Assessment of Tidal Hydrology and Wetland Surface Elevation in the Wheeler Refuge, York Maine

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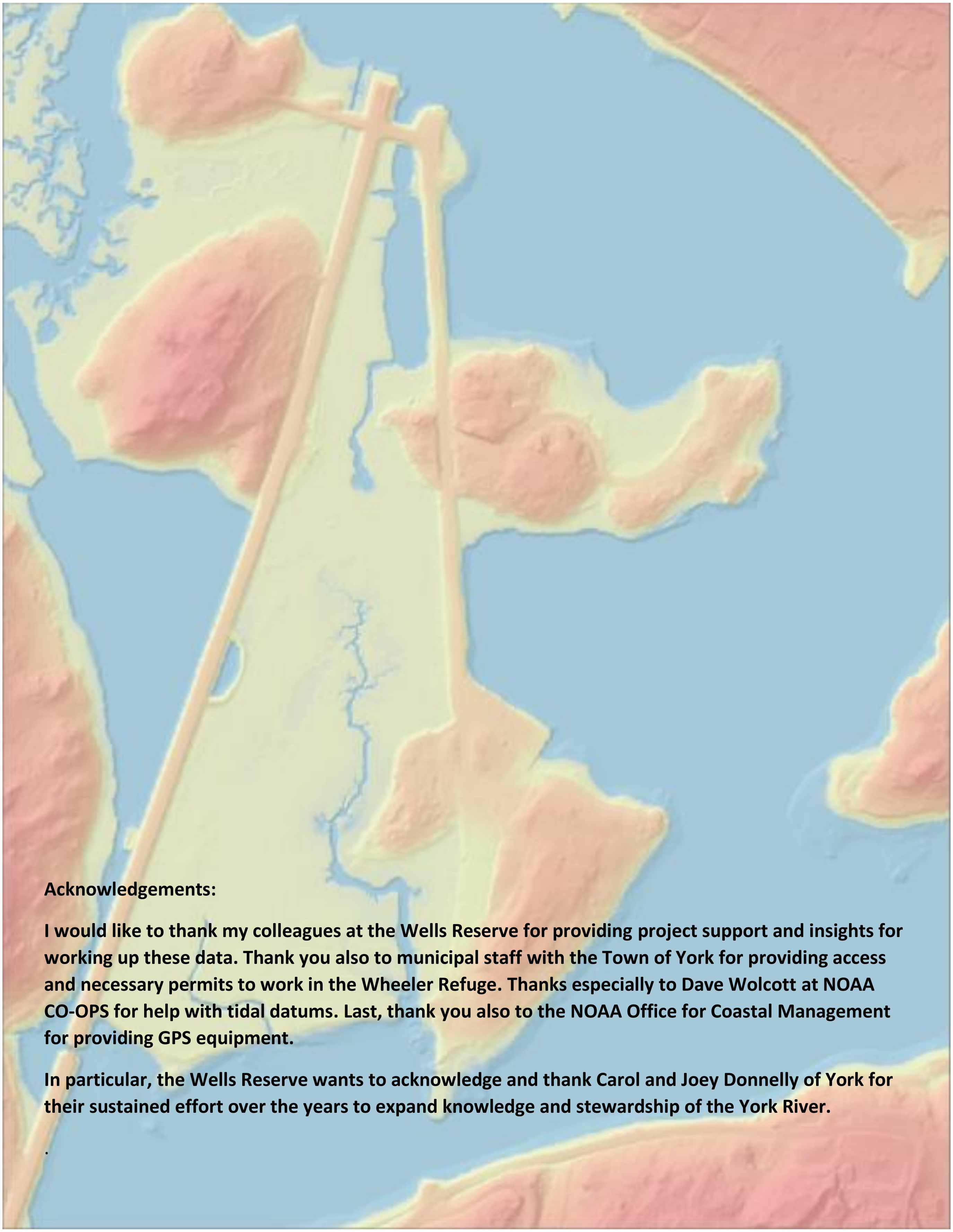

Acknowledgements:

I would like to thank my colleagues at the Wells Reserve for providing project support and insights for working up these data. Thank you also to municipal staff with the Town of York for providing access and necessary permits to work in the Wheeler Refuge. Thanks especially to Dave Wolcott at NOAA CO-OPS for help with tidal datums. Last, thank you also to the NOAA Office for Coastal Management for providing GPS equipment.

In particular, the Wells Reserve wants to acknowledge and thank Carol and Joey Donnelly of York for their sustained effort over the years to expand knowledge and stewardship of the York River.

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Summary

In Fall 2020 the Wells Reserve conducted a limited assessment of wetland condition in the Wheeler Refuge marsh. The study examines present day tidal hydrology, marsh elevation, remote sensing and GIS data, and marsh vulnerability to sea level rise. The study also examines past data to make comparisons with present day conditions. The methods and findings of the study, along with management recommendations based on these findings, are included in this report. The primary finding of this study is that the marsh continues to experience restricted tidal flow, despite restoration efforts a decade ago. Sea level rise will alter the flooding patterns in the marsh potentially alleviating the restrictions in the future, but when this will occur and how the marsh will respond is not clear. Future management actions could be taken to enhance tidal hydrology in the short term and continued monitoring should be utilized to track changes related to sea level rise.

History of Wheeler Refuge Monitoring

The Wheeler Wildlife Refuge is located in York, Maine approximately 40 miles south of Portland, between State Route 103 and Harris Island Road, on the south side of the York River (Figure 1). There are approximately 18 acres of tidal wetland within this protected area, created from harbor dredge spoils in 1961 (Town of York, 2021) and a small adjacent area of naturally occurring salt marsh. The Refuge was designated by town ordinance as protected habitat for wildlife and natural communities in 1985. In 2001, the town received funding through the Maine State Planning Office to conduct a study to improve tidal flow and sediment transport to the marsh by removing existing tidal restrictions (Burdick and Konisky, 2001). During the winter of 2003 – 2004 a dike was breached at the southern end of the marsh and a new channel started, and a small culvert at the northern end was replaced with a larger structure to permit increased tidal flow from the York River. From 2008 to 2010 the Wells Reserve monitored the hydrology and biota of the salt marsh as part of a regional assessment of salt marsh restoration project success in southern Maine (Dionne and Peter, 2011).

The 2001 study analyzed marsh hydrology and elevation survey data to determine the potential for improving tidal flooding within the refuge to increase marsh vegetation abundance. Researchers found that the marsh was at a high elevation relative to the local tidal cycle and that only spring tides flooded the marsh surface, which accounted for the limited distribution of salt marsh plants. The study found that only 50% of tides high enough to inundate the marsh were able to reach the marsh interior, and even then, the inundation was abbreviated and did not reach maximum height. The authors recommended physical alterations to increase tidal flooding to the interior of the marsh, which were ultimately implemented as part of the restoration project. A detailed drawing of the restoration was created by a consulting firm, TRC, and is included in Appendix A.

From 2008 to 2010 the Wells Reserve used a novel approach to assess the success of the restoration six years after tidal hydrology was improved in Wheeler Refuge marsh. The study compared functional and structural wetland parameters between four restored marshes (including Wheeler Refuge) and a reference study site within the Webhannet River in Wells, ME. Monitoring data were used to create a Restoration Performance Index, a simple method to track change by comparing the difference between restoration and reference sites across an interval of time. The researchers found that Wheeler Refuge had experienced the greatest degree of recovery relative to the reference site, scoring the maximum amount for species richness and tidal elevation (Dionne and Peter, 2011).

Study Methods

Water Level

Maine experiences semi-diurnal tidal cycles, with two high and low tides each day. One high tide is usually higher elevation than the other. The National Oceanic and Atmospheric Administration (NOAA) computes long term averages for these tides, known as tidal datums, which are Mean High Water (lesser) and Mean Higher High Water (greater). These tidal datums are referred to throughout this report.

Localized water level data were collected at three stations: two in tidal creeks in Wheeler Refuge marsh (WMNORTH and WMSOUTH) and one in the outlet to the York River downstream of the tidal road crossing on Harris Island Road (DOCK1) (Figure 1). Each station consisted of a non-vented In-Situ Aqua TROLL 200 data logger deployed at the bottom of a PVC stilling well secured to a metal fence post driven into the channel sediment, so that the sensor was positioned a few inches above the channel bottom. A barometric pressure sensor was deployed in the nearby upland to record atmospheric pressure, which would be used later to correct the water level data. Loggers were deployed where they would not be exposed to air at low tide to ensure continuous readings and so that sensors were just above the channel bottom. Data logger clocks were synchronized to Eastern Standard time prior to deployment and the loggers set to record data at 6-minute intervals to enable comparison with the NOAA National Water Level Observation Network (NWLON).

Water level stations measured daily fluctuations in tidal flooding within the Wheeler Refuge marsh.

Upon retrieval data were downloaded and post-processed using the Win-Situ desktop application to compensate for barometric pressure changes and convert depth to water level by applying the sensor orthometric height. Data were reviewed manually and plotted in MS Excel, and out-of-water readings were removed. Data were then formatted for compatibility with the online NOAA Tidal Datum Calculator (NOAA 2021), and National Tidal Datum Epoch (NTDE) equivalent tidal datums were calculated for each local water level station. Verified water level data from the study period, and published tidal datums, were obtained for the NOAA tide stations in Portland (8418150) and Seavey Island, Kittery (8419870) (NOAA 2020). These data were used as a quality check on accuracy of the local water level data and tidal datum calculations. Tidal inundation statistics were calculated for each local dataset, as well as two sea level rise scenarios, using an MS Excel Macro (Buck 2019).

Figure 1. Wheeler Refuge is located in York, Maine 40 miles south of Portland. Water level stations were deployed in the adjacent York River (DOCK1) and within main tidal creeks in the north (WMNORTH) and south (WMSOUTH) ends of the marsh.

Vertical Control

Establishing vertical control in Wheeler Refuge allows elevation measurements to be collected within the National Spatial Reference System used by NOAA to maintain tide stations and forecast flood elevations.

