Assessment and monitoring of tidal marshes along the Tuckahoe River

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Time Period

This report covers the period from June 1, 2021 to January 31, 2024.

Background

The Mid-Atlantic Coastal Wetlands Assessment (MACWA; www.macwa.org) was started as a joint effort between two National Estuary Programs (The Partnership for the Delaware Estuary and Barnegat Bay Partnership) together with the Academy of Natural Sciences to better understand and monitor ecosystem responses to anthropogenic disturbances and climate change. This monitoring program was also designed to complement the wetland sentinel site monitoring programs of the National Estuarine Research Reserve System, a NOAA-supported program. In addition to the original partners, the approach has also been used most notably by New York City Parks and the states of New Jersey and Delaware. MACWA builds off of the three-tiered framework of a wetland assessment system developed by the US EPA which includes tier one, a landscape assessment using remote sensing, tier two, a rapid assessment using a 2-3 hour site visit, and tier three, which includes intensive physicochemical assessments (Nestlerode et al. 2014). MACWA monitoring adapts the three-tiered framework to include a fourth tier, assessing change over time, at a fixed station. With respect to MACWA, the stations installed in the Tuckahoe Wildlife Management Area will address a coverage gap in the state of New Jersey's wetland assessment and monitoring.

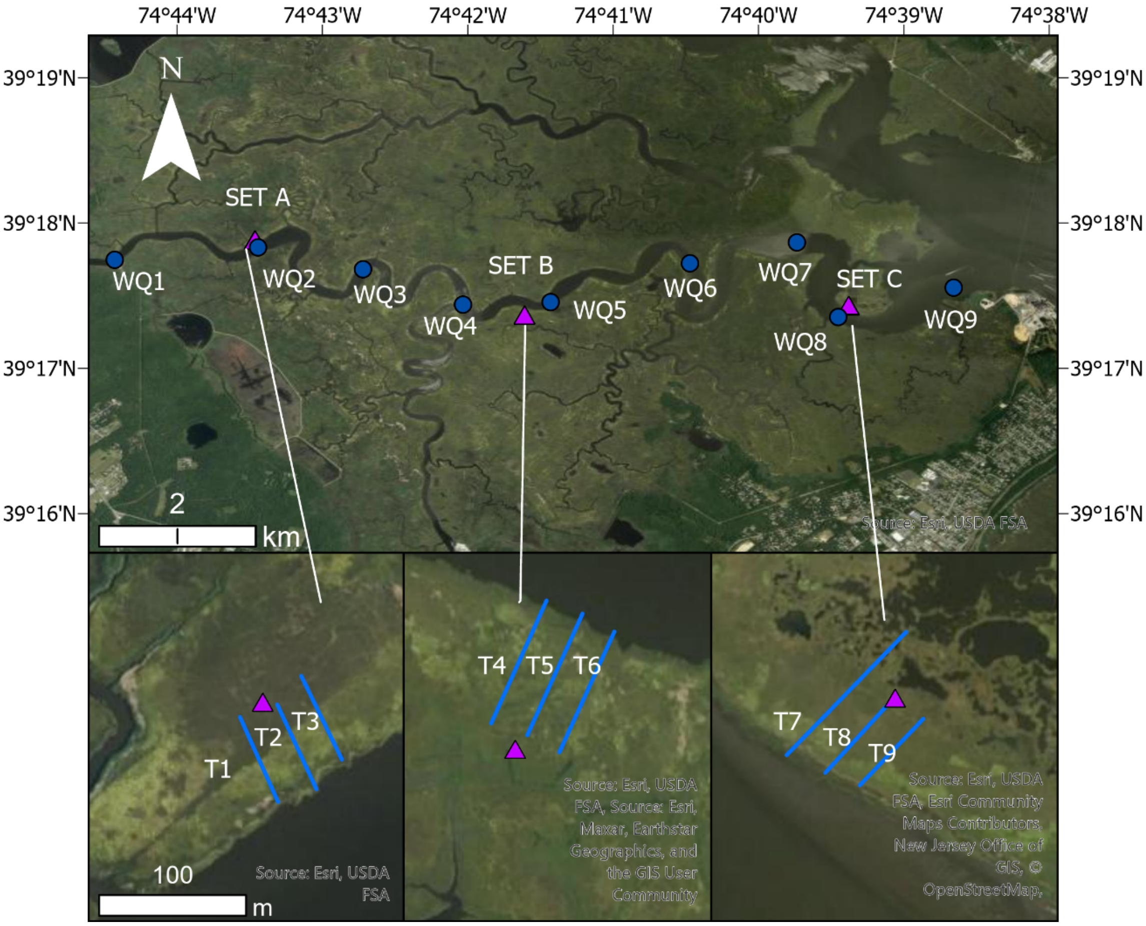
The Tuckahoe Wildlife Management Area comprises over 18,000 acres of tidal marsh, woodlands, fields, and impoundments. Six impoundments totaling 940 acres were constructed in the 1940s and have recently been retrofitted in cooperation with Ducks Unlimited. Two major rivers feed into the Tuckahoe Wildlife Management Area, which is part of Great Egg Harbor Bay: the Tuckahoe River and the Great Egg Harbor River. The Tuckahoe River is one of the few blackwater rivers in the northeastern U.S., owing its dark water color to dissolved organic matter that accumulates as the river slowly flows through the Pinelands. The river stretches nearly 20 km; it starts as a small stream in the forest, and runs east, forming the boundary between Cape May and Atlantic counties, eventually emptying into the Great Egg Harbor Bay, south of Atlantic City. The Great Egg Harbor River is an 88 km long river, and like the Tuckahoe River, traverses the largely pristine Pinelands. At 18,000 acres, the Tuckahoe Wildlife Management area is the third largest wildlife management area in the state and is the largest area of tidal wetlands managed by the State of New Jersey.

The purpose of establishing this wetland monitoring effort is to provide important baseline data about an area of coastal wetlands that is relatively unstudied in coastal New Jersey but comprises a large portion of coastal marsh under state management. In this monitoring program, we are principally assessing vegetation cover along transects, sediment accretion, marsh elevation change, and water column suspended sediment concentration, along with other water quality attributes. These metrics have been used to understand resilience of coastal wetlands to sea level rise, as marsh accretion, vegetation stability, and water column suspended sediments may be associated with long term marsh stability (Raposa et al. 2016, Wasson et al. 2019).

Site Monitoring & Assessment

Site Selection

Monitoring stations were selected spanning the salinity gradient of the Tuckahoe River in New Jersey (Figure 1). Three Surface Elevation Table – Marker Horizon (SET-MH) stations were installed to monitor changes in marsh elevation while nine sampling stations were established in the river to monitor water quality. Sampling locations were also established along transects at each of the SET-MH stations to assess vegetation and soil conditions.



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Source: Esri, USDA FSA

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Figure 1. Map of water quality stations and Surface Elevation Table – Marker Horizon (SET-MH) stations. The insets show the vegetation transects associated with each SET-MH station.

Soils

Six soil cores (6 x 30 cm) were collected from the middle transect at SETs A and C to measure soil characteristics. Cores were divided into depths of 0-5 cm, 5-10 cm, 10-20 cm, and 20-30 cm and homogenized. Sediments were analyzed gravimetrically for bulk density and percentage of water by drying a known volume of sediment (50cc) at 105°C for 24 hours. Organic matter content was measured using Loss on Ignition (LOI), where sediments were combusted at 550°C for 4 hours, and the mass lost through combustion was recorded as the percent organic matter (Heiri et al. 2001).

Sediments from these six soil cores sampled for bulk density (50 cc) were analyzed for carbon, nitrogen, phosphorus, and stable carbon and nitrogen isotopes. Sediments were weighed and analyzed for carbon and nitrogen concentration, and stable isotope ratios were measured using an Elementar Vario Micro elemental analyzer connected to a continuous flow Isoprime 100 isotope ratio mass spectrometer (Elementar Americas, Mt. Laurel, NJ). Replicate analyses of isotopic standard reference materials USGS 40 ($\delta^{13}C = -26.39‰$; $\delta^{15}N = -4.52‰$) and USGS 41 ($\delta^{13}C = 37.63‰$; $\delta^{15}N = 47.57‰$) were used to normalize isotopic values of working standards (blue mussel homogenate) to the air ($\delta^{15}N$) and Vienna Pee Dee Belemnite ($\delta^{13}C$) scales (Paul et al., 2007). Isotope values are expressed in δ notation following the formula $\delta X\ (‰) = [(R_{sample}/R_{standard}) - 1] \times 10^3$, where X is ^{13}C or ^{15}N and R is $^{13}C/^{12}C$ or $^{15}N/^{14}N$ isotopic ratio, respectively. Working standards were analyzed after every 24 samples to monitor instrument performance and check data normalization. The precision of the laboratory standards was better than ±0.3‰ for $\delta^{13}C$ and $\delta^{15}N$. The %C and %N were calculated by comparing the peak area of the unknown sample to a standard curve of peak area versus the C or N content of a known standard.

Sediments were pre-treated for analysis of phosphorus using a dry oxidation method modified from Aspila et al. (1976) and Ruttenberg (1992). Solubilized inorganic phosphorus was measured with standard phosphate procedures using an Alpkem Rapid Flow Analyzer.

