WALK PHOTOGRAPHS (February 17, 2022) select images:

Figure 1: Transect 1.

Figure 2: Transect 2.

Figure 3: Transect 3.

Figure 4: Transect 4.

Figure 5: Transect 5.

Figure 6: Transect 6.

Figure 7: Transect 7.

Appendix B – Gradistat results for 2021 sediment cores, using Folk and Ward methodology

SAMPLE STATISTICS

SAMPLE IDENTITY: **T1FS2**

ANALYST & DATE: JB/AN, February 9, 2022

SAMPLE TYPE: Polymodal, Poorly Sorted

TEXTURAL GROUP: Mud

SEDIMENT NAME: Medium Silt

	μm	ϕ
MODE 1:	7.482	7.066
MODE 2:	9.875	6.665
MODE 3:	14.97	6.066
D_{10}:	1.962	4.878
MEDIAN or D_{50}:	9.048	6.788
D_{90}:	34.00	8.993
(D_{90} / D_{10}):	17.33	1.843
(D_{90} - D_{10}):	32.03	4.115
(D_{75} / D_{25}):	5.027	1.412
(D_{75} - D_{25}):	15.88	2.330

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	0.2%	MEDIUM SAND:	0.0%
MUD:	99.8%	FINE SAND:	0.0%
		V FINE SAND:	0.2%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	11.6%
COARSE GRAVEL:	0.0%	COARSE SILT:	20.4%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	22.7%
FINE GRAVEL:	0.0%	FINE SILT:	20.2%
V FINE GRAVEL:	0.0%	V FINE SILT:	14.9%
V COARSE SAND:	0.0%	CLAY:	9.9%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	13.98	8.647	6.854	8.638	6.855	Medium Silt
SORTING (σ):	13.40	2.816	1.493	2.975	1.573	Poorly Sorted
SKEWNESS (Sk):	1.454	-0.143	0.143	-0.069	0.069	Symmetrical
KURTOSIS (K):	4.618	2.108	2.108	0.860	0.860	Platykurtic

SAMPLE STATISTICS

SAMPLE IDENTITY: **T1MS3**

ANALYST & DATE: JB/AN, February 9, 2022

SAMPLE TYPE: Trimodal, Poorly Sorted

TEXTURAL GROUP: Mud

SEDIMENT NAME: Coarse Silt

	μm	φ
MODE 1:	34.38	4.866
MODE 2:	52.11	4.266
MODE 3:	4.937	7.666
D_{10}:	2.510	4.176
MEDIAN or D_{50}:	18.34	5.769
D_{90}:	55.32	8.638
(D_{90} / D_{10}):	22.04	2.068
$(D_{90} - D_{10})$:	52.81	4.462
(D_{75} / D_{25}):	5.553	1.515
$(D_{75} - D_{25})$:	29.30	2.473

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	6.6%	MEDIUM SAND:	0.0%
MUD:	93.4%	FINE SAND:	0.0%
		V FINE SAND:	6.6%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	24.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	24.2%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	16.8%
FINE GRAVEL:	0.0%	FINE SILT:	11.7%
V FINE GRAVEL:	0.0%	V FINE SILT:	10.1%
V COARSE SAND:	0.0%	CLAY:	6.6%

	METHOD OF MOMENTS Arithmetic μm	Geometric μm	Logarithmic φ	FOLK & WARD METHOD Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	23.89	14.52	6.106	14.66	6.092	Medium Silt
SORTING (σ):	20.42	3.104	1.634	3.266	1.708	Poorly Sorted
SKEWNESS (Sk):	0.927	-0.546	0.546	-0.283	0.283	Fine Skewed
KURTOSIS (K):	2.997	2.292	2.292	0.876	0.876	Platykurtic

SAMPLE STATISTICS

SAMPLE IDENTITY: **T2F S1**

ANALYST & DATE: JB/AN, February 9, 2022

SAMPLE TYPE: Trimodal, Poorly Sorted

TEXTURAL GROUP: Mud

SEDIMENT NAME: Medium Silt

	μm	ϕ
MODE 1:	13.03	6.265
MODE 2:	3.257	8.266
MODE 3:	4.298	7.866
D_{10}:	1.754	5.295
MEDIAN or D_{50}:	8.021	6.962
D_{90}:	25.48	9.156
(D_{90} / D_{10}):	14.53	1.729
(D_{90} - D_{10}):	23.72	3.861
(D_{75} / D_{25}):	4.918	1.385
(D_{75} - D_{25}):	12.78	2.298

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	0.0%	MEDIUM SAND:	0.0%
MUD:	100.0%	FINE SAND:	0.0%
		V FINE SAND:	0.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	4.9%
COARSE GRAVEL:	0.0%	COARSE SILT:	21.1%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	24.8%
FINE GRAVEL:	0.0%	FINE SILT:	19.3%
V FINE GRAVEL:	0.0%	V FINE SILT:	17.6%
V COARSE SAND:	0.0%	CLAY:	12.3%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	11.08	7.236	7.111	7.255	7.107	Fine Silt
SORTING (σ):	9.721	2.665	1.414	2.793	1.482	Poorly Sorted
SKEWNESS (Sk):	1.255	-0.190	0.190	-0.135	0.135	Fine Skewed
KURTOSIS (K):	4.121	1.998	1.998	0.806	0.806	Platykurtic

SAMPLE STATISTICS

SAMPLE IDENTITY: **T2S5** ANALYST & DATE: JB/AN, February 9, 2022

SAMPLE TYPE: Trimodal, Poorly Sorted

TEXTURAL GROUP: Mud

SEDIMENT NAME: Coarse Silt

	μm	ϕ
MODE 1:	19.75	5.666
MODE 2:	14.97	6.066
MODE 3:	3.257	8.266
D_{10}:	2.396	4.966
MEDIAN or D_{50}:	12.43	6.330
D_{90}:	32.00	8.705
(D_{90} / D_{10}):	13.36	1.753
(D_{90} - D_{10}):	29.61	3.740
(D_{75} / D_{25}):	3.983	1.362
(D_{75} - D_{25}):	16.51	1.994

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	0.0%	MEDIUM SAND:	0.0%
MUD:	100.0%	FINE SAND:	0.0%
		V FINE SAND:	0.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	10.8%
COARSE GRAVEL:	0.0%	COARSE SILT:	29.3%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	26.0%
FINE GRAVEL:	0.0%	FINE SILT:	16.0%
V FINE GRAVEL:	0.0%	V FINE SILT:	10.7%
V COARSE SAND:	0.0%	CLAY:	7.2%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN (x):	15.19	10.44	6.581	10.56	6.565	Medium Silt
SORTING (σ):	11.77	2.605	1.381	2.701	1.433	Poorly Sorted
SKEWNESS (Sk):	0.989	-0.554	0.554	-0.261	0.261	Fine Skewed
KURTOSIS (K):	3.479	2.471	2.471	0.940	0.940	Mesokurtic

SAMPLE STATISTICS

SAMPLE IDENTITY: **T3MS2**

ANALYST & DATE: JB/AN, February 9, 2022

SAMPLE TYPE: Polymodal, Poorly Sorted

TEXTURAL GROUP: Sandy Mud

SEDIMENT NAME: Very Fine Sandy Very Coarse Silt

	µm	ϕ
MODE 1:	39.49	4.666
MODE 2:	59.86	4.066
MODE 3:	26.06	5.266
D_{10}:	3.008	3.917
MEDIAN or D_{50}:	22.72	5.460
D_{90}:	66.21	8.377
(D_{90} / D_{10}):	22.02	2.139
$(D_{90} - D_{10})$:	63.21	4.460
(D_{75} / D_{25}):	5.418	1.543
$(D_{75} - D_{25})$:	36.40	2.438

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	12.0%	MEDIUM SAND:	0.0%
MUD:	88.0%	FINE SAND:	0.0%
		V FINE SAND:	12.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	27.1%
COARSE GRAVEL:	0.0%	COARSE SILT:	21.7%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	15.2%
FINE GRAVEL:	0.0%	FINE SILT:	10.8%
V FINE GRAVEL:	0.0%	V FINE SILT:	7.9%
V COARSE SAND:	0.0%	CLAY:	5.3%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic µm	Geometric µm	Logarithmic ϕ	Geometric µm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	29.23	17.81	5.811	18.31	5.771	Coarse Silt
SORTING (σ):	24.46	3.141	1.651	3.265	1.707	Poorly Sorted
SKEWNESS (Sk):	0.848	-0.640	0.640	-0.297	0.297	Fine Skewed
KURTOSIS (K):	2.798	2.479	2.479	0.907	0.907	Mesokurtic

SAMPLE STATISTICS

SAMPLE IDENTITY: T3MS4 ANALYST & DATE: JB/AN, February 9, 2022

SAMPLE TYPE: Trimodal, Poorly Sorted

TEXTURAL GROUP: Mud

SEDIMENT NAME: Coarse Silt

	μm	φ
MODE 1:	29.93	5.066
MODE 2:	14.97	6.066
MODE 3:	4.298	7.866
D_{10}:	2.050	4.898
MEDIAN or D_{50}:	11.33	6.463
D_{90}:	33.54	8.930
(D_{90} / D_{10}):	16.36	1.823
(D_{90} - D_{10}):	31.49	4.032
(D_{75} / D_{25}):	5.232	1.437
(D_{75} - D_{25}):	18.34	2.387

