1. Activity Title:
Mitigating Marshes Against Sea Level Rise: Thin-Layer Placement Experiment

2. Focus:
Coastal restoration techniques: scientific method, replication, vegetation cover, sea level rise in salt marshes, and thin-layer placement

3. Grade Levels/ Subject:
9th -12th

4. VA Science Standard(s) addressed: BIO.1, BIO.8 c-d, ES.1, ES.8 a, ES.10 a, d-e.
Meets objectives for The Virginia Environmental Science Course:
I. Scientific Skills and Processes
V. Human impact, global climate change, and civic responsibility

5. Learning objectives/outcomes

a. Students will explain why the zones of a salt marsh are different
b. Students will summarize how sea level rise, erosion, and subsidence affect coastal marshes
c. Students will describe the process and goals of thin-layer placement as a restoration strategy
d. Students will understand the benefits of the thin-layer placement restoration technique

6. Summary:
Students will learn about thin-layer placement restoration techniques by using data from the first year of a plot-based thin-layer restoration science project being conducted by the Chesapeake Bay National Estuarine Research Reserve in Virginia (CBNERR-VA). In groups, students will analyze images of vegetation plots exposed to different treatments and decide which is performing best and could be used as a possible restoration technique to combat sea level rise in the marsh. Students will also interpret graphs of vegetation percent cover, and use classroom discussion to come to a conclusion using critical thinking.

7. Total length of time required for the lesson: 60-90 minutes (may work best if spread between 2 class sessions)

8. Key words/Vocabulary:

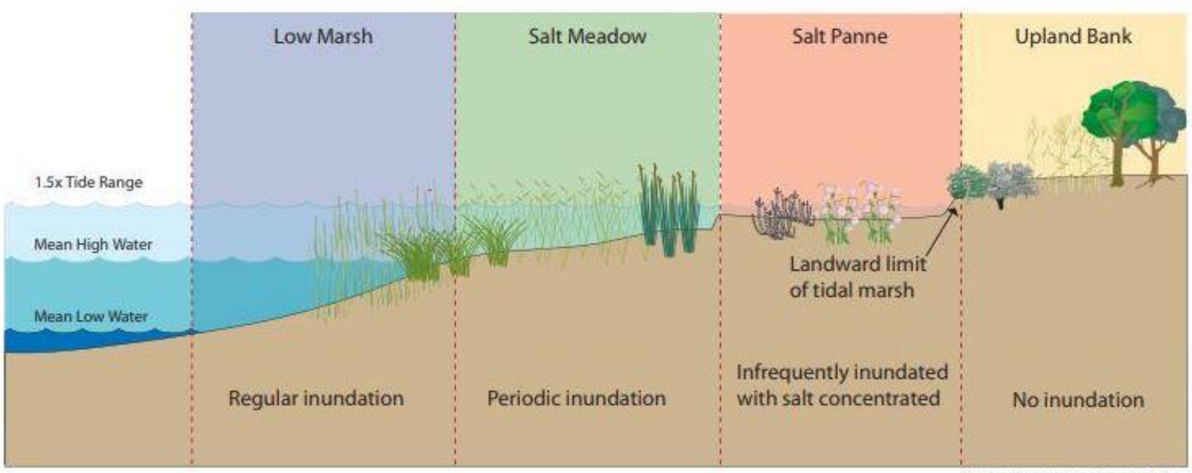
Accretion
Beneficial Reuse
Biochar
Community Structure
Control
Dredging
Ecosystem Services
Erosion
Estuary
Inundation

Reference Plot
Resilience
Restoration
Subsidence
Thin-Layer Placement

9. Background information

Marshes are a type of wetland dominated by grasses that are frequently flooded with water, a process called *inundation*. Marshes provide a variety of *ecosystem services* for humans including buffering wave energy to protect coastlines, trapping sediments and filtering runoff to improve water quality, reducing impacts of flooding, and providing recreational opportunities. In addition, these habitats are important for many fish (especially as nursery areas) and wildlife (Barbier et al., 2011).

Since marshes are a transition area between land and sea, they vary in properties such as salinity, water level, temperature and oxygen, as you move inland from the shoreline. Marsh zonation is heavily influenced by the frequency and duration of flooding. The zones can be thought of as four different parts: “low marsh”, with regular flooding by high tide, “salt meadow” with periodic flooding during extremely high tides, “salt panne” with infrequent flooding, and the “upland bank”, with flooding only during extreme weather events or irregular conditions. This zonation is visible by the different dominant species of vegetation in each zone that are adapted to grow there (Chesapeake Bay Program, 2004) (CCRM, 2019).



The zones in a salt marsh are maintained by physical interactions with the tides, salinity, and extreme weather events or flooding. In addition, competition between species keeps them in their respective zones. When moving from the shore to the high marsh zone, vegetation species change in abundance and dominance. Few species are adapted to lower elevations, like Smooth cordgrass (*Spartina alterniflora*), which dominates the low marsh area, which has high salinity and is flooded often. In higher elevations, there is less flooding and salinity, which allows species such as Saltmeadow cordgrass (*Spartina patens*) and Salt grass (*Distichlis spicata*) to dominant in a mixed marsh species *community structure* (Bertness, 1991; Morris, Sundareshwar, Nietch, Kjerfve, & Cahoon, 2002; Chesapeake Bay Program, 2004; Perry and Atkinson, 2009).

Global sea level rise (SLR) is affecting many coastlines, including the areas surrounding the Chesapeake Bay *estuary* (Morris et al., 2002; VIMS, 2018). In addition, *subsidence*, sinking of the ground, is a major factor contributing to local sea level rise which varies throughout the Bay. Subsidence could be caused by a combination of the retreat of glaciers from the previous ice age, sediment loading adding too much weight on the wetlands, and sediment compaction after groundwater removal (Eggleston & Pope, 2013). *Erosion* is also occurring on the shoreline, causing loss of the marsh land on the coast. Salt marshes are able to migrate towards the forests and further inland to try and survive, but they may not be able to keep up with the rate of SLR (Kirwan, Walters, Reay, & Carr, 2016).

