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2021

## Growing Up Is Hard: Vertical Accretion in Salt Marshes

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### Recommended Citation

Smith, A. (2021) Growing Up Is Hard: Vertical Accretion in Salt Marshes. VA SEA 2021 Lesson Plans. Virginia Institute of Marine Science, William & Mary. doi: 10.25773/ge8f-xz14

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# GROWING UP IS HARD: VERTICAL ACCRETION IN SALT MARSHES

**Alex Smith**

Virginia Institute of Marine Science

**Grade Level**

High School

**Subject Area**

Biology, Environmental Science, Oceanography

*The 2020-21 VA SEA project was made possible through funding from the National Estuarine Research Reserve System Margaret Davidson Fellowship Program which supports graduate students in partnership with research reserves where fieldwork, research, and community engagement come together. VA SEA is currently supported by the Chesapeake Bay National Estuarine Research Reserve, Virginia Sea Grant, and the Virginia Institute of Marine Science Marine Advisory Program.*



**Title** Growing Up Is Hard: Vertical Accretion in Salt Marshes

**Focus** Students will use graphing to examine the importance of natural environmental feedbacks on marsh survival

**Grade Level** Life Sciences, Biology; target 7<sup>th</sup> grade,

### **VA Science Standards**

**LS.1** The student will demonstrate an understanding of scientific and engineering practices by

- c) identify, interpret, and evaluate patterns in data
- e) construct and use models and simulations to illustrate, predict, and/or explain observable and unobservable phenomena, life processes, or mechanisms

**LS.5** The student will investigate and understand that biotic and abiotic factors affect an ecosystem.

- a) matter moves through ecosystems via the carbon, water, and nitrogen cycles;

**LS.8** The student will investigate and understand that ecosystems, communities, populations, and organisms are dynamic and change over time.

- d) large-scale changes such as eutrophication, climate changes, and catastrophic disturbances affect ecosystems.

**LS.9** The student will investigate and understand that relationships exist between ecosystem dynamics and human activity.

- c) variations in biotic and abiotic factors can change ecosystems.

### **Grade Seven Mathematics Standards of Learning**

Patterns, Functions, and Algebra

- 7.10 a) determine the rate of change in a proportional relationship between two quantities

### **Learning Objectives**

- ✓ Students will record observations of water level and elevation in a modeled experiment
- ✓ Students will plot observations and compare plots to determine how sea level affects marsh survival
- ✓ Students will calculate rates of change using data generated from their observations and compare these rates
- ✓ Students will integrate dynamic feedbacks into their simulations to further examine marsh survival

### Total length of time required for the lesson

70-80 minutes total

Advance preparation of lab materials and lab setup– 5 minutes

Introduction

Designing Marsh Worksheet and Discussion – 15 minutes

1<sup>st</sup> Part of Activity – 20 to 25 minutes

2<sup>nd</sup> Part of Activity -- 15-20 minutes

### Key words, vocabulary:

- **Sea Level Rise:** an increase in the level of the world's oceans due to the effects of global warming and local properties such as subsidence. **Eustatic sea level rise** describes the globally average rate of sea level rise while **relative sea level rise** describes the rate of sea level rise happening at a specific point around the world.
- **Feedback:** a response in an ecosystem that influence the activity or rate of another process in that ecosystem. Feedbacks can both induce or reduce other processes.
- **Vertical Accretion:** The deposition of sediments and expansion of soils in marshes that allows the marsh platform to maintain its position relative to rising sea levels
- **Inundation:** flooding from sea water
- **Thermal Expansion:** the tendency for matter to increase in volume as temperature increases. Thermal expansion of ocean water is responsible for a portion of sea level rise
- **Subsidence:** the caving in of land
- **Isostatic Rebound:** the rising of land masses following the removal of the huge weight that ice sheets were forcing on continents
- **Hydro-saline Differentials:** the difference in water density at the equator and poles driven by temperature and salinity. The greater the difference in water density, the faster global ocean currents flow.
- **Phenotypic Plasticity:** the idea that species can adapt to conditions beyond where they are most specialized or often found. There is a limit to every specie's phenotypic plasticity, beyond which it cannot survive.
- **Ecosystem Services:** the various benefits that humans receive from the environment. They can range from the actual material goods that we extract from them or the enjoyment of nature's innate beauty.