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	0.0%	MEDIUM SAND:	0.0%
MUD:	100.0%	FINE SAND:	0.0%
		V FINE SAND:	0.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	12.6%
COARSE GRAVEL:	0.0%	COARSE SILT:	26.1%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	22.6%
FINE GRAVEL:	0.0%	FINE SILT:	16.2%
V FINE GRAVEL:	0.0%	V FINE SILT:	13.5%
V COARSE SAND:	0.0%	CLAY:	9.2%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	14.88	9.616	6.700	9.735	6.683	Medium Silt
SORTING (σ):	12.37	2.792	1.482	2.932	1.552	Poorly Sorted
SKEWNESS (Sk):	0.938	-0.398	0.398	-0.218	0.218	Fine Skewed
KURTOSIS (K):	3.066	2.110	2.110	0.812	0.812	Platykurtic

SAMPLE STATISTICS

SAMPLE IDENTITY: **T4FS1**

ANALYST & DATE: JB/AN, February 9, 2022

SAMPLE TYPE: Trimodal, Poorly Sorted

TEXTURAL GROUP: Mud

SEDIMENT NAME: Medium Silt

	μm	φ
MODE 1:	13.03	6.265
MODE 2:	4.937	7.666
MODE 3:	34.38	4.866
D_{10}:	1.847	5.335
MEDIAN or D_{50}:	8.363	6.902
D_{90}:	24.78	9.080
(D_{90} / D_{10}):	13.41	1.702
(D_{90} - D_{10}):	22.93	3.746
(D_{75} / D_{25}):	4.373	1.355
(D_{75} - D_{25}):	12.14	2.129

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	0.0%	MEDIUM SAND:	0.0%
MUD:	100.0%	FINE SAND:	0.0%
		V FINE SAND:	0.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	5.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	20.2%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	27.1%
FINE GRAVEL:	0.0%	FINE SILT:	20.4%
V FINE GRAVEL:	0.0%	V FINE SILT:	16.1%
V COARSE SAND:	0.0%	CLAY:	11.1%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric Logarithmic μm	φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	11.11	7.471	7.064	7.486	7.062	Fine Silt
SORTING (σ):	9.408	2.583	1.369	2.714	1.440	Poorly Sorted
SKEWNESS (Sk):	1.245	-0.257	0.257	-0.155	0.155	Fine Skewed
KURTOSIS (K):	4.108	2.122	2.122	0.865	0.865	Platykurtic

SAMPLE STATISTICS

SAMPLE IDENTITY: **T4MS2** ANALYST & DATE: JB/AN, February 9, 2022

SAMPLE TYPE: Bimodal, Poorly Sorted

TEXTURAL GROUP: Mud

SEDIMENT NAME: Medium Silt

	μm	φ
MODE 1:	14.97	6.066
MODE 2:	4.298	7.866
MODE 3:		
D_{10}:	1.697	5.567
MEDIAN or D_{50}:	7.403	7.078
D_{90}:	21.10	9.202
(D_{90} / D_{10}):	12.43	1.653
$(D_{90} - D_{10})$:	19.40	3.636
(D_{75} / D_{25}):	4.522	1.354
$(D_{75} - D_{25})$:	10.97	2.177

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	0.0%	MEDIUM SAND:	0.0%
MUD:	100.0%	FINE SAND:	0.0%
		V FINE SAND:	0.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	3.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	17.5%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	27.6%
FINE GRAVEL:	0.0%	FINE SILT:	20.6%
V FINE GRAVEL:	0.0%	V FINE SILT:	18.0%
V COARSE SAND:	0.0%	CLAY:	13.2%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric Logarithmic μm	φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	9.851	6.637	7.235	6.593	7.245	Fine Silt
SORTING (σ):	8.531	2.553	1.352	2.650	1.406	Poorly Sorted
SKEWNESS (Sk):	1.481	-0.187	0.187	-0.157	0.157	Fine Skewed
KURTOSIS (K):	5.448	2.059	2.059	0.814	0.814	Platykurtic

SAMPLE STATISTICS

SAMPLE IDENTITY: **T6FS2**

ANALYST & DATE: JB/AN, February 9, 2022

SAMPLE TYPE: Trimodal, Poorly Sorted

TEXTURAL GROUP: Mud

SEDIMENT NAME: Coarse Silt

	μm	φ
MODE 1:	29.93	5.066
MODE 2:	22.68	5.466
MODE 3:	4.298	7.866
D_{10}:	2.509	4.528
MEDIAN or D_{50}:	15.78	5.986
D_{90}:	43.34	8.639
(D_{90} / D_{10}):	17.27	1.908
(D_{90} - D_{10}):	40.83	4.110
(D_{75} / D_{25}):	4.585	1.430
(D_{75} - D_{25}):	22.73	2.197

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	2.3%	MEDIUM SAND:	0.0%
MUD:	97.7%	FINE SAND:	0.0%
		V FINE SAND:	2.3%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	19.6%
COARSE GRAVEL:	0.0%	COARSE SILT:	28.5%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	20.4%
FINE GRAVEL:	0.0%	FINE SILT:	12.6%
V FINE GRAVEL:	0.0%	V FINE SILT:	9.9%
V COARSE SAND:	0.0%	CLAY:	6.8%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric Logarithmic μm	φ	Geometric μm	Logarithmic φ	Description
MEAN (x):	19.89	12.83	6.284	12.92	6.274	Medium Silt
SORTING (σ):	16.40	2.859	1.515	2.990	1.580	Poorly Sorted
SKEWNESS (Sk):	1.031	-0.569	0.569	-0.275	0.275	Fine Skewed
KURTOSIS (K):	3.470	2.435	2.435	0.936	0.936	Mesokurtic

SAMPLE STATISTICS

SAMPLE IDENTITY: **T6S5**

ANALYST & DATE: JB/AN, February 9, 2022

SAMPLE TYPE: Trimodal, Poorly Sorted

TEXTURAL GROUP: Mud

SEDIMENT NAME: Medium Silt

	μm	ϕ
MODE 1:	14.97	6.066
MODE 2:	4.937	7.666
MODE 3:	3.257	8.266
D_{10}:	1.950	5.243
MEDIAN or D_{50}:	9.535	6.713
D_{90}:	26.40	9.002
(D_{90} / D_{10}):	13.54	1.717
(D_{90} - D_{10}):	24.45	3.759
(D_{75} / D_{25}):	4.366	1.364
(D_{75} - D_{25}):	13.41	2.126

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	0.0%	MEDIUM SAND:	0.0%
MUD:	100.0%	FINE SAND:	0.0%
		V FINE SAND:	0.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	5.6%
COARSE GRAVEL:	0.0%	COARSE SILT:	23.9%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	27.5%
FINE GRAVEL:	0.0%	FINE SILT:	18.5%
V FINE GRAVEL:	0.0%	V FINE SILT:	14.5%
V COARSE SAND:	0.0%	CLAY:	10.0%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN ($\bar{x}$):	12.08	8.197	6.931	8.231	6.925	Medium Silt
SORTING (σ):	9.803	2.594	1.375	2.712	1.439	Poorly Sorted
SKEWNESS (Sk):	1.096	-0.370	0.370	-0.213	0.213	Fine Skewed
KURTOSIS (K):	3.698	2.178	2.178	0.862	0.862	Platykurtic

SAMPLE STATISTICS

SAMPLE IDENTITY: **T7FS4** ANALYST & DATE: JB/AN, February 9, 2022

SAMPLE TYPE: Polymodal, Poorly Sorted

TEXTURAL GROUP: Mud

SEDIMENT NAME: Coarse Silt

	μm	φ
MODE 1:	22.68	5.466
MODE 2:	14.97	6.066
MODE 3:	34.38	4.866
D_{10}:	2.212	4.867
MEDIAN or D_{50}:	11.88	6.395
D_{90}:	34.26	8.821
(D_{90} / D_{10}):	15.49	1.812
$(D_{90} - D_{10})$:	32.05	3.954
(D_{75} / D_{25}):	4.662	1.406
$(D_{75} - D_{25})$:	17.71	2.221

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	0.0%	MEDIUM SAND:	0.0%
MUD:	100.0%	FINE SAND:	0.0%
		V FINE SAND:	0.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	13.0%
COARSE GRAVEL:	0.0%	COARSE SILT:	26.6%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	23.7%
FINE GRAVEL:	0.0%	FINE SILT:	16.4%
V FINE GRAVEL:	0.0%	V FINE SILT:	12.3%
V COARSE SAND:	0.0%	CLAY:	8.1%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic φ	Geometric μm	Logarithmic φ	Description
MEAN ($\bar{x}$):	15.26	10.07	6.633	10.18	6.617	Medium Silt
SORTING (σ):	12.47	2.722	1.444	2.847	1.509	Poorly Sorted
SKEWNESS (Sk):	0.978	-0.439	0.439	-0.226	0.226	Fine Skewed
KURTOSIS (K):	3.202	2.237	2.237	0.868	0.868	Platykurtic