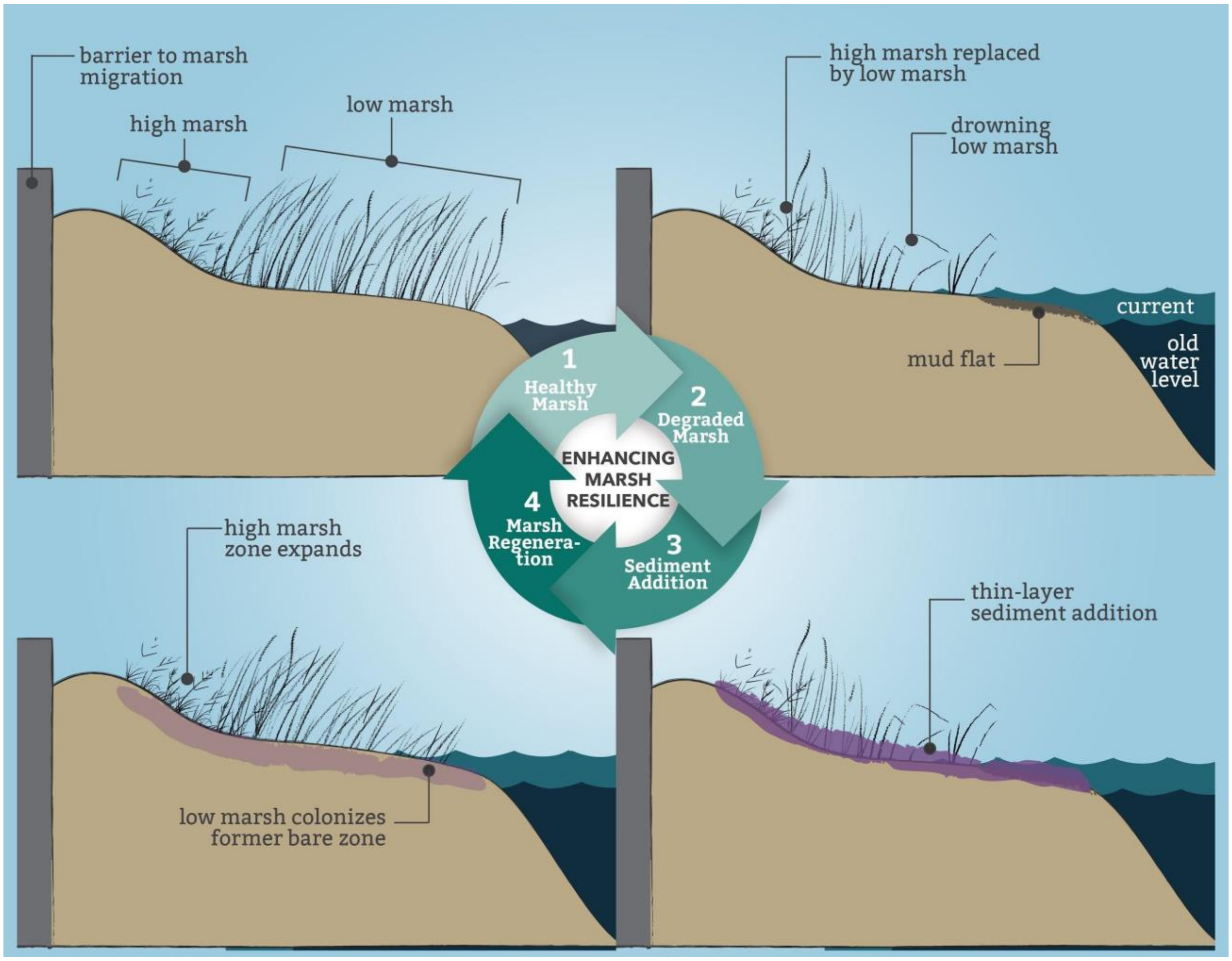
In response to sea level rise, marshes have two mechanisms: 1) vertical accretion and 2) horizontal migration. Some marshes are able to build vertically by accumulating sediments and organic matter. This vertical development is referred to as *accretion*. Secondly, some marshes can migrate horizontally away from the shoreline into higher elevations.

For example, as flooding becomes more frequent and gets more intense, the high marsh species drown and cannot withstand the rising water level and salinity. High marsh species die and the lower marsh species begin to take over that space (Raposa, Weber, Ekberg, & Ferguson, 2015; Kirwan et al., 2016). This can cause a narrowing of the high marsh and potential loss of some intertidal habitat (Pontee, 2013). In addition, some marshes cannot migrate if there are barriers such as roads, houses, rocky cliffs, or any kind of shoreline armor (The Nature Conservancy & NOAA, 2011). If the rate of SLR is too high, marshes or grass species will not be able to migrate or accrete fast enough to maintain elevation, and will drown (Weis & Butler, 2009).

Scientists are trying to improve the ability of marshes to withstand change, known as their *resilience*, by increasing marsh elevation for maximum vegetation growth and to keep marshes from eroding away. To do this, a relatively new *restoration* strategy being tested and/or implemented in many places to enhance marsh resilience is *thin-layer placement* (TLP). TLP can be defined by the US Army Corps of Engineers as

"purposeful placement of thin layers of sediment (e.g., dredged material) in an environmentally acceptable manner to achieve a target elevation or thickness. Thin-layer placement projects may include efforts to support infrastructure and/or create, maintain, enhance, or restore ecological function" (Berkowitz, Welp, Piercy, & Vanzomeren, 2019, p. 6).

The goal of TLP is to maintain marsh communities in their position relative to sea level rise. In addition, this strategy has the potential to be a “win-win” situation if the sediment placed on the marsh surface is from local *dredging*, giving dredging sediments the opportunity for *beneficial reuse*. However, since this is a novel approach, more research is needed to evaluate the effectiveness across diverse conditions and to standardize a national framework for TLP and monitoring protocols (Raposa, West, Wasson, Woolfolk, Endris, & Fountain, 2017).



Researchers have begun evaluating different strategies and treatments for TLP across the nation. The National Estuarine Research Reserve (NERR) System Science Collaborative funded a two-year experiment at 8 different NERR sites to provide broad geographic scale, including the Chesapeake Bay NERR in Virginia (Raposa et al., 2017). The three core research questions about TLP they are trying to answer include: “Is sediment addition an effective adaptation strategy for marshes in the face of sea level rise? How does marsh resilience respond to different levels of sediment addition? How do low versus high marsh habitats differ in their response to this restoration strategy?” (Raposa et al., 2017).

Each reserve site also will be answering secondary questions, such as determining how the use of *biochar*, which is carbon rich material, or the use of a local dredged sediment sources affects plant growth and nutrition. At CBNERR-VA, for example, the study design includes an extra treatment using local dredge material from a recent shoreline enhancement project (Raposa et al., 2017).

The experiment is looking at three factors for change: marsh elevation, vegetation cover, and sediment properties. Each reserve has established locations in both the high marsh and low marsh habitats to test how different sediment thicknesses affect vegetation. At each reserve, there are five sites in the high marsh and five in the low marsh. In both the low and high marsh habitats, there are treatment plots enclosed by a 0.7 m x 0.7 m wooden frame in order to reduce sediment slumping, erosion, and loss. All reserves have between 40-50 treatment plots total.

All sites include one control plot with no frame, one control plot with a frame, one plot with a thin standard sediment treatment, and one plot with a thick standard sediment treatment. The *control* plot tests the effects of the frame and site selection because it does not receive treatment. One *reference plot* is chosen 10 to 20 centimeters higher in elevation than the treatment plots and represents the restoration goal. A standard composition of mud and sand is used as the sediment source in all reserves (Raposa et al., 2017).