A t-test was used to compare soil characteristics between upstream and downstream sites.

Biomass

Vegetation was harvested (clipped at ground level) from three 50 cm x 50 cm plots at SET A and C on 8 September 2021 (total of 6 harvests). The location of these plots was from the middle of the transects (on the right side of the transect facing the water; where vegetation measures were conducted to the left).

To analyze aboveground biomass, stem counts were made, the length of the longest three stems was measured, and material was split into the following categories: live leaves, live stems, dead stems, and dead leaves. Biomass was stored at 4°C until it was sorted, washed, and dried at 60°C until the material reached a constant weight.

Six cores (15cm x 30cm) were collected for the measurement of below-ground biomass from the middle section of three transects each at SET A and C. Biomass was washed to remove all sediment and separated into two classes of material: roots and rhizomes. Roots and rhizomes were then sorted once again into live and dead biomass. Biomass was washed and dried at 60°C until the material reached a constant weight.

Vegetation

For each SET, triplicate parallel vegetation transects of 50-100 meters in length were established with vegetation monitoring plots spaced 5 meters apart along their length (Figure1). Transect length varied based on the distance between the SET-MH stations and the shoreline. Vegetation monitoring plots were demarcated with PVC pipe, and a plot code tag was attached to each. For SET A, the transects were all 50 m in length, with 10 monitoring plots each. For SET B, the transects were 70, 75, and 70 meters in length with 14, 15, and 14 plots, respectively. For SET C, the transects were 95, 50, and 50 meters in length with 19, 10, and 10 plots respectively (Table 3). Transect numbers are labeled with the lower number transect at the upriver location and the highest number transect at the downriver location.

Vegetation was monitored between 8 – 26 September 2021, 31 August - 2 September 2022, and 14 – 30 August 2023. The point intercept method was used to quantify vegetation presence and cover in each plot using a 0.25 m^2 quadrat which was placed at each survey point. A dowel was lowered into the marsh surface at each point at the intersection of a 25 point grid, and plant species touched by the dowel were recorded. The number of ribbed mussels, *Geukensia demissa,* in each plot was also recorded. Light penetration was measured at each plot in 2023 using Photosynthetically Active Radiation (PAR) meters (Odyssey Light Meters, Dataflow Systems Ltd., Christchurch, NZ). PAR meters were placed in each plot at a height of 16 cm above the surface for 5 minutes and light was analyzed as a percentage of the total light available that was recorded by an ambient PAR with no canopy cover.

Rapid assessments were conducted using the Mid-Atlantic Tidal Wetland Rapid Assessment method (MidTRAM; Rogerson and Haaf, 2017; https://delawareestuary.s3.amazonaws.com/MidTRAM+4.1+with+Data+Sheets.pdf) on 1 September 2022, at all three SETs. Elevation measures were made at SET benchmarks during 31 August - 2 September 2022, and 24 – 30 August 2023 using a Leica AX1202 GG.

Elevation surveys were conducted along transects 14 – 30 August 2023 using the benchmarks set in SET concrete bases using a Leica Sprinter 250M with internal memory using a barcode staff gauge.

Water Quality

Nine water quality stations were established on 19 Aug 2021, approximately 1 mile apart and spanning the full distance from Mosquito Landing to Beesely's Point (Table 1).

Table 1. Water quality monitoring station locations

WQ	River mile*	Latitude	Longitude
1	0	39.295778°	-74.740472°
2	1.1	39.297222°	-74.724056°
3	2.2	39.294667°	-74.712000°
4	3.3	39.290667°	-74.700556°
5	4.1	39.290917°	-74.690528°
6	5.2	39.295361°	-74.674556°
7	6.7	39.297750°	-74.662250°
8	7.6	39.289222°	-74.657500°
9	8.4	39.292556°	-74.644306°

*measured from Mosquito Landing boat launch.

Water samples were collected from just below the surface at the nine sampling stations for analysis of Total Suspended Solids (TSS). Field-based measurements of water temperature, dissolved oxygen, pH, specific conductivity, and salinity were measured using a calibrated YSI Model 556. Water quality samples and field measurements were collected in spring and fall of each year from 2021 – 2023.

Total Suspended Solids was determined using standard methods (Eaton et al. 1995) where glass fiber filters were rinsed with reverse osmosis water, pre-dried in a drying oven for one hour at 105ºC and weighed. Subsequently, 500 mL of well mixed channel water was introduced into a vacuum flask connected to a vacuum pump and filtered. The filters were dried at 105ºC until a constant weight was achieved. The difference in weight between pre-filtering and post-filtering was divided by the volume of water filtered to determine TSS in milligrams per liter.

Surface Elevation Tables and Marker Horizons

Surface Elevation Table (SET) sites were selected to span the salinity gradient of the Tuckahoe River and to coincide with the boat launch ramps located at Mosquito Landing (39.2956°, 74.7400°) and Beesley's Point (39.2880°, -74.6270°). Three SET monitoring locations were installed in fall of 2021 (Tables 3 - 5), each with four feldspar marker beds installed on 7 Nov 2021. SETs were installed by hammering sections of stainless-steel rod into the substrate until the point of refusal. The rod depth was 10 m for SET A and 12 m for SETs B & C. Brass benchmarks were set in concrete in the PVC SET bases. Measures of benchmark elevation were collected using static GPS surveys on 31 August – 2 September 2022 and were repeated during summer of 2023 on 14 – 30 August 2023.

Table 2. Surface Elevation Table (SET) locations

SET	Installation date	Latitude	Longitude	benchmark elevation
A	24 Oct 2021	39.298194°	-74.724417°	0.612 m NAVD88
B	30 Oct 2021	39.289611°	-74.693500°	0.671 m NAVD88
C	7 Nov 2021	39.290667°	-74.656306°	0.915 m NAVD88

Table 1. SET A Vegetation sampling stations. Elevation is shown in meters relative to the North American Vertical Datum of 1988 (NAVD88).

SET	Transect	Site code	Latitude	Longitude	Elevation
A	1	1123	39.297716°	-74.724323°	0.43 m
A	1	1124	39.297754°	-74.724334°	0.63 m
A	1	1125	39.297788°	-74.724347°	0.66 m
A	1	1126	39.297835°	-74.724374°	0.67 m
A	1	1127	39.297880°	-74.724415°	0.60 m
A	1	1128	39.297919°	-74.724435°	0.60 m
A	1	1129	39.297963°	-74.724457°	0.59 m
A	1	1130	39.298005°	-74.724486°	0.61 m
A	1	1131	39.298039°	-74.724514°	0.57 m
A	1	1132	39.298078°	-74.724539°	0.56 m
A	1	1133	39.298118°	-74.724556°	0.57 m

SET	Transect	Site code	Lattitude	Longitude	Elevation
A	2	1112	39.297776°	-74.724088°	0.02 m
A	2	1113	39.297814°	-74.724113°	0.58 m
A	2	1114	39.297848°	-74.724136°	0.62 m
A	2	1115	39.297893°	-74.724164°	0.69 m
A	2	1116	39.297935°	-74.724191°	0.65 m
A	2	1117	39.297974°	-74.724215°	0.61 m
A	2	1118	39.298014°	-74.724235°	0.63 m
A	2	1119	39.298056°	-74.724265°	0.62 m
A	2	1120	39.298107°	-74.724287°	0.59 m
A	2	1121	39.298141°	-74.724315°	0.62 m
A	2	1122	39.298177°	-74.724328°	0.60 m

SET	Transect	Site code	Lattitude	Longitude	Elevation
A	3	1101	39.297916°	-74.723932°	0.45 m
A	3	1102	39.297957°	-74.723954°	0.58 m
A	3	1103	39.297995°	-74.723979°	0.63 m
A	3	1104	39.298031°	-74.724005°	0.68 m
A	3	1105	39.298074°	-74.724027°	0.67 m
A	3	1106	39.298115°	-74.724051°	0.62 m
A	3	1107	39.298157°	-74.724075°	0.63 m
A	3	1108	39.298199°	-74.724102°	0.56 m
A	3	1109	39.298235°	-74.724125°	0.60 m
A	3	1110	39.298274°	-74.724150°	0.58 m
A	3	1111	39.298312°	-74.724181°	0.62 m

Table 2. SET B Vegetation sampling stations. Elevation is in meters relative to NAVD88.

