

**CASC FINAL PROJECT REPORT:
Mapping Salt Marsh Response to Sea Level Rise and Evaluating 'Runneling' as an Adaptation
Technique to Inform Wildlife Habitat Management in New England**

SECTION 1. ADMINISTRATIVE INFORMATION:

- Name and contact information of the award recipient
 - Dr. Linda A. Deegan
 - Email: ldeeган@woodwellclimate.org
- Agency or Institution of the recipient
 - Woodwell Climate Research Center
 - 149 Woods Hole Rd., Falmouth, MA 02540
- Project title: Mapping Salt Marsh Response to Sea Level Rise and Evaluating 'Runneling' as an Adaptation Technique to Inform Wildlife Habitat Management in New England
- Agreement number: UMASS subaward 016188-9344 A00/USGS G21AC10192-00
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- Actual total cost of the project: \$370,055

SECTION 2. PUBLIC SUMMARY:

Salt marsh loss is a major threat to coastal areas in the Northeast, putting coastal towns, wildlife and ecosystems at risk. Salt marshes filter nutrient runoff, store carbon, protect coastal properties from storm impacts including flooding and erosion, and support a variety of wildlife species. Salt marsh habitats are critical for wildlife species like the Saltmarsh Sparrow, which faces steep population declines and could disappear within 50 years if salt marshes are lost. Rising sea levels are drowning marshes, killing plants, eroding soil, and worsening the problem.

To help restore these vital habitats, we studied an emerging restoration technique called "runneling," which involves creating tiny channels to restore natural tidal flushing in salt marshes and bring them back to life. In a large-scale experiment in two Massachusetts saltmarshes, researchers showed that runneling successfully restored critical saltmarsh vegetation, even in challenging conditions. Our work demonstrated that across a wide range of elevations and initial conditions, critical saltmarsh vegetation wildlife habitat recovered after runnel installation whereas habitat decline

continued without any intervention. As runneling is gaining popularity by practitioners concerned about saltmarsh loss, this project provided rigorous data about the effects of runneling to help practitioners and regulators make decisions about future runneling projects. This project also developed maps to help identify the marshes that might benefit from runneling and high-priority areas for wildlife protection.

The goal is to give resource managers the tools they need to restore marshes, protect wildlife, and combat the effects of climate change. By identifying target areas with the best chances of recovery, this work will help ensure the survival of these vital ecosystems and the species that depend on them.

SECTION 3. PROJECT SUMMARY:

The project objective was to increase understanding of salt marsh habitat responses to hydrologic change and adaptive management of salt marshes used by species of conservation concern. The project leveraged an existing installation of experimental runnels. Runnels are an emerging adaptation technique being rapidly adopted by Northeast managers to address marsh loss. While observational results of runnel projects have shown promising increases in vegetation, rigorous monitoring of the changes in habitat had not been undertaken. Through this project, detailed field measurements were performed to assess saltmarsh habitat changes relevant to wildlife management. In addition, salt marsh, stressors, and runnel suitability were mapped across Buzzards Bay salt marsh sites and the potential for eCognition machine learning tools to enhance wildlife habitat mapping was explored.

This project was a collaboration of researchers and conservation practitioners representing a range of organizations from academic organizations (Woodwell Climate Research Center) to federal agencies (U.S. Geological Survey) to mosquito control agencies (Bristol County Mosquito Control Project) to a national estuary program (Buzzards Bay National Estuary Project) and regional non-profits (Buzzards Bay Coalition, Save the Bay RI). The collaboration provided essential expertise on a range of topics.

The project was implemented across two marsh complexes that included marshes spanning gradients in tidal height, size, level of degradation, and tidal restriction. We used a replicated-BACI design to study runnel effects on salt marsh hydrology and vegetation. Twenty pannes were selected as study sites with runnels implemented at ten and ten pannes left as no-action controls. At all sites, measurements were collected of elevation and vegetation. At a subset of sites, additional measurements were made of water level. Generalized mixed-effects models were used to analyze responses of minimum daily water level, percent live vegetation, percent bare ground, *Spartina patens* percent cover, stem density, and *Spartina alterniflora* height. Models included an interaction between treatment (control, experimental/runnel) and year, as this provided better fits and allowed comparison of response rates rather than overall effects. We additionally tested models with environmental factors which could mitigate ecosystem responses to runnels including: level of degradation (sites separated into two groups based on percent cover of live vegetation before runnel creation), platform elevation, panne-bottom elevation, or marsh complex.

Our results demonstrated that runnels increased wildlife habitat suitability by lowering water table heights, increasing vegetative cover (total live and *Spartina patens*), reducing bare ground, and increased *Spartina alterniflora* stem density and height over four years. Control sites saw rising water tables, more bare ground, reduced live vegetation, and no changes in stem metrics or *Spartina patens* cover. Runnels boosted live vegetation by 60%, while control sites lost 5%. Vegetation cover reached nearly 100% within three years, regardless of elevation or degradation. *Spartina patens*, a critical habitat species in the region, increased by 40% at runnel sites.

An unexpected result was that relative changes in water table heights did not completely correspond with observed vegetation dynamics as predicted. At some control sites, vegetation declined while water levels either stayed the same or also declined. At some high elevation runnel sites, vegetation recovered while water levels did not change – possibly due to runnels enhancing the frequency of flushing and exchange with tidal water.

The primary conclusion was that manipulating hydrologic connectivity using runnels allowed for vegetative restoration to nearly 100% cover in marshes with a tidal range of at least 0.5 m, and platform elevations between 0.2 and 0.9 m above local mean sea level. The mechanism for the vegetative restoration may have been due to draining impounded surface water, lowering the water table, or by increasing flushing with fresh tidal water, or some combination of these mechanisms. While microtidal marshes are widely considered vulnerable to sea level rise, this work reveals sufficient resilience within these marshes to recover ecosystem function.

The field results filled a key knowledge gap on an emerging adaptive intervention in salt marshes (runnels). The experimental results illuminated how salt marsh adaptive interventions may affect vegetation that is critical wildlife habitat. Key marsh attributes relevant to vulnerable species of marsh-breeding wildlife (stem height, percent cover of *Spartina patens*) are improved with runnel intervention relative to areas where no action was taken. This information was used to develop maps at marsh areas around Buzzards Bay that indicate where runnel implementation is likely to improve habitat. The maps are a tool that resource managers can use to help prioritize direct vs. indirect adaptation actions for salt marsh and wildlife habitat management.

Longer-term study is needed to understand whether revegetation that is occurring within the open water pannes will allow marsh elevation accretion rates (biological and mineral) to reach equivalency with the surrounding vegetated marsh. Two important directions for further work include understanding: 1) if the mechanisms and the function of a runnel continues indefinitely or has a limited lifetime and 2) the impacts on marsh accretion (mineral deposition, peat decomposition and formation).

SECTION 4. Body of Report:

A. Purpose and Objectives:

The project addressed understanding salt marsh habitat responses to hydrologic change and adaptive management of salt marshes used by species of conservation concern. The project activities relate to the Northeast region CASC Priority 1 by increasing knowledge of a salt marsh — a critical habitat for species of concern across the United States — response to climate change. In response to NE CASC Priority 2 we assessed the response of salt marshes to coastal development and sea level rise induced inundation and evaluated runnels as an adaptive management strategy for increasing the persistence of salt marsh. “Runneling” is an emerging adaptation technique being rapidly adopted by Northeast managers to address marsh loss. Runneling implementation has been ad hoc with minimal evaluation, usually just % plant cover which is not sufficient to understand suitability for wildlife. Knowledge of which marshes are most important, and if adaptive management can improve habitat, is an immediate need for state and federal fish and wildlife agencies, and other non-governmental stakeholders.

The primary project goal was to enhance understanding of runneling's potential to improve saltmarsh resilience by extending field measurements to assess saltmarsh habitat changes relevant to wildlife management. The project leveraged an existing project funded by the EPA Southeast New

England Program (SNEP) that included installing experimental runnels across a marsh degradation gradient, and mapping salt marsh loss and stressors across Buzzards Bay. It also explored using eCognition machine learning tools for better wildlife habitat mapping and provided maps combining runnel experiment results with ongoing mapping to identify marshes potentially suitable for runnel adaptation.

Most effort on the project was dedicated to saltmarsh ecosystem responses to experimental manipulation of hydrology via runneling as this was the most critical knowledge gap. Along with our collaborator, Dr. James Nelson (University of Georgia) we explored the potential for using eCognition with existing satellite information on marshes. We also collaborated with the Buzzards Bay Coalition/Buzzards Bay National Estuary Program Long-term monitoring and mapping project, led by Dr. Jakuba and Dr. Joe Costa, to develop products useful as a Decision Support Tool.

B. Organization and Approach:

This section of the report should explain in task orientated terms how the research activities of the project were conducted. Briefly list which research methods were used to achieve results and why they were chosen by the team.

The primary goal of this project was to evaluate the restoration success of runnels in creating suitable fish and wildlife habitat as measured by elevation, drainage and vegetation characteristics relevant to wildlife (percent cover, height, density, species). The questions and runnel experimental design were developed based on discussions at our Runnel workshop (Mar 2020). Our team included experienced environmental managers and restoration practitioners from several agencies and institutions. We also consulted with RI Save the Bay and Bristol County Mosquito Control, and the Salt marsh Working Group (funded by the NE CASC). Thus, we followed best practices gleaned by a variety of experts as learned over years of practical experience measuring saltmarshes and installing runnels in New England (Besterman et al. 2022). We used Buzzards Bay, MA as a study system because it is typical of the region and is experiencing dramatic salt marsh loss.

Task 1: Choose saltmarsh areas and restore hydrology with runnels.

Within the Buzzards Bay watershed we chose study marshes spanning gradients in tidal height, size, level of degradation, and tidal restriction. We used a replicated-BACI design to study runnel effects on salt marsh hydrology and vegetation. Twenty panes were selected based on expert input, recent expansion, and firm peat in panne bottoms. Two low-elevation sites with unconsolidated sediments were included to test near degradation limits, while deep, stable ponds were avoided. Runnels were created in fall/winter of 2020 using a combination of a low-ground pressure excavator and hand-digging with shovels.

Task 2: Measure Ecosystem responses to runneling.

At each site, a transect (30–60 m) was established from the high marsh boundary through the panne. Twelve sites were intensively monitored with additional vegetation sampling and water level loggers. Elevations were measured between June to August along 20 transects using a digital laser level (Leica Sprinter 250m) and barcode staff to estimate platform and panne elevations, depth, and degradation levels. Water levels were monitored with Onset HOB0 Water Level Loggers (U20L-04) in PVC wells at each site. Vegetation data were collected in 10-m zones (5-m upland of panne center, and 5-m seaward of panne center), and extended to the upland boundary to capture high marsh species, with up to 9 plots per site, adjusting for panne proximity. Surveys during August's neap tides estimated percent cover of live vegetation, bare ground, dead vegetation, and plant species using point-intercept

in 1-m plots. *Spartina alterniflora* stems were counted in 25×25 cm subplots, and the tallest stems were measured in the 1-m plot.

We used generalized mixed-effects models to analyze responses of minimum daily water level, percent live vegetation, percent bare ground, *Spartina patens* % cover, stem density, and *Spartina alterniflora* height. Models included an interaction between treatment (control, experimental/runnel) and year, as this provided better fits and allowed comparison of response rates rather than overall effects. We additionally tested models with environmental factors which could mitigate ecosystem responses to runnels including level of degradation (sites separated into two groups based on percent cover of live vegetation before runnel creation), platform elevation, panne-bottom elevation, or marsh (Little Bay or Ocean View Farm).