## Background information – For the Instructor

**Sea Level Rise.** Sea levels are rising globally due to the slumping of continental ice sheets into the world's oceans. This added addition of mass raises sea levels as does the thermal expansion of water under warming conditions. These globally averaged changes in sea level are often called eustatic sea level rise. Locally, sea level varies. This is because things like subsidence and isostatic rebound also contribute to changes in coastal elevation and therefore local rates of sea level rise. Isostatic rebound, the raising of the earth's elevation due to changes in weight over the mantle, specifically can influence local sea level rise so much that some parts of the world experience falling sea level. Along the Atlantic Coast, sea level is maximized in the mid-Atlantic from the aforementioned isostatic rebound as well as the slowing of the Gulf Stream caused by lessening hydro-saline differentials between polar and equatorial waters. Along the Gulf Coast, sea level rise is maximized in Louisiana where massive amounts of subsidence from ground water removal lower the elevation of the ground surface. Rising sea levels has massive implications for humans and ecosystems that call the coastal landscapes their home. Not only is inundation becoming more frequent, but the increased severity of storms in these areas further exacerbate the effects of rising sea levels.

Salt marshes are located in the intertidal zone, between high tide and low tide, and therefore at great risk of being affected by sea level rise. As sea levels rise, the vegetation within the marsh that physically holds the sediment together begins to die. Despite being adapted to salty and wet environments, this vegetation has limited phenotypic plasticity and will die under prolonged inundation. With vegetation death, the surface of the marsh erodes quicker and the numerous ecosystem services and critical habitat is lost.

**Vertical Accretion.** Vertical accretion is one of the essential survival mechanisms that salt marshes have in response to sea level rise. Vertical accretion is the marshes ability to sequester sediments and expand the soil volume to keep pace with rising sea levels. Biophysical feedbacks between vegetative communities and rising sea levels are integral to this process. As sea levels rise, some salt marsh plants experience an increase in aboveground and belowground production. This is largely in response to the added nutrients supplied with increased inundation. With increased production, the soil volume expands as root growth displace soil volume upward. In addition to nutrients, increased inundation also delivers sediment deposited to the marsh surface that can raise the marsh platform. As the marsh elevation rises, inundation lessens and the strength of these feedbacks lessen. Think of vertical accretion as a response to sea level rise in that it is maximized when sea levels are high.

## Student handouts

- Designing Your Marsh worksheet
- Vertical Accretion Worksheet (key provided for instructor)
- Dynamic Vertical Accretion Worksheet (key provided for instructor)

## Materials & Supplies

- Lego blocks or other type of stackable, uniform height blocks
  - Make sure that these blocks are able to sink in water. If the Lego blocks you have float or stack taller than your container, a good alternative can be pennies, just change the wording in the worksheets to coins instead of blocks
  - If you are using something that floats, I found that taping pennies to the bottom piece as an anchor is a good way to weigh down floating objects
- Waterproof container that can contain approximately 40 stacked blocks (takeout soup container size works well). The container does not need markings on the side as measurements of height are in units of number of blocks in a stack.
- Container for pouring water into the waterproof container (can be a pipette or simply a smaller cup)
- Worksheets, graph paper, and colored pencils. If colored pencils aren't available, changing the wording in the graphing exercise to different types of dashed lines.

## Classroom set up

- Students should work in groups of 3 to 4 and the room should be set up for group work
- Water is involved with this lesson so remove electronic devices or station groups as far from them as possible
- Graphing and questions after the simulated experiments should be done in groups, but can also be completed individually

## Virtual set up

- If done virtually, students should still be in groups of 3 to 4 over zoom with either only one student running the simulation (and the other students completing their own worksheet while working together as a group) or every student running their own simulations. If the latter option is taken, every student needs to be supplied with the required stackable blocks.

## Procedure

### Advance preparation of lab materials – 5 minutes

Prepare lesson activity by placing approximately 40 Lego blocks per group and water proof containers throughout the room and worksheet for students in advance. Each group will need some water source to fill their containers with, you may want to set up cups of water that the students can use as water sources at each station before the activities or during the first activity

**Each group should have a copy of:**

Part 1: Designing Your Marsh Worksheet

Part 2: Vertical Accretion Worksheet

Part 3: Dynamic Vertical Accretion Worksheet

Worksheets do not need to be printed in color and are not designed to be reusable

### **Introduction – 20 minutes**

Before showing the videos, project the exploration questions so that students have something to focus on during the videos. Videos and questions are also included in the background information PowerPoint.

*Getting to Know a Tidal Salt Marsh – Delaware Estuary, National Estuary Program*

<https://www.youtube.com/watch?v=PhmoxJasIYs>

(3:23 to 7:00)

*Coastal Wetlands: Powerful Ecosystems in Need of Protection – Pew Charitable Trusts*

<https://www.youtube.com/watch?v=-mCR0pKInsM>

### **Exploration**

Following the videos, review some of the important takeaways that these videos emphasized as a class discussion. These questions are also included in the comment section of the Background Information PowerPoint.