SET	Transect	Site code	Lattitude	Longitude	Elevation
B	4	1274	39.290309°	-74.693308°	0.08 m
B	4	1275	39.290269°	-74.693333°	0.64 m
B	4	1276	39.290232°	-74.693357°	0.68 m
B	4	1277	39.290189°	-74.693387°	0.67 m
B	4	1278	39.290150°	-74.693404°	0.67 m
B	4	1279	39.290114°	-74.693429°	0.73 m
B	4	1280	39.290070°	-74.693461°	0.67 m
B	4	1281	39.290032°	-74.693480°	0.62 m
B	4	1282	39.289988°	-74.693506°	0.58 m
B	4	1283	39.289943°	-74.693543°	0.60 m
B	4	1284	39.289901°	-74.693556°	0.62 m
B	4	1285	39.289862°	-74.693583°	0.63 m
B	4	1286	39.289819°	-74.693610°	0.57 m
B	4	1287	39.289773°	-74.693635°	0.54 m
B	4	1288	39.289727°	-74.693647°	0.58 m

SET	Transect	Site code	Lattitude	Longitude	Elevation
B	5	1257	39.290247°	-74.693088°	0.12 m
B	5	1258	39.290213°	-74.693114°	0.44 m
B	5	1259	39.290168°	-74.693134°	0.63 m
B	5	1260	39.290120°	-74.693158°	0.66 m
B	5	1261	39.290084°	-74.693182°	0.68 m

B	5	1262	39.290041°	-74.693204°	0.68 m
B	5	1263	39.289995°	-74.693227°	0.64 m
B	5	1264	39.289956°	-74.693251°	0.64 m
B	5	1265	39.289916°	-74.693274°	0.63 m
B	5	1266	39.289879°	-74.693296°	0.44 m
B	5	1267	39.289841°	-74.693319°	0.58 m
B	5	1268	39.289803°	-74.693345°	0.61 m
B	5	1271	39.289760°	-74.693370°	0.61 m
B	5	1272	39.289711°	-74.693394°	0.59 m
B	5	1273	39.289671°	-74.693426°	0.62 m

SET	Transect	Site code	Lattitude	Longitude	Elevation
B	6	1242	39.290162°	-74.692893°	-0.25 m
B	6	1243	39.290133°	-74.692910°	0.58 m
B	6	1244	39.290089°	-74.692938°	0.68 m
B	6	1245	39.290045°	-74.692966°	0.72 m
B	6	1246	39.290003°	-74.692989°	0.67 m
B	6	1247	39.289966°	-74.693013°	0.69 m
B	6	1248	39.289928°	-74.693032°	0.66 m
B	6	1249	39.289881°	-74.693063°	0.65 m
B	6	1250	39.289843°	-74.693080°	0.63 m
B	6	1251	39.289792°	-74.693108°	0.60 m
B	6	1252	39.289755°	-74.693126°	0.62 m
B	6	1253	39.289713°	-74.693154°	0.63 m
B	6	1254	39.289675°	-74.693180°	0.63 m
B	6	1255	39.289633°	-74.693204°	0.61 m
B	6	1256	39.289590°	-74.693230°	0.60 m

Table 3. SET C Vegetation sampling stations. Elevation is shown in meters relative to NAVD88.

SET	Transect	Site code	Lattitude	Longitude	Elevation
C	7	1219	39.290391°	-74.656969°	0.18 m
C	7	1218	39.290418°	-74.656917°	0.69 m
C	7	1217	39.290449°	-74.656881°	0.82 m
C	7	1216	39.290511°	-74.656812°	0.78 m
C	7	1215	39.290523°	-74.656792°	0.78 m
C	7	1214	39.290572°	-74.656743°	0.76 m
C	7	1213	39.290602°	-74.656689°	0.77 m
C	7	1212	39.290637°	-74.656666°	0.78 m
C	7	1211	39.290663°	-74.656612°	0.78 m

C	7	1210	39.290699°	-74.656606°	0.77 m
C	7	1209	39.290736°	-74.656573°	0.77 m
C	7	1208	39.290761°	-74.656509°	0.79 m
C	7	1207	39.290776°	-74.656477°	0.80 m
C	7	1206	39.290829°	-74.656424°	0.80 m
C	7	1205	39.290844°	-74.656394°	0.77 m
C	7	1204	39.290886°	-74.656359°	0.81 m
C	7	1203	39.290962°	-74.656278°	0.79 m
C	7	1202	39.290915°	-74.656312°	0.78 m
C	7	1201	39.290974°	-74.656238°	0.72 m

SET	Transect	Site code	Lattitude	Longitude	Elevation
C	8	1220	39.290307°	-74.656733°	0.24 m
C	8	1221	39.290323°	-74.656696°	0.75 m
C	8	1222	39.290369°	-74.656664°	0.80 m
C	8	1223	39.290408°	-74.656629°	0.76 m
C	8	1224	39.290420°	-74.656582°	0.78 m
C	8	1225	39.290464°	-74.656549°	0.76 m
C	8	1226	39.290494°	-74.656514°	0.78 m
C	8	1227	39.290529°	-74.656467°	0.78 m
C	8	1228	39.290568°	-74.656431°	0.78 m
C	8	1229	39.290616°	-74.656381°	0.79 m
C	8	1230	39.290625°	-74.656356°	0.79 m

SET	Transect	Site code	Lattitude	Longitude	Elevation
C	9	1231	39.290248°	-74.656522°	0.45 m
C	9	1232	39.290261°	-74.656487°	0.74 m
C	9	1233	39.290267°	-74.656454°	0.80 m
C	9	1234	39.290331°	-74.656429°	0.81 m
C	9	1235	39.290362°	-74.656372°	0.79 m
C	9	1236	39.290395°	-74.656338°	0.76 m
C	9	1237	39.290404°	-74.656271°	0.77 m
C	9	1238	39.290454°	-74.656248°	0.77 m
C	9	1239	39.290487°	-74.656215°	0.76 m
C	9	1240	39.290526°	-74.656160°	0.76 m
C	9	1241	39.290563°	-74.656133°	0.77 m

Results

Soils

Based on a total of six soil cores collected at the upstream and downstream SET stations, the Tuckahoe River Wildlife Management area has organic soils with low bulk density, and organic and carbon contents at the higher end of the range found in New Jersey tidal marshes (Table 6; Elsey-Quirk et al., 2022). Soil nitrogen isotope ratios were among the lowest measured in New Jersey (Krause et al., 2022), with high CN and CP ratios, suggesting oligotrophic conditions and little anthropogenic nitrogen pollution in the system. Based on a t test, we found no significant difference in soil characteristics between the upstream and downstream locations for bulk density, percent water, percent organic content, percent carbon, or nitrogen, CN ratio, CP ratio, or d^{13}C. Based on a threshold probability of p =0.05, we found greater soil phosphorus values upstream (p =0.005). We also found greater NP ratios (p =0.008) and d^{15}N values at the downstream station (p =0.023).

Table 6. Soil characteristics measured on six soil cores collected and processed from transects at SETs A & C. Means and standard deviations are shown for n=6 cores.

soil measure	mean ± standard deviation
bulk density	0.23 ± 0.031 g cc^{-1}
fraction water	80 ± 4.7 %
organic content (LOI)	54 ± 8.1 %
percent carbon	25 ± 5.2 %
percent nitrogen	1.1 ± 0.20 %
percent phosphorus	0.067 ± 0.014 %
CN ratio	23 ± 3.8
CP ratio	400 ± 130
NP ratio	17 ± 3.6
d^{13}C	-15.3 ± 0.52 ‰
d^{15}N	1.21 ± 0.51 ‰
carbon density	0.059 g cc^{-1}

Biomass

Overall, we found standing aboveground biomass of 713.6 ± 324.5 g m^{-2} at the six plots where we harvested plant material (mean ± standard deviation). Although there was high variability and therefore no statistically significant differences between upstream and downstream plots, we found greater biomass (852 g m^{-2} upstream vs. 575 g m^{-2} downstream) and stem density (3445 stems m^{-2} upstream vs. 1817stems m^{-2} downstream) at the upstream plots than the downstream plots (Table 7).

Table 7. Mean biomass measures for plots harvested and processed. Uncertainty is standard deviation.

Biomass measure	Upstream plots	Downstream plots
live stems	112 ± 168 g m^{-2}	139 ± 31 g m^{-2}
dead stems	323 ± 325 g m^{-2}	65 ± 39 g m^{-2}
live leaves	227 ± 192 g m^{-2}	87 ± 55 g m^{-2}
dead leaves	67 ± 33 g m^{-2}	150 ± 36 g m^{-2}
litter	122 ± 82 g m^{-2}	136 ± 59 g m^{-2}
Total living AG biomass	339 ± 257 g m^{-2}	225 ± 24 g m^{-2}
Total dead AG biomass	513 ± 296 g m^{-2}	350 ± 68 g m^{-2}
Total AG biomass	852 ± 451 g m^{-2}	575 ± 49 g m^{-2}
Stem density	3,445 ± 2397 stems m^{-2}	1,817 ± 540 stems m^{-2}
Longest mean stems	43 ± 7.6 cm	40 ± 3.5 cm
Total belowground biomass	9,900 ± 2700 g m^{-2}	10,300 ± 1100 g m^{-2}

Vegetation

In total, nine species were found along the marsh vegetation transects: *Spartina cynosuroides* (Big cordgrass)*,* short and tall form *Spartina alterniflora* (saltmarsh cordgrass, synonym *Sporobolus alterniflorus), Spartina patens* (Salt hay, synonym *Sporobolus pumilus), Salicornia depressa* (common glasswort)*, Distichlis spicata* (saltgrass)*, Iva fructescens* (high tide bush)*, Atriplex patula* (spear saltbush)*, Pluchea odorata* (Sweetscent), and *Eleocharis parvula* (dwarf spikerush) (Figure 2)*.* The ecotype of *S. alterniflora* (short or tall form) was determined by location and height. *Spartina alterniflora* was recorded as tall form if it was taller than 20 – 30 cm and short-form if it was less than 20 – 30 cm in height. In addition, we recorded bare ground and wrack (dead organic material deposited by tides). *Spartina cynosuroides* and *Pluchea odorata* were found only at the most upstream location. We have retained the past names for *Spartina* species, although it is important to note that a recent revision of the *Spartina* genus has established primary names of *Sporobolus pumilus* for *Spartina patens* and *Sporobulus alterniflorus* for *Spartina alterniflora,* although these synonyms are not yet commonly used by wetland scientists (Bortolus et al. 2019).