C. Project Results, Analysis and Findings:

Major discoveries and accomplishments:

Runnel experiment: Runnels increased wildlife habitat suitability by lowering water table heights, increasing vegetative cover (total live and *Spartina patens*), reducing bare ground, and increased *Spartina alterniflora* stem density and height over four years. Control sites saw rising water tables, more bare ground, reduced live vegetation, and no changes in stem metrics or *Spartina patens* cover. Runnels boosted live vegetation by 60%, while control sites lost 5%. Vegetation cover reached nearly 100% within three years, regardless of elevation or degradation. *Spartina patens*, a critical habitat species in the region, increased by 40% at runnel sites.

An unexpected result was that relative changes in water table heights did not completely correspond with observed vegetation dynamics as predicted. At some control sites, vegetation declined while water levels either stayed the same or declined. At some high elevation runnel sites, vegetation recovered while water levels did not change possibly due to runnels enhancing the frequency of flushing and exchange with tidal water rather than simply lowering the water table.

To develop products useful as a Decision Support Tool, we combined our data on determinates of runnel success with GIS maps of marshes in Buzzards Bay.

Detailed Results and analysis:

Water level

Qualitative analysis of hydrographs showed a clear response at most experimental sites, with more ambiguous responses at control sites (statistical model results presented in subsequent paragraphs). Hydrographs showed a reduction in minimum daily water level (approximately the water table) from before runnels were installed (2020) to after (2021-2023) at most of the sites (Fig. 2, Appendix S1: Figures S1 – S3). In 2020, the water table at most sites sat perched near the soil surface (from 1-2 cm below to about 10 cm above) for days to weeks at a time. After runnel creation, the water table at experimental sites rose and fell in coordination with lunar tide phases and precipitation rather than sitting stagnant at or above the soil surface. The water table at some experimental sites began rising in 2022 and 2023 (e.g., Fig. 2c). One experimental site showed almost no response in the water table after runnel creation (Fig. 2d). However, this was anomalous across experimental sites, which almost universally showed a restoration of tidal dynamics. Meanwhile, the water table at control sites showed divergent responses including becoming more pond-like, staying approximately the same, or decreasing the pond-like conditions (Fig. 2b, Appendix S1: Figures S4 – S7).

Model results showed minimum daily water level decreased in response to runnels overall (trend = -0.867 cm/yr, SE = 0.139, $p < 0.0001$), while control sites increased (trend = 0.409 cm/yr, SE = 0.140, $p = 0.003$), but responses differed based on other environmental variables (Table 2, Fig. 3). All of the environmental variables tested were significant except for level of degradation ($p < 0.0001$, Appendix S1: Table S2). Panne elevation was the most important explanatory variable, followed by platform elevation, and then marsh (Table 2). We estimated water level trends (marginal mean trends) over time for pannes at low (0.25 m above lmsl), medium (0.50 m above lmsl), and high (0.75 m above lmsl) elevations (Fig. 3, Appendix S1: Table S3). Experimental and control sites differed at all three elevations ($p < 0.0001$, Fig. 3). Water level trends differed the most at low elevation sites, where the water table increased its position at control sites while lowering at experimental sites (Fig. 3). The water table at low-elevation experimental sites decreased by an average of 1.5 cm per year, SE = 0.19 (Fig. 3, Appendix S1: Table S3). Meanwhile, low elevation control sites increased, by an average of 2.4 cm per year, SE = 0.20. Experimental and control sites differed from each other at medium and high panne elevations as well (Fig. 3, Appendix S1: Table S3). At medium elevations, experimental-site water levels decreased by 0.9 cm per year, SE = 0.14, while control sites slightly increased in water level (trend = 0.40 cm/yr, SE = 0.14). At high elevations, control sites decreased by 1.7 cm per year, SE = 0.20, while experimental sites showed a non-significant change.

Panne elevation was a significantly better predictor of water table response to experimental treatments than marsh ($\Delta AIC = 55.64$, Table 2). However, we still explored pattern with marsh given the overarching differences in marsh hydrodynamics (tidal range, geomorphic setting). Water level changes at the two marshes also differed by whether a site received a runnel or control treatment (LB: $p = 0.0002$, and OV: $p < 0.0001$). Water levels significantly increased at Ocean View control sites (2.1 cm per year, SE = 0.20). Water levels significantly decreased at Ocean View experimental sites (1.5 cm per year, SE = 0.19) (Fig. 3). Meanwhile, Little Bay control sites showed a significant decrease in water level (1.2 cm per year, SE = 0.19), while experimental sites showed no significant change (Fig. 3).

Vegetation cover change

Live vegetation changed in response to experimental treatment (runnels or no-action control) in the overall model ($p < 0.0001$, Fig. 1, Fig. 4, Appendix S1: Table S4). The experimental sites increased live vegetation cover significantly (trend coefficient = 1.28, SE = 0.06, $p < 0.0001$). For this model and all subsequent models, we estimated marginal means that accounted for effects from other fixed and random effects. In 2020, mean live vegetation cover across all experimental sites was estimated as 60.4% (SE = 14.5), and by 2023 increased to 98.6% (SE = 0.85) (Fig. 1, Fig. 4). Control sites decreased live vegetation cover significantly (trend coefficient = -0.20, SE = 0.04, $p < 0.0001$). At control sites, live vegetation cover estimates decreased from 93.5% (SE = 3.69) in 2020 to 88.7% (SE = 6.11) in 2023.

The model including level of degradation best explained the variation in live vegetation change with experimental treatment (Table 3, Appendix S1: Table S3), and was significantly better than the overall model ($\Delta AIC = 52.63$, Table 3). Live vegetation increased with runnels at both levels of degradation, but the rate of recovery was faster [contrast (low – advanced) = -0.6975, SE = 0.0966, $p < 0.0001$] at more advanced degradation sites (trend coefficient = 1.43, SE = 0.06, $p < 0.0001$) than low degradation sites (trend coefficient = 0.728, SE = 0.09, $p < 0.0001$) (Fig. 4). Experimental sites with low initial degradation had a marginal mean of 95.0% live vegetation cover in 2020 (SE = 3.20), and increased cover to 99.4% (SE = 0.41) (Fig. 4). At advanced degradation sites that received runnels, initial vegetation cover was estimated as 22.6% (SE = 9.54) and increased to 95.5% (SE = 2.40) by 2023 (Fig. 4). Live vegetation decreased at similar rates at both low-degradation control sites (trend coefficient = -0.24, SE = 0.04, $p < 0.0001$) and at advanced-degradation control sites (trend coefficient = -0.20, SE = 0.07, $p = 0.003$). Estimates at low-degradation control sites decreased from 95.4% (SE = 2.09) live vegetation

cover to 91.1% (SE = 3.88), and estimates decreased at advanced-degradation sites from 78.2% (SE = 16.0) to 66.2% (SE = 21.1) (Fig. 4). The standard errors were large for advanced-degradation control sites partly because only two sites were in this group.

The three-way interactions between live vegetation recovery rate and the three other environmental variables were not significant at $\alpha = 0.01$, meaning the rate of recovery was similar across gradients of panne and platform elevation, and between the two marshes. Explanatory power based on AIC was significantly worse for the other three models than the degradation model ($\Delta\text{AIC} \geq 50.5$). The model including panne elevation was still slightly better than the overall model ($\Delta\text{AIC} = 2.13$), thus we proceeded to estimate response rates at low (0.25 m lmsl), medium (0.5 m lmsl), and high (0.75 m lmsl) panne elevations consistent with water level model tests. Live vegetation cover increased significantly at all three elevations ($p < 0.0001$). For sites with runnels at low elevations (0.25 m), the model predicted live vegetation increased from 30.3% (SE = 17.8) in 2020 to 95.9% in 2023 (SE = 3.31), with trend coefficient = 1.33, SE = 0.07. At high elevations (0.75 m), the model predicted an increase in vegetation from runnels from 81.4% (SE = 11.7) in 2020 to 99.4% (SE = 0.48) in 2023, with trend coefficient = 1.21, SE = 0.08. Estimates for control sites at low elevations decreased from 89.6% (SE = 7.44) in 2020 to 79.3% (SE = 13.1) in 2023 (trend coefficient = -0.27, SE = 0.05). Estimates decreased slightly from 95.9% (SE = 3.04) at high elevation sites in 2020 to 93.7% (SE = 4.54) in 2023 (trend coefficient = -0.15, SE = 0.05, $p = 0.003$).

Bare ground cover changed as would be expected, in the inverse patterns from live vegetation. The overall model showed a significant decrease in bare ground cover at runnel sites (trend coefficient = -1.24, SE = 0.07, $p < 0.0001$), and significant increase at control sites (trend = 0.357, SE = 0.05, $p < 0.0001$) (Fig. 4). The three-way interaction with degradation was again the best at explaining variation in response rate, despite significant interactions identified for all of the three-way interactions (Table 3, Appendix S1: Table S3). Responses were larger and faster at the advanced degradation sites, with runnel-site bare ground estimates decreasing ($p < 0.0001$) from 67.4% (SE = 13.2) in 2020 to 3.38% (SE = 1.20) in 2023. Low-degradation runnel sites had an estimated decline ($p < 0.0001$) in bare ground cover from 5.47% (SE = 3.86) in 2020 to 0.20% (SE = 0.16) in 2023 (Fig. 4). Both low ($p = 0.001$) and advanced ($p < 0.0001$) degradation control sites showed a significant increase in bare ground cover (Fig. 4). Estimated bare ground across all three panne elevation positions (0.25 m, 0.5 m, and 0.75 m above lmsl) significantly declined with runnels ($p < 0.0001$). Control sites at low (0.25 m, $p < 0.0001$) and medium (0.5 m, $p < 0.0001$) panne elevations above lmsl showed an increase in bare ground from 3.68% (SE = 3.02) and 3.21% (SE = 1.82) in 2020 to 12.3% (SE = 9.22) and 6.62% (SE = 3.63) in 2023, respectively. Bare ground at high elevation control sites (0.75 m above lmsl) did not change significantly ($p = 0.15$).

In high marsh areas where *Spartina patens* was present, percent cover increased at experimental sites (trend coefficient = 0.24, SE = 0.06, $p < 0.0001$), while there was no significant change at control sites (Fig. 4, Appendix S1: Table S3). Plot-level percent cover was estimated to increase at sites receiving runnels from 43.7% (SE = 13.0) in 2020 to 61.5% (SE = 12.7) in 2023. Three-way interactions were non-significant for all of the environmental variables (Appendix S1: Table S3). The model fit for *Spartina patens* cover was poorer than other models probably due to high variability and reduced sample size (only presence-plots used, $n = 77$ total observations across four years).

Vegetation Stem count and height

Stem densities were highly variable, ranging from 0 in bare areas of the panne, to 4800 stems/m². Highest densities (> 2000 stems/m²) represented the top 15% of all observations and occurred only at Little Bay. The overall model showed a significant effect of runnels ($p < 0.0001$, Appendix S1: Table S3), with an estimated increase of stem densities at experimental sites with runnels (count trend coefficient = 0.2867, SE = 0.0681, $p < 0.0001$), and no change at control sites. The best

model including an environmental interaction was the degradation model (Table S3), which showed a significant increase in stem density at advanced-degradation experimental sites, but no significant change at either set of control sites or at low-degradation experimental sites (Fig. 5). The advanced-degradation runnel sites has an estimated 163 stems/m² (SE = 91.2) in 2020, which increased to 611 stems/m² (SE = 344) by 2023.

There was an overall significant effect of runnel treatment on stem heights ($p < 0.0001$, Appendix S1: Table S3). Stem heights at experimental runnel sites increased by 3.52 cm per year (SE = 0.687, $p < 0.0001$), while control sites did not change. The environmental model including panne elevation best explained variation in response to runnels (Table 3), with significant increases in stem height at low and medium elevations for runnel sites (Fig. 5). Low elevation pannes (0.25 m above lmsl) that received runnels showed an estimated increase in stem height from 48.6 cm (SE = 5.35) in 2020 to 70.2 cm (SE = 5.42) in 2023. Estimates for medium elevation pannes (0.5 m above lmsl) included an increase from 37.6 cm (SE = 3.48) in 2020 to 49.4 cm (SE = 3.60) in 2023.