Local vertical control was established on site to tie water level and marsh elevation to the National Spatial Reference System (NSRS) via a survey benchmark in Wheeler Refuge established for previous studies. Vertical control is critical for relating water level to marsh elevation and sea level rise. The benchmark was originally installed by the U.S. Fish and Wildlife Service, consisting of a brass disc stamped “GPS7 2000” set in a buried concrete post located in a roadside berm adjacent to the marsh. The benchmark is not part of any published network, and previous studies utilized static GPS survey to determine its coordinates. The previous GPS survey of the mark was conducted by Wells Reserve in 2010, and the orthometric height was adjusted using GEOID03, which has since been superseded (GEOID18 is the current model). In order to have the most accurate coordinates for the vertical control mark a new static survey was carried out using a Trimble R8 GNSS antenna set on a fixed height GPS tripod and recording positional coordinates every 15 seconds for approximately 5.5 hours. Data were downloaded and post-processed with the NOAA Online Positioning User Service (OPUS) (NOAA 2021) to obtain a network adjusted solution with a vertical error of <2 cm. The resulting solution was used to correct RTK GPS baselines. In order to assess the stability of the benchmark, and as a quality control check on the updated GPS survey, the 2010 data were reprocessed in OPUS using GEOID18.

Marsh Surface Elevation

Marsh surface elevation was measured along transects across Wheeler Refuge Marsh using a Trimble R8 RTK GPS base station and rover. Horizontal coordinates were collected in NAD83 Maine State Plane 1802 West meters, and vertical measurements were collected relative to the North American Vertical Datum of 1988 (NAVD88). All coordinates were measured in metric units. Transects were established running east-west along the reference frame gridlines and were spaced 80 meters apart from south to north with the position of the first transect randomly chosen within the first 80 meters of the southern end of the marsh. The first transect was located along UTM gridline 32870 m, the next transect was 80 meters in the northerly direction at 32950 m, the next at 33030 m, and so on, with the final transect located at 33430, for a total of 8 transects.

The RTK GPS base station was deployed over the existing benchmark adjacent to the marsh. Realtime corrections were broadcast to the rover via radio. Points were measured with the rover along each transect starting first in the adjacent roadway, then proceeding to the upland/marsh boundary and taking a measurement every 10 paces, approximately 8 m, across the marsh up to the opposite upland/marsh boundary, with a final point in the adjacent roadway at the end of the transect. In some instances, when a measurement would have been located in a marsh pool, it was instead measured at the nearest adjacent point on the transect. Other features that were measured included the top and bottom of creek banks, and several stone berms running across the channels. Each point was assigned a descriptor which indicated whether it was from the road, upland edge, marsh surface, or channel.

Marsh elevation data were downloaded and post-processed in Trimble Business Center software (Trimble 2020). Data underwent manual quality review and final data products were created for GIS mapping and analysis.

Marsh elevation data were also collected in 2010 as part of the earlier Wells Reserve study and provide a basis for assessment of marsh elevation change over the past 10 years. To enable comparison with the 2020 data, the 2010 data were checked for quality and adjusted based on the updated OPUS solution for the benchmark, essentially improving the accuracy of the older data by placing them in the newer reference frame. Since all marsh elevation measurements in 2010 were relative to this mark the adjustment required only adding the difference between the original benchmark elevation and the reprocessed elevation to the marsh elevation points.

As a final assessment of data quality and marsh elevation, a digital elevation model (DEM) was obtained from the NOAA Data Access Viewer (NOAA 2021) to enable a comparison of the RTK GPS data with remotely sensed elevations. The DEM is based on lidar data obtained by the Town of York in 2017, which represent the most accurate public remote sensing data for Wheeler Refuge. The DEM was loaded into ArcGIS Pro (ESRI 2021) and elevation values were extracted by the location of the 2020 RTK points. The extracted values were then compared with the RTK elevation measurements.

Sea Level Rise and Marsh Migration

For this study we examined the current projections for sea level rise at Wheeler Refuge and evaluated the potential change relative to current conditions. Sea level rise data were obtained from the online Sea Level Change Curve Calculator (USACE 2021) for two scenarios (Intermediate and High from Sweet et al. 2017) that have been adopted by the state of Maine for resource management and planning (MCC STS, 2020). Under these two scenarios for the Portland tide station, by 2050 we could expect to see 0.39 m and 0.84 m of sea level rise above current levels. These values were used to assess the potential impacts to the Wheeler Refuge marsh over the next 30 years. The DEM was modified to create new layers representing different tidal inundation elevations. The ArcGIS Extract By Attribute tool was used to create new layers from the DEM which include only flood elevations of interest and are referred to in this report as inundation layers. These layers were overlayed with aerial imagery base maps (ESRI 2021) to create visualizations of tidal flooding at each elevation.

Marsh migration potential in Wheeler Refuge has been mapped by the Maine Natural Areas Program (MNAP) as part of a statewide spatial dataset that is publicly available (MNAP 2021). The online data viewer can be used to assess the potential for areas adjacent to marshes to change to marsh habitat in response to sea level rise. Areas of lower gradient with intact upland or freshwater marsh habitat are ideal for supporting future marsh migration, while area of higher gradient or with hardened infrastructure are unsuitable.

Discussion of Findings

Water Level Observations

The water level stations were deployed and began logging data on November 20th, 2020. Due to freezing temperatures the loggers were removed after 15 days on December 5th, a shorter duration than planned to observe a complete lunar cycle, but adequate for calculating approximate tidal datums for comparison with the NWLON stations.

The orthometric height of each water level sensor was measured on the first day of the deployment with the RTK GPS. The sensor heights and associated vertical error for each station were: DOCK1, -1.45 m, 0.022 m; WMNORTH, 0.14 m, 0.023 m; WMSOUTH, 0.11 m, 0.016 m.

All three local water level stations were located above the lowest low-tide elevation, which precludes analysis of low tide statistics during the study period, however high-tide statistics are most relevant to marsh function, so this was not a major limitation of the study. Tidal datums were computed for each station dataset using the online Tidal Datum Calculator. The Portland Tide Station was selected as a control station in order to compute National Tidal Datum Epoch (NTDE) equivalent datums, which adjusts the datums to be comparable with the current 18-year tidal epoch from 1983 to 2001, and is more reflective of longer-term trends.

Water level data from the DOCK1 station were compared with the Portland (40 away) and Seavey Island (5 miles away) tide stations (Figure 2). While the DOCK1 data curve had a similar timing to Seavey Island, which is closer than Portland, the Wheeler Refuge station experienced higher elevation flooding, and likely would have recorded lower elevation tides as well were it not set above the low water mark in the York River. The Portland tide station had a more similar high tide range to DOCK1. Of the 29 high tides observed during the study, only six (21%) exceeded the Mean Higher High Water elevation published for the Portland Tide station, indicating that this was a period of below average tides.

A comparison of the water level data from the three Wheeler Refuge stations showed some variation in tidal flooding, particularly between WMNORTH and the other two stations (Figure 3). The stations in the marsh, WMSOUTH and WMNORTH, were set at higher elevation than DOCK1, and low tide elevation was determined by the elevation of the channel where the stations were located, while the DOCK1 station reached most, but not all, maximum low tide elevations during the study period. The WMNORTH tidal curve was slightly behind the other stations, and the outgoing tide took longer to reach its low point, indicating that this site experiences a tidal restriction at the culvert under Harris Island Road.

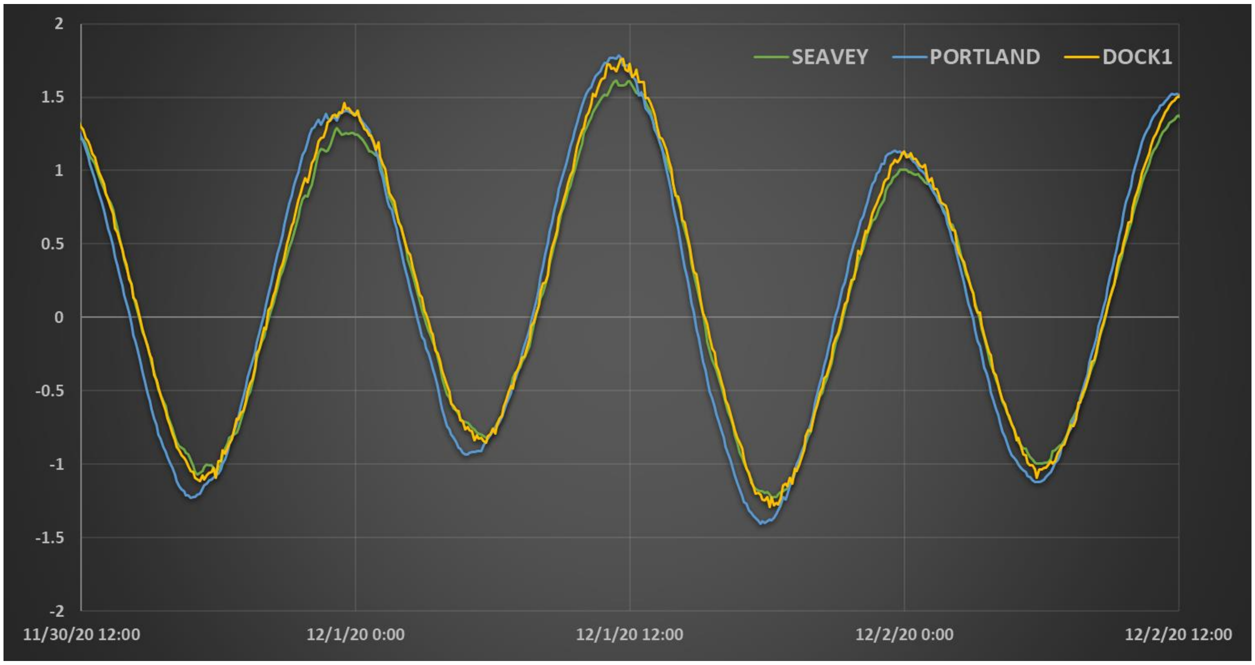

Figure 2. Hydrograph of DOCK1 station data plotted with those of Portland and Seavey Island tide stations, the two closest stations with verified water level data from NOAA.