At the NERRs in Chesapeake Bay, Virginia, North Carolina, and San Francisco Bay, there is an additional treatment plot within each site with 14 cm of local dredged material. At the NERRS in

Elkhorn Slough, Caliornia, Narraganesett Bay, Rhode Island, and Waquoit Bay, Massachusetts, there is an additional treatment plot within each site with 14 cm treatment with biochar added.

Researchers at the reserves monitor changes in marsh vegetation, elevation, and sediment properties in these plots over the two years to capture two growing seasons. The results in this lesson are not conclusive; instead, scientists are still experimenting on which treatment is best and if this will work in all areas. However, this is an example of experimenting before restoration, or a controlled, small scale experiment. It will be useful for comparison to larger scale experiments and will supplement research in the field of thin-layer placement. Ultimately, these results will help marshland managers understand their options and the effectiveness of potential restoration projects.

10. Student handouts and other materials needed

- ❑ TLP activity PowerPoint
- ❑ **Appendix 1**: Treatment plot images and graphs for each 3 treatments for the low marsh habitats (1 treatment per group)
- ❑ **Appendix 2**: Treatment plot images and graphs for each 3 treatments for the high marsh habitats (1 treatment per group)
- ❑ **Appendix 3**: Student worksheet
- ❑ **Appendix 4**: Student Assessment
- ❑ **Appendix 5**: Student Assessment answer key
- ❑ **Optional**: Online Story Map

11. Classroom/Lab/Field Study Setup

Lesson is appropriate in a classroom setting with large working tables and counter space for students to lay out materials. The lesson can also incorporate the online Story Map, which would require a computer or tablet and internet for each student, or for small groups to use. This tool is designed for students to gain the background information of the lesson in an interactive way, similar to the provided PowerPoint. There is also a portion where students could do an abridged version of the activity provided in the lesson plan. You can use both this lesson plan and the Story Map to help reinforce the concepts. For example, the Story Map can be a review of concepts the class period after the lesson, or you can guide students using the powerpoint through the Story Map, or just let students explore on their own.

12. Procedure:

Advance preparation of lab materials – 10 minutes
Lab Set-up – 5 minutes
Introduction – 15 minutes
Activity – 25 minutes
Discussion - 15 minutes
Breakdown and Clean-up – 5 minutes

Preparation

Print out the time series images of treatment plots for both low and high marsh habitats <u>one-sided</u> (or determine how to transfer to students if using the computer files)

Introduction

Information to aid in the discussion points listed below is provided in the background information section

1. Introduce the topic and help students understand marsh issues by using the PowerPoint designed to accompany the lesson.
2. Ask students what they already know about marshes and consider making a list. This could include: species that live there, ecosystem services, known threats, and where some are located near the students or school.
3. Use the PowerPoint to explain the different zones of a marsh to students and the flooding patterns that create those special habitats.
    a. Further name the species that live in each zone.
4. Describe some climate threats to marshes: erosion, SLR, and subsidence.
5. Ask students if they know how marshes respond to these issues.
    a. Have students talk to the person next to them to brainstorm ideas.
6. Transition into explaining vertical accretion and horizontal migration.
7. Walk students through the TLP experiment using the slides to help them understand:
    a. How TLP works
    b. The NERR Experiment
        i. The benefit of a wide geographic area among many types of marsh habitats (TLP NERR map slide)
        ii. The goals of the experiment
        iii. CBNERR-VA study design
            1. Advantages of using dredged material
        iv. Experimental design and the use of:
            1. Replication
            2. Controls
    c. Explain how CBNERR-VA researchers monitor these plots, with emphasis on vegetation and elevation.
8. Have students practice percent cover on the screen. Allow them 5-10 seconds, it is only supposed to be used as an estimate.
9. Begin the activity!

Activity

1. For large classes (20-30 students), split students into 6 groups. If you have a smaller class, split the class into 3 even groups. Group size should be 3-5 students per group. Each group will be analyzing images and graphs for one single treatment in both the low marsh and high marsh habitat. First, assign groups to their experimental treatment (14 cm, 7 cm, dredge).

Group number	**Treatment**
Group 1	14 cm low and high marsh
Group 2	7 cm low and high marsh
Group 3	Dredge low and high marsh
Group 4-6	Duplicates of 1-3

2. Before students begin, show them an example explaining the time series images and the associated graphs.
    a. In the graphs, column colors are associated with different marsh grass species:
        i. Red = *Spartina alterniflora* (low marsh species), but name recently changed to *Sporobolus alterniflorus*
        ii. Green = *Distichlis spicata* (high marsh species)
        iii. Blue = *Spartina patens* (high marsh species)
        iv. Ref = reference plot
    b. Images have time stamps:
        i. Reference plot = the goal for vegetative growth after sediment addition. This image taken at higher elevation to represent what is healthy for that elevation in the marsh
        ii. Pre-sediment addition = before sediment was added to the treatment plots
        iii. September 2018 = 6 months post sediment addition
        iv. June 2019 = 14 months post sediment addition
3. Begin the activity by having the groups first analyze the images from the high marsh zone and have students look at percent cover changes.

4. After a few minutes, give groups the percent cover graphs associated with their treatment and have students analyze the graphs for community structure changes.
5. In groups, students will analyze the images and the associated graph of percent cover to determine how well their experimental treatment is working. Students will fill out their worksheet and answer the associated questions.
6. If applicable, after completing their group's questions, pair students between groups with the same treatment to share what they think and discuss.
7. Then, groups will present to the class their consensus on the treatment they were assigned.
8. Explain to students that they just studied individual sites. However, this experimental process requires students to look at the average percent cover between all sites to understand how the treatment worked overall, not just in that one site.
9. Show them the slide with 3 high marsh graphs that show the average percent covers to determine which treatment performed the best. As a class, students will determine which treatment they think has performed well in the high marsh and try to think of explanations for that.
    a. Possible explanations:
        i. Some treatments too thick and smothering plants
        ii. Some treatments too thin and not helping plants elevate effectively
        iii. Not enough nutrients in some plots
        iv. Wrong composition of sediment
10. Next, in the same groups, assign students to same treatment plots but this time for the low marsh habitat.
11. Have students repeat the same activity, analyzing first how their images change over time and then give them the graphs. Students will continue filling out their worksheet.
12. Have each group share their consensus on the effectiveness of the treatment they were assigned with the class.
13. Lastly, remind them again that it is necessary to look at averages from all the plots. Show them the next slide that shows the 3 graphs for average percent cover for each treatment in the low

marsh to determine which treatment performed the best for the low marsh. Have them try to think of explanations.

   a. Possible explanations:
      i. Some treatments too thick and smothering plants
      ii. Some treatments too thin and not helping plants elevate effectively
      iii. Not enough nutrients in some plots
      iv. Wrong composition of sediment

14. Discussion: as a class, compare the low and high marsh habitats.
   a. Ask students questions such as:
      i. Which would you use if you were going to do TLP in the near future?
      ii. Were there differences in successful treatments in the low and high marsh?
      iii. What are the pros and cons of TLP?
   b. Encourage students to also discuss the experimental design:
      i. Would you do anything differently?
15. Close the activity by continuing the PowerPoint to share scientists' hypotheses for the experiments current progress.
   a. Emphasize that this experiment has one more year left and these are NOT final results.
16. Wrap up with a discussion asking students about their thoughts on TLP. Teachers should guide student reflection as best fits to enhance learning.
17. Give students the post-monitoring questions to use as an assessment to be completed individually.