Decision Support Tool

To develop a Decision Support Tool, we combined our data on determinates of runnel success with GIS maps of elevation and wetland delineations of marshes in Buzzards Bay. This Decision Support Tool is at: <https://buzzardsbay.org/living-resources/salt-marshes/runnel-support-tool/>. This page is still being improved as we learn new information.

SUPPORTING TABLES AND FIGURES

Table 1. Background data for runnel and control sites at two experimental marshes in Buzzards Bay, MA. Elevation refers to platform position in meters above local mean sea level. Initial vegetation cover refers to percent cover of vegetation the central pool or panne area. Depth refers to the bottom of the panne below the platform (not the surface of standing water in the panne) determined by elevation surveys.

Marsh		Elevation (m LMSL)	Panne elevation (m LMSL)	Initial Vegetation Cover	Depth (m)
Little Bay	Control				
	Range	0.63 – 0.88	0.60 – 0.88	0.71 – 0.98	0 – 0.08
	Mean (\pm SD)	0.76 (\pm 0.88)	0.74 (\pm 0.10)	0.87 (\pm 0.11)	0.03 (\pm 0.03)
	Runnel				
	Range	0.70 – 0.79	0.67 – 0.80	0.39 – 0.96	0 – 0.03
	Mean (\pm SD)	0.75 (\pm 0.04)	0.74 (\pm 0.05)	0.66 (\pm 0.21)	0.01 (\pm 0.02)
Ocean View	Control				
	Range	0.25 – 0.44	0.17 – 0.44	0.58 – 0.99	0 – 0.25
	Mean (\pm SD)	0.32 (\pm 0.08)	0.28 (\pm 0.10)	0.73 (\pm 0.18)	0.09 (\pm 0.09)
	Runnel				
	Range	0.24 – 0.43	0.13 – 0.39	0.37 – 0.98	0.02 – 0.12
	Mean (\pm SD)	0.36 (\pm 0.08)	0.30 (\pm 0.11)	0.54 (\pm 0.25)	0.06 (\pm 0.04)

Table 2. Model parameters for the 4 models with significant two or three-way interactions for water level, and affiliated ΔAIC .

Response Variable	Model Parameters	ΔAIC
Water Level	Year \times Treatment \times Panne Elevation	0
	Year \times Treatment \times Platform Elevation	36.72
	Year \times Treatment \times Marsh	55.64
	Year \times Treatment	192.47

Table 3. Model parameters for the 4 models with significant two or three-way interactions for vegetation variables, and affiliated Δ AIC.

Response Variable	Model Parameters	ΔAIC
Percent Live Vegetation	Year \times Treatment \times Degradation	0
	Year \times Treatment	52.63
Percent Bare Ground	Year \times Treatment \times Degradation	0
	Year \times Treatment \times Platform Elevation	7.79
	Year \times Treatment \times Panne Elevation	9.54
	Year \times Treatment \times Marsh	14.69
	Year \times Treatment	38.21
Stem Density	Year \times Treatment \times Degradation	0
	Year \times Treatment	8
Stem Height	Year \times Treatment \times Panne Elevation	0
	Year \times Treatment \times Platform Elevation	1.77
	Year \times Treatment	54.40
Percent <i>Spartina patens</i>	Year \times Treatment	NA

Figure 1. Photographs from permanent photo stations taken of a representative experimental runnel and control site at Ocean View marsh.

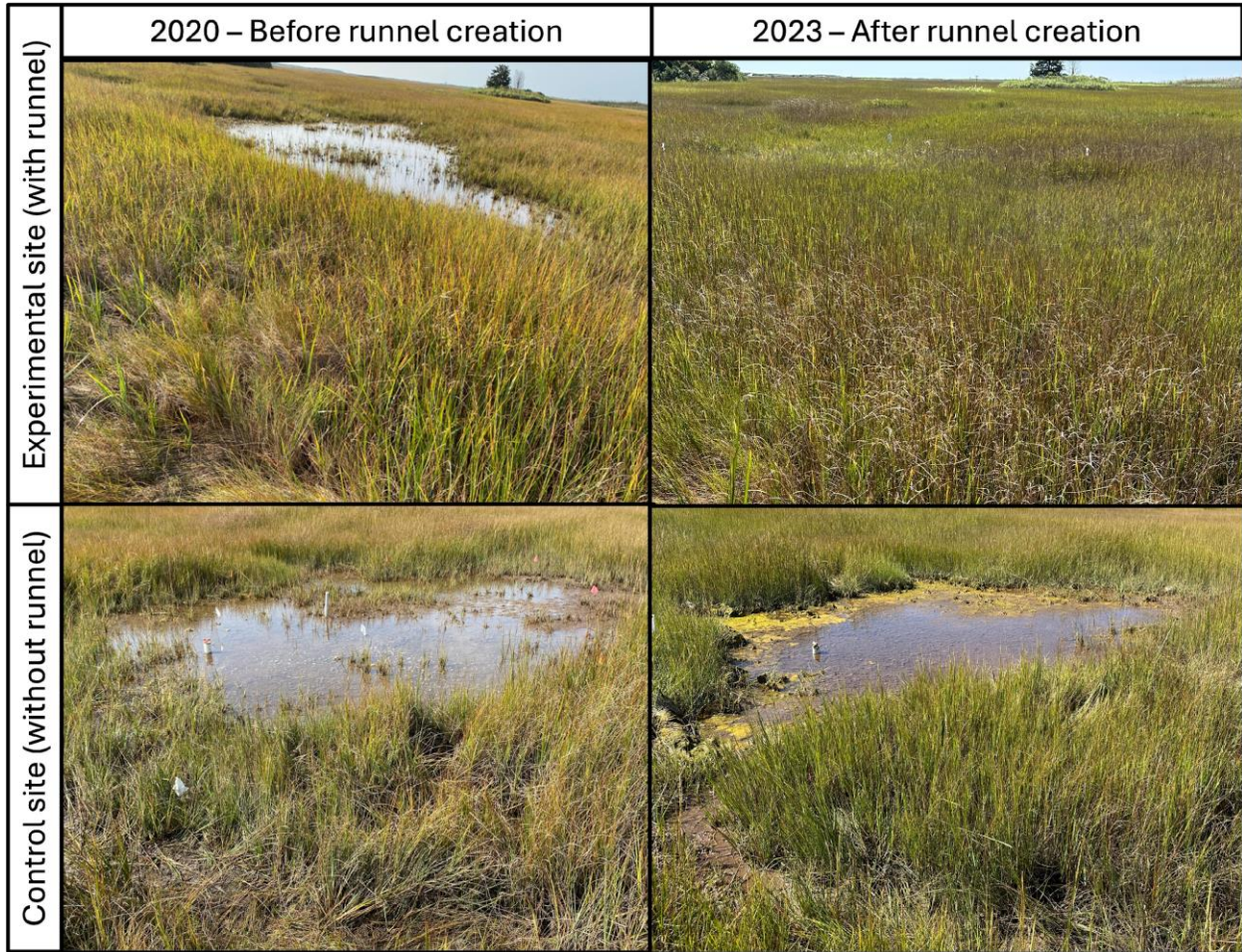


Figure 2. Hydrographs showing minimum daily water level (approximate water table height) over four years at experimental and control sites in Oceanview (a, b) and Little Bay (c, d). Horizontal dashed line shows the soil height.

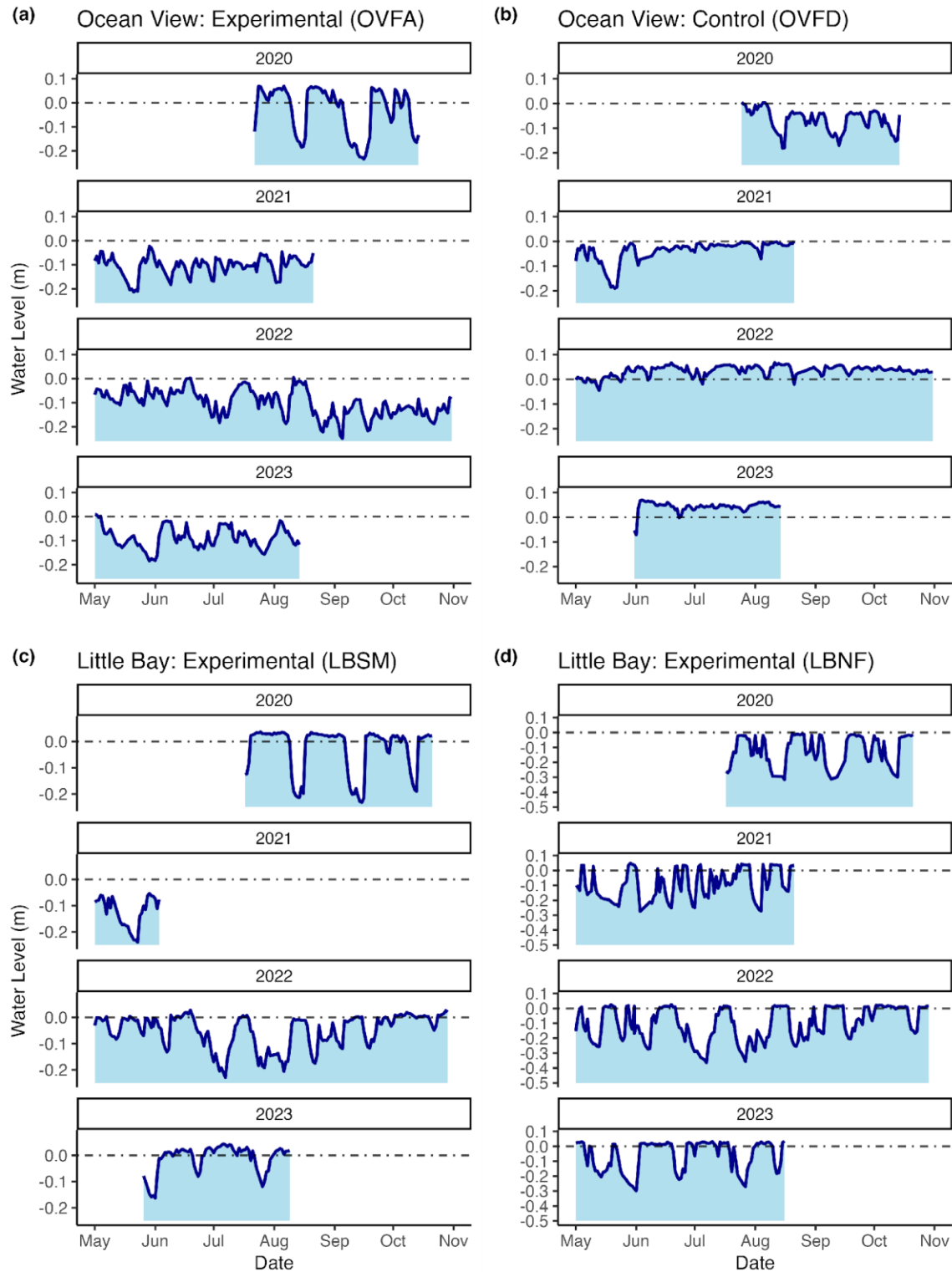


Figure 3. Water level responses across four years and 12 intensive sites. Plots (a) and (b) show data, and plots (c) and (d) show modeled responses. P-values indicate the difference between control and experimental sites was significant at that treatment level, (*) indicate trend was significant at $\alpha = 0.01$. Plots (a) and (c) show responses across panne elevations, and plots (b) and (d) show responses at two marshes.