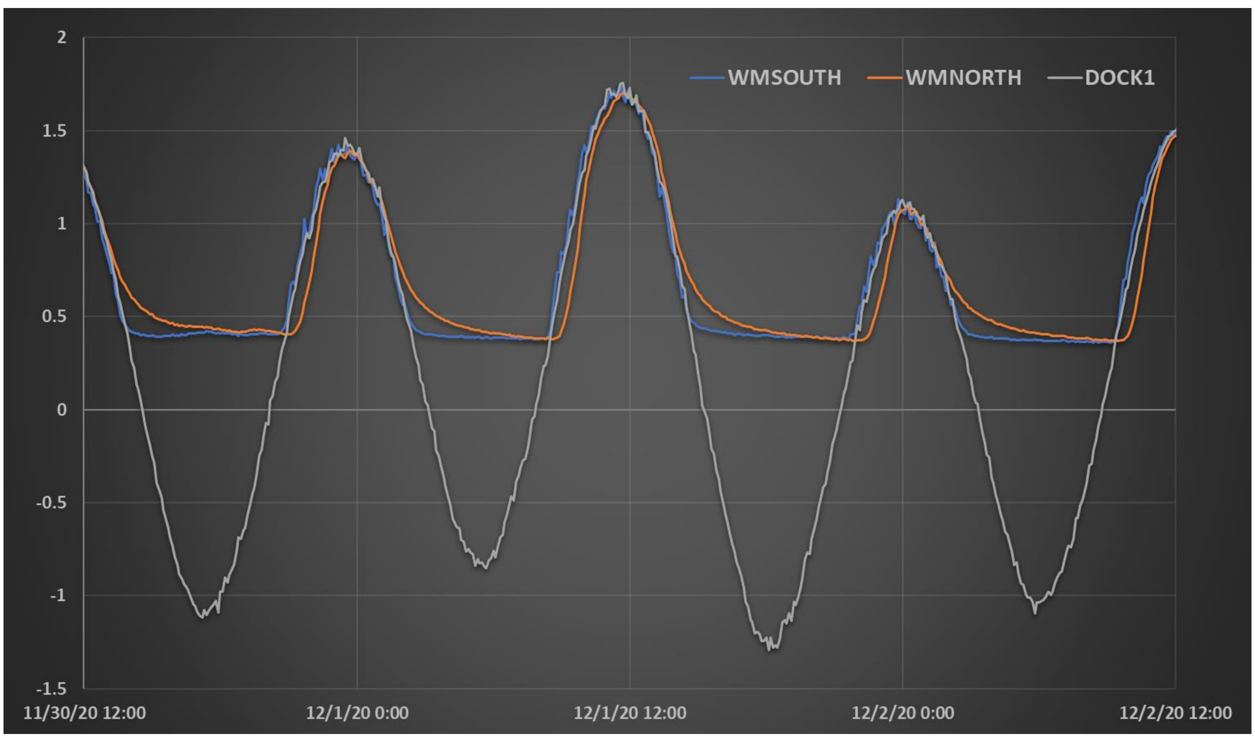

Figure 3. Comparison of the hydrographs from the three Wheeler Refuge water level stations around the December 1st high tides, the highest observed during the study.

Both WMSOUTH and WMNORTH stations experienced slightly lower mean tide elevations than DOCK1 (Table 1). This further indicates a tidal restriction at the northern end of the marsh and may indicate that the southern marsh is also experiencing a restriction in tidal flooding. If that is the case, then tidal flooding is likely restricted across the entire marsh since the north and south channels are the main source of daily flooding. The DOCK1 tidal datums closely resemble those of the Portland tide station, which may indicate that use of Portland tide station data is appropriate for future tidal assessments in the vicinity of Wheeler Refuge. Ideally, this should be confirmed with a longer data series that can document a complete spring and neap tidal cycle.

Table 1. NTDE equivalent mean higher-high water and mean high water datums for Wheeler Refuge stations, and control datums from the Portland tide station.

Tidal Datums NAVD88	DOCK1	WMNORTH	WMSOUTH	Portland, ME 8418150
MHHW (m)	1.409	1.277	1.298	1.418
MHW (m)	1.279	1.110	1.153	1.285

Marsh inundation patterns were examined by calculating the duration and depth of flooding during the observed time period relative to the average marsh elevation (1.4 m) (Table 2). The DOCK1 station experienced the most flooding, followed by WMSOUTH, and then WMNORTH with the least. During the study period the mean marsh elevation was exceeded less than 2% of the time at the marsh water level stations, and slightly above 2% for the DOCK1 station. The two sea level rise projections were also added to the DOCK1 tide data, and the same inundation analysis showed an increase of 12% and 31% for the Intermediate and High scenarios, respectively.

Table 2. Inundation statistics were calculated for each Wheeler Refuge station as well as for the theoretical sea level rise elevations (INT, HIGH) added to the DOCK1 data.

	WMSOUTH	WMNORTH	DOCK1	DOCK1 INT	DOCK1 HIGH
Flood Hours	6.5	5.8	7.7	53	120.8
% Flooded	1.82	1.62	2.15	14.82	33.77
Max Depth (m)	0.35	0.31	0.36	0.75	1.20

Vertical Control

The "GPS7 2000" benchmark was recovered easily thanks to a USFWS marker post that was installed adjacent to the disc. However, a nearby white pine tree had grown substantially, and many branches obstructed the setup of a GPS tripod and clear view of the satellites. In coordination with the Town of York, a shoreland permit was obtained to allow the trimming of branches, which were left onsite to provide habitat and not remove biomass from the system. The benchmark was occupied with a static GPS survey on November 19th for a total of 5.5 hours with data recorded at 15 second intervals. The data were downloaded and submitted to OPUS after 24 hours to obtain a rapid solution for checking the initial quality of the occupation. After the data passed the initial review the session data were processed OPUS Projects (NOAA 2021), which allows more control over the selection of reference stations and improves overall accuracy of the solution. The network solution achieved a vertical error of 0.018 m, an improvement of 0.035 meters from the rapid solution. The orthometric height obtained from the new 2020 static GPS data is 2.700 m. Updated benchmark coordinates were recorded for use in setting up the RTK GPS base station during the marsh elevation surveys.

The 2010 raw GPS data files were located with some trial and error due to problems with project archiving. It was discovered that the original solution included on an incorrect antenna offset, and this was corrected in the updated submission to OPUS. The 2010 static GPS occupation was carried out on August 13, 2010, and included just over 4 hours of 15 second observations. A new network solution was obtained for the 2010 data using OPUS Projects, achieving a vertical error of 0.018 m, an improvement of almost 0.08 m over the original 2010 solution. The updated orthometric height obtained from the 2010 GPS data is 2.731 m. The previous orthometric height was 2.815 m, a difference of 0.084 m. This difference is the value that was then used to adjust the 2010 marsh elevation data.

All GPS files, including raw data, rinex files, and computed OPUS solutions have been archived in the Wheeler Refuge project folder on the Wells Reserve server. To enhance the utility of the GPS survey the 2020 observations were submitted to NGS and accepted for inclusion in the online OPUS Shared Solutions database which is publicly available. The OPUS ID for the benchmark is BBHM54 and the shared solution is available at this link:
https://www.ngs.noaa.gov/OPUS/getDatasheet.jsp?PID=BBHM54&ts=21253180944

RTK GPS Survey and Lidar

Prior to the Wheeler Refuge restoration in 2004, Konisky and Burdick reported that the mean marsh elevation was 1.66 m relative to the National Geodetic Vertical Datum of 1929 (NGVD29). In order to compare mean marsh elevation before and after the restoration, the pre-restoration elevation was adjusted to NAVD88. This was accomplished by obtaining a local adjustment value using the online VDatum tool (NOAA 2021) which converts coordinates from one vertical datum to another. The Wheeler Refuge is actually situated just outside the VDatum grid, so a coordinate was chosen from near the York River mouth, which was assumed to be close enough for the datum transformation to be valid. At that location NAVD88 is 0.233 m below NGVD29, so the adjusted mean marsh elevation is 1.43 m.

Table 3. Summary statistics for 2010 and 2020 marsh elevation points. Elevation in meters NAVD88.

Year	2010	2020
Mean	1.4	1.4
Minimum	0.38	0.67
Maximum	1.72	1.89
Count	154	137

The marsh elevation data from 2010 were compiled in a single spreadsheet and formatted to include a descriptor field that identified marsh surface points. The 2010 elevation data are associated with vegetation data that was also collected at that time, and this information was used to identify points that were taken only in the vegetated marsh to use in this analysis. Once compiled, the elevation values were adjusted by -0.084 m, reflecting the updated benchmark elevation obtained by reprocessing the 2010 static GPS data in OPUS Projects. The 2010 survey included 154 points taken on the marsh surface, either at vegetation plots, vegetation transects, or salinity monitoring wells. The mean marsh elevation for these data was 1.40 m (Table 2).

New marsh elevation measurements were collected on December 10th, 2020. A total of 173 points were measured including 139 points in the marsh, and 34 additional points representing features of interest including the marsh channels and adjacent roadway surface. The overall precision of the vertical coordinates was relatively good, with a mean value of 0.027 m. Marsh points that achieved <0.04 m vertical precision, 137 of 139, were included in the analyses.

The mean marsh elevations from 2010 and 2020 are both 1.4 m. This is both a validation of the measurements, and also an indication that no significant elevation changes have taken place over the past 10 years. However, accretion rate may be too low to detect within the range of error associated with the elevation measurements. Mean marsh elevation was plotted against the local water level hydrographs and tidal datums (Figure 4).