SAMPLE STATISTICS

SAMPLE IDENTITY: **T7MS7**

ANALYST & DATE: JB/AN, February 9, 2022

SAMPLE TYPE: Polymodal, Poorly Sorted

TEXTURAL GROUP: Mud

SEDIMENT NAME: Coarse Silt

	μm	ϕ
MODE 1:	22.68	5.466
MODE 2:	14.97	6.066
MODE 3:	29.93	5.066
D_{10}:	2.174	4.840
MEDIAN or D_{50}:	12.19	6.358
D_{90}:	34.91	8.845
(D_{90} / D_{10}):	16.06	1.827
(D_{90} - D_{10}):	32.74	4.005
(D_{75} / D_{25}):	4.795	1.416
(D_{75} - D_{25}):	18.34	2.262

GRAIN SIZE DISTRIBUTION

GRAVEL:	0.0%	COARSE SAND:	0.0%
SAND:	0.0%	MEDIUM SAND:	0.0%
MUD:	100.0%	FINE SAND:	0.0%
		V FINE SAND:	0.0%
V COARSE GRAVEL:	0.0%	V COARSE SILT:	13.6%
COARSE GRAVEL:	0.0%	COARSE SILT:	27.0%
MEDIUM GRAVEL:	0.0%	MEDIUM SILT:	23.3%
FINE GRAVEL:	0.0%	FINE SILT:	15.5%
V FINE GRAVEL:	0.0%	V FINE SILT:	12.3%
V COARSE SAND:	0.0%	CLAY:	8.3%

	METHOD OF MOMENTS			FOLK & WARD METHOD		
	Arithmetic μm	Geometric μm	Logarithmic ϕ	Geometric μm	Logarithmic ϕ	Description
MEAN (x):	15.57	10.21	6.614	10.31	6.600	Medium Silt
SORTING (σ):	12.70	2.758	1.464	2.895	1.534	Poorly Sorted
SKEWNESS (Sk):	0.935	-0.459	0.459	-0.239	0.239	Fine Skewed
KURTOSIS (K):	3.069	2.226	2.226	0.861	0.861	Platykurtic

A River in Transition – the Restoration of the Halfway River and its Tidal Wetlands

Prepared for:

NS Department of Transportation and Infrastructure Renewal (NSTIR)

Prepared by:

Bowron, T.M.; Graham, J.; van Proosdij, D.

CBWES Inc.

November 2018

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Purpose of Study

Halfway River historically, and naturally, was a free-flowing tidal river with extensive salt marshes comprising the lower reaches of the river's flood plain, transitioning into brackish and tidal fresh with distance upstream. As with many of the salt marshes and tidal rivers throughout the Bay of Fundy, these were lost due the construction of barriers (e.g., dykes & aboiteau, causeways) to tidal flow and fish passage. Although these "reclaimed" landscapes served important social and economical purposes for many years and in some cases still do, changing values (e.g., agricultural practices, land use, societal) and the need to adapt to climate change and sea level rise has led to considerable efforts to restore and protect tidal systems like the Halfway River – regionally and globally.

The failure of the Halfway River causeway in 2017 has resulted in the re-establishment of a more natural hydrological regime to the river and has reconnected the watershed to the broader Minas Basin and Bay of Fundy ecosystem. The re-establishment of tidal flow has initiated the recovery of a significant amount of provincially significant salt marsh and tidal wetland habitat throughout the now tidally influenced segment of the river. It has also resulted in the availability and accessibility of the river and wetlands for a range of resident and migratory fish and bird species that are ecological, socially and economically important.

The purpose of this study was to begin the process of documenting the area, extent, and condition of the recovering Halfway River tidal wetlands. This research was conducted at the request of the Nova Scotia Department of Transportation and Infrastructure Renewal (NSTIR).

Study Area

The Halfway River in Hantsport, NS, flows into the Avon River, which is part of the Southern Bight of the Minas Basin, Bay of Fundy (Figure 1, Figure 2). Tidal flow to the former macrotidal river was eliminated by the historical construction and operation of a railway causeway across the mouth of the river. Freshwater drainage was primarily facilitated by the presence of a large wooden aboiteau structure within the base of the causeway and a series of overflow culverts. Lack of adequate maintenance of the causeway and aboiteau structure in recent years contributed to its deterioration and the re-introduction of limited tidal flow to the river. Full tidal flow returned to the river in November 2017 with the complete failure of the causeway and aboiteau (Figure 2, Figure 3).

Figure 1 Location of Halfway River near Hantsport, NS.

Figure 2 Run of the river looking upstream from the Highway 1 at high (neap) tide on 5 September 2018.

Figure 3 Part of the aboiteau, construction material and rail line remain within the crossing (breach) location and continue to negatively impact the hydrology. Note – the rail lines visible in this picture from February 2018 have since been removed for safety reasons. Photograph by CBWES Inc.

Figure 4 Aerial photograph of mouth of the Halfway River and breach site. Photograph was taken at high (neap) tide on 5 September 2018.

Methodology

Site Visits and Habitat Assessment

Site visits were carried out during winter (February 7, 2018), spring and summary (June 26, July 6, September 5 & 24, 2018) conditions. During all site visits flow conditions through the breach and within the river were noted (high and low water, eddies, etc.) and documented with photographs, observed species were identified and recorded, and sedimentation conditions noted. During the July 26th visit pore water salinity was recorded using a Field Scout EC Meter and a topographic survey using an RTK-GPS was carried out on NSTIR properties (PID 45121258; PID 45060365).

Habitat Delineation, Restorable Area and Areas of Vulnerability

Habitat delineation, restorable area and areas of vulnerability were analysed using a combination of aerial photography, ground photography, and elevation models. An orthomosaic and Digital Surface Model (DSM) were derived from a series of georeferenced low-altitude aerial flights carried out on September 5, 2018 using a DJI Phantom 3 Professional lightweight UAV and post-processed using industry approved software Pix4D. Over 1300 vertical and oblique photos were taken covering ~80 hectares, including the upland adjacent to the marshland. An example of an oblique image is provided in Figure 5. The orthomosaic and DSM had a 4 cm horizontal pixel resolution and 14 ground control points (GCPs) were used to georeference them to real-world coordinates (NAD83 CSRS98 Epoch2010 UTM Zone 20N) (Figure 6). No GCPs were placed south of Highway 101 and no flight lines crossed the highway (due to access and flight restrictions), making elevations south of the highway unreliable. The mean horizontal error for validated parts of the DSM was 11 cm and the RMSEz (vertical) was 13.5cm. This is mostly due to the fact the points used in the accuracy assessment (i.e., the RTK survey) were slightly vegetated, causing the DSM to be slightly higher. In true bare earth areas, the DSM accuracy was <5 cm (vertical). Observed die-off was manually delineated from the orthophoto, with aid from the DSM. The estimate of naturally restoring salt marsh and tidal wetland habitat was identified from these products by comparing the observed vegetation die-off boundary/sediment deposition boundary (minimum area) to the predicted flood extents (maximum area, see below). Aerial imagery, the DSM, and ground photography were also used to assess areas of vulnerability on the marshland.

Figure 5 Oblique aerial photograph of Highway 1 where it crosses the Halfway River. Photograph by CBWES Inc., 5 September 2018.

Figure 6 Orthomosaic and DSM derived from the georeferenced low-altitude aerial photography.

Hydrology

To determine flooded area water levels identified by Earth-water Concepts Inc.'s hydraulic analysis (Gagne & Casey, 2018) and Saint Mary's University (van Proosdij, 2018) were mapped on the DSM identified above. The surface generated using the UAV imagery and Structure from Motion algorithms is a DSM, not a Digital Elevation Model (DEM), and includes the tops of trees/shrubs/ structures and is not a bare earth model (Carrivick et al, 2016). However, given that much of the Halfway River's flood plain was unvegetated mudflat (exposed surface) at the time of the flight, the DSM was considered an accurate representation of ground surface elevation and therefore viable for hydrological analysis (RMSEz = 13.5 cm). Flood extents extrapolated from a 2007 LiDAR Digital Elevation Model (DEM) by Raymond Jahncke (Maritime Provinces Spatial Analyst Research Centre, Saint Mary's University (SMU)) were also considered in the analysis. The bare ground extents were used in part to validate the observed die-off, but also to see how the site may have changed since 2007. Finally, a hypsometric curve, which describes how a site will flood, was generated from the DSM.

Table 1 Key water heights used for flood extent mapping.

Tide Height (m CGVD28)	Tide Height (m CGVD2013)	Year	Source	Description
8.13	7.50	2000	earth-water Concepts inc.(2018) from (Richards and Daigle 2011)	High High Water Large Tide (HHWLT)
9.53 (not mapped)	8.90 (not mapped)	2000	earth-water Concepts inc.(2018) from (Richards and Daigle 2011)	HHWLT + peak surge (1.5 m)
8.03	7.40	2009	van Proosdij (2018) from R.J. Daigle Enviro (2016)	HHWLT
8.36	7.73	2055	van Proosdij (2018) from R.J. Daigle Enviro (2016)	HHWLT

Results

Site visits and Habitat Assessment

Although historically and naturally tidal wetland dominated, the Halfway River flood plain prior to the causeway breaching was a mix of agricultural, freshwater wetland and encroached terrestrial habitats. The restoration of a more natural hydrological regime (flood pattern) to the system has resulted in the deposition of sediment throughout the flood plain and the death of terrestrial vegetation species. The combination of heavy sedimentation and saline water which reaches significant depths at high spring tides, has resulted in the loss of the agricultural and freshwater species which dominated the site while the causeway remained intact (Figure 7). Sedimentation was observed to be greatest (~40 cm) in the dales and low areas, and while the crowns and other higher elevation areas had experienced less sediment accumulation, it was still sufficient in most areas to bury grasses and other pasture species (Figure 8).