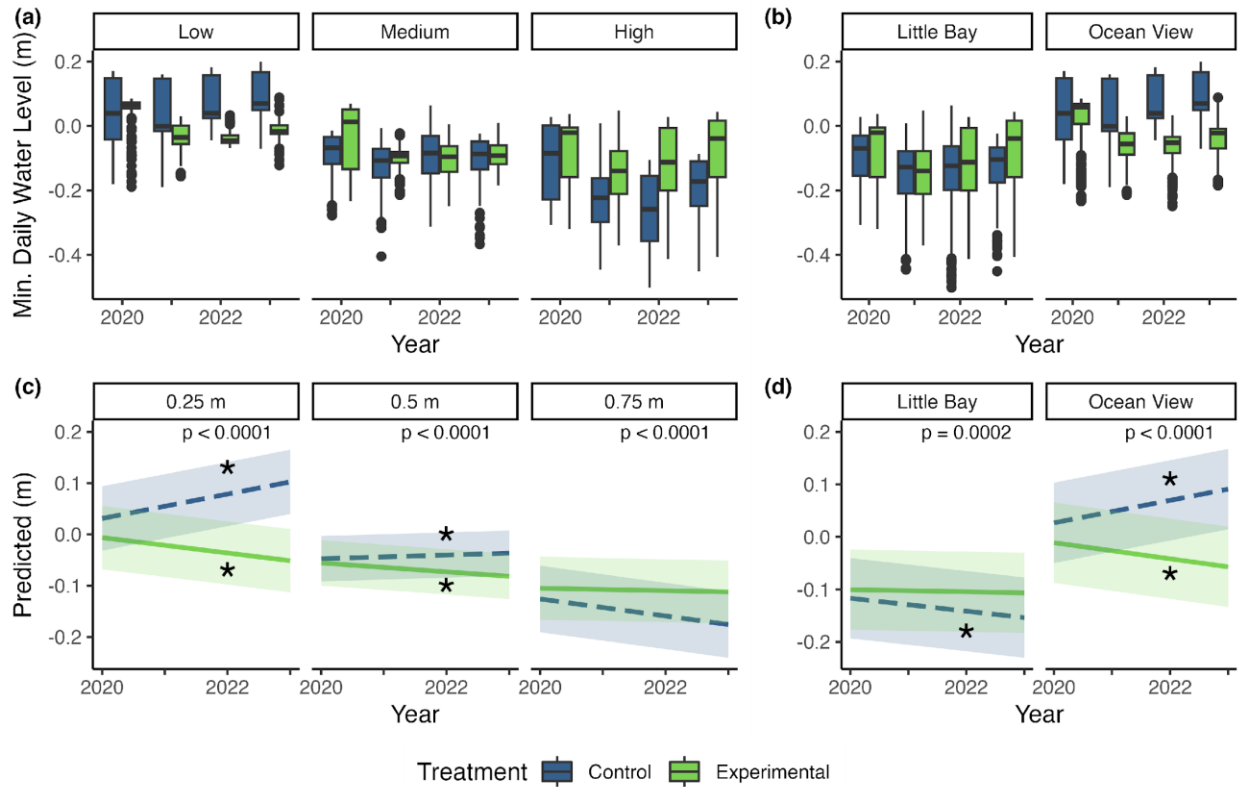


Figure 4. Percent cover of live vegetation, bare ground cover, and *Spartina patens* across four years and all 20 sites. Plots (a) through (c) show data, and plots (d) through (f) show modeled responses. P-values indicate the difference between no-action control (blue; solid) and experimental (green; hatched) sites was significant at that treatment level, (*) indicate trend was significant at $\alpha = 0.01$. Plots (a), (b), (d), and (e) show responses at low (1) and advanced (2) level of degradation, and plots (c) and (f) show average responses.

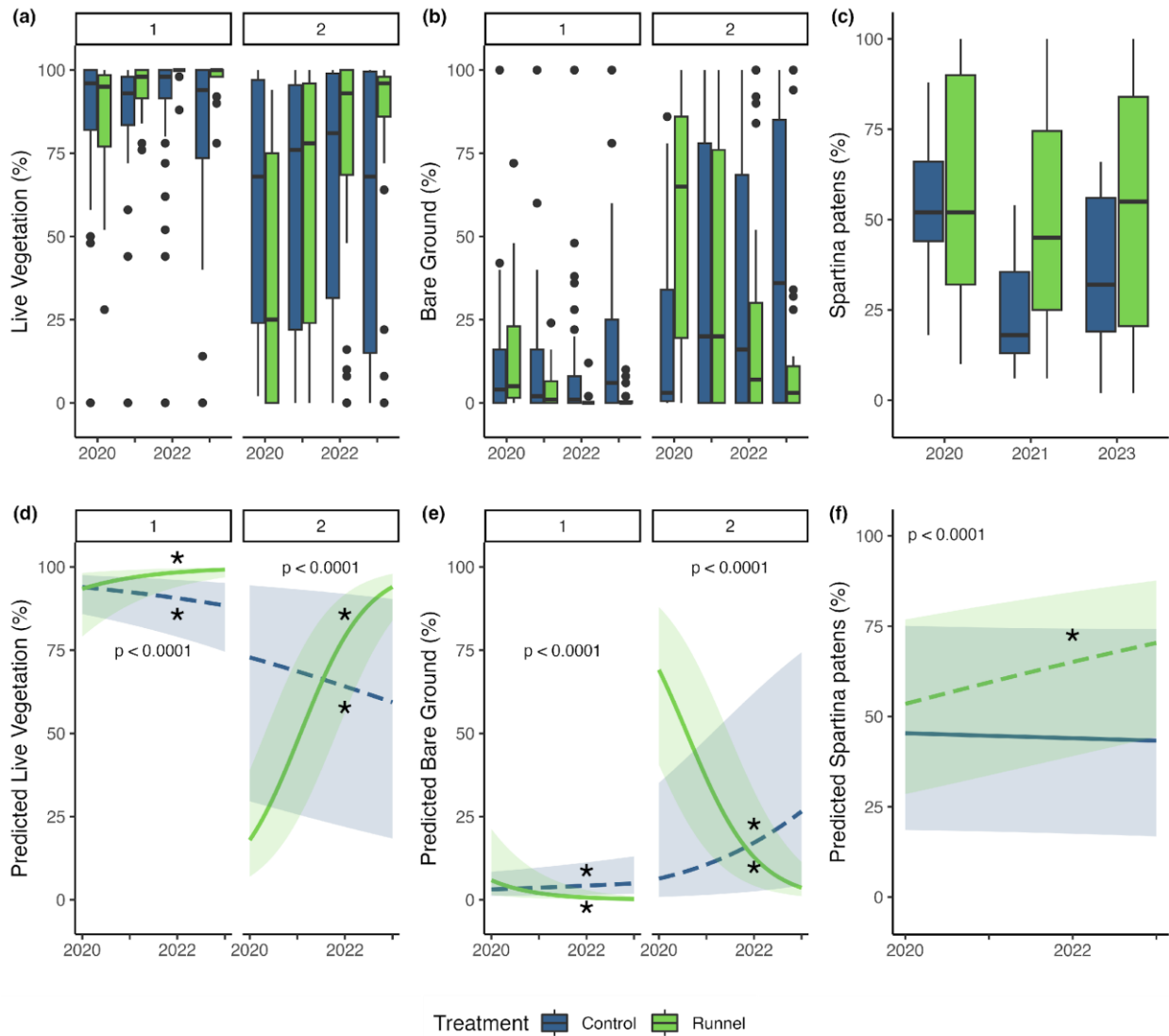
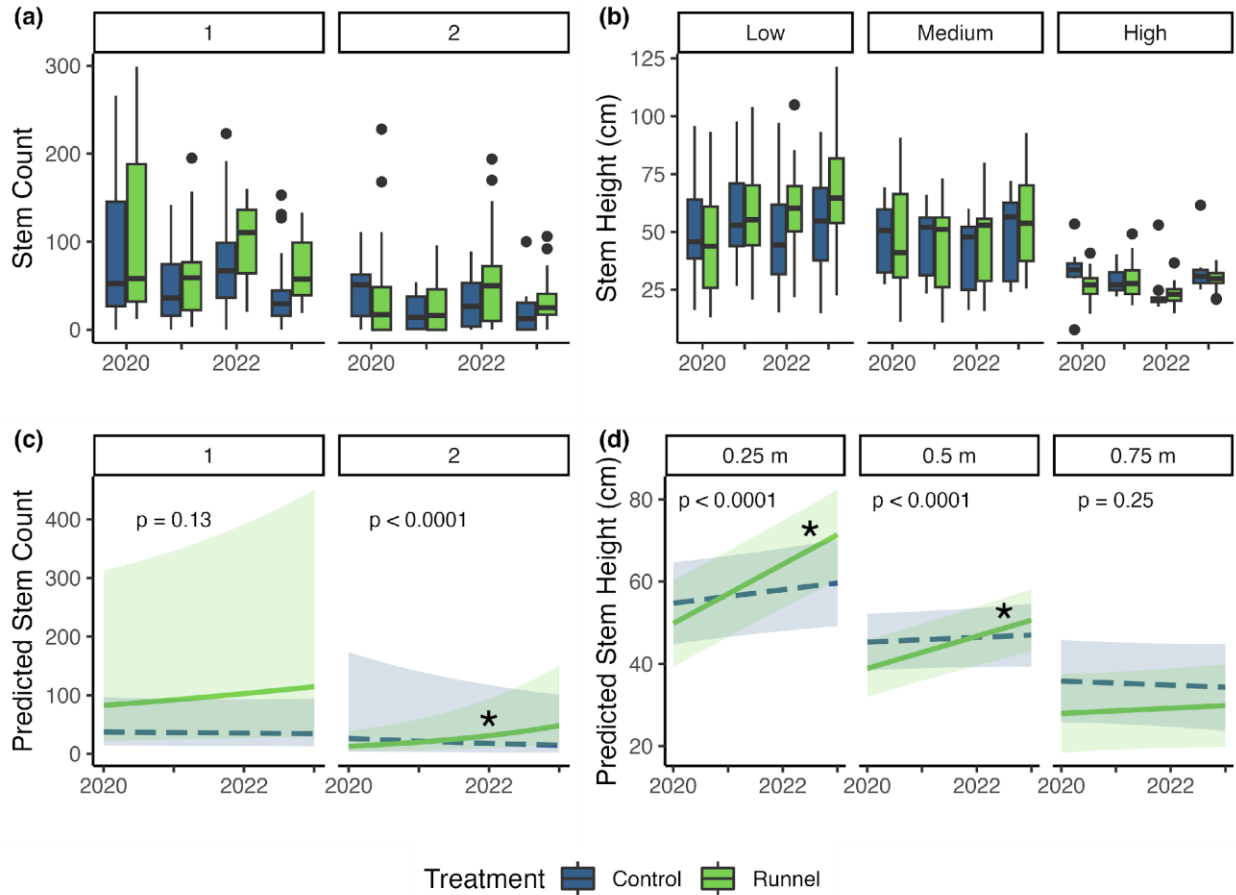


Figure 5. Stem count and height across four years and all 20 sites. Plots (a) and (b) show data, and plots (c) and (d) show modeled responses. P-values indicate the difference between control and experimental sites was significant at that treatment level, (*) indicate trend was significant at $\alpha = 0.01$. Plots (a) and (c) show responses at low (1) and advanced (2) level of degradation, and plots (b) and (d) show responses across panne elevations.



APPENDIX S1: Supplemental data, analysis and figures.

Table S1. Model fitting details. All modelling completed in R, all functions (fxn in table below) from the *lme4* package.