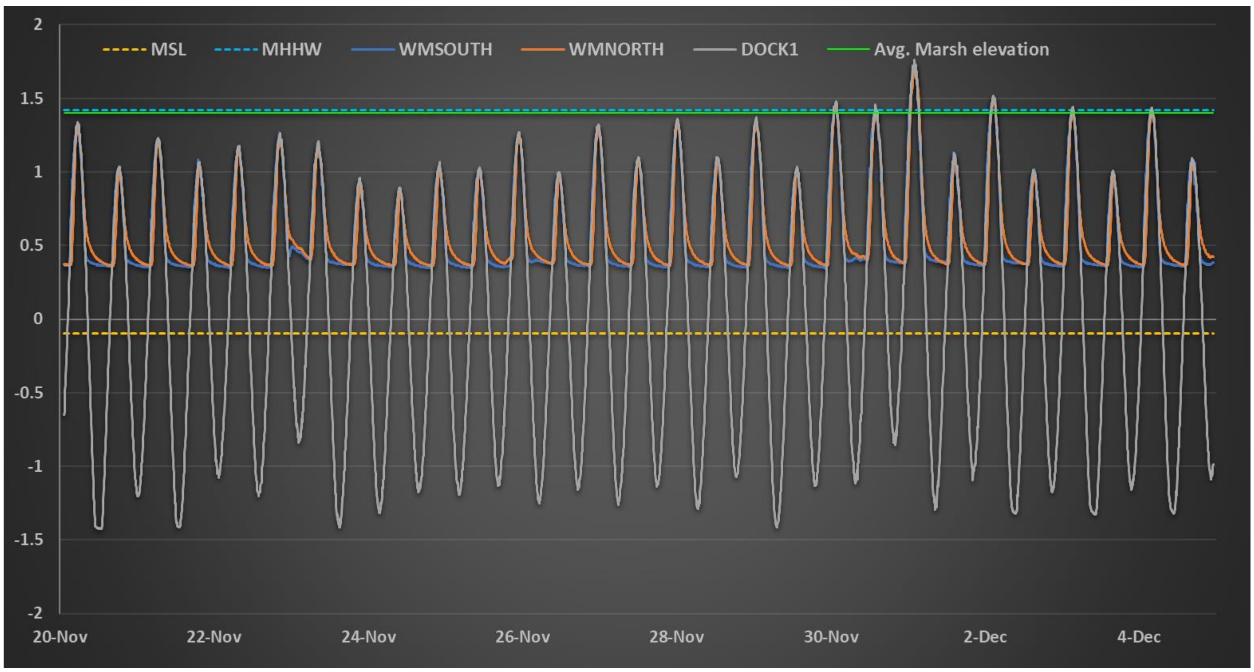

Figure 4. Wheeler Refuge tide station data is plotted with mean marsh elevation and Portland tide station datums. All data are in meters relative to NAVD88.

Marsh elevation points were loaded into GIS and symbolized by using stretched values based on the elevation value of each. The points were overlayed on aerial imagery to create a map showing the variation in elevation across the marsh (Figure 5). Each elevation transect was also plotted in MS Excel with identical ranges for the y and x axis to create comparable topographic profiles (Figure 6).

Figure 5. Marsh Elevation points are symbolized along a color gradient with dark colors representing lower values and light colors representing higher values.

Figure 6. Elevation profiles illustrate the variation across each transect

The 2017 York DEM data were loaded into ArcGIS pro along with the 2020 RTK GPS points. The 2017 DEM cell size is 0.5 m, with a reported vertical accuracy of 8 cm in open terrain. Lidar is not as accurate in dense wetland vegetation because the light does not penetrate to the bare ground as easily. We used the 2020 RTK data to evaluate the DEM for systematic error in elevation values. DEM values were extracted at each point using the ArcGIS Extract Values to Points tool, which creates a new point feature which will then include the corresponding DEM value. A new attribute field was calculated representing the difference between the RTK elevation value and the extracted DEM value, and summary statistics were calculated for the resulting values (Figure 7). The lidar elevation was on average 0.04 meters higher than the RTK elevations, which is likely due to the lidar measuring vegetative canopy rather than the marsh surface. Overall, the DEM values corresponded well to the RTK GPS measurements, and the DEM was used in subsequent analysis outlined later in this report.

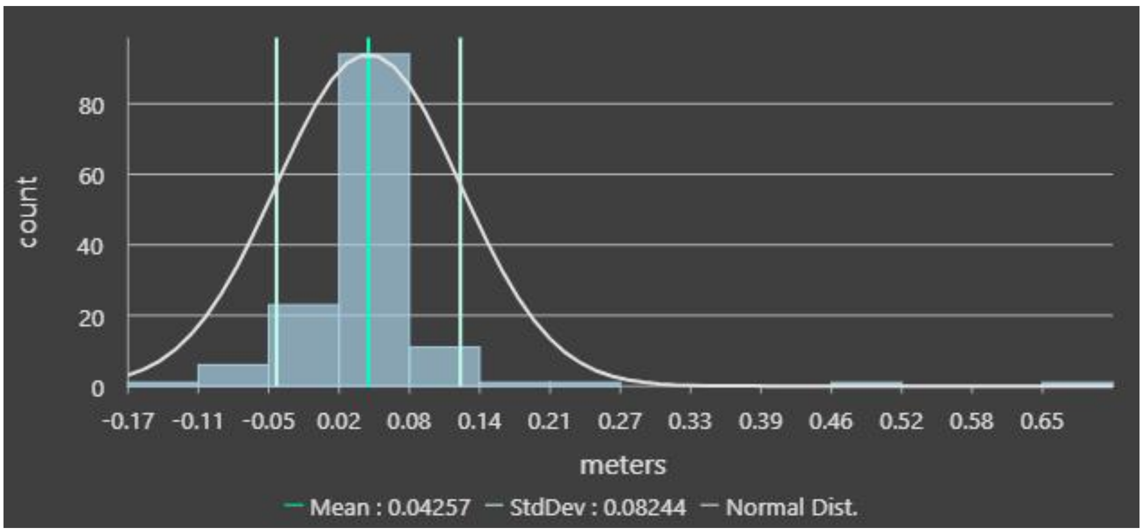

Figure 7. Distribution of the difference between RTK elevation and extracted DEM elevation.

Marsh Inundation and Sea Level Rise Mapping

Sea level rise presents an imminent threat to the continued sustainability of coastal wetlands. Increased marsh flooding will cause shifts in vegetation, with more flood tolerant species moving upgradient and lower elevation marsh converting to unvegetated mudflats. Accretion rates of sediment and organic matter on the marsh surface may not be sufficient to keep pace with sea level rise and maintain an adequate marsh elevation.

Inundation layers were created from the DEM to help visualize the extent of flooding across the Wheeler Refuge marsh. The base elevations for the inundation layers are the DOCK1 MHHW 1.41 m, and MHW 1.28 m (Table 4). The MHW elevation corresponds closely to the NTDE MHHW calculated for WMNORTH and WMSOUTH and can be used to visualize current mean flood conditions. Sea level rise inundation layers were created with the same process by adding the target sea level rise values to the base tidal elevations. A total of 6 inundation layers were created and overlayed with aerial imagery to produce inundation maps (Figures 8, 9, 10).

Table 4. Sea level rise elevations were added with the DOCK1 NTDE equivalent high tide datums to calculate inundation elevations. Elevations are in meters relative to NAVD88.

	MHHW	MHW
2020	1.41	1.28
2050 Intermediate	1.80	1.67
2050 High	2.25	2.12

The change in flooded area between the MHW and MHHW elevations is dramatic and indicates additional improvements to restore tidal flow to the interior of the marsh could have near term benefits including the potential for suspended sediment to be deposited in the interior and help increase elevation where it is at its lowest. However, increases in sea level will likely overcome the restrictions and provide significantly more flooding as the mean high tide conditions begin to overtop the southern berm.   Over time as the berm is overtopped it may begin to erode from the hydraulics of the tidal restriction. Eventually the depth of flooding will be enough to submerge the marsh for substantial periods, which should drive changes in marsh vegetation to more flood tolerant species or unvegetated flats.

This photo was taken in Wheeler Refuge by former Research Director Michelle Dionne on 10/4/2011, a day when the Portland, ME tide station recorded an above average high water level of 1.67 m. The conditions in this photo approximate what Mean High Water flooding will look like in the year 2050 under the Intermediate sea level rise scenario.