Spartina cynosuroides and tall form *Spartina alterniflora* grew along the edges of the marsh but were not found in the marsh interior. *Spartina cynosuroides* was more common at the upstream location and was not found at the seaward most site. Short form *Spartina alterniflora* was the most common plant growing on the marsh platform. *Spartina patens* and *Distichlis spicata* were also found to be abundant.

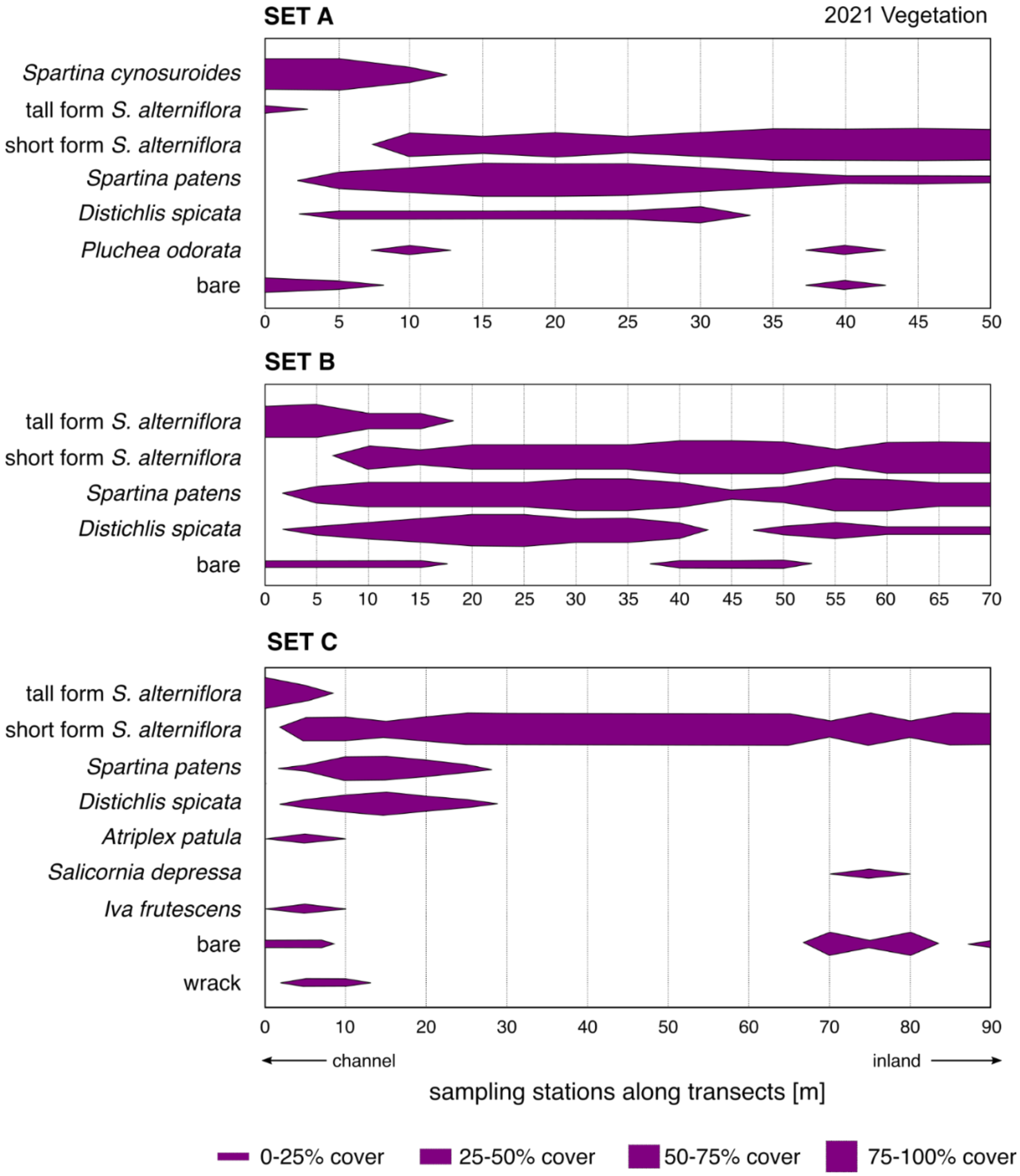

Figure 4. Violin plots showing distribution of 2021 marsh vegetation across nine transects associated with the three Surface Elevation Tables (SETs): SET A, which is at the freshest and upstream location along the Tuckahoe River, SET B, which is at the middle location, and SET C, which is at the saltiest and most downstream location. Thickness of the horizontal bar indicates the percent cover of vegetation, bare ground, and organic material deposited by tides (wrack).

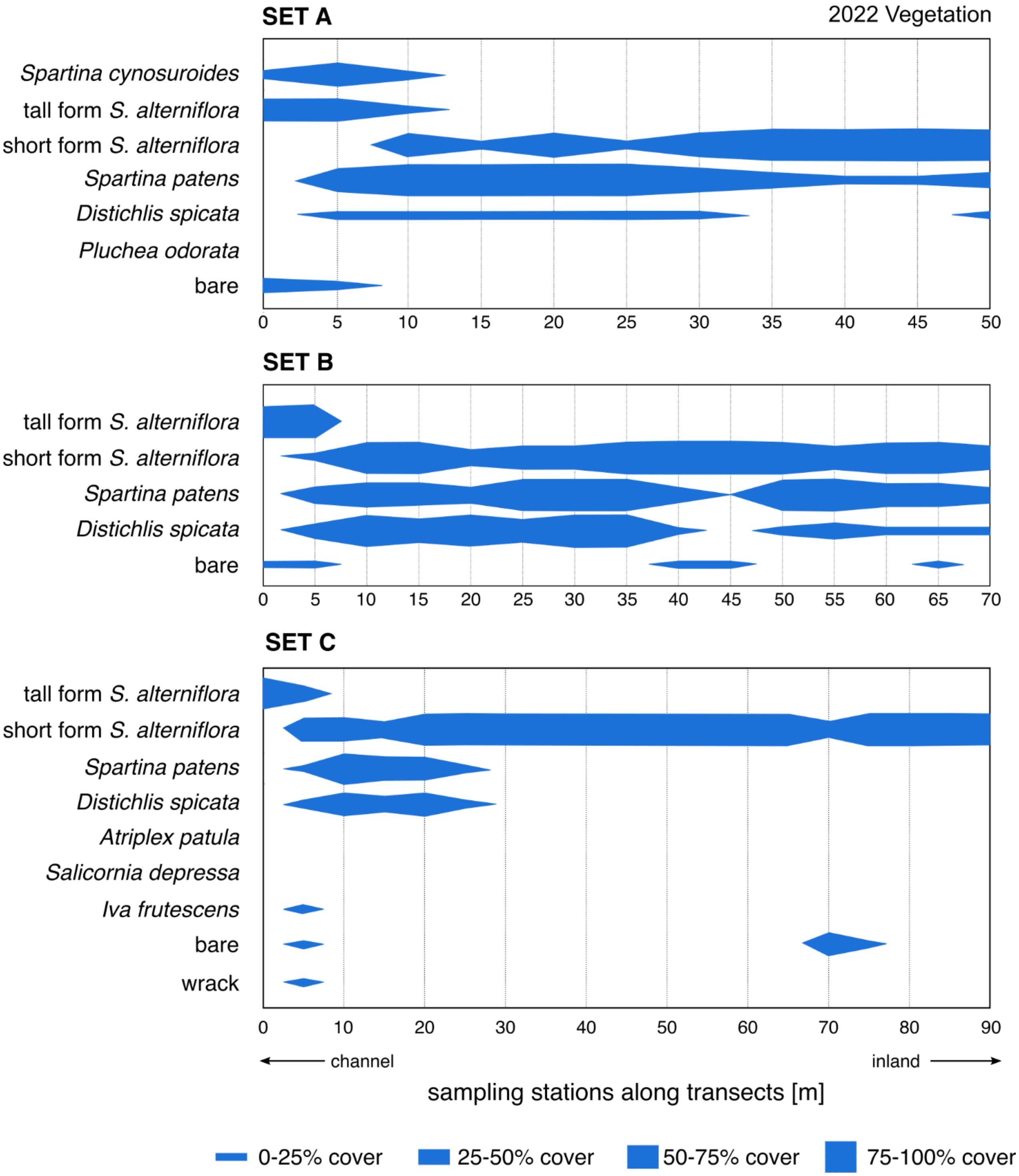

Figure 4. Distribution of 2022 marsh vegetation across nine transects associated with the three Surface Elevation Tables (SETs): SET A, which is at the freshest and upstream location along the Tuckahoe River, SET B, which is at the middle location, and SET C, which is at the saltiest and most downstream location.