Optional Extension Activity

Ask students: Have students prepare a debate between a homeowner and a restoration scientist about implementing TLP near residential areas. Have them answer the following questions in the debate: based on this result would you implement TLP in a degrading salt marsh? What are the pros and cons of this strategy? Each should do research and represent their side of the argument.

13. References:

Barbier, E. B., Hacker, S. D., Kennedy, C., Koch, E. W., Stier, A. C., & Silliman, B. R. (2011). The value of estuarine and coastal ecosystem services. *Ecological Monographs*, *81*(2), 169–193. https://doi.org/10.1890/10-1510.1

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Center for Coastal Resources Management (CCRM), Virginia Institute of Marine Science. (2019). Salt & Brackish Marsh. Retrieved from https://www.vims.edu/ccrm/outreach/living_shorelines/native_plants/salt_marsh/index.php

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The Nature Conservancy and the NOAA Coastal Services Center. (2011). *Marshes on the Move: A Manager's Guide to Understanding and Using Model Results Depicting Potential Impacts of Sea Level Rise on Coastal Wetlands*. Accessed at www.csc.noaa.gov/publications/Marshes_on_the_move.pdf.

New Hampshire Department of Environmental Services. (2004). *What is a Salt Marsh?* [Brochure]. Concord, NH.

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Raposa, K. B., Weber, R. L. J., Ekberg, M. C., & Ferguson, W. (2015). Vegetation dynamics in Rhode Island salt marshes during a period of accelerating sea level rise and extreme sea level events. *Estuaries and Coasts, 38(5)*. doi:10.1007/s12237-015-0018-4.

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Other Useful Resources:

https://coastalscience.noaa.gov/news/nccos-usace-help-marines-keep-pace-with-sea-level-rise-at-camp-lejeune-video/

https://www.delmarvanow.com/story/news/2019/06/06/army-corps-details-plan-use-dredge-spoils-marsh-restoration/1343440001/

https://nerrssciencecollaborative.org/project/Raposa17

http://www.waquoitbayreserve.org/thin-layer-sediment-placement-evaluating-an-adaptation-strategy-to-enhance-coastal-marsh-resilience-across-the-nerrs/

https://arcg.is/09yDmL

https://dnr.maryland.gov/ccs/Pages/Beneficial-Use.aspx

https://coastalchangelab.wordpress.com/projects/thin-layer-sediment-placement/

https://www.vims.edu/cbnerr/_docs/ctp_docs/MPPDC%20Sea%20Level%20Rise%20Fact%20Sheet%20FINAL%202011.pdf

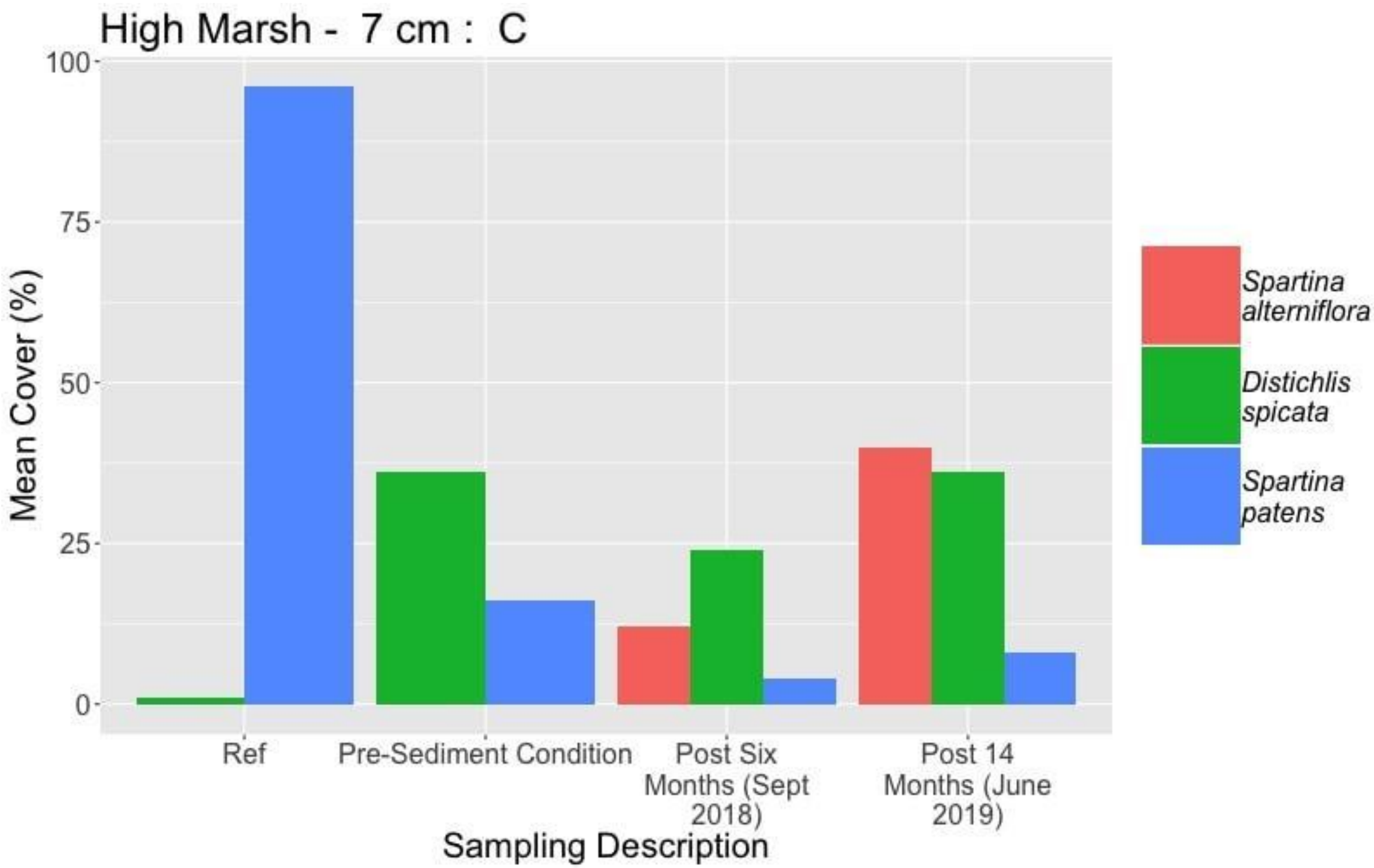
https://tlp.el.erdc.dren.mil/

Appendix 1: Treatment plot images and graphs for each of the 3 treatments for the high marsh habitats