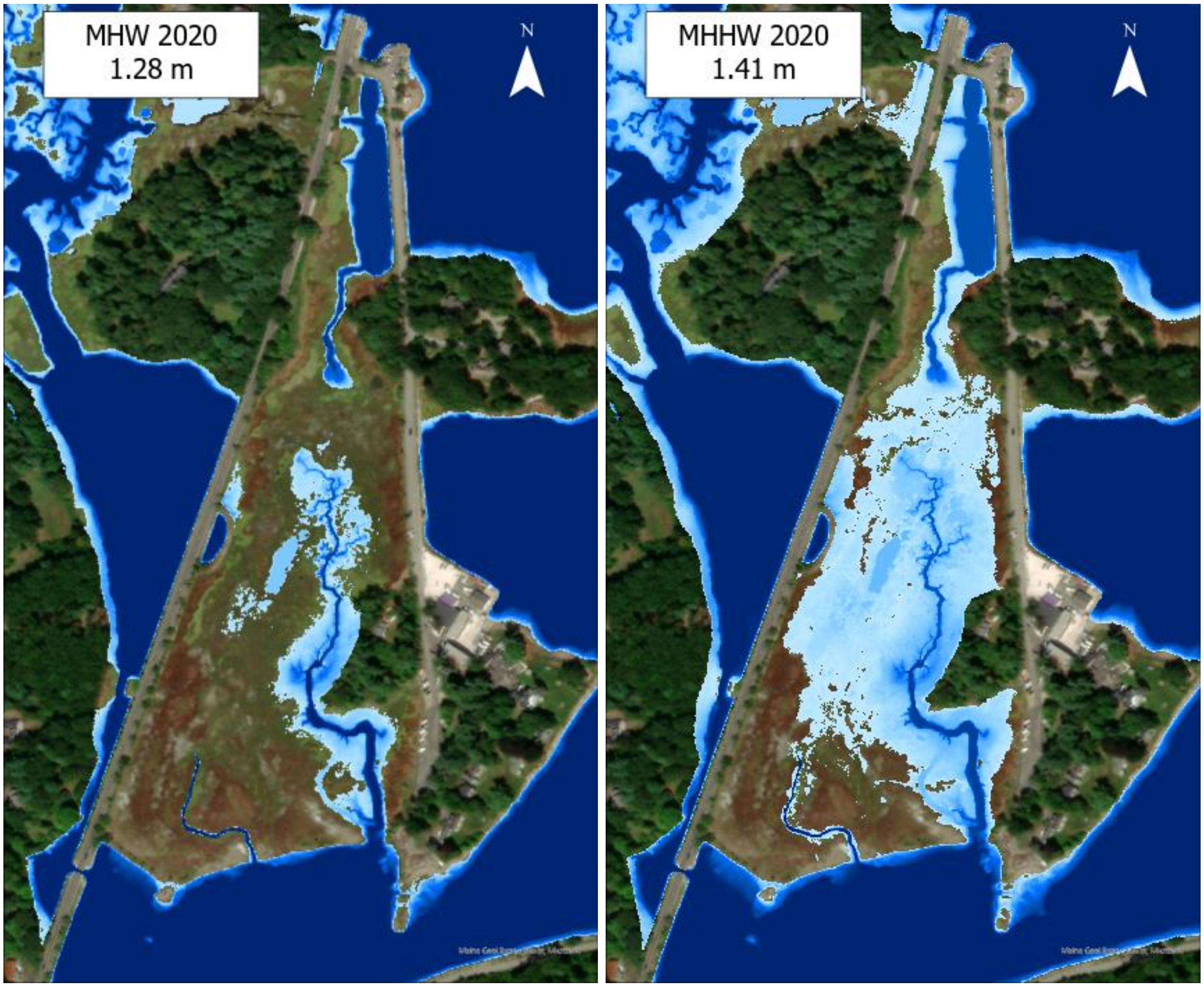

Figure 8. Innundation maps of the MHW and MHHW NTDE equivilent datums derived from the DOCK1 tide data. The MHW map likley represents the current mean higher-high water conditions within the marsh, which are lowered due to tidal restrictions.

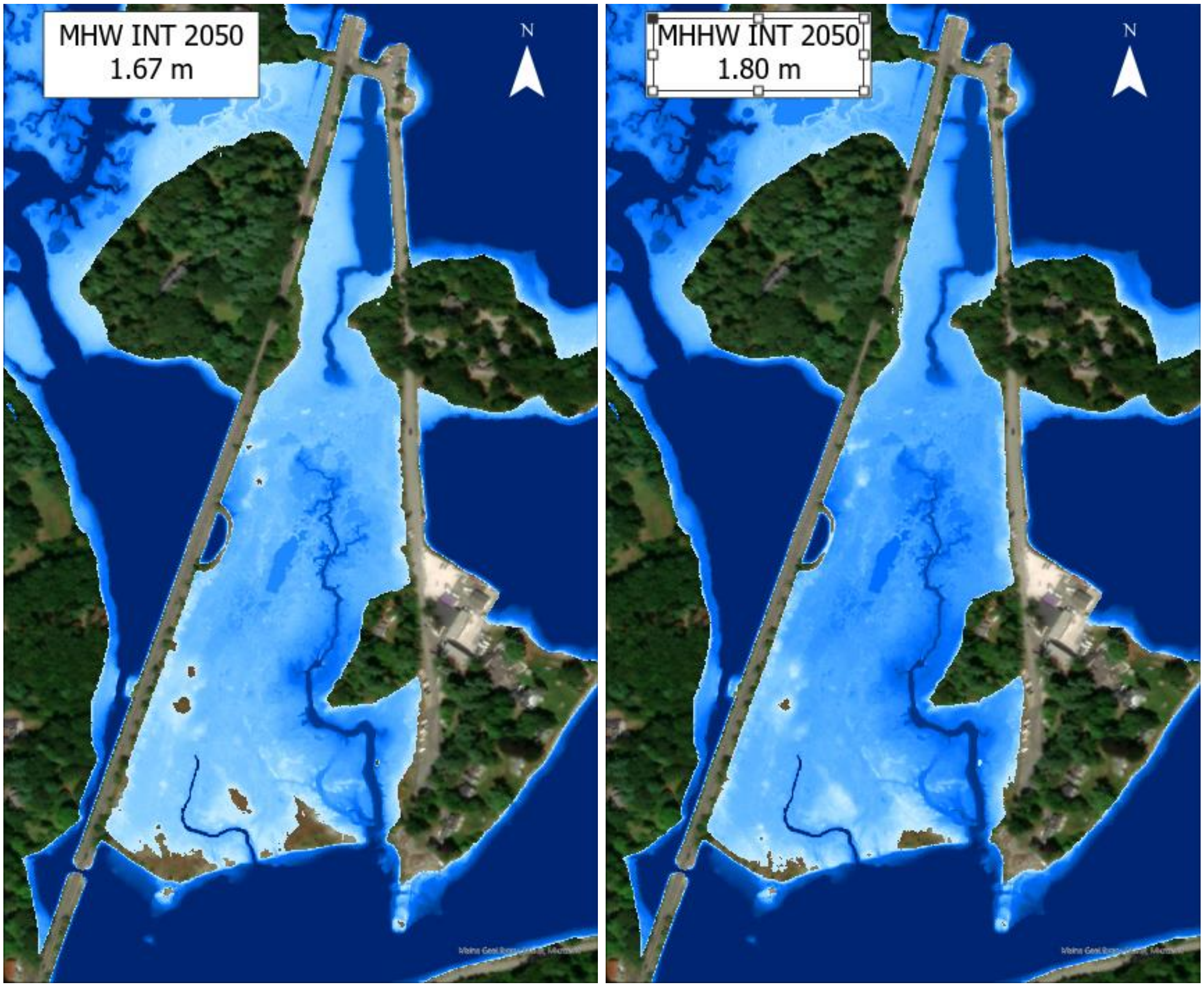

Figure 9. Inundation maps of the showing the Intermediate sea level rise scenarios at year 2050 added to the DOCK1 high tide datums. Tidal flooding begins to frequently flood the entire marsh surface.

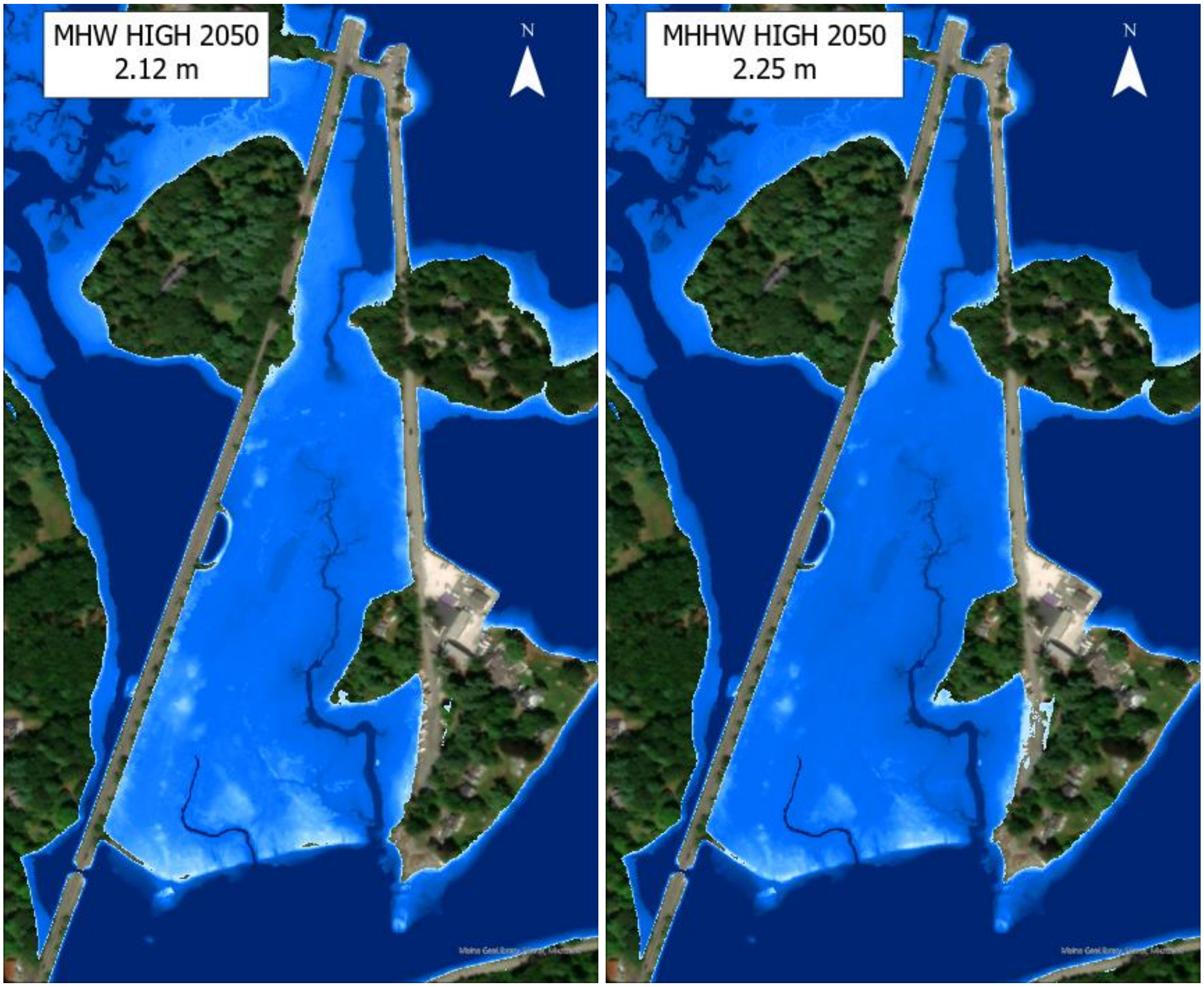

Figure 10. Inundation maps show the High sea level rise scenario at year 2050 added to the DOCK1 high tide datums. The entire marsh is deeply inundated; however, the adjacent roads remain above mean flood levels.