Response variable	Distribution	R-fxn used	Control parameters	Data range	Data included
Minimum Daily Water Level	gaussian	lmer	Optimizer = "Nelder_Mead"	-0.5 – 0.2	All available measurements from loggers May-October, at 12 intensive sites.
Percent Live Vegetation	binomial	glmer	Optimizer = "bobyqa" Maximum iterations = 2×10^5	0 – 1	5 Zone 1 plots, all 20 transects.
Percent Bare Ground	binomial	glmer	Optimizer = "bobyqa" Maximum iterations = 2×10^5	0 – 1	5 Zone 1 plots, all 20 transects.
Percent <i>Spartina patens</i>	binomial	glmer	Optimizer = "bobyqa" Maximum iterations = 2×10^5	0 – 1	12 intensive transects, all sampling plots including Zone 1 and high marsh. Data set reduced to ONLY include plots where <i>Spartina patens</i> > 0. NOTE: Model results were the same when all plots were used (including zeros), but so many zeros that rates and marginal means were biased very low.
Stem counts	negative binomial	glmer.nb	None	0 – 299	5 Zone 1 plots, all 20 transects. NOTE: Model fits were better when using counts, and negative binomial distribution. Poisson distribution (counts) led to overdispersion. Using density

					(count/0.0625) with gaussian distribution was a poorer fit as well.
Stem Height	Gaussian	lmer	None	8 – 121	5 Zone 1 plots, all 20 transects. Only included plots where <i>Spartina alterniflora</i> present (stem heights NA otherwise)

Table S2. Degrees of freedom (df), χ^2 value and significance level (p-value).

	df	χ^2	p-value
Yr:Treat	1	42.009	<0.0001
Yr:Treat:Deg	1	2.163	0.14
Yr:Treat:Marsh	1	146.828	<0.0001
Yr:Treat:Pann	1	181.975	<0.0001
Yr:Treat:Elev	1	140.723	<0.0001

Table S3. Water level response from model using three-way interaction with panne elevation. Significance test results for three-way interaction presented as chi-square (χ^2) and p-value for panne elevations of 0.25 m, 0.5 m, and 0.75 m above local mean sea level. Estimated trends with upper and lower confidence levels, (*) indicates significant at $\alpha = 0.01$.

Prediction values						
0.25 m	Interaction Statistics		Estimated Marginal Trends			
	χ^2	p-val		Trend	Upper CL	Lower CL
	200.400	<0.0001	Control	0.024*	0.019	0.029
			Experimental	-0.015*	-0.020	-0.010
0.50 m	χ^2	p-val		Trend	Upper CL	Lower CL
	40.601	<0.0001	Control	0.004*	5.6e-5	0.007
			Experimental	-0.009*	-0.012	-0.005
0.75 m	χ^2	p-val		Trend	Upper CL	Lower CL
	26.188	<0.0001	Control	-0.017*	-0.022	-0.011
			Experimental	-0.002	-0.007	0.002

Table S4. Model statistics for the response of vegetation responses to three-way interaction term between year (Yr), treatment (Treat), and environmental covariates level of degradation (Deg), marsh (Marsh), panne elevation (pann), and platform elevation (Elev). Presenting model degrees of freedom, χ^2 , and p-value.

Model	Model	Stat	Percent Live Vegetation	Percent Bare Ground	Stem Density	Stem Height	SPAT
	Yr:Treat	df	1	1	1	1	1
		χ^2	715.608	790.927	23.662	15.163	17.820
		p-val	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Yr:Treat:Deg	df	1	1	1	1	NA
		χ^2	31.1684	24.234	10.132	1.074	NA
		p-val	<0.0001*	<0.0001	0.001	0.300	NA
	Yr:Treat:Marsh	df	1	1	1	1	1
		χ^2	3.567	9.151	1.246	5.587	0.064
		p-val	0.059	0.002	0.264	0.018	0.800
	Yr:Treat:Pann	df	1	1	1	1	1
		χ^2	4.645	8.970	2.466	8.702	0.001
		p-val	0.031	0.003	0.116	0.003	0.975
	Yr:Treat:Elev	df	1	1	1	1	1
		χ^2	4.137	8.020	2.399	9.782	0.016
		p-val	0.042	0.005	0.121	0.002	0.898

Figure S1. Hydrographs for minimum daily water level at Ocean View Experimental site, OVFE. Prior to runnel installation (2020), the minimum daily water level is above the sediment surface (dot-dash line) for extended periods of time. After runnel installation (2021 - 2023) marsh tidal hydrology is restored with water draining at each low tide.

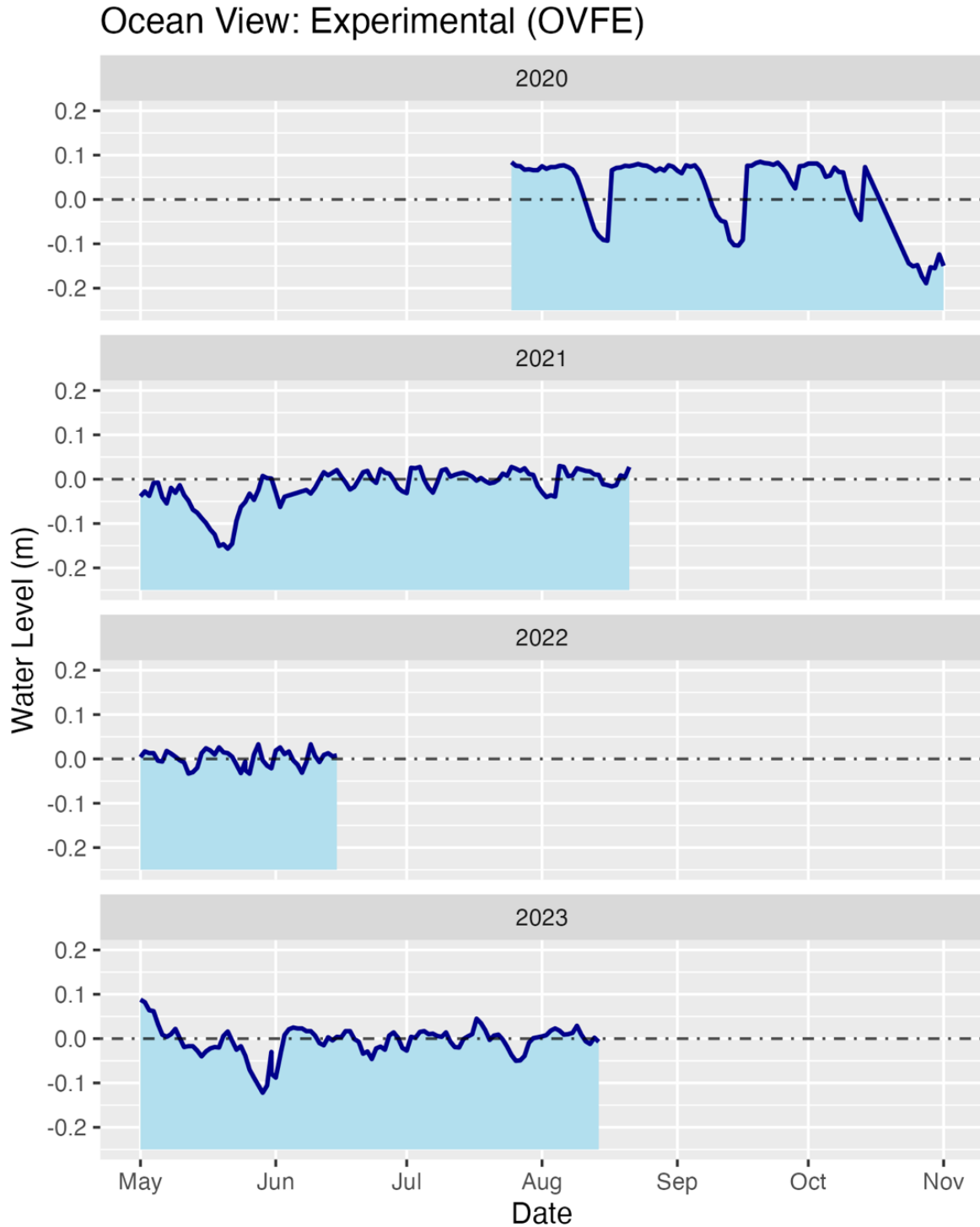


Figure S2. Hydrographs for minimum daily water level at Ocean View Experimental site, OVFH. Prior to runnel installation (2020), the minimum daily water level is above the sediment surface (dot-dash line) for extended periods of time. After runnel installation (2021 - 2023) water is no longer standing on the surface.

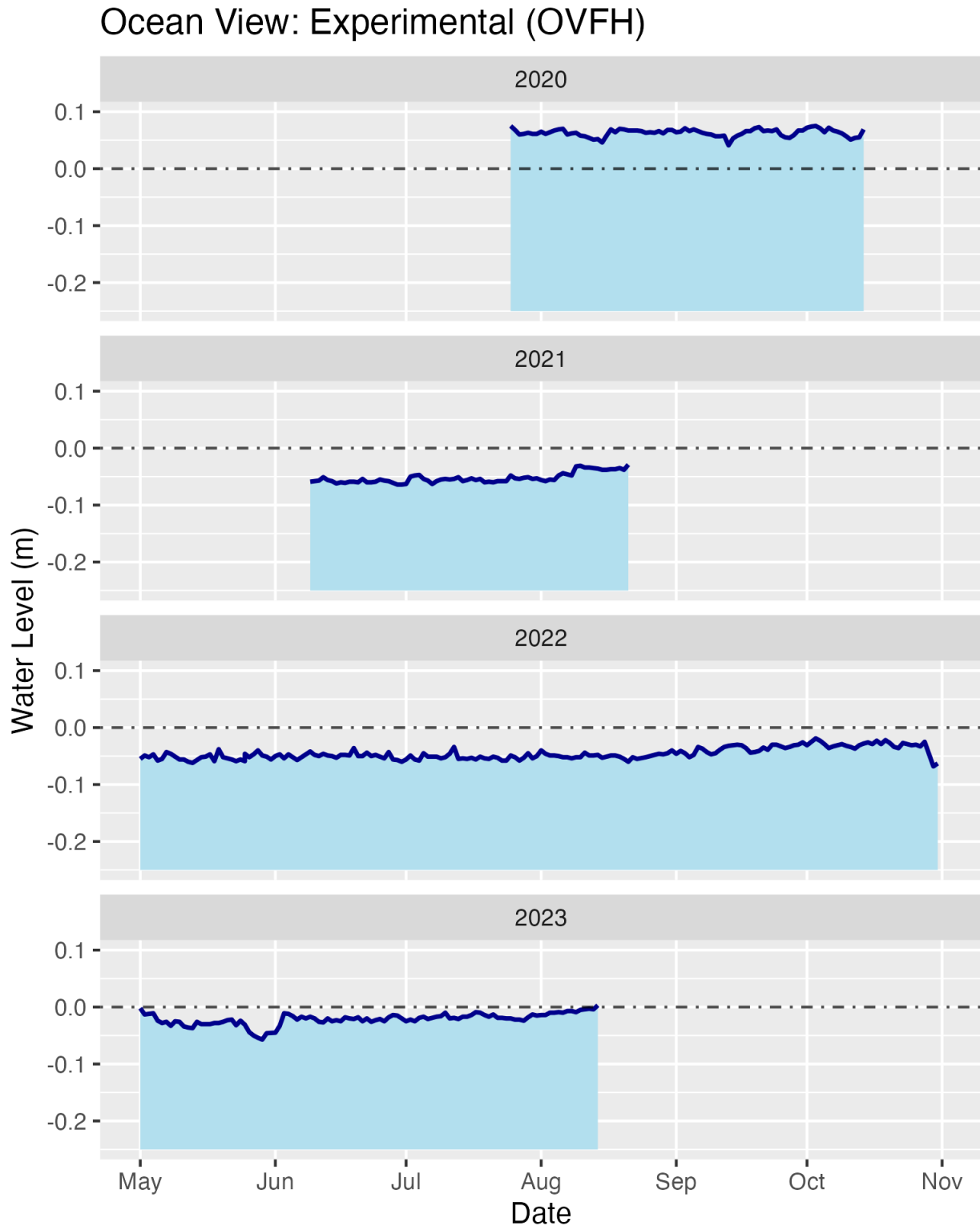


Figure S3. Hydrographs for minimum daily water level at Little Bay Experimental site, LBND. At this site, both prior to (2020) and after (2021 - 2023) runnel installation, the minimum daily water level is below the sediment surface (dot-dash line) at each low tide.