Although the extensive sediment deposition and vegetation loss (e.g., the trees), is very visually dramatic, it is a pattern of change that is actually quite typical, and expected, as the system transitions back to its natural tidal condition. The loss of the terrestrial (non-wetland) species and the development of mudflat like conditions on tidally restricted systems and subsided dykelands, has been observed at tidal river and salt marsh restoration sites throughout the region (Bowron et al, 2015a; Bowron et al, 2015b; Boone et al;. 2018). Depending on the degree of subsidence and the available sediment load, this phase of habitat recovery has been observed to last for several years (1-3 at recent restoration sites). Mudflat development typically precedes colonization by halophytic vegetation (salt marsh plants) such as the ecological engineering species *Spartina alterniflora*. In the case of Halfway River, vegetation recovery appears to be occurring quickly. During each of the spring and summer site visits, a variety of halophyte species were observed to be establishing and thriving throughout the marsh including *Spartina alterniflora, Spartina pectinata, Atriplex sp., Salicornia europea, Suaeda sp., Limonium nashi,* and *Spergularia sp. Suaeda* and *Atriplex sp* should be sampled and identified in the lab as the species can be difficult to correctly key in the field and several potential species were observed (3 *Suaeda*, 2 *Atriplex*). However, definitive identification of these species requires the presence of mature seeds and will not occur until mid to late October.

Spartina alterniflora and *S. pectinata* were generally found in concentrated patches, with *S. alterniflora* found in the areas that would normally consider being low marsh zones and in lower elevation areas on the platform (high marsh) that were retaining water (Figure 9). The low marsh at this site is terraced and is several meters lower than the platform, with steep sloped banks in most places. *S. pectinata* was found primarily in higher elevation areas and near ditches where it may have previously had a foothold. The succulent halophytes, particularly *Suaeda, Atriplex,* and *Salicorniai,* are annual plants and were found scattered throughout the site (Figure 10).

Pore water salinity was collected during the June 26th site visit at multiple locations across the site and the measurements are shown in Table 2. The salinity data was collected during a spring tide cycle several hours prior to high tide. Average pore water salinity was 4.18 ppt, with the maximum reported value at 7.564 ppt in the low marsh. For low, mid and top of bank salinities shallow readings were more saline than deep readings, while readings from the platform were roughly equal.

Figure 7 Landscape shots of Halfway River taken from the Hantsport Connector at high spring tide (left) and low spring tide (right). Photographs by CBWES Inc. 26 June 2018.

Figure 8 Heavy sedimentation in one of the main dales (left) and exposed crowns with dead grass visible (right). Photographs by CBWES Inc., 26 June 2018.

Figure 9 *S. alterniflora* growing on the low marsh river edge (above), and on the marsh platform (below left). In many cases the plants were observed to be growing in the cracks that form as the sediment dries (below right). Photographs by CBWES Inc. July 7 (top), 5 September 2018 (bottom).

Figure 10 *Suaeda* (top left, bottom right), *Atriplex* (top right), and *Spergularia* (bottom left) species. These succulent halophytes were found scattered throughout the site. Photographs by CBWES Inc. 5 September 2018.

Table 2 Pore water salinity measurements, Halfway River. Tide condition – low and rising, spring tide cycle. June 26, 2018.

		Shallow (15 cm)		**Deep (45 cm)**		
Pid	**Position**	**Salinity (ppt)**	**Temp (deg C)**	**Salinity (ppt)**	**Temp (deg C)**	**Notes**
1	High Marsh	4.108		2.611	13.9	*S. pectinata* & bare ground
67	High Marsh	4.089	13.8	2.888	14.3	*Salincornia Europea*
76	High Marsh	3.729	13.6	3.189	14.2	On crown
116	High Marsh	3.988	14.1	5.598	14.4	Dead veg and *Juncus sp*
168	High Marsh	4.811	14.2	6.36	14.8	Bare Ground
25	Low Marsh	7.564	13.9	6.66	14.4	Can hear and see Corophium
27	Low Marsh	7.311	14.2	7.54	14.1	30% veg cover (*S. pectinata*)

Pid	Position	Shallow (15 cm)		Deep (45 cm)		Notes
		Salinity (ppt)	Temp (deg C)	Salinity (ppt)	Temp (deg C)	
50	Low Marsh	4.502	13	2.535	13.5	Low area
154	Low Marsh	3.253	14.1	0.384	14.3	
155	Low Marsh	2.901	14.5	0.364	14.6	In standing water
14	Mid Marsh	4.592	14.2	2.836	15	
81	Mid Marsh	4.068	14	0.62	14.5	In trough, muddy
96	Mid Marsh	2.719	14.4	1.606	13	Bare ground on crown
158	Mid Marsh	4.66	15.5	6.096	16	In standing water
159	Mid Marsh	3.777	13.8	5.407	14.7	Bare ground
156	Mid Marsh	3.659	13.6	4.675	13	Bare ground
157	Mid Marsh	4.596	15.7	5.146	15.9	In standing water
19	Top of Bank	2.045	14.21			Bare Ground w/ small *suaeda*
33	Top of Bank	4.37	14	2.353	14.8	Bare ground
89	Top of Bank	2.922	13.9	0.341	14.5	Bare ground
High Marsh		4.15	13.93	4.13	14.32	
Low Marsh		5.11	13.94	3.50	14.18	
Mid Marsh		4.01	14.46	3.77	14.59	
Top of Bank		3.11	14.04	1.35	14.65	
All		**4.18**	**14.14**	**3.54**	**14.42**	

Hydrological Restoration and Re-establishing Salt Marsh and Tidal Wetland

To determine the area of re-establishing salt marsh and tidal wetland habitat (“restored area”), the flood extents produced by SMU and extracted from the DSM were compared to the observed die-off line to produce a range of potential area. Die-off was manually delineated from the orthomosaic and was determined to be on the order of 65 ha within the captured floodplain. Flood extents generated from the DSM matched well to this observed line in most places (Figure 11). As GCPs were not used south of Highway 101, flood extents in this area are unreliable. The SMU flood extents were on the order of 80 ha and included areas not captured in the orthomosaic domain (e.g, upper reaches south of highway, floodplain east of Hantsport Connector). The DEM flood extents slightly exceed the observed die-off on the main marsh platform. This is due in part to the presence of trees on the edge of the marsh which obscure the true surface. However, it also may be the case that the full extent of die-off and restoration is not yet fully evident, as upland edges flood much less frequently and will take longer to transition. The hypsometric curve indicates the marsh will flood in a somewhat typical salt marsh pattern, though the presence of low marsh terraces leads to flooding early on the rising tide. The platform itself floods between 5 and 6 m CGVD2013, indicating that water depth on the marsh could exceed two meters in some areas. This supports a subsided platform as a result of the exclusion of tidal flooding for an extended period of time.