Marsh Migration

Review of the MNAP marsh migration data layer indicates that there is little suitable upland adjacent to the Wheeler Refuge marsh to allow for future migration of marsh vegetation. The reason for this is that the site is surrounded by roads or low elevation tidal channels, and the few areas of undeveloped upland are higher in gradient and will not be flooded to a great degree with sea level rise. The DEM also illustrates the potential tidal restriction at the southern end of the marsh where a berm is still mostly intact despite enlargement of the tidal channels as part of the the restoration (Figure 11).

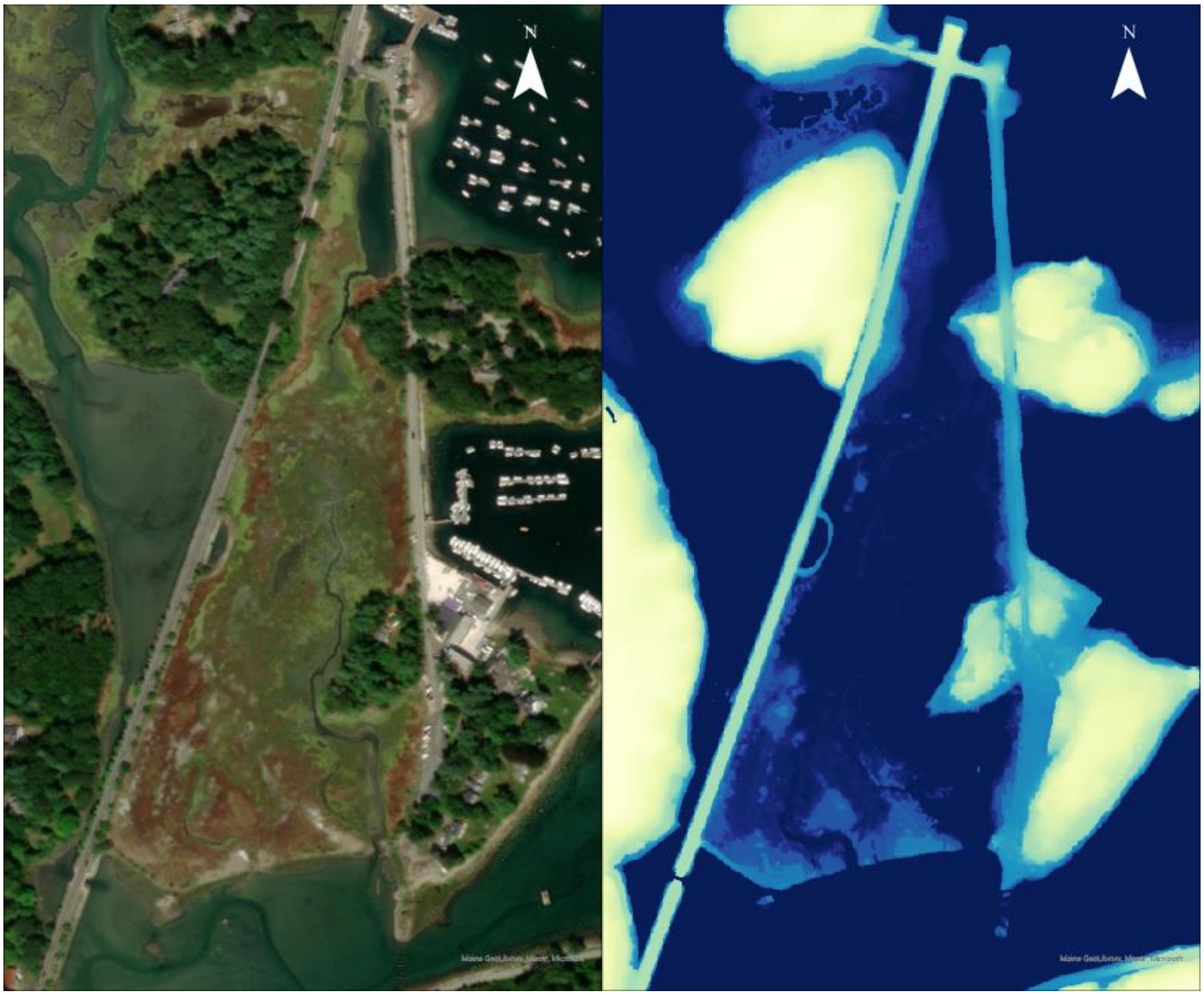

Figure 11. Aerial imagery of Wheeler Refuge marsh (left) and 2017 lidar based DEM (right). In the DEM, the colors have been adjusted to highlight the higher elevation areas (lighter colors) including the roads, upland, and southern end of the marsh.

Concluding Thoughts

The future of the Wheeler Refuge marsh is uncertain in the face of sea level rise. Just the Intermediate scenario alone will be a substantial enough increase to drive dramatic changes, and under the High scenario those changes would happen faster; the Intermediate elevation at 2050 is reached under the High scenario by 2030.

Tidal hydrology and marsh elevation in Wheeler Refuge should be monitored periodically, perhaps every 10 years, to track the trajectory of these changes. Vegetation too should be monitored if time and funding allow. Additionally, accretion rates within the marsh could be studied through the establishment of surface elevation tables (SETs).

This study has provided a basis for future comparison of conditions. However, new data and monitoring methods, including updated lidar and water level products, may become available within the next decade and future investigations should seek to take advantage of these advances.

The Town of York, as manager of the Wheeler Refuge, should consider seeking funding for further improvements to the marsh over time including improvements to tidal hydrology at the Harris Island Road culvert and the southern berm. In the 2011 report similar findings and recommendations were made regarding the remaining tidal restrictions.

Sustaining the marsh elevation relative to sea level may depend on the artificial addition of sediment, which may be feasible if a local source of material is available, such as dredge spoils from maintenance of the nearby harbor.

Salt marsh vegetation community structure is an important metric for assessing marsh health but was beyond the scope of this study. Vegetation data were collected in 2008, 2009, and 2010 as part of the earlier Wells Reserve study. These data are summarized In Appendix B to provide an overview of the marsh vegetation in Wheeler Refuge.

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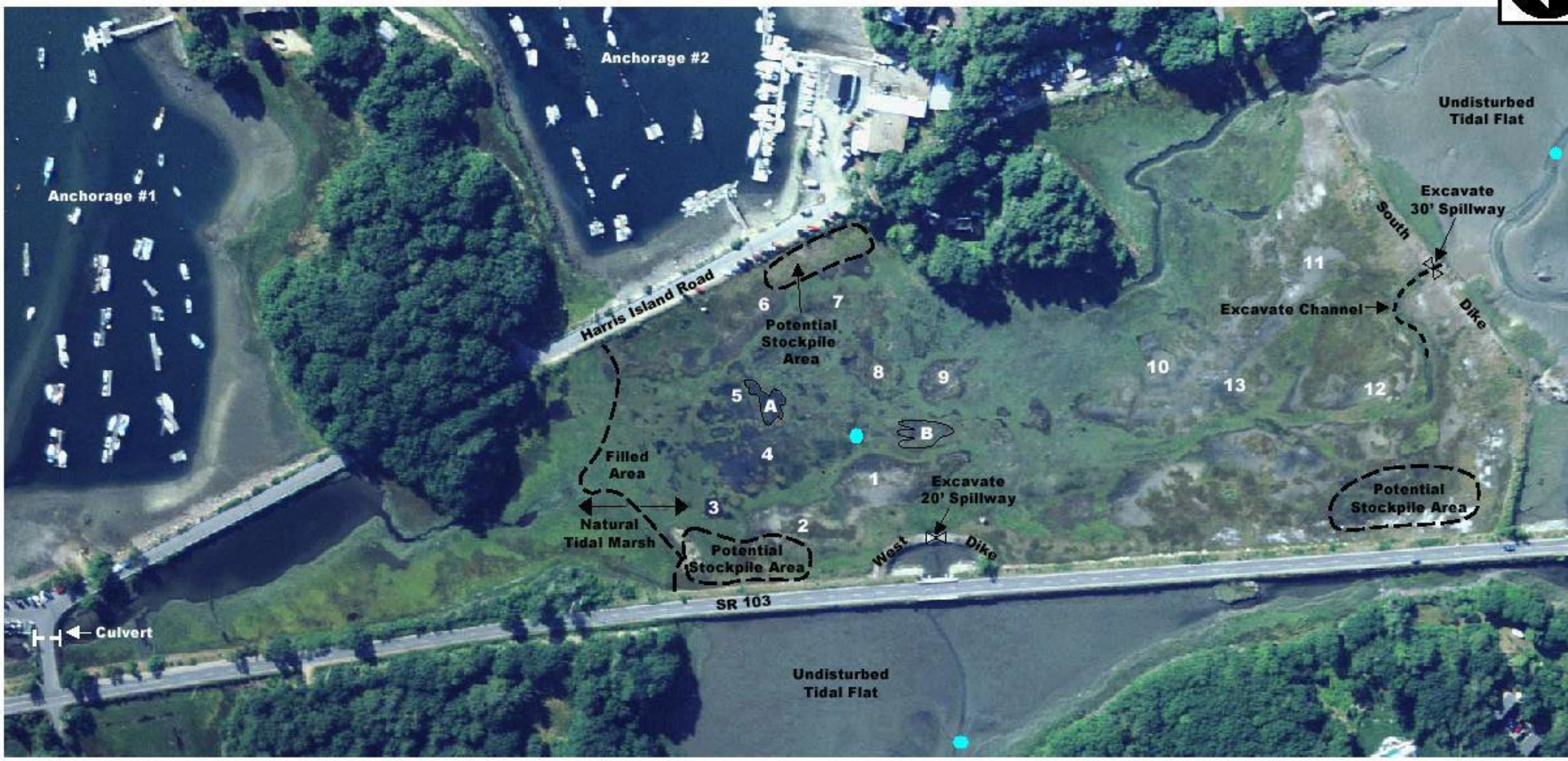