High Marsh Habitat
7 cm

Reference Plot	April 2018: Pre-Sediment Addition
	

September 2018: Post 6 Months	June 2019: Post 14 Months
	

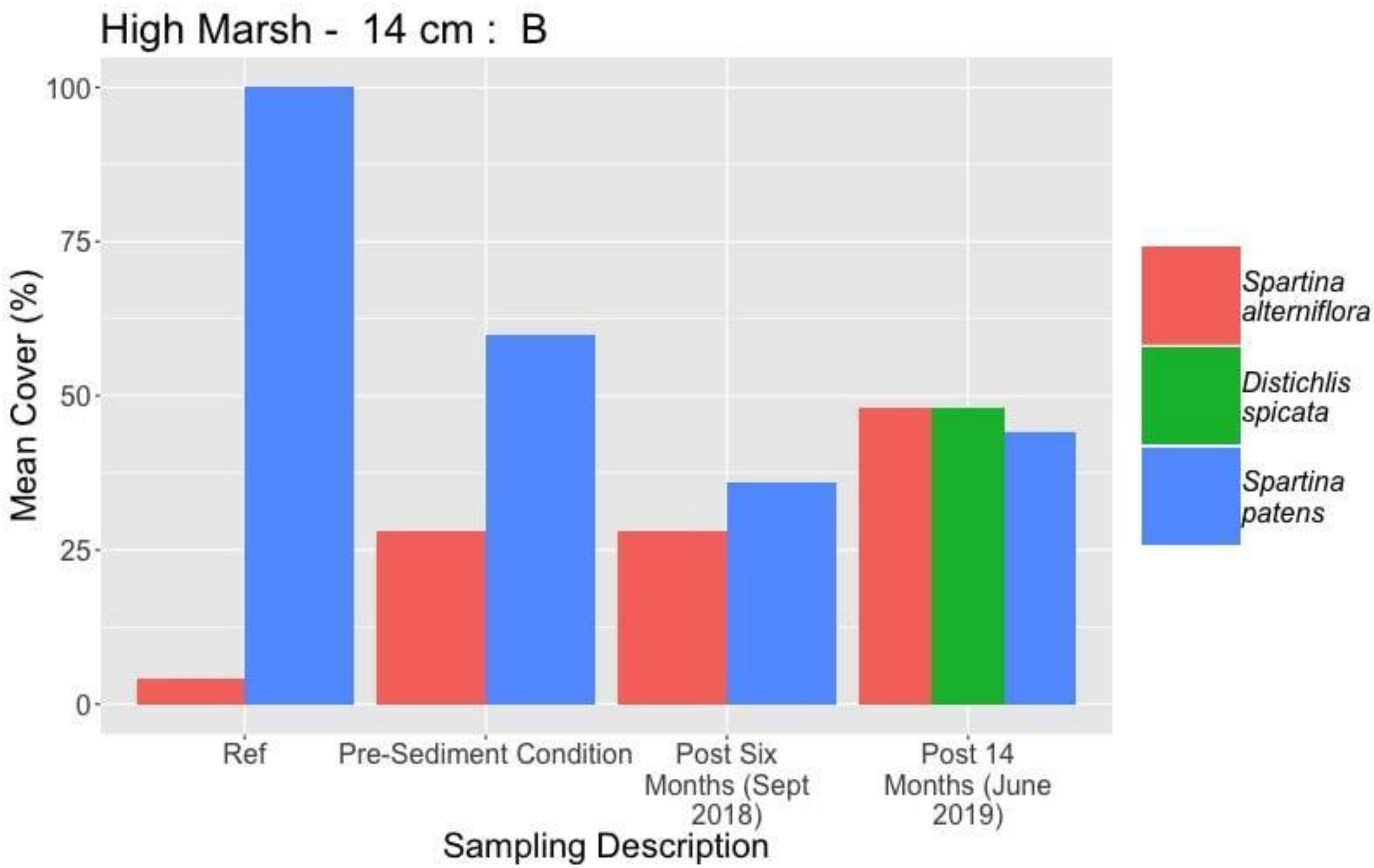

High Marsh - 7 cm : C
Mean Cover (%)
100
75
50
25
0
Ref
Pre-Sediment Condition
Post Six Months (Sept 2018)
Post 14 Months (June 2019)
Sampling Description
Spartina alterniflora
Distichlis spicata
Spartina patens