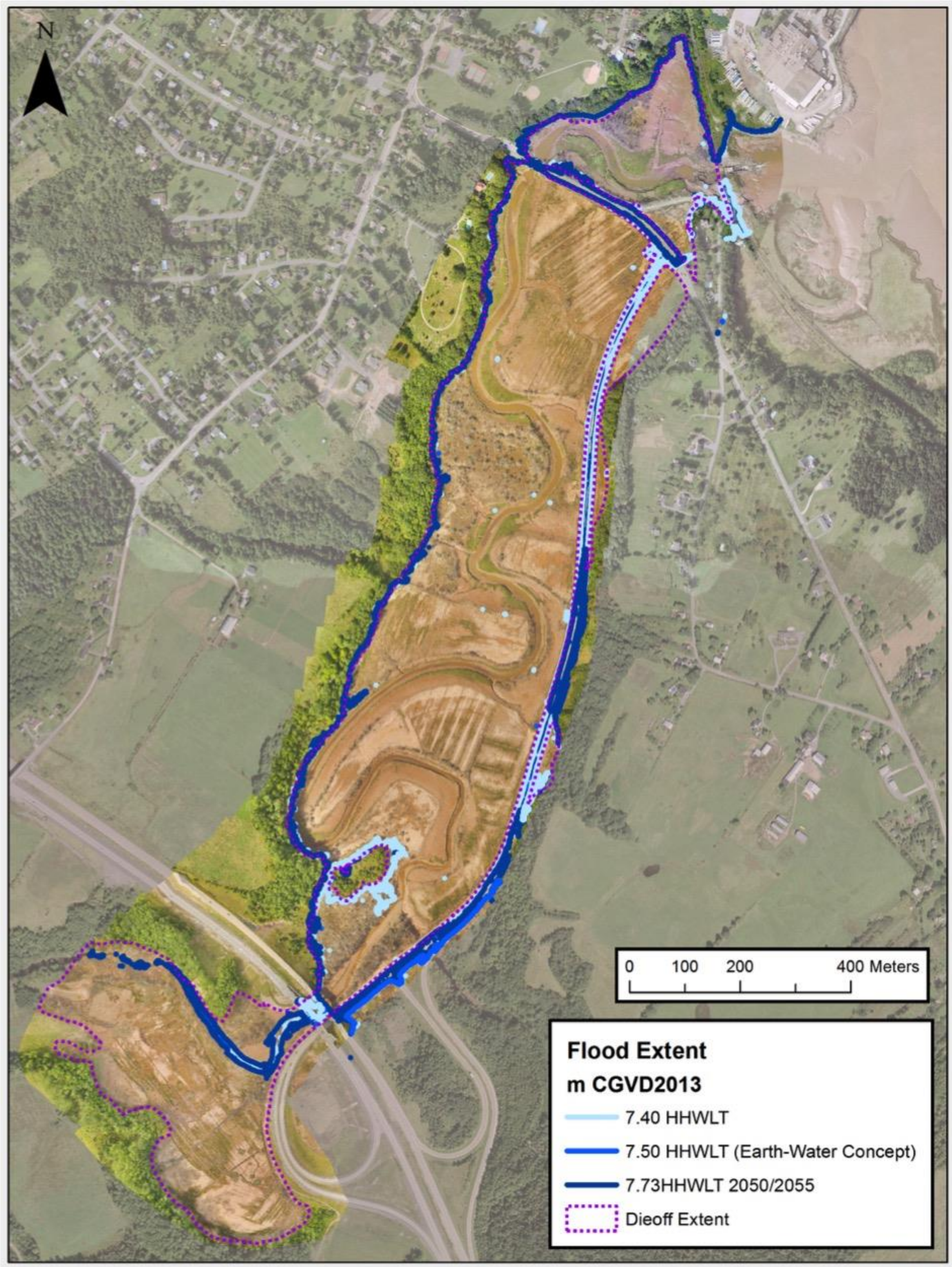

Figure 11 Flood extent generated from 2018 DSM line up well with the die-off extent observed in the orthomosaic, except south of the highway where no GCPs were deployed and elevations were invalid.

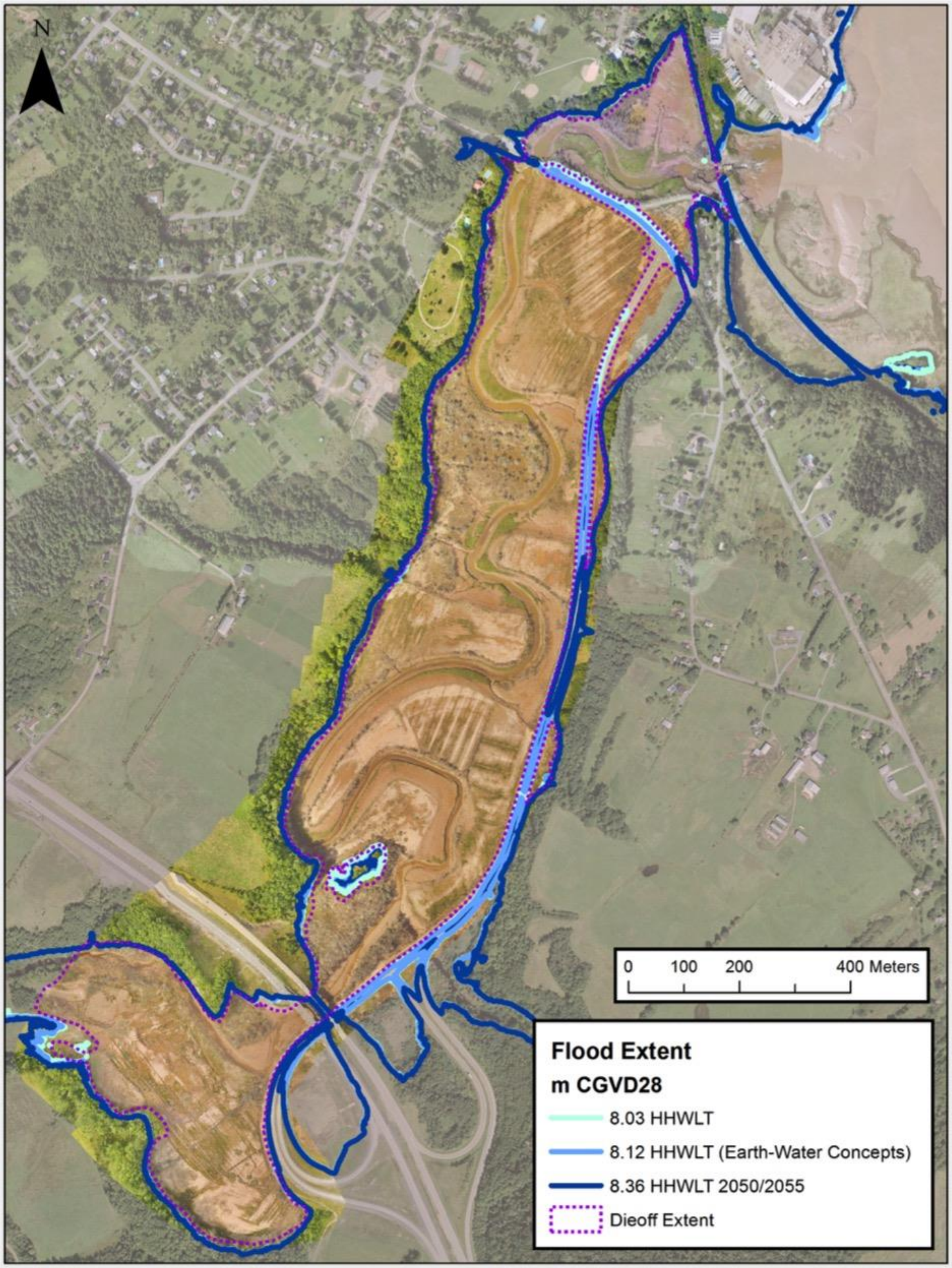

Figure 12 Flood extent generated from 2007 DEM (AGRG/SMU) slightly exceed die-off extent observed in the orthomosaic.

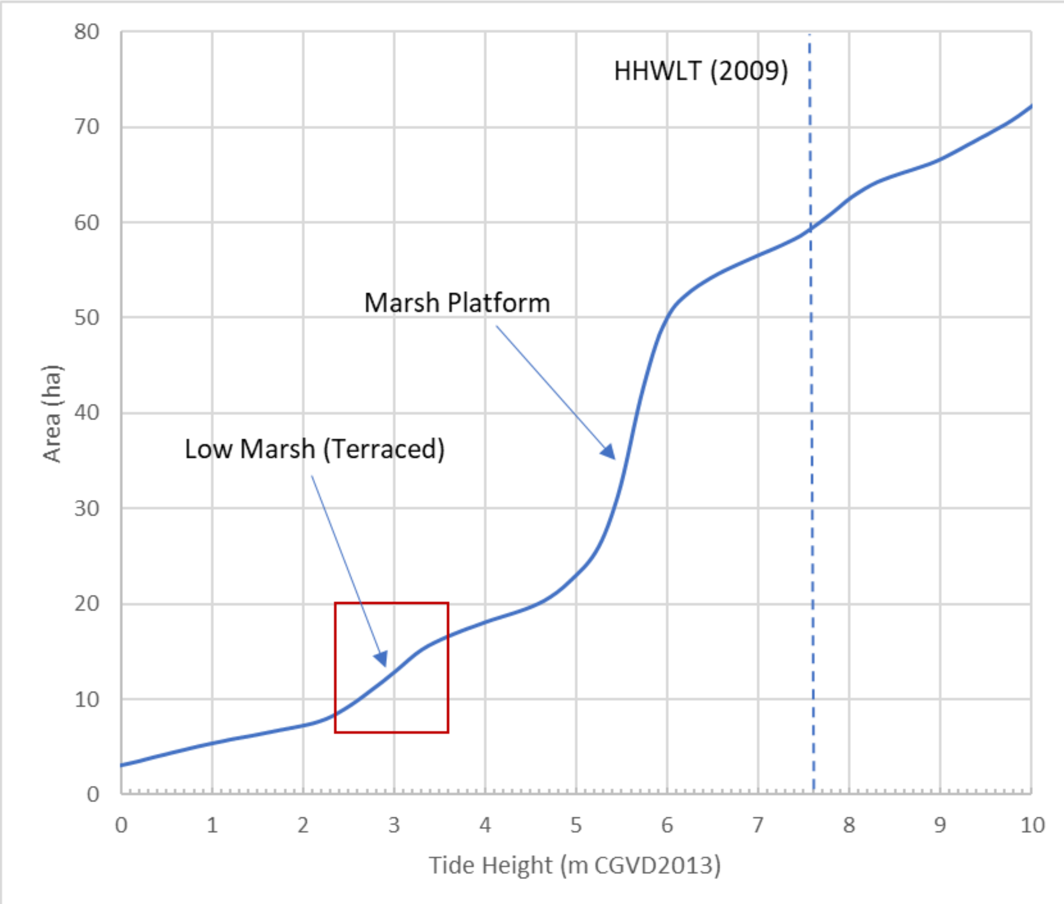

Figure 13 Hypsometric curve generated from 2018 DSM for Halfway River

Areas of Vulnerability

The return of tidal flow has brought several areas of vulnerability along the river to the attention of both the local community and the Province. Areas of concern that were identified during community meetings in August and September 2018 include several locations along the western bank of the river (sports field, graveyard), the section of the road that are on and border the floodplain, as well as both the Highway 1 and 101 bridges.