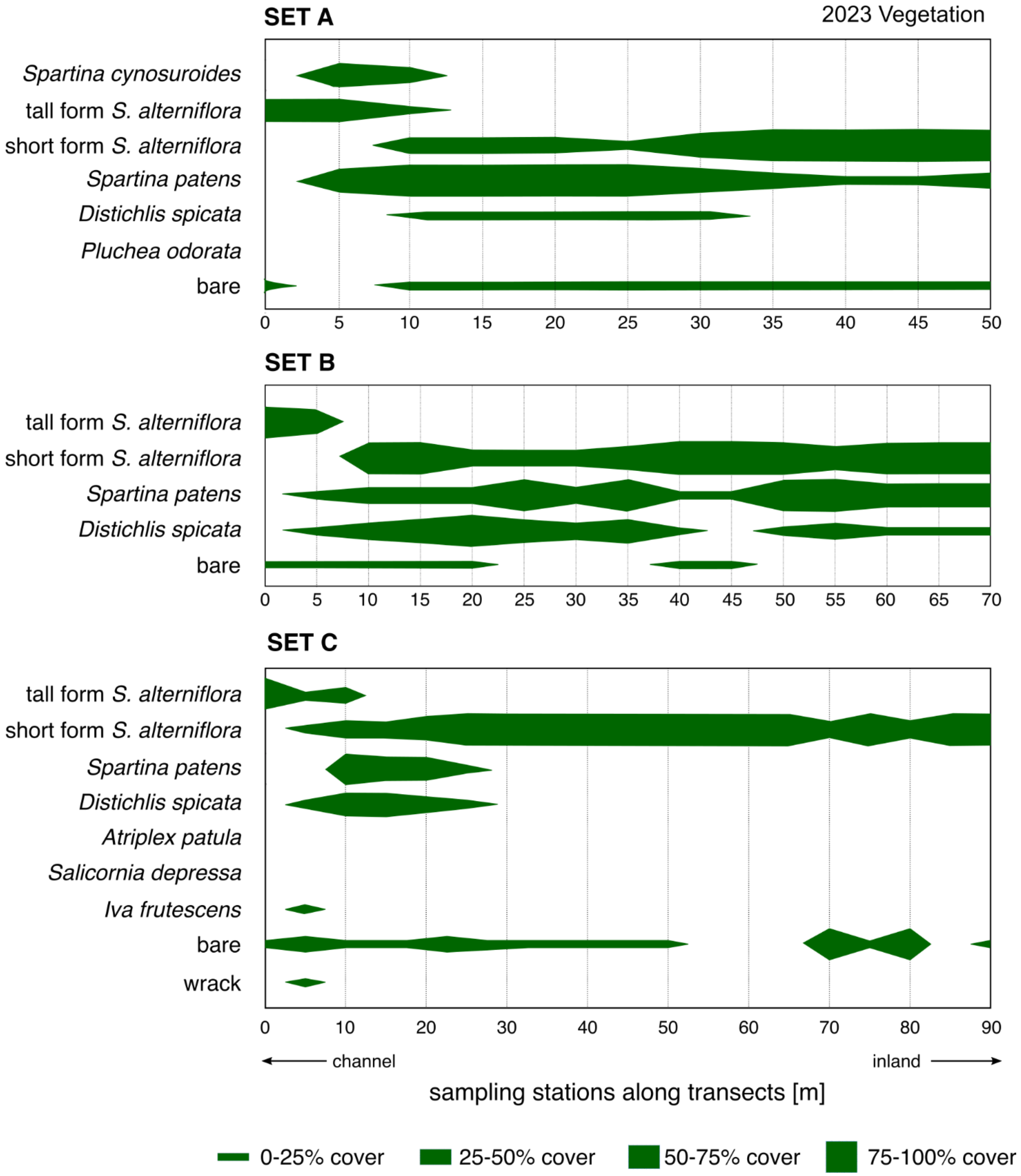

Figure 5. Distribution of 2023 marsh vegetation across nine transects associated with the three Surface Elevation Tables (SETs): SET A, which is at the freshest and upstream location along the Tuckahoe River, SET B, which is at the middle location, and SET C, which is at the saltiest and most downstream location.

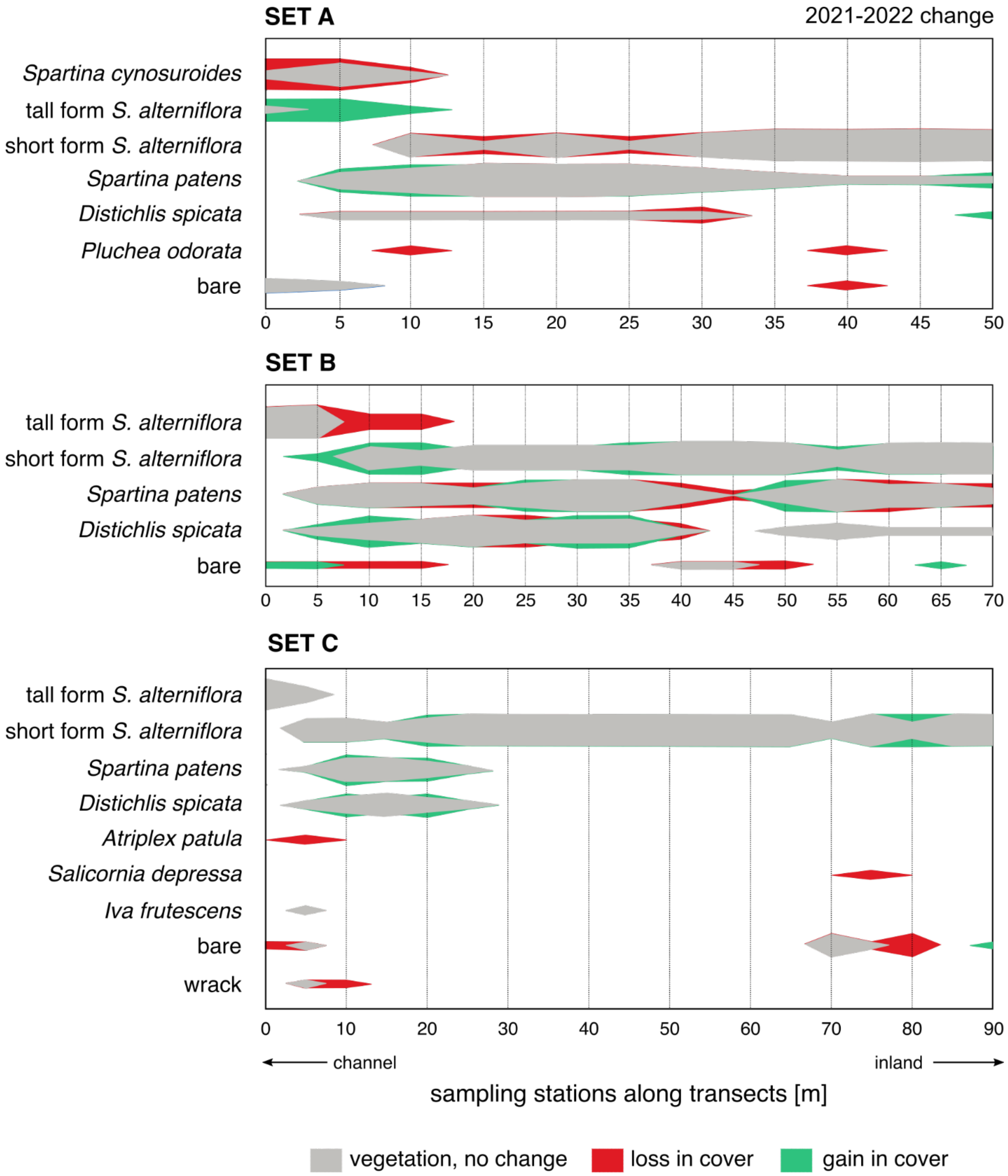

Figure 6. Changes in vegetation cover between 2021 and 2022 at each Surface Elevation Table (SET) location. Thickness of the horizontal bars indicates the percent cover and color indicates the change in cover from 2021 – 2022.