High Marsh Habitat

14 cm

Reference Plot	April 2018: Pre-Sediment Addition
	

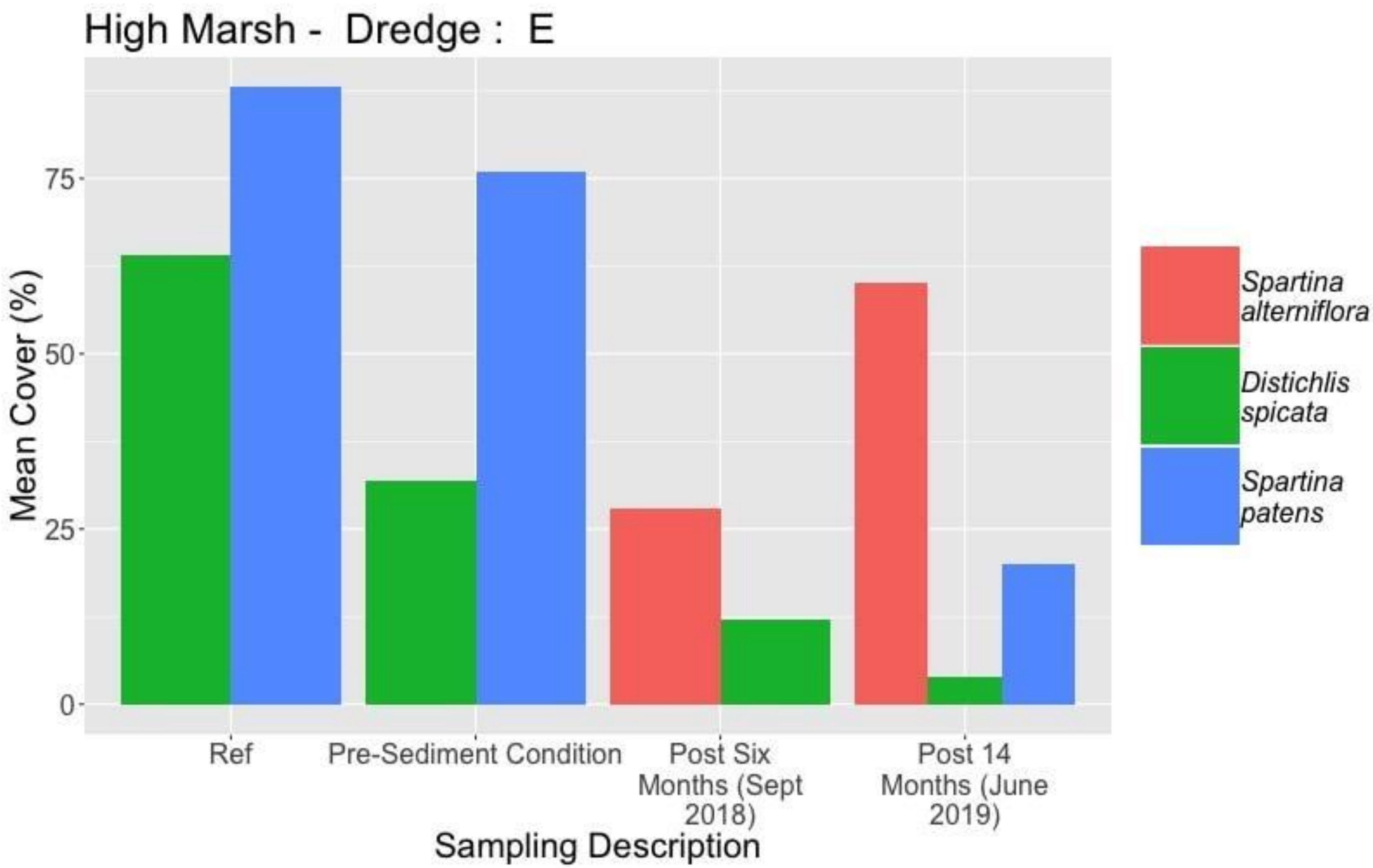
September 2018: Post 6 Months	June 2019: Post 14 Months
	


High Marsh - 14 cm : B
Mean Cover (%)
100
75
50
25
0
Ref
Pre-Sediment Condition
Post Six Months (Sept 2018)
Post 14 Months (June 2019)
Sampling Description
Spartina alterniflora
Distichlis spicata
Spartina patens

High Marsh Habitat
14 cm Dredge

Reference Plot	April 2018: Pre-Sediment Addition
	

September 2018: Post 6 Months	June 2019: Post 14 Months
	



High Marsh - Dredge : E
Mean Cover (%)
0
25
50
75
Ref
Pre-Sediment Condition
Post Six Months (Sept 2018)
Post 14 Months (June 2019)
Sampling Description
Spartina alterniflora
Distichlis spicata
Spartina patens

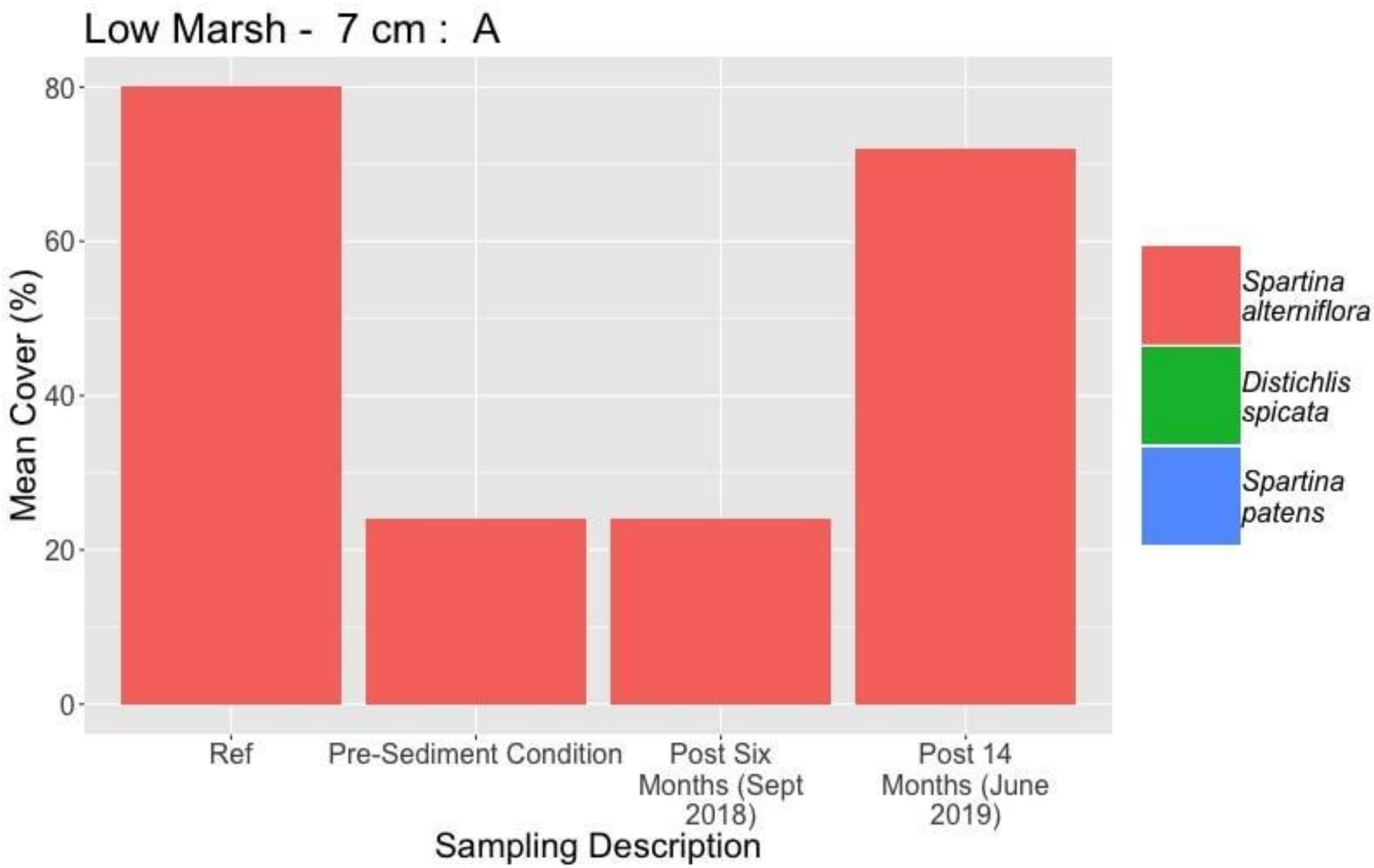
Appendix 2: Treatment plot images and graphs for each 3 treatments for the low marsh habitats