The Halfway River floodplain has abrupt upland slopes, or bluffs, on either side of the river. Local residents raised concerns during two public meetings held in August and September 2018 in Hantsport, of the potential risk to the Riverbank Cemetery (Figure 14, Figure 15, Figure 16) and the Hantsport Community Center (Figure 18, Figure 19) from erosion of the bank that was believed would occur as a result of the re-introduction of tidal flow. Examination of aerial photographs, a 2013 LiDAR DEM obtained from the Province of Nova Scotia's DataLocator webservice (Internal Services Department), and on-site observations indicate that most of the dead and dying vegetation (trees) is limited to the floodplain surface and not the bank slope. Continued monitoring of the bank for signs of increased vulnerability or potential failure is recommended in order allow for adaptation and mitigation measures to be taken. One such action, which is a routine shoreline erosion management technique, would be to cut down any dead or dying trees at the toe or on the slope before they naturally fall and potentially taking a part of the slope with them and further exposing and destabilizing the bank. The cut trees could also then be used to further protect the toe of the slope and aid in the re-establishing of wetland plant species which would further stabilize the site. The slope failure observed downstream of Highway 1 (below the Community Centre and sports fields) predates the failure of the aboiteau. The downed trees and bank slumping in this location that is visible from Highway 1, can clearly be observed in the Google Earth imagery from 2015. This was further confirmed through discussions with local residents. No additional movement was evident from either the 2018 aerial imagery or on-site observations. Although there are some adjacent tress that appear to be unstable, there is new vegetation growth on the slump which will help stabilize the area. Further, the trees which did fall previously are being actively incorporated into the river channel. Again, continued monitoring and nature-based interventions, should they be deemed necessary, are recommended.

Regarding the transportation infrastructure that is within and bordering the river system, specifically sections of Highway 1 near the mouth of the river, the Highway 101 Exit 8 on/off ramps, and a low-lying section of Schurman Rd., are vulnerable to flooding during peak spring tides and storm surge events (Figure 20; Figure 21). However, it is our understanding that NSTIR is aware of these areas of vulnerability and are prepared to take the necessary actions to upgrade their infrastructure to alleviate the risk. Eddies and scour pools were observed both downstream and upstream side of the Highway 1 bridge which is indicative of restricted tidal flow (Figure 22, Figure 23). Monitoring of conditions and the bridge by NSTIR is ongoing.

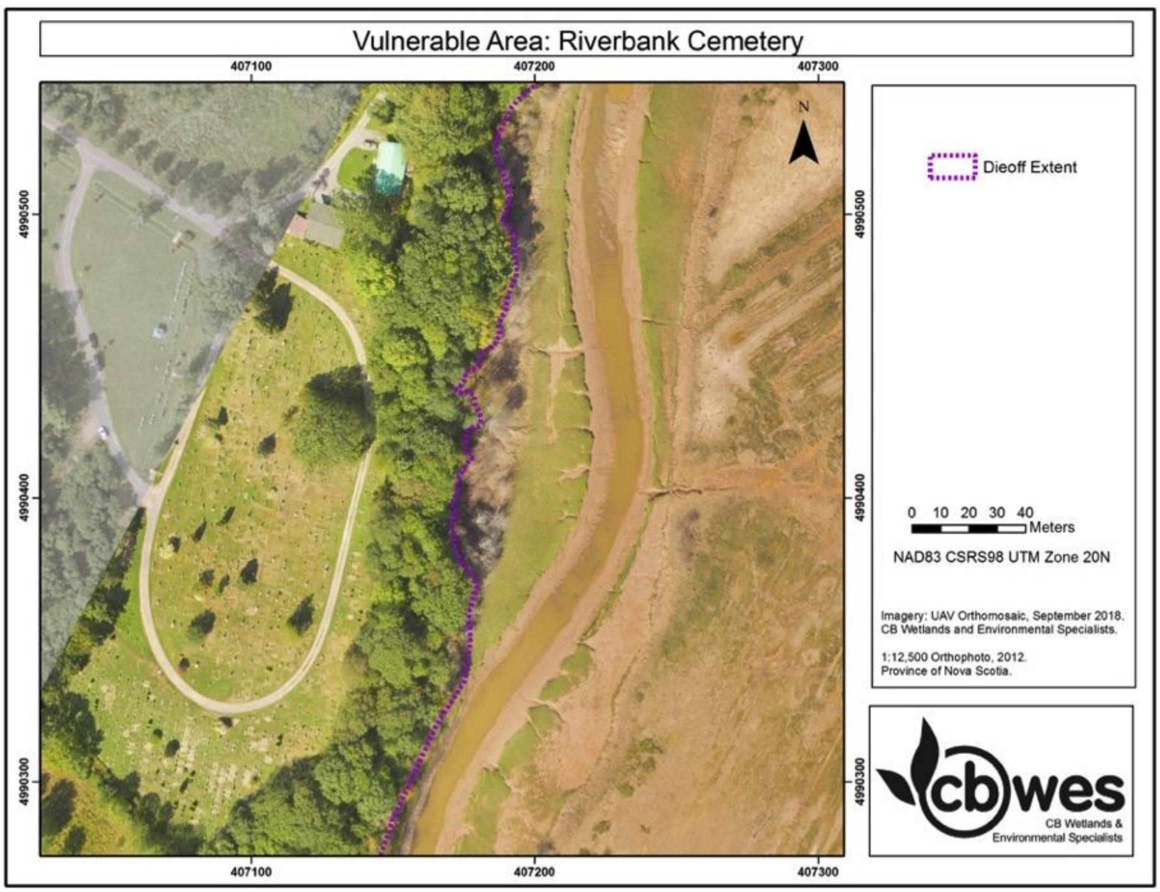

Figure 14 Aerial view of the River Bank Cemetery. The dead trees at the base of the bluff are located primarily on the floodplain directly and not the slope, which appears to be stable at this time.

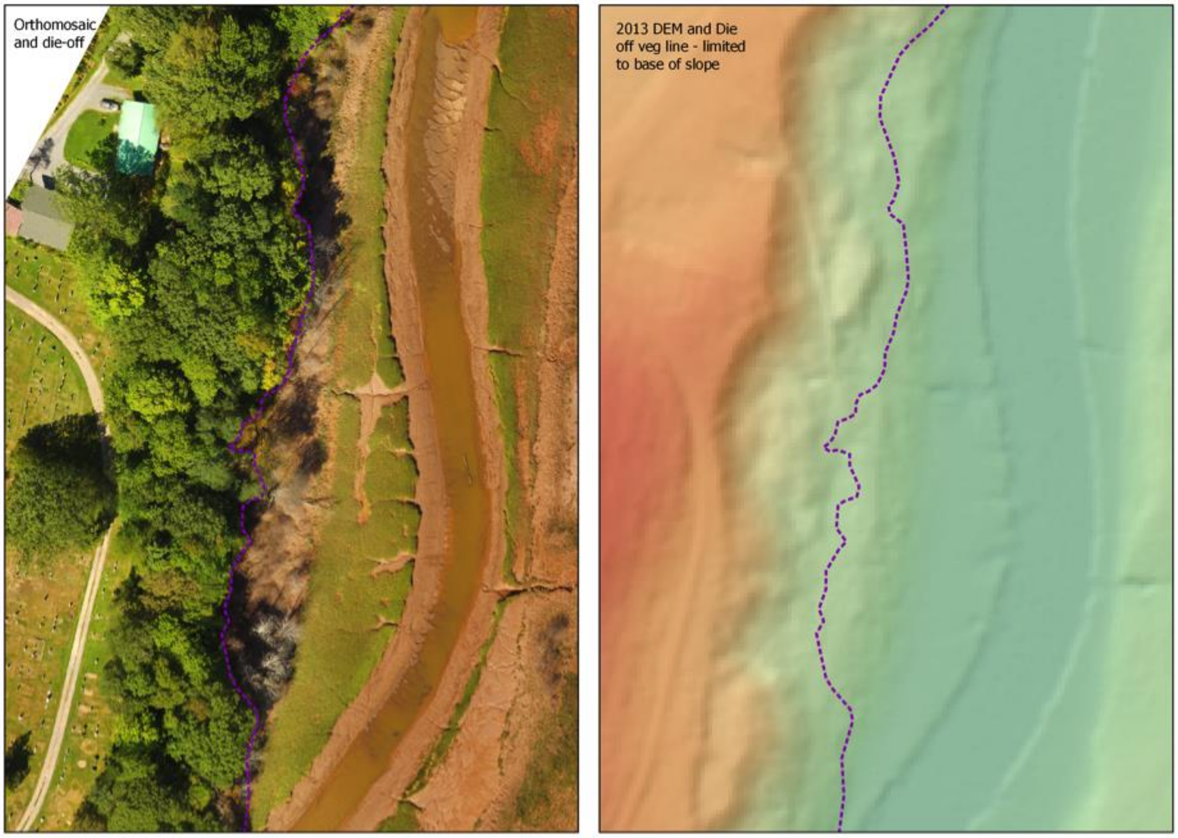

Figure 15 Close up of die back over both orthomosaic and 2013 DEM surface.

Figure 16 Dead trees on the marsh platform below the River Bank Cemetery. Photograph by CBWES Inc. June 26, Rising tide.

Figure 17 Trees and shrubs dying on the platform upstream for the Riverbank Cemetery. Photograph by CBWES Inc. September 24, falling spring tide.