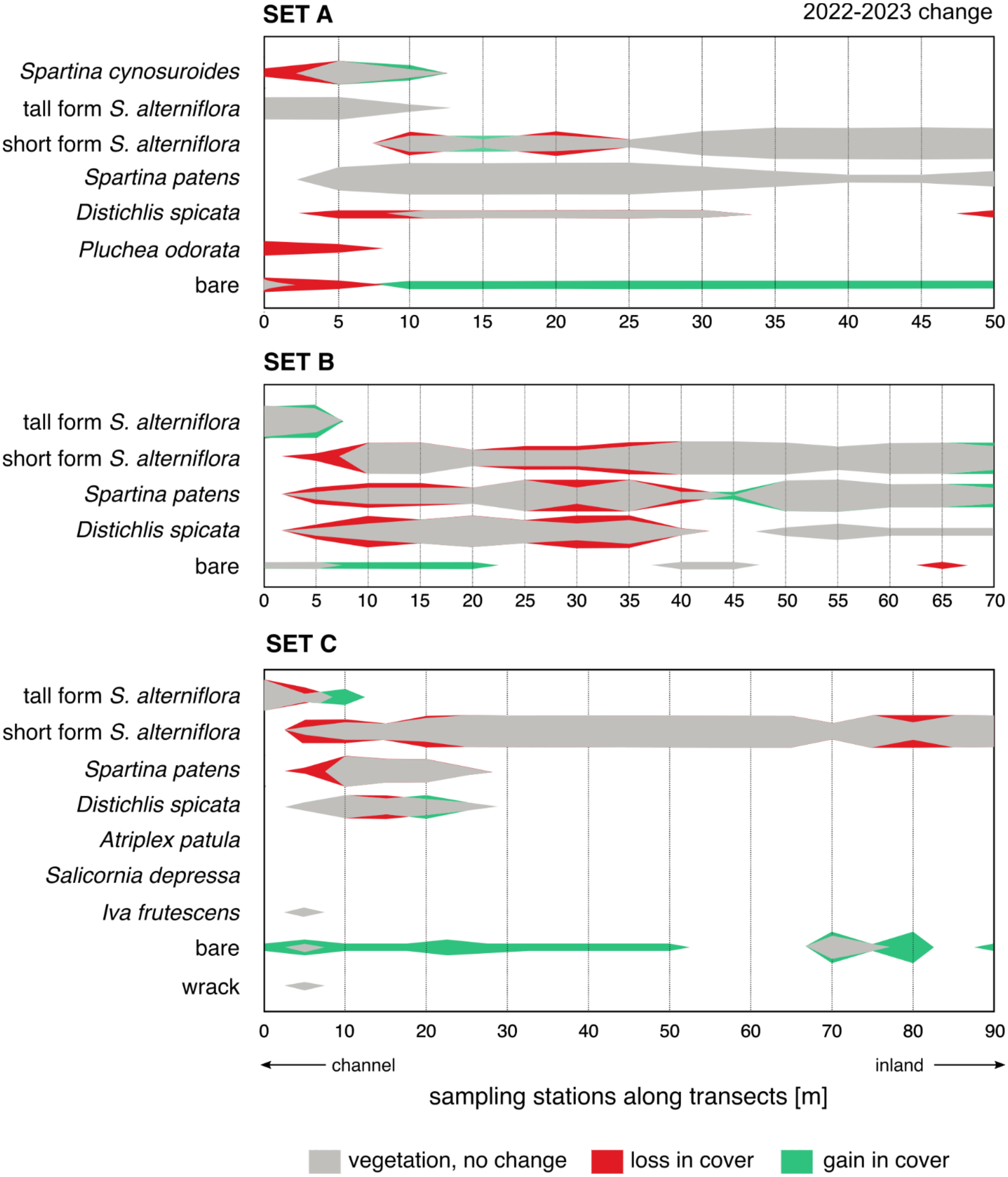

Figure 7. Changes in vegetation cover at each Surface Elevation Table (SET) between 2022 and 2023. Thickness of the horizontal bars indicates the percent cover and color indicates the change in cover from 2021 – 2022.

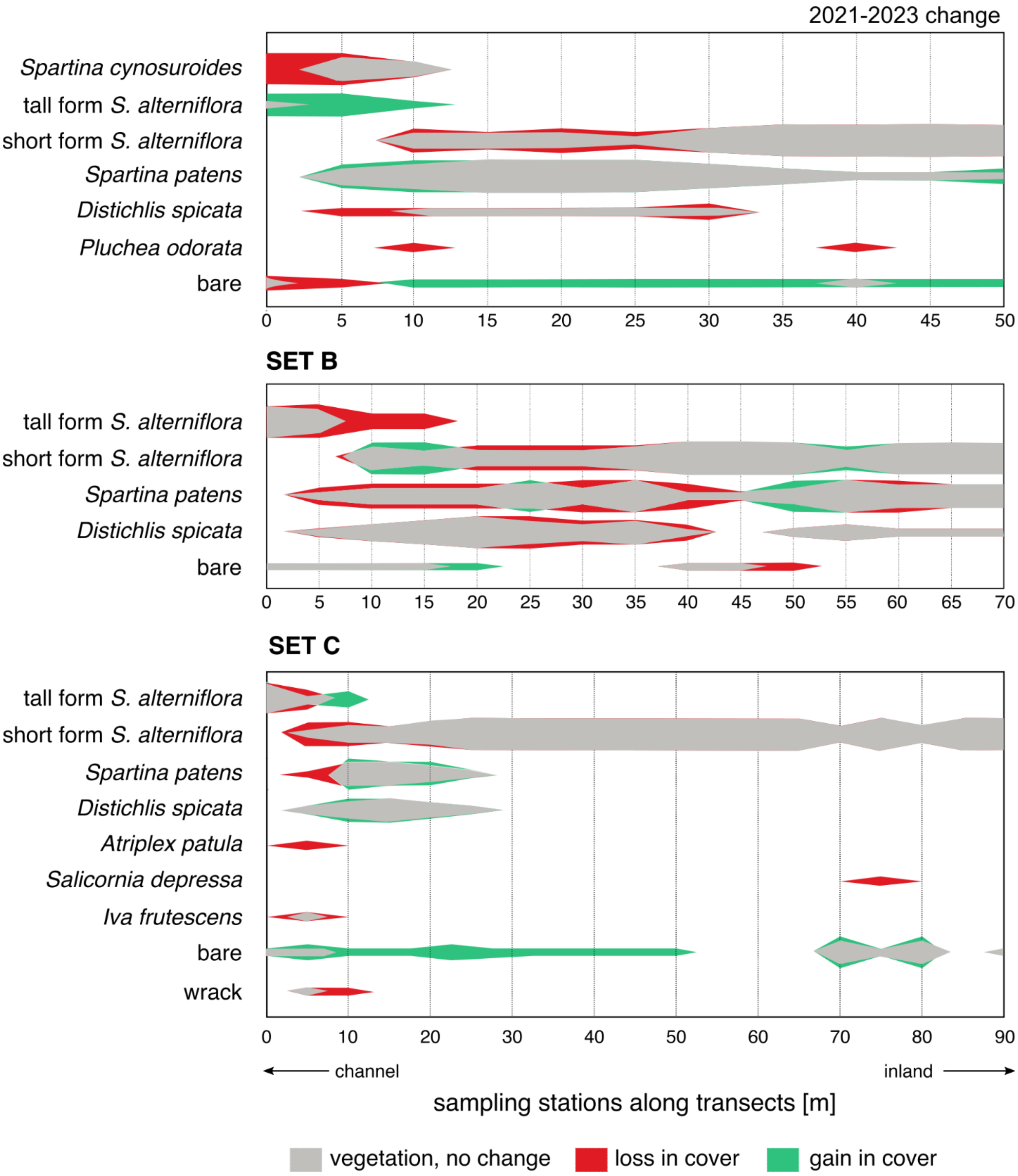

Figure 8. Changes in vegetation cover at each Surface Elevation Table (SET) between 2021 and 2023.

Elevations along transects ranged from -0.24 to 0.82 m NAVD88, with the median marsh platform elevation at 0.64 m. The platform height was lowest at the upstream location (median = 0.61m), at a midlevel a midstream location (median = 0.63m), and highest at the downstream location (median = 0.78 m).

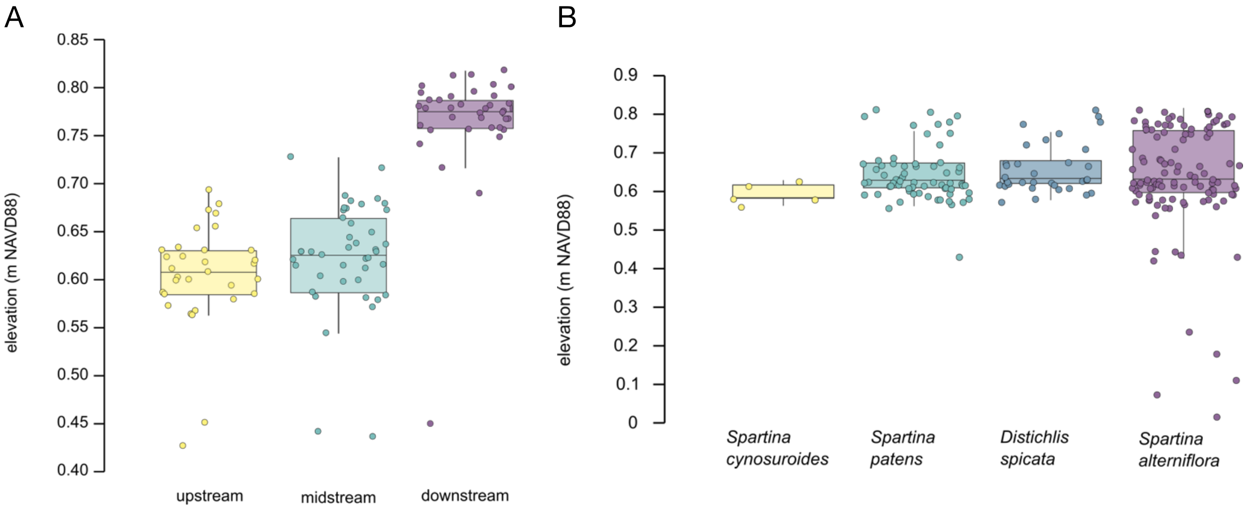

Figure 2. Box plots of marsh elevations for upstream, midstream, and downstream Tuckahoe River marshes (A) and most common plant types (B). *Spartina alterniflora* includes both the tall and short ecotypes. The centerline in the boxplots shows the median, boxes show the interquartile range, whiskers show 1.5 x the interquartile range, and dots show the individual data points.