0 100 200
approximate scale in feet

LEGEND

1-13: Approximate Location of 13 Reservoirs to be Excavated

A,B: Existing Pools to be Retained Undisturbed

TRC

Boott Mills South
Foot of John Street
Lowell, MA 01852
978-970-5600

WHEELER WILDLIFE REFUGE RESTORATION/ ENHANCEMENT PROJECT

YORK HARBOR, MAINE

AERIAL SITE PLAN | Date: 4/2/03

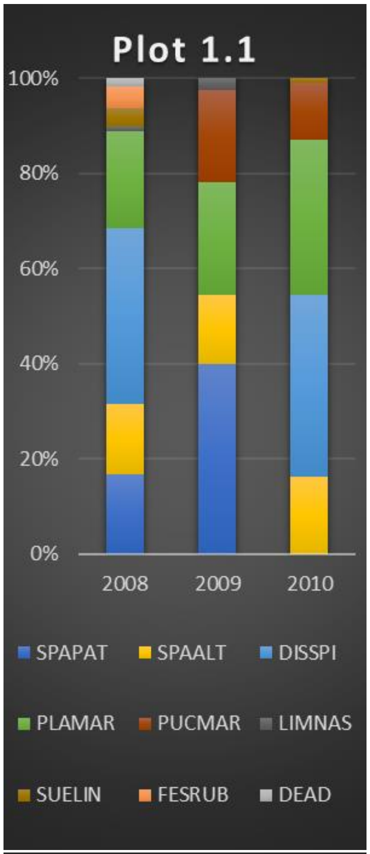
WHEELER/REV 1/AERIAL

Appendix B. Salt Marsh Vegetation Data

Vegetation community structure was assessed by the Wells Reserve in 2008, 2009, and 2010. Sample plots were established along transects running from the tidal creek edge to the upland boundary. Plots were measured each year. For details on the methodology used in this study refer to Dionne and Peter 2011 listed in the Reference section above. The graphs below show the percentage of each plant species, or non-living cover type, occurring within the plot for each year. These graphs enable quick viewing if dominant species and change in dominance between sample years. A key to the plant species and common names is included below (Table B.1). A map has also been included below to show the plot distribution within the marsh (Figure B.1).

Table B.1. Vegetation Codes and corresponding species name and common name.