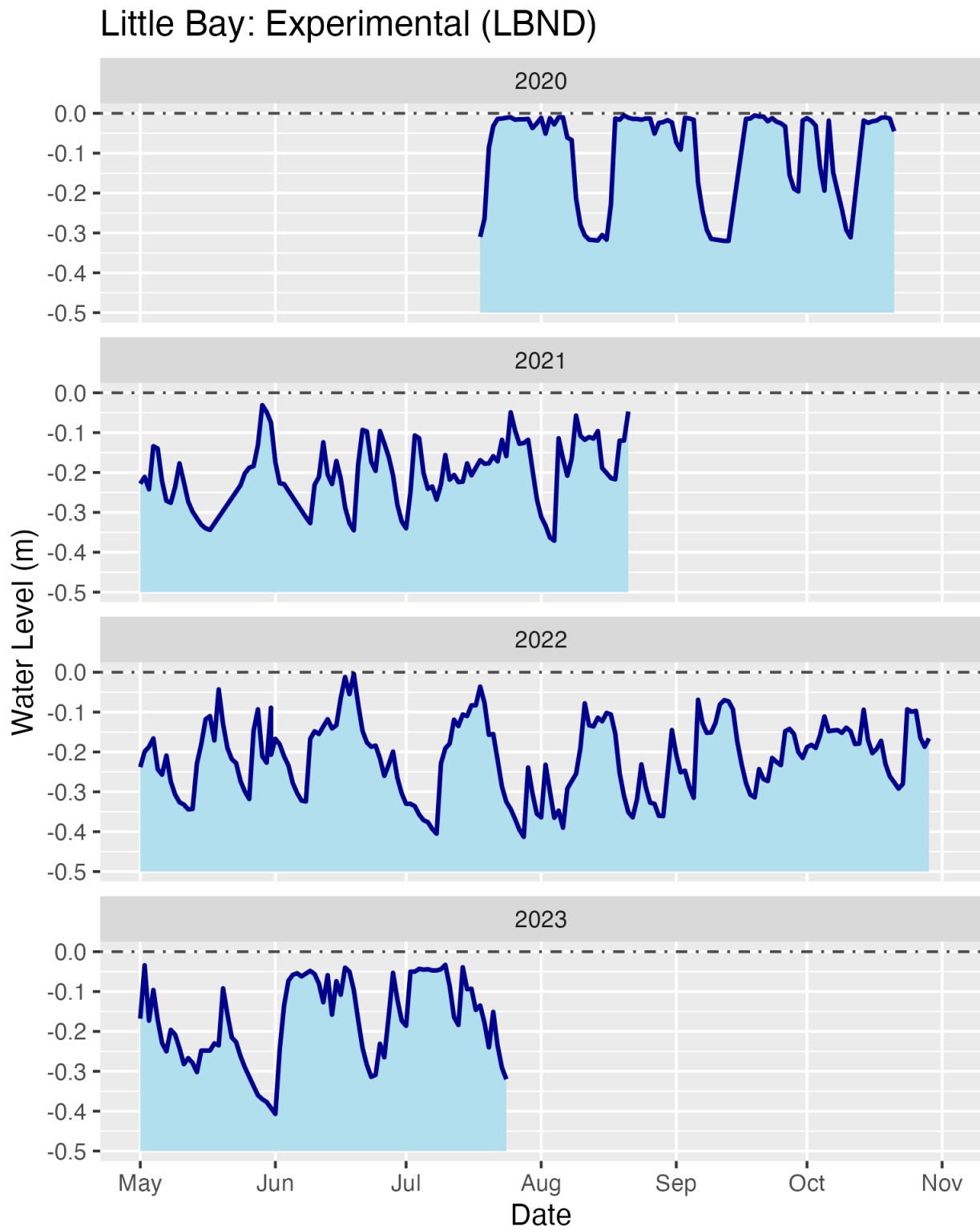


Figure S4. Hydrographs for minimum daily water level at Ocean View Control site, OVFF. The minimum daily water level at this control site is above the sediment surface (dot-dash line) for extended periods of time for most years of observation.

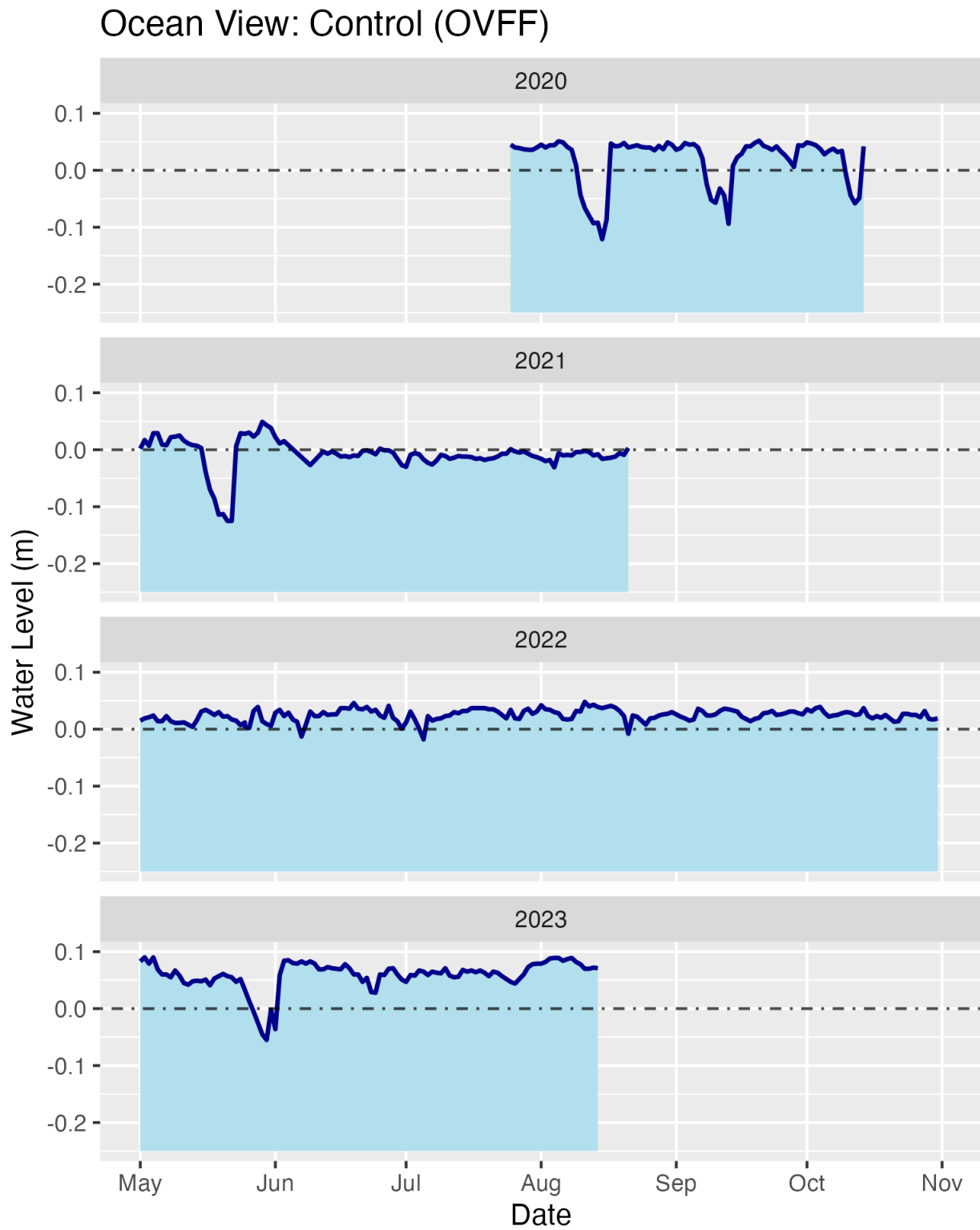


Figure S5. Hydrographs for minimum daily water level at Ocean View Control site, OVFG. The minimum daily water level at this control site is above the sediment surface (dot-dash line) throughout all years of observation.

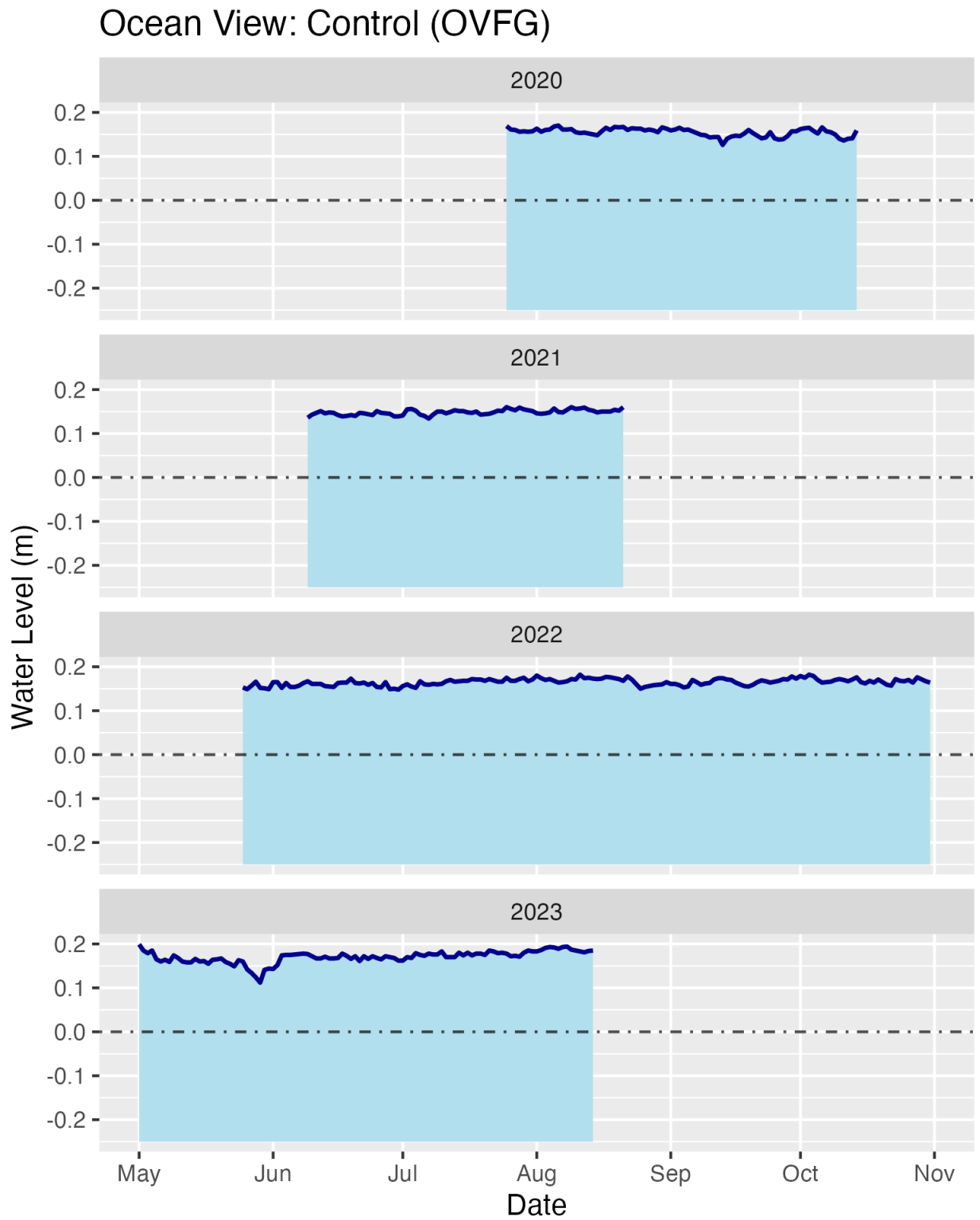


Figure S6. Hydrographs for minimum daily water level at Little Bay Control site, LBSB. The minimum daily water level at this control site was periodically above the sediment surface (dot-dash line) in 2020 but below the sediment surface for most years of observation.