Light intensity was highly variable in vegetation plots, especially at the marsh edge (Figure 3). Low light intensity at the marsh edge was likely due to shading by tall grasses such as tall form *S. alterniflora* and *S. cynosuroides*, whereas plots with higher light intensity at the marsh edge may be more bare due to erosion. There was a slight trend of increasing light intensity with distance from the creek, potentially due to the decrease in abundance of tall form *S. alterniflora*.

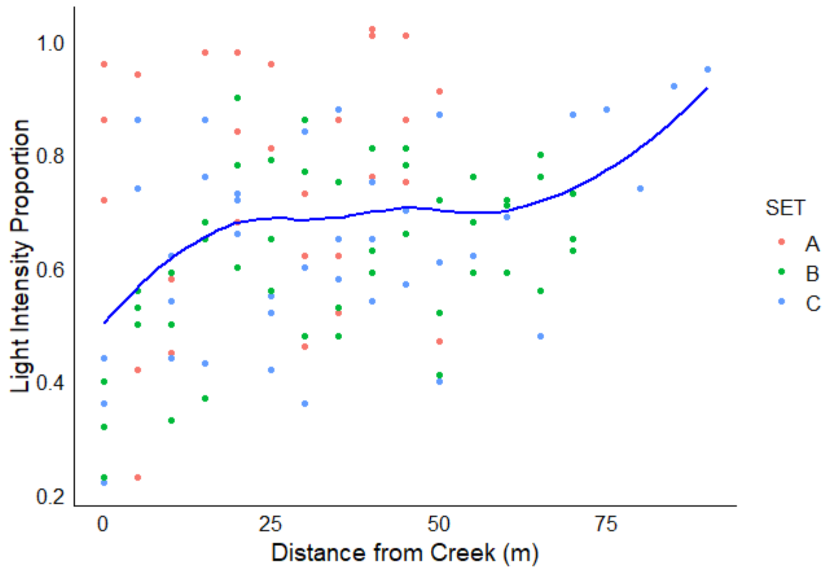

Figure 3. Light intensity in vegetation plots at the different Surface Elevation Table (SET) stations. Light intensity is shown as a proportion of the total light available with no obstructions from plant cover.

Mussel Distribution

Ribbed mussel (*Geukensia demissa*) density was greater downstream. Ribbed mussels were absent both years at the upstream location (SET A), were found at low densities at SET B and were found at greater densities at SET C, the most downstream location (Table 8). Mussels were only found in plots that were adjacent to the Tuckahoe River. Therefore, mussel densities were only calculated for the most shoreward plots. Oysters (*Crassostrea virginica*) were also growing intermixed with mussels at the downstream location, although not along the monitoring transect.

Table 8. Mussel densities in plots along transects at each Surface Elevation Table (SET) station. Shown are arithmetic means ± standard error of the most shoreward plots at each station (*n*=3 per site). Few mussels were found at other locations.

	2021	**2022**	**2023**
Station	Mussel Density (#/m^2)	Mussel Density (#/m^2)	Avg. Mussel Density per station (#/m^2)
SET A	0.0	0.0	0.0
SET B	6.7 ± 1.7	6.0 ± 4.6	16.0 ± 14.0
SET C	33 ± 2.2	170 ± 20.	56 ± 28

Water Quality

Salinity was variable between ~10-25psu, increasing with distance moving downstream (Figure 9; Tables 9 - 11). Our August 2021 sampling data was collected the morning after Tropical Storm Fred passed over New Jersey and shows much lower salinities than the November sampling date, potentially due to higher rainfall associated with the storm. These salinity data reflect polyhaline conditions found throughout the Tuckahoe River.

Other values varied along the upstream-downstream gradient of the river. Generally, dissolved oxygen, pH, and TSS increased from upstream to downstream. Suspended sediment concentrations ranged from 15 to 35 mg L^{-1}, similar to concentrations reported in other east coast marshes (Kirwan et al. 2010; Zhang et al. 2020). There was no temperature difference during the summer of 2021, but during the fall of 2021, we saw lower temperatures upstream, and higher temperatures downstream. During spring of 2022, we saw higher temperatures upstream, and during fall of 2022, we saw higher temperatures downstream.

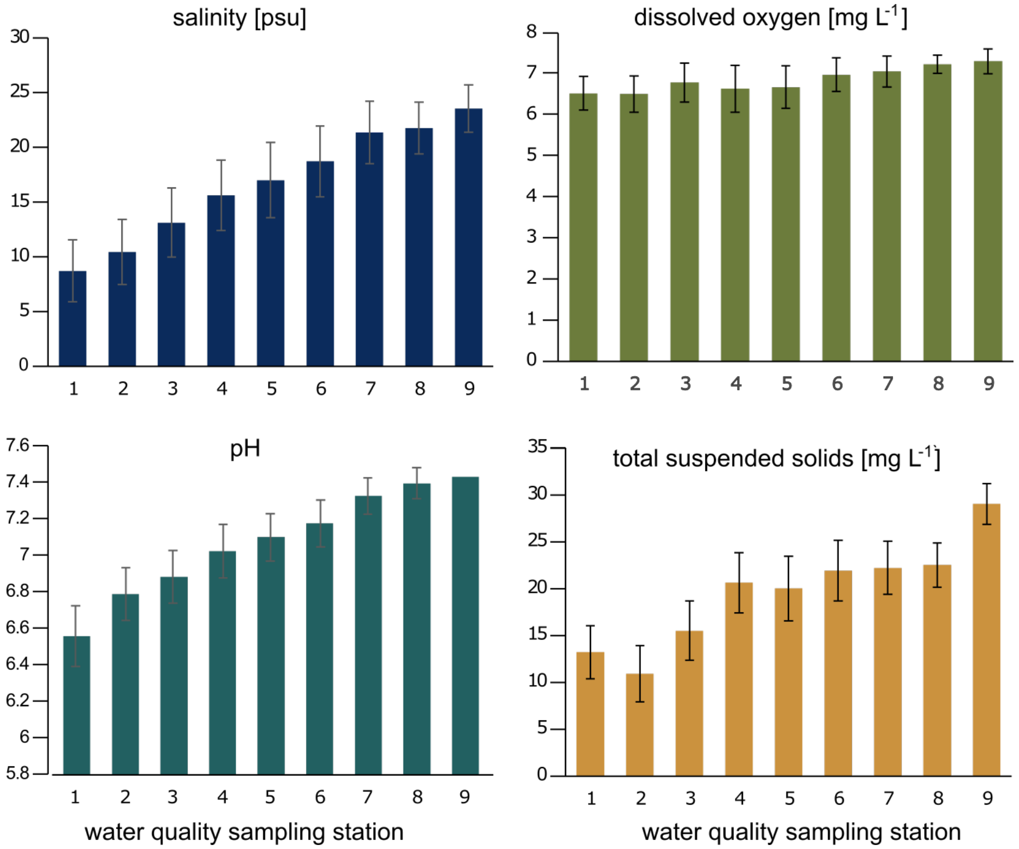

Figure 9. Mean water quality parameters for sampling stations along the Tuckahoe River. Station numbers increase from upstream to downstream with 9 being the farthest downstream. Shown are means of six samples taken from different dates (aside from the last pH measure, which was excluded). Error bars show standard error.

Table 9. 2021 Water quality data. Water quality parameters included temperature (temp.), dissolved oxygen (DO), pH, salinity, and Total Suspended Solids (TSS).