CODE	*Species*	Common Name
ACHMIL	*Achillea millefoleum*	yarrow
ATRPAT	*Atriplex patula*	fat hen/Marsh Orach/Spear Saltbush
DISSPI	*Distichlis spicata*	Salt grass/Spike grass
FESRUB	*Festuca rubra*	red fescue
GERMAR	*Geralia maritima*	Seaside Gerardia
JUNGER	*Juncus gerardi*	Black Grass
LIMNAS	*Limonium nashii*	Sea Lavender
PLAMAR	*Plantago maritima*	seaside plantain
PUCMAR	*Puccinellia maritime*	Goose Grass
SALEUR	*Salicornia europaea*	Common Glasswort
SALSP	*Salicornia sp.*	Salicornia sp.
SPAALT	*Spartina alterniflora*	Saltwater Cordgrass/Smooth Cordgrass
SPAALS	*Spartina alterniflora short form*	Saltwater Cordgrass/Smooth Cordgrass
SPAPAT	*Spartina patens*	Salt Hay Grass/Salt Meadow Cordgrass
SUELIN	*Sueda linearis*	Sea Blite
TRIMAR	*Triglochin maritimum*	seaside arrowgrass
BARE	*Bare sediment*	
DEAD	*Dead vegetation*	
WRACK	*Tidal wrack*	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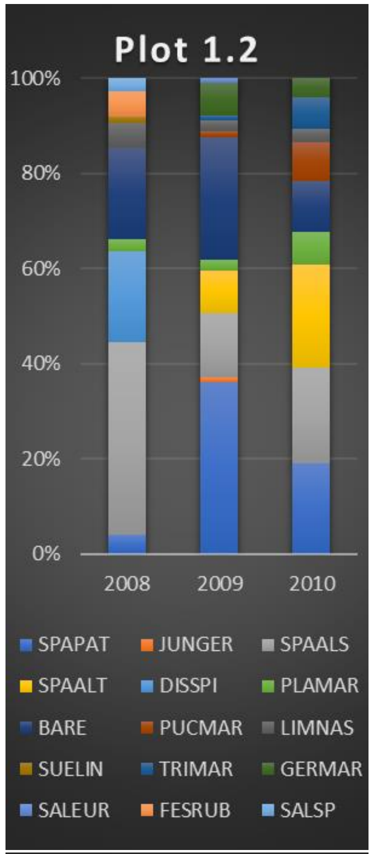
2008
2009
2010
SPAPAT
SPAALT
DISSPI
PLAMAR
PUCMAR
LIMNAS
SUELIN
FESRUB
DEAD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SPAPAT
JUNGER
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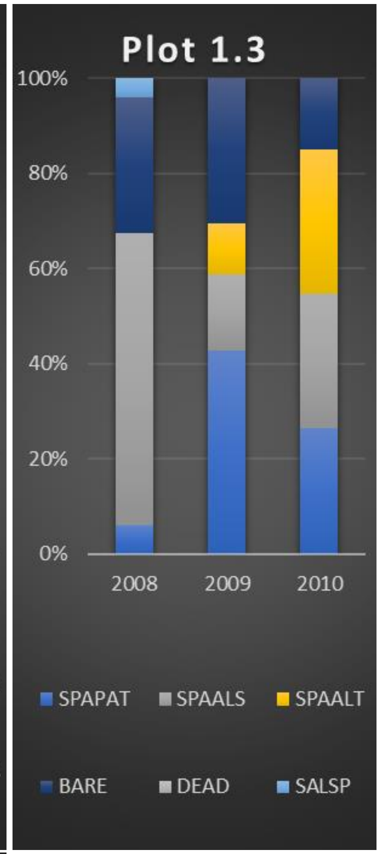
DISSPI
PLAMAR
BARE
PUCMAR
LIMNAS
SUELIN
TRIMAR
GERMAR
SALEUR
FESRUB
SALSP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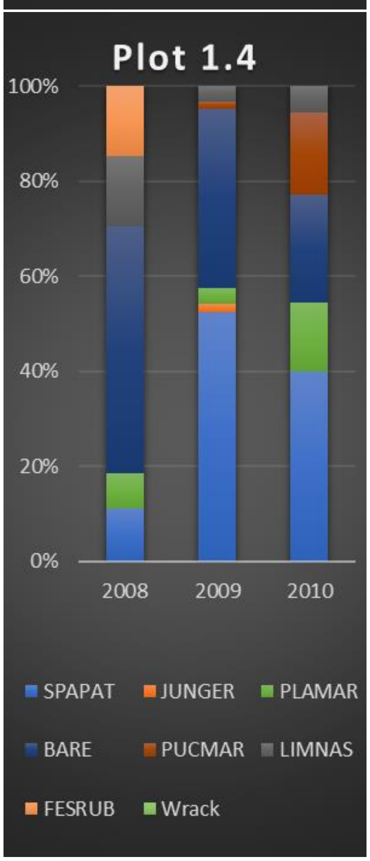
SPAALS
SPAALT
BARE
DEAD
SALSP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2009
2010
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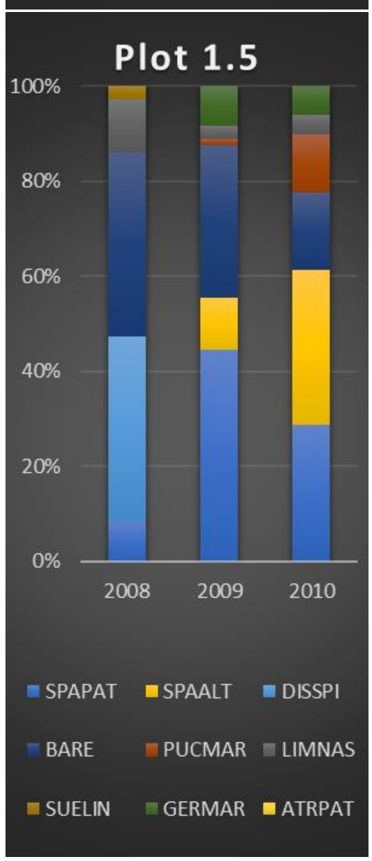
JUNGER
PLAMAR
BARE
PUCMAR
LIMNAS
FESRUB
Wrack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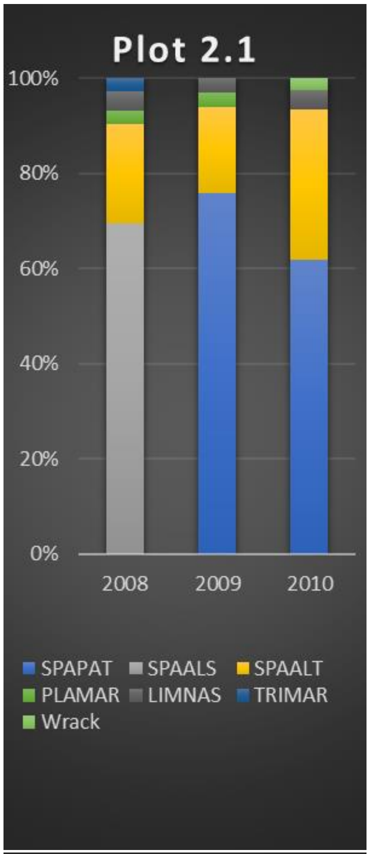
2009
2010
SPAPAT
SPAALT
DISSPI
BARE
PUCMAR
LIMNAS
SUELIN
GERMAR
ATRPAT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2008
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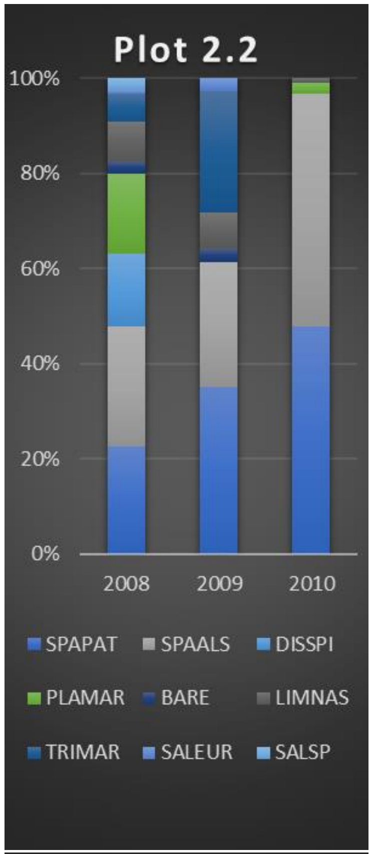
2010
SPAPAT
SPAALS
SPAALT
PLAMAR
LIMNAS
TRIMAR
Wrack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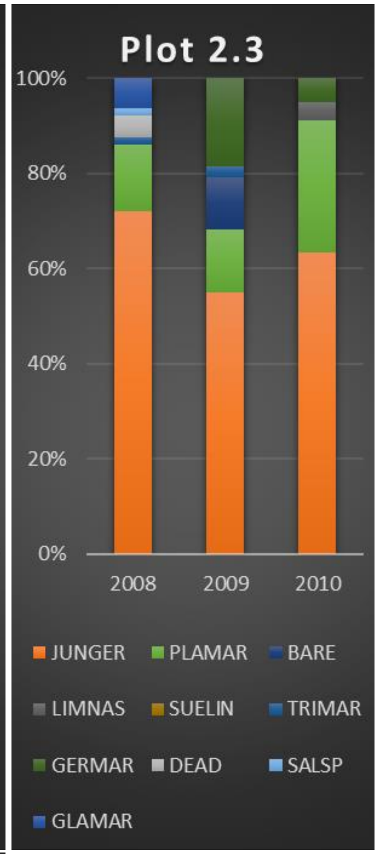
2009
2010
SPAPAT
SPAALS
DISSPI
PLAMAR
BARE
LIMNAS
TRIMAR
SALEUR
SALSP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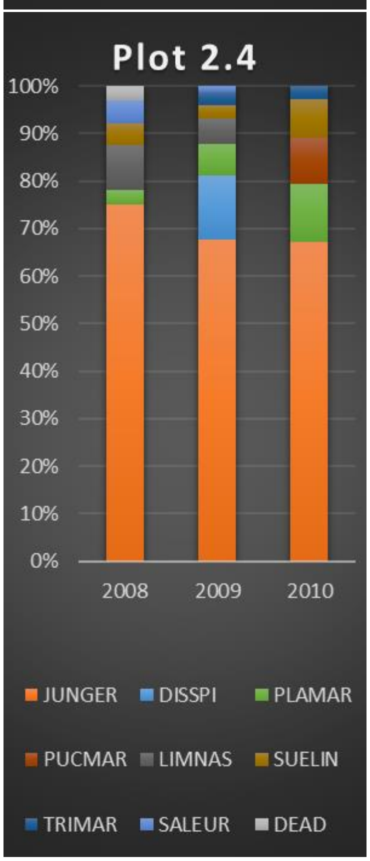
JUNGER
PLAMAR
BARE
LIMNAS
SUELIN
TRIMAR
GERMAR
DEAD
SALSP
GLAMAR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2008
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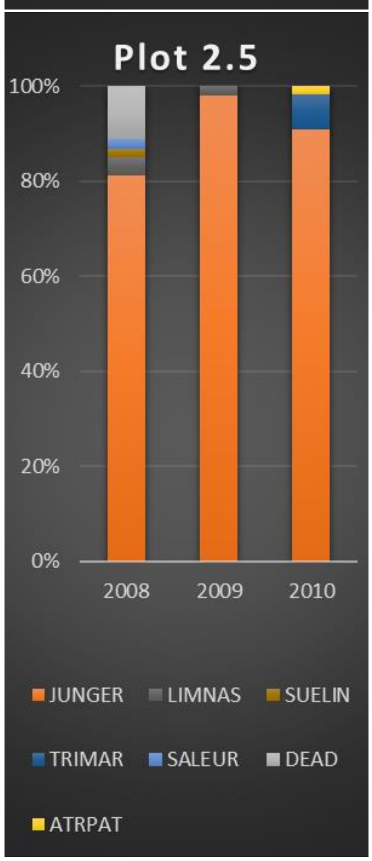
JUNGER
DISSPI
PLAMAR
PUCMAR
LIMNAS
SUELIN
TRIMAR
SALEUR
DEAD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2008
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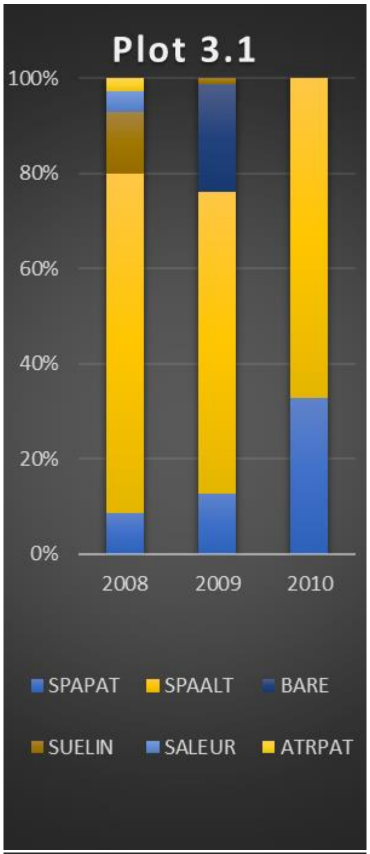
JUNGER
LIMNAS
SUELIN
TRIMAR
SALEUR
DEAD
ATRPAT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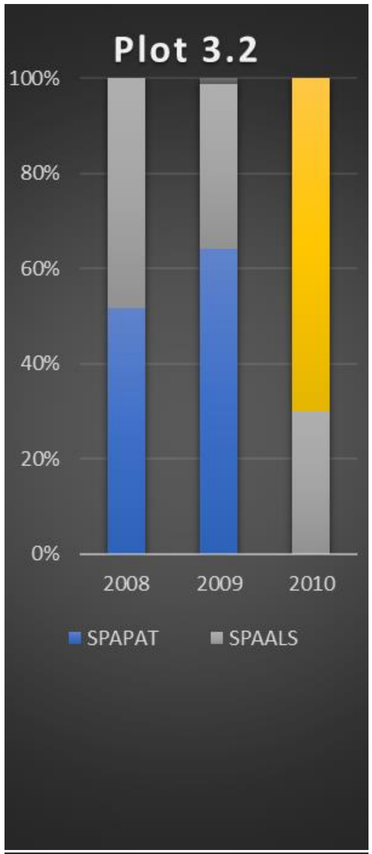
SPAPAT
SPAALT
BARE
SUELIN
SALEUR
ATRPAT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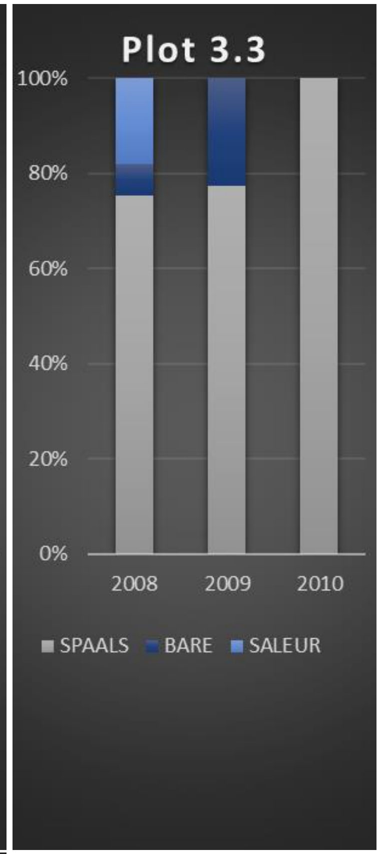
2008
2009
2010
SPAPAT
SPAALS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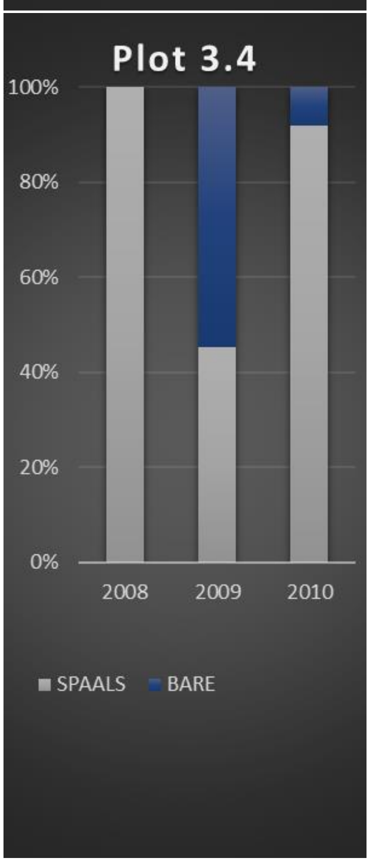
2008
2009
2010
SPAALS
BARE
SALEUR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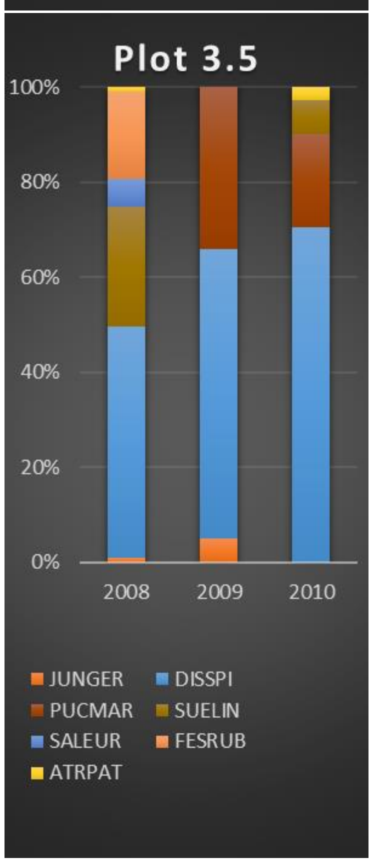
2008
2009
2010
SPAALS
BARE


Plot 3.5
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2008
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JUNGER
DISSPI
PUCMAR
SUELIN
SALEUR
FESRUB
ATRPAT

Figure B.1. Map of vegetation plots in Wheeler Marsh.