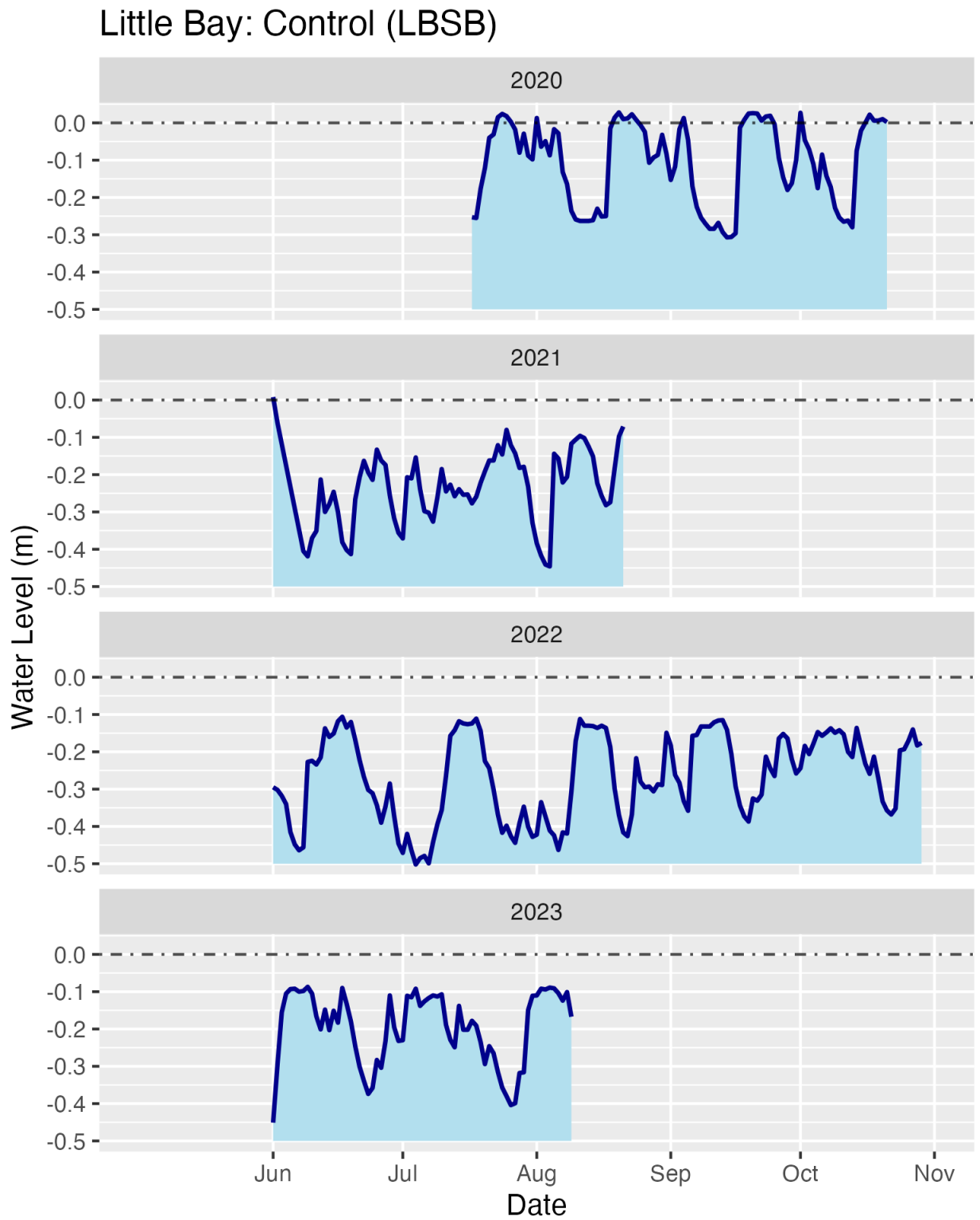
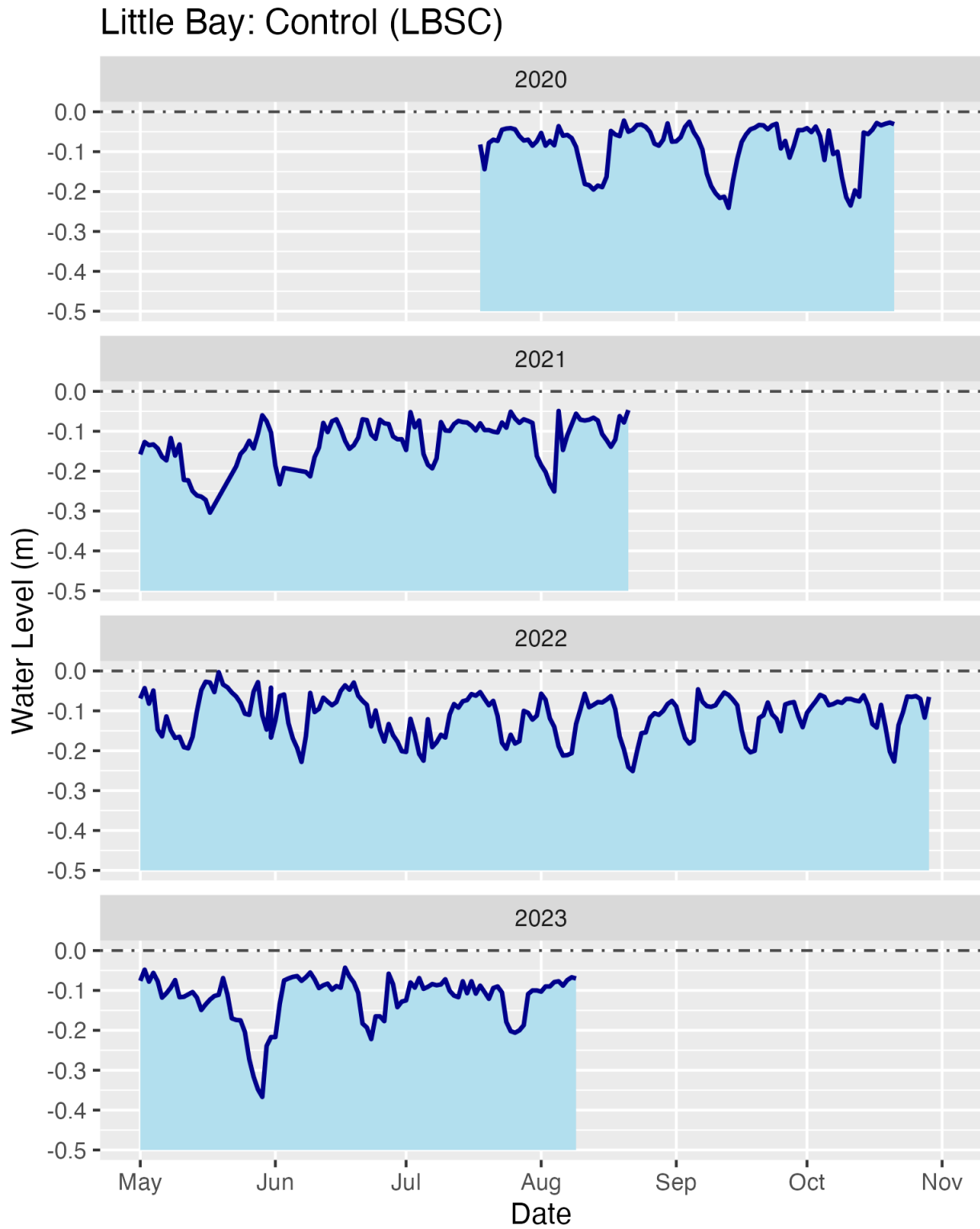


Figure S7. Hydrographs for minimum daily water level at Little Bay Control site, LBSC. The minimum daily water level at this control site was below the sediment surface for all years of observation.



D. Conclusions and Recommendations

Conclusions: Manipulating hydrologic connectivity in the marsh platform using runnels provided a test of marsh resilience by determining how readily marsh vegetation recovered to levels that restored wildlife habitat. These results provide strong evidence that marshes with a tidal range of at least 0.5 m, and platform elevations between 0.2 and 0.9 m above local mean sea level have the capacity for vegetative restoration to nearly 100% cover when hydrologic connectivity is restored. Hydrologic connectivity from runnels may have caused vegetation to recover by draining impounded surface water, lowering the water table, or by increasing flushing with fresh tidal water, or some combination of these mechanisms.

Recommended next steps: Longer-term study is needed to understand whether revegetation within the pannes will allow marsh elevation accretion rates (biological and mineral) to reach equivalency with the surrounding vegetated marsh. In addition to understanding if the mechanisms and if the function of a runnel continues indefinitely or has a limited lifetime, understanding the impacts on marsh accretion (mineral deposition, peat decomposition and formation) are important directions for further work. While microtidal marshes are widely considered vulnerable to sea level rise, this work reveals sufficient resilience within these marshes to recover ecosystem function with restored hydrology.

From a conservation management perspective, identifying poor habitat incorrectly as good quality habitat is a bigger problem than missing some good quality habitat during classification. During our study, we evaluated the use of eCognition software to train models to identify vegetation characteristics important as wildlife habitat. Unfortunately, the availability of existing imagery and using eCognition with predefined user-interface tools were determined not to be suitable for this assessment. This approach to broadly defining suitable habitat should be explored using drone imagery that provides more detailed images instead of satellite imagery.

Advancement of knowledge: This project provided fundamental, and previously not well understood, information on the relationship between small hydrologic changes and ecological function in saltmarshes. In addition, we have identified attributes of saltmarsh systems which indicate resilience (understood here as an ability to recover from either short or long-term disturbance). This project provides information on vegetation recovery after restoring tidal hydrology to areas of interior open-water expansion by draining impounded surface water, lowering the water table, or by increasing flushing with fresh tidal water. This study reveals the resilience of Buzzards Bay marshes, in that ecosystem function did recover after the press disturbance of impounded water was mitigated using runnels. Using these results, we can begin to extrapolate to other systems to better understand vulnerability and resilience. Specifically, as we found that vegetation recovery was rapid and consistent independent of panne elevation or marsh system, we can conclude that both back-barrier and fringing marshes with tidal amplitudes between 0.5 and 1.1 m and elevations between 0.2 and 0.9 m above LMSL can recover with intervention. Thus, they have likely not crossed a tipping point beyond which recovery is not possible. Finally, we identified that key marsh attributes relevant to vulnerable species of marsh-breeding wildlife (stem height, percent cover of *Spartina patens*) are improved with intervention relative to areas where no action was taken.

Relevance to natural and/or cultural resource managers: Our work provided an improved understanding of salt marsh habitat and adaptive management. Resource managers require data to prioritize direct vs. indirect adaptation actions for salt marsh and wildlife habitat management. Evaluation of adaptive management techniques is a critical component of adoption but is rarely done. "Runneling" is an emerging adaptation technique being rapidly adopted by Northeast managers to address marsh loss. The Runnel experiment development involved mosquito control agents, land trusts, and NGOs all helping design and structure the project to deliver the most relevant and useful data. Our work

delivered to natural resource managers, NGOs and decision-makers key science on an emerging adaptive intervention in salt marshes (runnels) to understand how salt marsh adaptive interventions may affect wildlife habitat assessed by vegetation characteristics. Understanding if adaptive management via runnels can improve habitat is an immediate need for US Fish and Wildlife Service (USFWS) and other stakeholders.