Low Marsh Habitat

7 cm

Reference Plot	April 2018: Pre-Sediment Addition
	

September 2018: Post 6 Months	June 2019: Post 14 Months
	

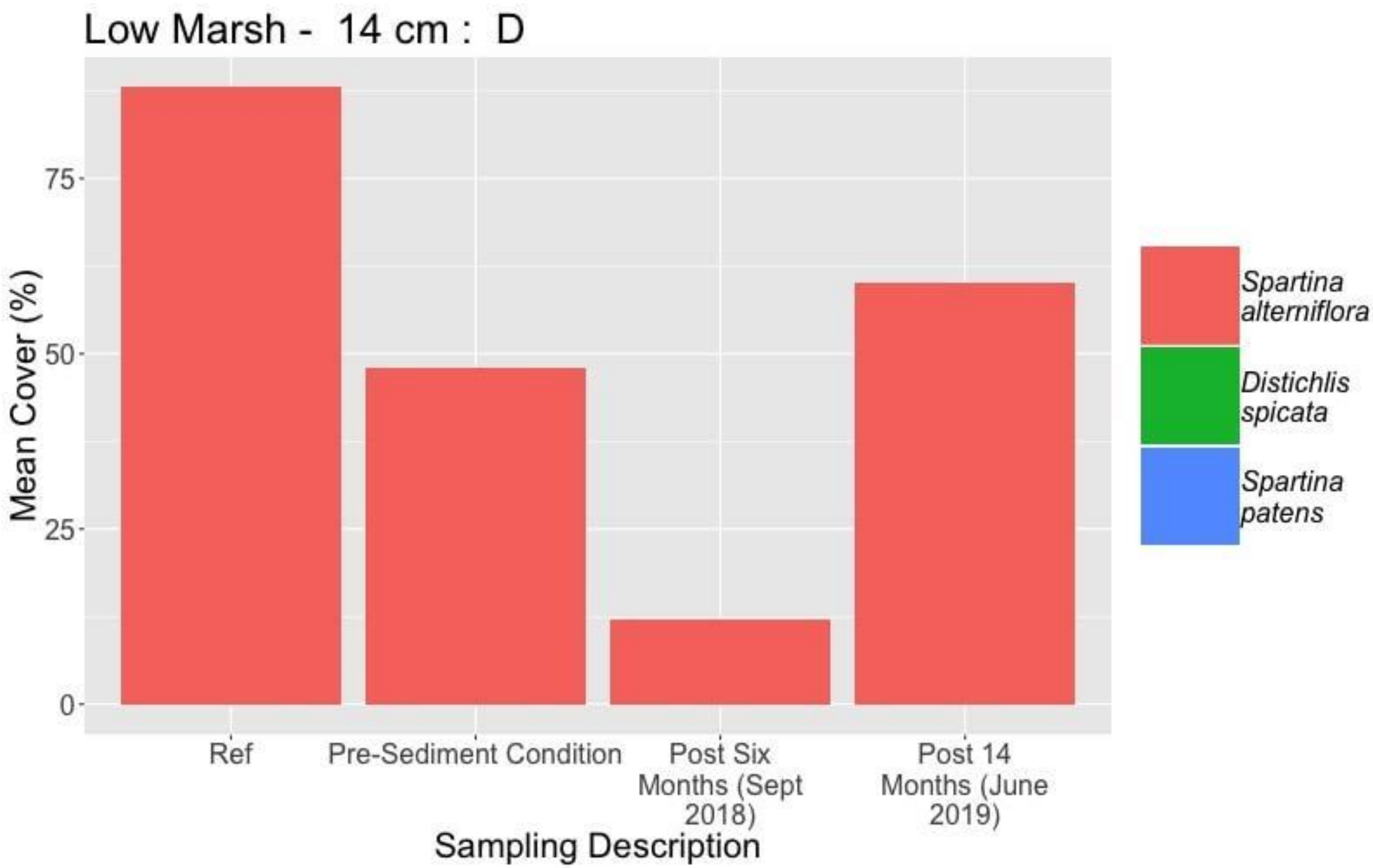


Low Marsh - 7 cm : A
Mean Cover (%)
80
60
40
20
0
Ref
Pre-Sediment Condition
Post Six Months (Sept 2018)
Post 14 Months (June 2019)
Sampling Description
Spartina alterniflora
Distichlis spicata
Spartina patens

Low Marsh Habitat
14 cm

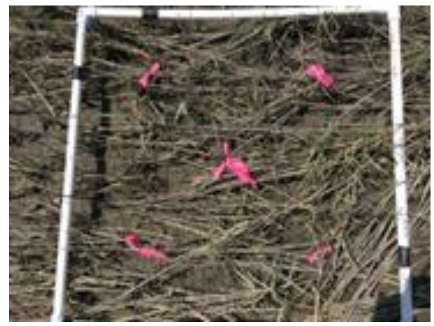
Reference Plot	April 2018: Pre-Sediment Addition
	

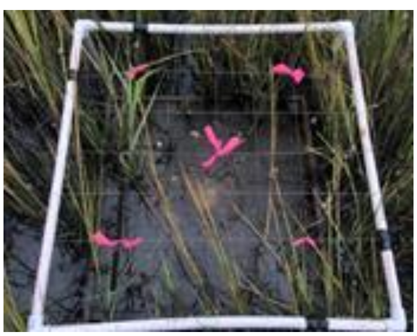
September 2018: Post 6 Months	June 2019: Post 14 Months
	