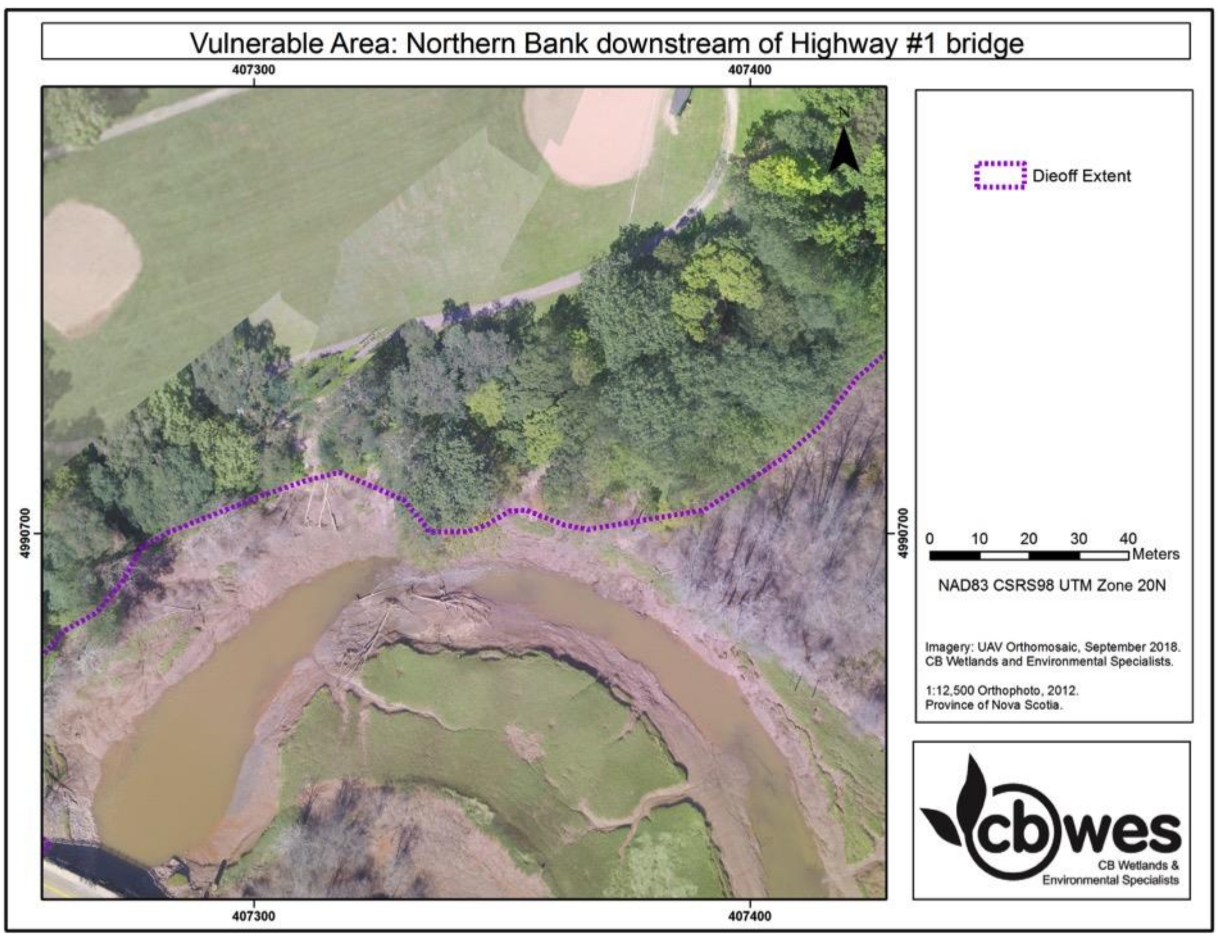

Figure 18 Failure of slope near the Hantsport Community Center, which pre-dates the aboiteau failure.

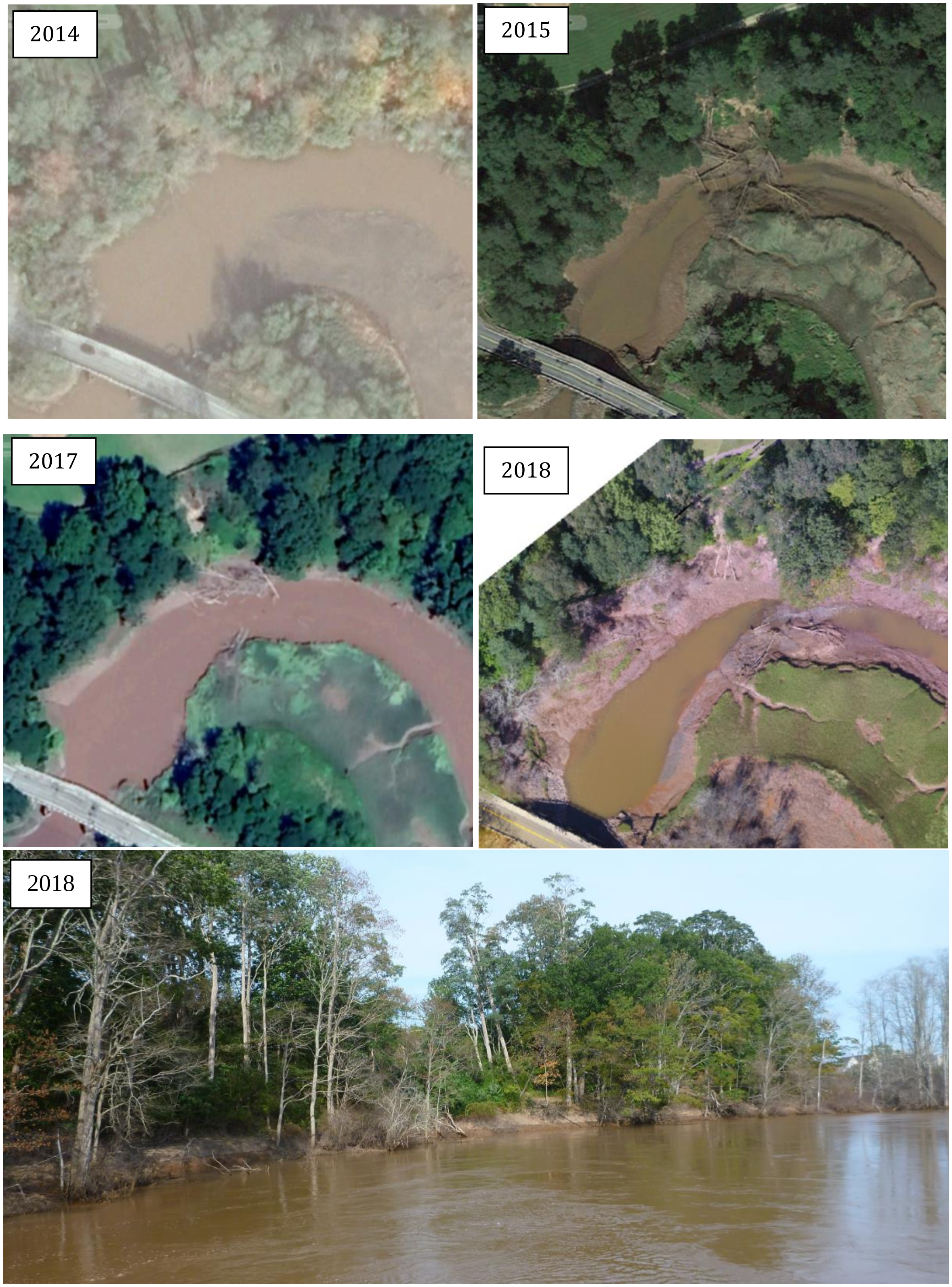

Figure 19 Progression of slope failure below Hantsport Community Center, 2014-2018 and landscape view at high spring tide, 24 September 2018.