E. Outreach and Products:

General description of outreach:

Outreach activities included marsh site visits for public, land-trust, mosquito control, environmental regulator, resource manager, and scientific audiences (5 events, 30-40 total visitors); public audience presentations (3); an NPR interview; regional oral presentations (3) and posters (2); international/national meeting oral presentations (8); invited seminars and webinars for universities or professional societies (8); peer-reviewed and open source scientific articles (1 published, 1 in-prep), and public-audience reports (1). The team also participated in a number of outreach activities with students, including graduate students at the Vanderbilt Climate Change Workshop hosted at SEA Education Association about salt marshes, how they are impacted by climate change, and restoration activities. We then took a trip to the marsh for hands – on learning. Additional programs for high school students were run twice a summer from 2022 through 2024, where Sullivan gave a general lecture on salt marshes, what is threatening them and restoration activities including runneling. We then went into the marsh with stations for students to assess the impacts of vegetation loss by looking at sediment cores, percent cover, and water quality.

Accessible to resource management: Webinars, articles, and reports have been made publicly available and shared with resource management communities. Besterman has continued collaborations with regional resource managers in Maryland, Massachusetts, Rhode Island, and those working across the Northeast and Mid-Atlantic, and through these activities has directly shared knowledge and advice on site selection and project design based on knowledge gained from this project. Modeling efforts and reports from ACJV and National Audubon Society have been informed by Besterman’s advising, as well as a large-scale restoration project underway in Maryland.

Products:

Project-related journal papers and reports.

Besterman, A.F., Brennan, D., Costa, J.E., Deegan, L.A., DeWaters, J.M., Ferguson, W., Ganju, N., Jakuba, R.W. Recovery of salt marsh ecosystems with experimental tidal restoration: Wide applicability in varied environments. *In prep.*

Besterman, A. F., Jakuba, R. W., Ferguson, W., Brennan, D., Costa, J. E., & Deegan, L. A. (2022). Buying time with runnels: A climate adaptation tool for salt marshes. *Estuaries and Coasts*, 45(6), 1491-1501.

Jakuba, R. W., Besterman, A., Hoffart, L., Costa, J. E., Ganju, N. K., & Deegan, L. (2023). Buzzards Bay salt marshes: Vulnerability and adaptation potential. Report. Publisher: Buzzards Bay Coalition. <https://www.savebuzzardsbay.org/about-us/publications/special-reports/>

Sullivan, H. L., Besterman, A. F., Jakuba, R. W., Costa, J.E., Mezan, D., Deegan, L. A., and Bowen, J. L. (2025) Salt marsh decomposition rates after hydrologic restoration with runnels. *Submitted*.

Project-related conference presentations, seminars, webinars, workshops, or other presentations to the public made by research team members.

Besterman, A.F. (2021, May 12) Buying Time: Adapting Salt Marshes to 21st Century Sea Level Rise. [Invited Oral presentation] Brandford Rotary Club. Brandford, CT.

Besterman, A.F. (2022, Sep 8) Salt Marshes & Climate Change: Sea Level Rise. [Invited Oral presentation] Dartmouth Cultural Center. Dartmouth, MA.

Besterman, A.F., Brennan, D., Costa, J.E., Deegan, L.A., Ferguson, W., Jakuba, R.W. (2023, Nov 12-16). Tidal restoration may help salt marshes recover from incipient open-water conversion. [Oral presentation]. Coastal and Estuarine Research Federation 27th Biennial Conference, Portland, Oregon.

Besterman, A.F., Brennan, D., Costa, J.E., Deegan, L.A., Ferguson, W., Jakuba, R.W. (2021, Nov 1-4 and 8-11). 'Runneling' toward climate adaptation: Can interior drowning be reversed?." [Oral presentation]. Coastal and Estuarine Research Federation 26th Biennial Conference, Virtual.

Besterman, A.F., Jakuba, R.W., Deegan, L.A., Ferguson, W., Brennan, D., Costa, J.E., Ganju, N.K. (2021, Apr 27-30). 'Runneling' toward climate adaptation: An emerging hydrologic management strategy for salt marshes. [Oral presentation] New England Estuarine Research Society & Atlantic Estuarine Research Society Spring Meeting, Virtual.

Besterman, A.F., Jakuba, R.W., Deegan, L.A., Ferguson, W., Brennan, D. (2020, Sep 29-Oct 1). Developing best practices in runnel project design and planning. [Oral presentation] Restore America's Estuaries National Coastal and Estuarine Summit. Virtual.

Bolt, D., Jakuba, R.W. (2024, Apr 18-20) Impacts of *Sesarma* crabs in a localized salt marsh study. [Oral presentation] New England Estuarine Research Society & Atlantic Estuarine Research Society Spring Meeting. Freeport, ME.

Bolt, D., Jakuba, R.W. (2024, Mar 17-19) Impacts of *Sesarma* crabs in a localized salt marsh study. [Oral presentation] Geological Society of America Northeastern Section Meeting, Manchester, NH.

Costa, J. (2022) Presentation to the Buzzards Bay Action Committee (NGO composed of municipal officials) on 27 October 2022. Title: *Mapping and monitoring Buzzards Bay salt marshes: vegetation shifts, loss, management opportunities, and long-term trends*.

Costa, J. (2024) Presentation to the Buzzards Bay Action Committee (NGO composed of municipal officials) on 13 June 2024. Title: *Buzzards Bay National Estuary Program support for salt marsh studies in Buzzards Bay: Findings to Date on Salt Marsh Loss and the Use of Runneling*.

Delgadillo, H.A., Besterman, A.F., Jakuba, R.W. (2022, Aug 11). Examining the tidal elevation positions of two cordgrass species. [Oral presentation]. Partnership Education Program Symposium. Woods Hole, MA

Herring, M., Besterman, A.F., Costa, J.E., Jakuba, R.W. (2021, Apr 27-30). Monitoring changes in *Spartina alterniflora* growth across a southern New England watershed. [Oral presentation] New England Estuarine Research Society & Atlantic Estuarine Research Society Spring Meeting, Virtual.

Hoffart, L., Besterman, A.F., Jakuba, R.W. (2021, Nov 1-4 and 8-11). Establishing baseline conditions for rapidly degrading marshes across a southern New England watershed. [Oral presentation]. Coastal and Estuarine Research Federation 26th Biennial Conference, Virtual.

Jakuba, R.W., Besterman, A.F., Brennan, D., Costa, J.E., Deegan, L.A., Ferguson, W. (2022, Jun 2-4). Early responses to runnels in two Buzzards Bay marshes." [Oral presentation]. New England Estuarine Research Society, Salem, MA.

Jakuba, R.W., Besterman, A.F., Costa, J.E., Deegan, L.A., Ferguson, W., Brennan, D., Ganju, N. (2022, May 18). Evaluating Management Actions to Promote Salt Marsh Resilience. [Oral presentation] Southeast New England Program Symposium. [Virtual]

Jakuba, R.W., Besterman, A.F., Costa, J.E., Ferguson, W., Deegan, L.A., Brennan, D., Ganju, N. (2021, Jul 15). Building Coastal Resiliency in Buzzards Bay Salt Marshes. [Invited Oral presentation] Wetlands and Coastal Resilience in Southeast New England Webinar Series. [Virtual]

Jakuba, R.W., Besterman, A.F., Costa, J.E., Ferguson, W., Deegan, L.A., Brennan, D., Ganju, N. (2022, Jul 21). Evaluating Runnels to Promote Salt Marsh Resilience. [Invited Oral presentation]. Martha's Vineyard Commission Water Alliance Meeting. [Virtual]

Jakuba, R.W., Besterman, A.F., Costa, J.E., Ferguson, W., Deegan, L.A., Brennan, D., Ganju, N. (2024, Sep 11). Impact of Climate Change: Promoting resilience in salt marshes. [Invited Oral presentation]. Highfield Hall Science Lecture Series. Falmouth, MA.

Macpherson, C., Jakuba, R.W., Besterman, A.F., Costa, J.E., Deegan, L.A., Ganju, N. (2024, Jun 12). Buzzards Bay Salt Marshes: Vulnerability and Adaptation Potential. [Oral presentation]. Southeast New England Program Symposium. Bristol, RI.

Mezan, D. & A.F. Besterman. (2024, Mar 21-23). Response of vegetation and soil properties to runnels used as a salt marsh restoration strategy. [Poster presentation]. Atlantic Estuarine Research Society Spring Meeting, Gloucester, VA.

Mezan, D. & A.F. Besterman. (2024, May 10). Response of vegetation and soil properties to runnels used as a salt marsh restoration strategy. [Poster presentation]. Towson University Spring Student Poster Symposium, Towson, MD.

Sullivan, H. L., Salt Marsh Speaker | Research at the Reserve | Waquoit Bay National Estuarine Research Reserve | Mashpee, MA | Mar 2024

Sullivan, H. L., W. Ferguson, L.A. Deegan, and J.L. Bowen (oral) | The impact of altered and restored hydrology on salt marsh N cycling | New England Estuarine Research Society (NEERS) Spring Meeting, Freeport, ME | Apr 2024

Sullivan, H. L., W. Ferguson, L.A. Deegan, and J.L. Bowen (oral) | The impact of altered and restored hydrology on salt marsh N cycling | Coastal Estuarine and Research Federation (CERF) Biennial Meeting, Portland, OR | Nov 2023

Sullivan, H. L., A. Besterman, R. Jakuba, L.A. Deegan, and J.L. Bowen (poster) | The impact of runneling as a hydrologic adaptation strategy on salt marsh carbon decomposition | National Estuarine Research Reserve Society (NERRS) Annual Meeting, Seattle, WA | Oct 2022

Sullivan, H. L., A. Besterman, R. Jakuba, L.A. Deegan, and J.L. Bowen (oral) | The impact of runneling as a hydrologic adaptation strategy on salt marsh carbon decomposition | Soil and Water Conservation Winter Meeting (virtual) | Apr 2022

Sullivan, H. L., A. Besterman, R. Jakuba, L.A. Deegan, and J.L. Bowen (virtual) | The impact of runneling as a hydrologic adaptation strategy on salt marsh carbon decomposition | Coastal Estuarine and Research Federation (CERF) Biennial Meeting | Nov 2021

Sullivan, H. L. Speaker | What is a runnel and can it save our marshes? | Margaret A. Davidson Graduate Fellowship Webinar Series | Virtual | Feb 2024

Communications with decision-makers.

We worked on site selection and project design in coordination with decision-makers including town conservation agents in the Towns of: Falmouth, Bourne, Marion, Mattapoisett, Wareham, Dartmouth, Fairhaven, and Westport, as well as mosquito control agencies in Bristol County (project partner), Plymouth County, and Cape Cod. We also worked with landowners (primarily land trusts) that owned marsh with high restoration potential using runnels. We shared a report with 1-year post-runneling results with all attendees of our 2020 workshop which included dozens of decision-makers (regulators, conservation agents, mosquito-control agents, land trusts, landowners, and restoration practitioners). Additionally, this information has been presented to Buzzards Bay Coalition (a local NGO) that has been instrumental in regional saltmarsh work, including Buzzards Bay Coalition members, Board of Directors, and Leadership Council. We have also communicated with the Waquoit Bay National Estuarine Research Reserve (WBNERR is funded by NOAA and MA Dept. of Conservation and Recreation). Based on these conversations the team was involved in the design and implementation of a program of marsh restoration via runneling at WBNERR.

We also developed a report that was designed and printed as a pamphlet for public and end-user accessibility to specifically address specifically stated management questions about salt marsh resilience. This report summarized the state of marshes around Buzzards Bay, including metrics indicative of vulnerability and resilience.

Websites created for the project and/or containing project information, data etc.

<https://www.woodwellclimate.org/assessing-new-salt-marsh-restoration-technique-in-buzzards-bay/>
<https://www.savebuzzardsbay.org/about-us/publications/special-reports/>

Other products, such as data or databases, audio/video productions, fact sheets etc.

Data sets:

- 1) Tidal marsh vegetation in response to hydrologic restoration using runnels
- 2) Water level data in tidal marshes in response to hydrologic restoration using runnels
- 3) Elevation and tidal datums for sites receiving hydrologic restoration using runnels