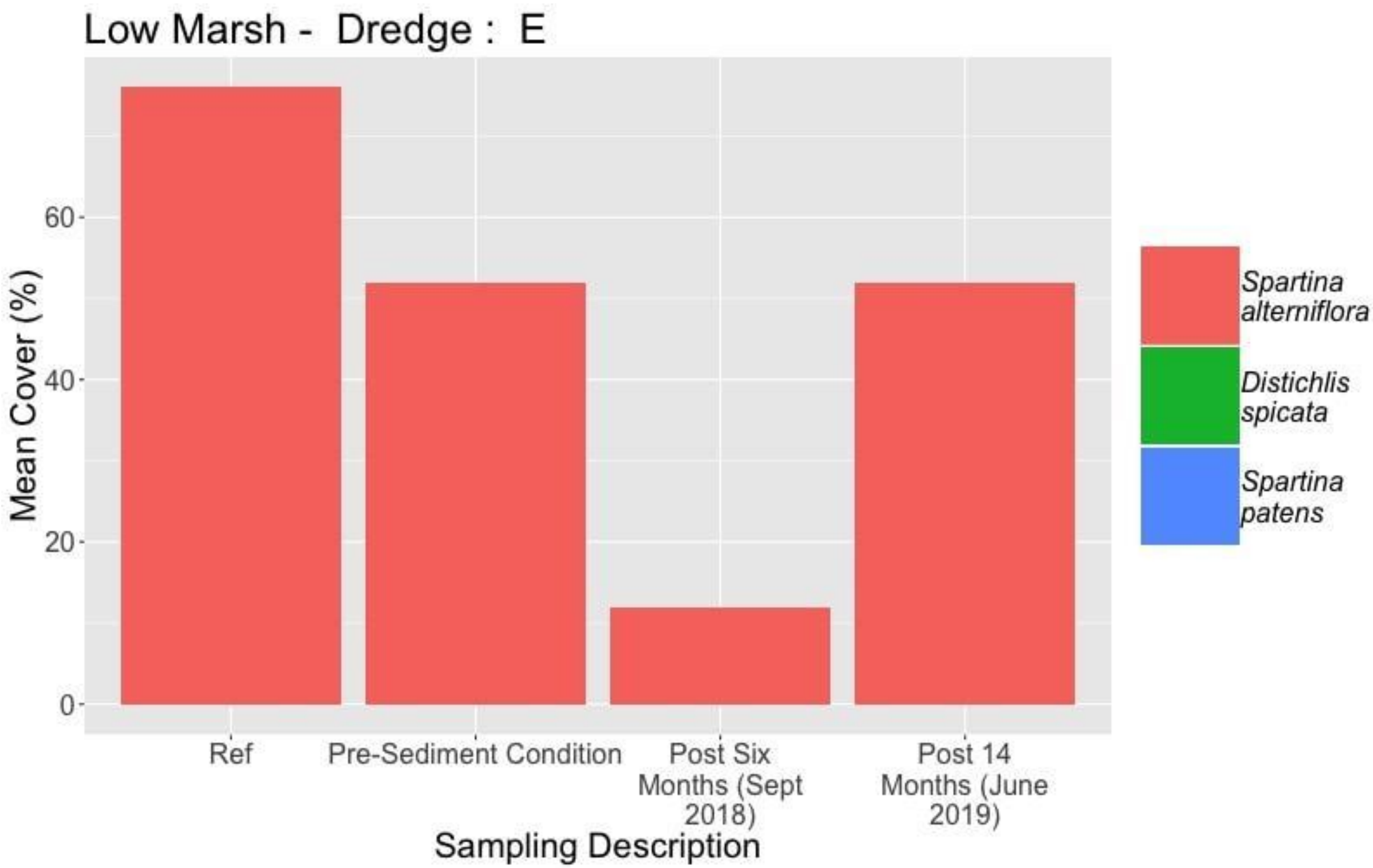


Low Marsh - 14 cm : D
Mean Cover (%)
0
25
50
75
Ref
Pre-Sediment Condition
Post Six Months (Sept 2018)
Post 14 Months (June 2019)
Sampling Description
Spartina alterniflora
Distichlis spicata
Spartina patens

Low Marsh Habitat
14 cm Dredge

Reference Plot	April 2018: Pre-Sediment Addition
	

September 2018: Post 6 Months	June 2019: Post 14 Months
	


Low Marsh - Dredge : E
Mean Cover (%)
60
40
20
0
Ref
Pre-Sediment Condition
Post Six Months (Sept 2018)
Post 14 Months (June 2019)
Sampling Description
Spartina alterniflora
Distichlis spicata
Spartina patens

Appendix 3: Student worksheet

Mitigating Marshes Against Sea Level Rise: Thin Layer Placement Experiment

Worksheet Date: _____________

Group Members: _____________ Your Name: _____________

Directions:

Look at the time series images showing the change in vegetation over time and the associated graphs that show percent cover of the vegetation.

a. Column colors are associated with different marsh grass species:
    i. **Red** = *Spartina alterniflora* (low marsh species), but name recently changed to *Sporobolus alterniflorus*
    ii. **Green** = *Distichlis spicata* (high marsh species)
    iii. **Blue** = *Spartina patens* (high marsh species)
    iv. **Ref** = reference plot
b. Images have time stamps:
    i. **Reference plot** = the goal for vegetative growth after sediment addition. This image was taken at higher elevation to represent what is healthy for that elevation in the marsh.
    ii. **Pre-sediment addition** - before sediment was added to the treatment plots
    iii. **September 2018** = 6 months post sediment addition
    iv. **June 2019** = 14 months post sediment addition

High Marsh Habitat Plot:

What treatment do you have?

In your treatment, explain the trend of change by looking at the images.

After receiving your percent cover graph, explain the trend of change for each species by looking both at the images and the associated graphs.

How has the abundance of different types of marsh grass species changed over time? Look at how the community structure has changed over time, which is the number of species in a community and their relative abundance. For example, a species can increase in abundance, remain stable, or decrease over time, changing which species is most dominant.

After hearing from the other groups, what do you/the class think is the best treatment?

Why do you think that treatment works the best? Why did yours may not work as well?

Low Marsh Habitat Plot:

What treatment do you have?

How has the abundance of different types of marsh grass species changed over time?

Explain the trend of change for each species by looking at the images and the associated graphs.

After hearing from the other groups, what do you think/the class is the best treatment?

Why do you think that treatment works the best? Why did yours may not work as well?

Appendix 4: Student Assessment

Post Monitoring Questions:

1. What is one of the environmental threats to marshes?

2. Name one way marshes defend themselves against these threats and why these responses help.

3. Describe why there is variation in the 4 zones found in marshes. For example, their formation, vegetation, weather, etc.

4. Summarize the goal of thin-layer placement and in what situation it should be used.

5. Identify one field method CBNERR-VA uses when assessing the TLP experiment.

6. Which treatment would you use if you were going to do TLP in the near future?

7. Think about the experimental design. Would you do anything differently? Explain or give an example.

Appendix 5: Student Assessment answer key

Post Monitoring Questions:

1. What is one of the environmental threats to marshes?

Sea-level rise, erosion, subsidence

2. Name one way marshes defend themselves against these threats and why these responses help.

Vertical Accretion: build vertically by accumulating sediments and organic matter. Allows marshes to increase elevation to protect habitat and vegetation from flooding.

Horizontal Migration: migrate horizontally away from the shoreline into higher elevations. Allows vegetation to move away from degrading areas and save the vegetative community.

3. Describe why there is variation in the 4 zones found in marshes. For example, their formation, vegetation, weather, etc.

Names of zones are not necessary as long as students show that they understand at least one of the factors that goes into marsh zonation.

Flooding/inundation, salinity, tides, weather events, competitive exclusion (competition between species)

4. Summarize the goal of thin-layer placement and in what situation it should be used.

   Goal: Adding sediment on top on a degraded marsh area to allow vegetation to regrow over time, and having an abundance of marsh regrowth with the desired species/community structure for that marsh habitat.

   Where: degraded marsh area affected by erosion, sea level rise, subsidence, increased flooding, shoreline loss, etc.

5. Which treatment would you use if you were going to do TLP in the near future?

Varies, answer must be justified

6. Think about the experimental design. Would you do anything differently? Explain or give an example.

Varies, answer must be justified