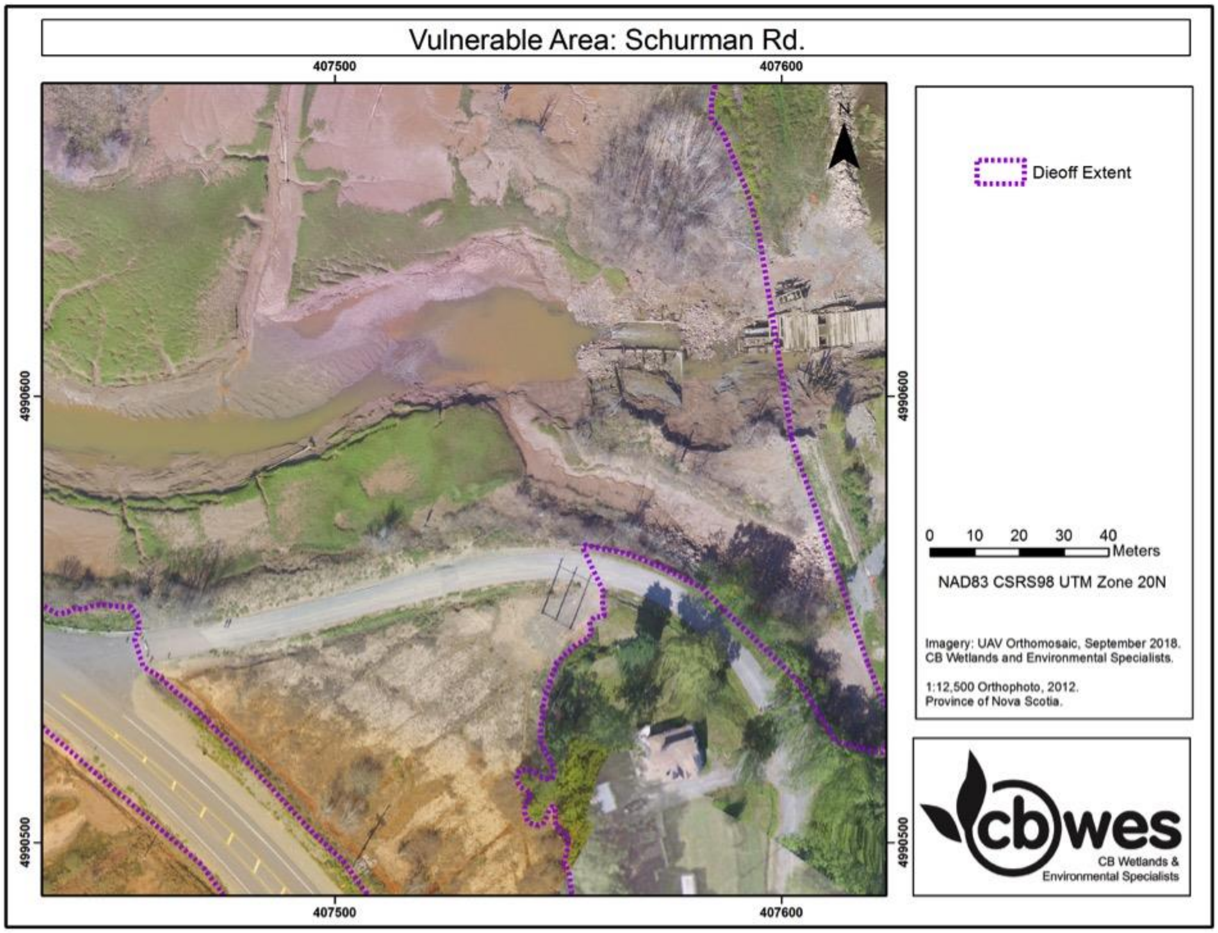

Figure 20 Sediment deposition due to flooding on the low-lying section of Schurman Road (currently closed due to flooding).

Figure 21 Highway 101, Exit 8 on/off-ramps. Upstream looking toward the mouth of the river. 5 September 2018.

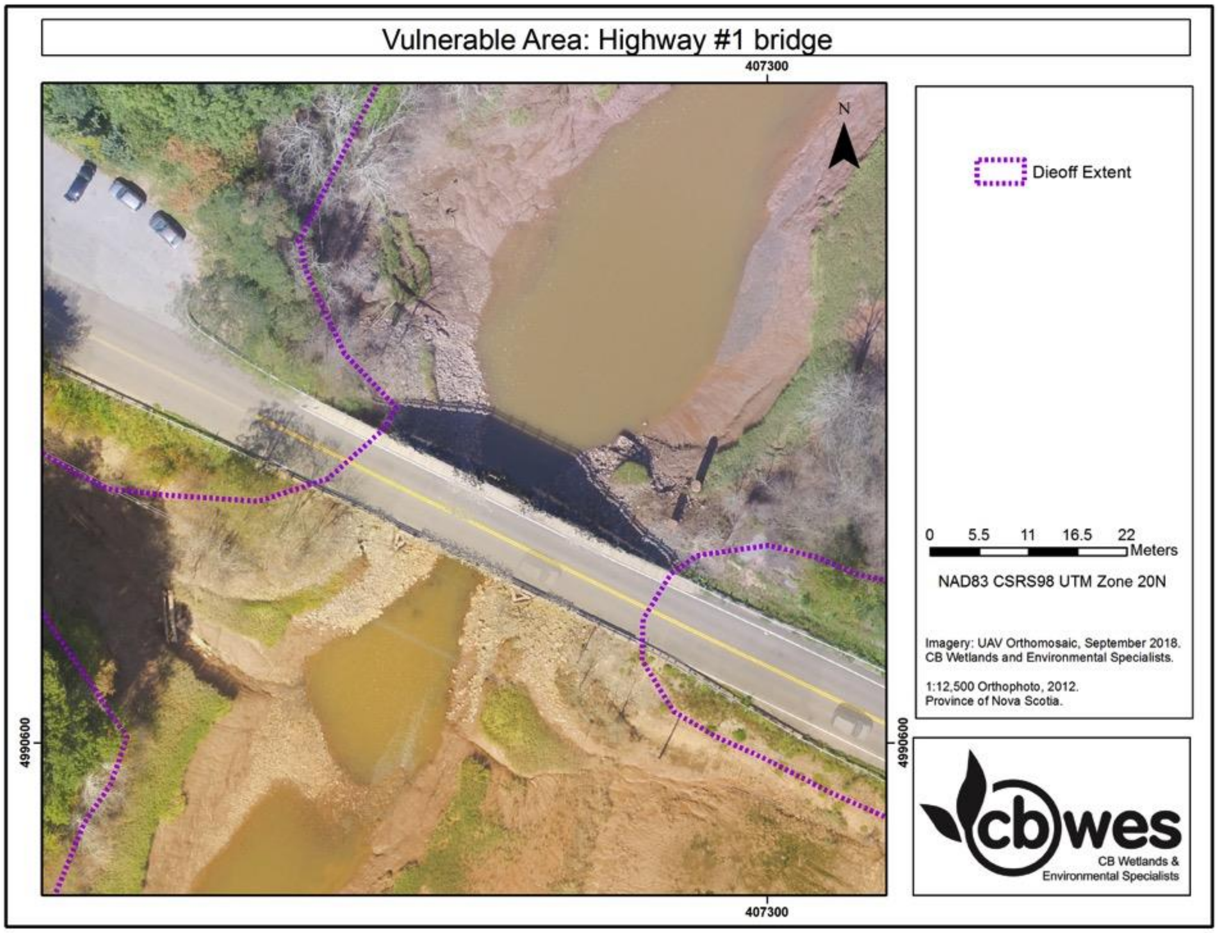

Figure 22 Highway 1 Bridge - scour and eddies observed

Figure 23 Highway 1 bridge at low tide from upstream marsh (left) and downstream eddies on outgoing tide (right). Photograph by CBWES Inc, 5 September and 7 February 2018.

Summary

The recovery of a significant amount of salt marsh and tidal wetlands has been initiated with the re-establishment of a more natural hydrological regime to the Halfway River system, by the failure and breaching of the railway causeway in 2017. Currently, heavy sedimentation and saline water brought in by high spring tides has resulted in the loss of agricultural and freshwater plant species which dominated the site prior to the breach. The resulting mudflat is quickly being colonized by range of salt marsh and tidal wetland plant species which have been observed to be thriving throughout the marsh. Based on experience with intentional tidal wetland restoration projects elsewhere in the Minas Basin, these plants will continue to increase in abundance, diversity and extent over the next several years to the point that the majority of the marsh surface will be re-vegetated within 3-5 years. The die-off of agricultural and freshwater species has been manually delineated to be at least 65 ha, though the furthest upstream reaches and some areas east of the Hantsport Connector were not captured in the orthomosaic and not delineated. The predicted flood extents match well with delineated die-off, and an additional 15 ha are flooded in areas not captured in the orthomosaic. The hypsometric curve for the system indicates that the flood plain will flood in a typical salt marsh pattern, though the presence of low marsh terraces does lead to early and more frequent flooding of these areas, and the extended period of eliminated tidal flow and agricultural use have resulted in a subsided platform. The main area of vulnerability is the highway infrastructure located within the now tidal portion of the system.

If the system is to remain open, it is recommended that consideration be given to the removal of the remaining aboiteau infrastructure from the breach and the stabilization/restoration of the mouth of the river. The clean up and restoration of the mouth of river would eliminate the continued influence of the structure on tidal flow and fish passage, allow for the fully naturalized movement of water and species into and out of the system, improve public safety and re-establish safe navigation. This would also reduce the velocity of water moving through the opening which would reduce the risk of erosion, particularly to vulnerable areas, immediately upstream and down. It should also be noted that if the aboiteau were to be repaired and the breach closed, the upstream habitats would not immediately return to their pre-breach condition. The marine sediments which have already been deposited would need to dewater, and time would be required for the salt to leech from the soil before the terrestrial vegetation could begin to recolonize. If the priority is green-up, habitat stabilization, long-term sustainability and resiliency, the most efficient way to achieve those objectives would be to allow the continuation of the restoration process that is already well underway.

Overall the reconnection of the Halfway River watershed to the broader Minas Basin and Bay of Fundy ecosystem has resulted in the availability and accessibility of the river and wetlands to a range of resident and migratory fish and bird species that are ecological, socially and economically important. If natural flow is allowed to continue, these processes will deepen and continue, and 65 to 80 ha of provincially significant salt marsh and tidal wetland habitat will be restored, directly adjacent to a Ramsar internationally-recognized wetland (Southern Bight-Minas Basin)[1] and an Important Bird Area of Canada (Southern Bight, Minas Basin)[2].

[1] https://rsis.ramsar.org/ris/379
[2] www.ibacanada.org/mobile/site.jsp?siteID=NS020

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