Station	Date	Time	Temp. (ºC)	DO (mg L^{-1})	DO (%)	pH	Salinity (‰)	TSS (mg L^{-1})
WQ1	19 Aug 21	10:40	27.7	5.97	75.9	7.32	5.1	12.8
WQ2	19 Aug 21	10:50	27.6	5.73	72.7	6.84	7.3	6.9
WQ3	19 Aug 21	10:58	27.5	6.46	81.8	6.85	9.2	8.6
WQ4	19 Aug 21	11:04	27.4	5.5	69.5	6.96	11.6	36.1
WQ5	19 Aug 21	11:10	27.4	5.71	72.2	7.02	12.0	24.6
WQ6	19 Aug 21	11:15	27.5	6.10	77.3	7.05	13.6	34.9
WQ7	19 Aug 21	11:22	27.5	6.15	77.9	7.07	15.8	20.0
WQ8	19 Aug 21	11:31	27.5	6.41	81.2	7.15	17.4	18.2
WQ9	19 Aug 21	11:36	27.4	6.65	84.1	7.21	18.8	36.6
WQ1	7 Nov 21	10:49	10.4	7.01	62.7	6.67	17.1	24.0
WQ2	7 Nov 21	10:55	10.8	7.32	66.2	7.12	18.6	25.4
WQ3	7 Nov 21	11:00	10.9	7.59	68.7	6.98	22.7	42.2
WQ4	7 Nov 21	11:05	11.0	7.76	70.4	7.15	25.0	50.8
WQ5	7 Nov 21	11:12	11.3	7.86	71.8	7.26	27.5	51.9
WQ6	7 Nov 21	11:21	11.6	7.92	72.8	7.32	29.2	49.3
WQ7	7 Nov 21	11:31	12.1	7.98	74.2	7.48	30.5	47.3
WQ8	7 Nov 21	11:39	12.1	7.97	74.1	7.64	30.4	39.0
WQ9	7 Nov 21	11:45	12.3	8.00	74.7	7.34	30.9	41.3

Table 10. 2022 Water quality data at nine sampling stations along the Tuckahoe River. Water quality parameters included temperature (temp.), dissolved oxygen (DO), pH, salinity, and Total Suspended Solids (TSS).

Station	Date	Time	Temp. (°C)	DO (mg L^{-1})	DO (%)	pH	Salinity (‰)	TSS (mg L^{-1})
WQ1	23-May-22	12:25	25.6	4.75	58.7	6.27	2.0	7.6
WQ2	23-May-22	12:31	25.1	4.76	58.5	6.45	3.6	8.2
WQ3	23-May-22	12:47	24.2	4.65	58.2	6.63	6.7	10.0
WQ4	23-May-22	12:56	23.3	4.46	56.3	6.76	9.5	10.8
WQ5	23-May-22	13:02	23.1	4.65	57.9	6.84	10.5	9.8
WQ6	23-May-22	13:09	22.8	5.39	68.6	6.97	12.9	10.0
WQ7	23-May-22	13:17	22.5	5.75	74.3	7.21	17.4	26.8
WQ8	23-May-22	13:23	22.7	7.11	80.3	7.32	18.7	24.0
WQ9	23-May-22	13:29	22.2	6.17	79.9	7.43	20.4	44.0
WQ1	24-Oct-22	10:45	14.6	7.56	81.7	7.00	14.3	12.0
WQ2	24-Oct-22	10:50	14.8	7.45	81.4	7.17	17.1	8.0
WQ3	24-Oct-22	10:58	15.1	7.66	86.2	7.38	19.9	12.0
WQ4	24-Oct-22	11:04	15.2	7.76	89.1	7.52	22.2	0.0
WQ5	24-Oct-22	11:07	15.3	7.72	89.5	7.59	23.7	8.0
WQ6	24-Oct-22	11:17	15.4	7.73	89.6	7.62	24.2	12.0
WQ7	24-Oct-22	11:24	15.5	7.89	92.8	7.76	26.2	12.0
WQ8	24-Oct-22	11:30	15.6	7.65	89.7	7.62	24.9	26.0
WQ9	24-Oct-22	11:36	15.7	7.85	93.1	7.73	26.5	28.0

Table 11. 2023 Water quality data along the Tuckahoe River. Water quality parameters included temperature (temp.), dissolved oxygen (DO), pH, salinity, and Total Suspended Solids (TSS).

Station	Date	Time	Temp. (°C)	DO (mg L^{-1})	DO (%)	pH	Salinity (‰)	TSS (mg L^{-1})
WQ1	29-May-23	11:25	20.4	6.82	77.2	5.54	0.79	12.2
WQ2	29-May-23	11:30	20.4	6.59	73.7	6.37	1.46	4.1
WQ3	29-May-23	11:36	20.4	6.77	75.8	6.58	3.52	9.5
WQ4	29-May-23	11:44	20	6.69	76	6.74	5.47	9.1
WQ5	29-May-23	11:50	19.8	6.67	75.9	6.8	6.52	8.8
WQ6	29-May-23	11:57	19.9	7.17	85.9	6.93	9	7.5
WQ7	29-May-23	12:06	19.9	7.05	83.7	7.12	12.8	7.1
WQ8	29-May-23	12:13	20.2	7.11	85.6	7.26	14.91	7.3
WQ9	29-May-23	12:18	20.5	7.8	96.1	7.46	17.81	8.2
WQ1	27-Oct-23	11:15	14.9	7.07	76.1	8.49	13.02	10.8
WQ2	27-Oct-23	11:23	15.1	7.21	78.5	7.21	14.66	13.0
WQ3	27-Oct-23	11:29	15.6	7.6	84.9	6.3	16.77	10.8
WQ4	27-Oct-23	11:42	15.9	7.67	87.3	6.28	20.04	16.6
WQ5	27-Oct-23	11:36	16	7.48	86.9	6.25	21.84	16.7
WQ6	27-Oct-23	11:47	16.2	7.59	89.6	6.01	23.48	17.8
WQ7	27-Oct-23	11:53	16.3	7.55	90.2	4.59	25.43	20.1
WQ8	27-Oct-23	11:58	16.8	7.2	86.1	4.88	24.38	20.5
WQ9	27-Oct-23	12:04	16.6	7.38	89.5	5.06	26.96	15.7

Surface Elevation Table and Marker Horizon Data

SETs and marker horizons were measured in spring and fall from 2022 - 2023. Marsh elevation appeared to increase by 4 – 6 mm between fall 2022 and fall 2023 (Table 12). There is some evidence of seasonal trends at SETs A and B, with generally lower elevations in the spring than in fall. However, these data only span one year, and 5 – 7 years of data are required to assess both seasonal and long-term trends in elevation change.

Between spring and fall of 2023, marker horizon depth appeared to decrease by ~1 mm at SETs A and C, potentially due to surface compaction or erosion, whereas MH depth increased by ~1 mm at SET B (Table 13). Although marker horizons were measured starting in 2022, data are only reported for 2023 because some marker horizons were still visible at the surface during the earlier sampling dates. These measurements are intended to provide baseline marker horizon depths, and therefore longer timescales are required to better assess trends in marsh surface accretion.

Table 12. Surface Elevation Table (SET) data. Means are shown ± standard deviation of 36 pin height measurements.

	Mean pin heights (mm)			
SET	**5/23/22**	**10/24/22**	**5/29/23**	**10/27/23**
A	207.9 ± 8.0	215.0 ± 7.4	211.3 ± 6.5	219.8 ± 10.0
B	163.6 ± 3.4	163.8 ± 5.0	160.0 ± 3.7	169.8 ± 3.2
C	127.1 ± 3.8	127.7 ± 4.0	128.8 ± 4.8	133.8 ± 3.9

Table 13. Marker Horizon (MH) data at the three SET locations. Means are shown ± standard deviation of 16 depth measurements.

	Marker horizon depth (mm)	
SET	**5/29/23**	**10/27/23**
A	3.0 ± 2.9	2.0 ± 1.3
B	3.5 ± 2.3	4.7 ± 3.7
C	4.3 ± 2.7	3.0 ± 1.9

Rapid Assessments

MidTRAM assessments showed scores ranging from 75-80 (Table 14). Scores increased from upstream to downstream sites due to firmer substrate and less *Phragmites australis* in the 250 m buffer zones at downstream sites.

Table 14. MidTRAM scores assessed at the tree Surface Elevation Table (SET) stations on 9/1/2022.

	SET A		SET B		SET C	
Attributes and Metrics	Raw Value	Score	Raw Value	Score	Raw Value	Score
Buffer/Landscape						
B1. % of AA Perimeter with 10m Buffer	100%	12	100%	12	100%	12
B2. Natural Land Use	56	6	60%	6	44%	3

B3. Surrounding Land Use	0	12	0%	12	0%	12
B4. 250 Landscape Condition		6		9		12
B5. Barriers to Landward Migration	0	12	0%	12	0%	12
Buffer Attribute Score		73.3		80.0		80.0
Hydrology						
H1. Ditching & Excavating (OMWM)	0	12	1.5%	9	0%	12
H2. Fill	0	12	0%	12	0%	12
H3. Diking/Restriction	0%	12	0%	12	0%	12
Hydrology Attribute Score		100.0		88.9		100.0
Habitat						
HAB1. Bearing Capacity	2.5	9	1.5	12	0.88	12
HAB2. Horizontal Vegetative Obstruction	12%	3	25%	3	33%	6
HAB3. Number of Plant Layers	2	9	2	9	2	9
HAB4. Species Richness	2	6	2	6	1	3
HAB5. Percent Invasives	0%	12	0%	12	0%	12
Habitat Attribute Score		53.0		60.0		60.0
Final Score		75.0		76.3		80.0

Changes to Scope of Work

We were unable to obtain useful Photosynthetically Active Radiation (PAR) data in 2021-2022 because PAR was impacted more by variations in sun than due to plant cover. In 2023, we collected PAR data using light meters deployed under ambient conditions and under the plant canopy to calculate the percent light intercepted.

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