- What is the vegetation like in the salt marsh?
  - Possible Answer: Mostly grasses
  - Follow-up: Why don't we see many trees living in salt marshes?
    - Answer: The salt water prevents any species not adapted to salty environments from living there. Most plants need water to live, but too much water or salt water will kill a majority of the tree species that we see in forests. Therefore, we'll only get specially equipped grasses living in these environments. Some of these grasses are able to process salts while others are made of hardy plant tissue, both of which allows them to survive!
  
- What types of species live in the salt marsh?
  - Possible Answers: Grassy vegetation, fiddler crabs, wading birds, juvenile fish species
  - Follow-up: Why might these species live here instead of elsewhere along the coast?
    - Answer: The grass that makes up a salt marsh is an incredibly friendly environment for juvenile fish. The grasses protect the fish from predators and shade them from the sun while also providing a nutrient rich habitat for them to grow in. Unfortunately, predator species, like blue crabs and blue herons, snowy egret, and great egret, are well aware that these juvenile species gather here and use salt marshes as a feeding ground. There is also an abundance of crabs in salt marshes. Unlike soils where our schools and homes are, salt marsh soil is rather squishy. Because the marsh is flooded everyday with the tides, the ground is extremely wet and muddy, making it prime burrowing real-estate for burrowing crabs.
  
- Why are salt marshes important to humans?

- Possible Answers: Storm buffering, juvenile fish habitat, biodiversity, carbon storage, recreation (kayaking, bird watching, etc.), intrinsic beauty
  - Possible Elaboration by Instructor: Salt marshes and other ecosystems protect our shores from large waves generated by storms. Instead of having a hard surface for the waves to hit against and scour, salt marshes provide a gradual gradient in elevation that slowly reduces wave energy. Therefore, coastal cities and towns that have salt marshes and other ecosystems around them have a bit of a barrier to waves during storm events. As we said before, young fish like to hang out in the shady, food rich salt marshes as they grow, but this also serves an important role to humans who make a living fishing on the water. Salt marshes provide a sheltered nursery for fish to grow up in, especially for fish that people sell. Therefore, salt marshes serve as fundamental nurseries for many of these fishing industries. Along with supporting fishing industries, juvenile fish in salt marshes also provide the foundation of an extremely biodiverse community. We like to see a lot of different species, or high biodiversity, in ecosystems because it signifies to us that the ecosystem is healthy and complex. With biodiversity, there are also animals that are unique to the ecosystem, which means that humans are going to want to see them. Kayaking, fishing, and bird watching are a few of the ways humans can directly value and appreciate salt marshes. Also, the beauty of the salt marsh, especially at sunset and sunrise, provides another service that the system gives for free.
- What are some of the things that threaten salt marshes?
    - Possible Answers: Human development
    - Possible Elaboration by Instructor: The destruction of habitats occur in both human caused and natural ways. Many salt marshes are being drained of the water within them by humans so that they can be converted to farmland. Other marshes are being paved over to make room for waterside attractions and housing. In other scenarios, marshes are being destroyed and replaced with shrimp farms. Marshes occupy a unique position between the tides and next to beautiful views, which unfortunately means that some people will want to develop that land.
    - Possible Answers: Sea level rise, erosion
    - Possible Elaboration by Instructor: Naturally, salt marshes are lost due to erosion and sea level rise. Erosion is when water eats away at the sediments and soils that make up a marsh. Sometimes when waves crash on the marsh surface, it knocks up the sediment on the surface and that sediment leaves the marsh. Typically, erosion doesn't happen in huge chunks all at once; instead, it is a small, but constant factor that slowly erodes the marsh surface reducing the size of the marsh. Sea level rise increases the amount of erosion occurring in a salt marsh and changes the ability of a marsh to respond to that erosion. As sea levels rise, the marsh becomes wetter and plants begin to suffer because even though they are adapted to living in a water-rich environment, there is still such a thing as too much water. As the plants begin to die, the soil becomes even muddier, making the soil much more susceptible to erosion. So as sea levels rise, the plants begin to die and the soil starts to decrease meaning that the ecosystem is collapsing. Fortunately, marshes have a survival mechanism called vertical accretion that lets them keep pace with sea level rise!
    - Emphasize the threat of sea level rise as it will provide a nice transition into the activity

## Activity Overview

- In this activity, students will control the vertical accretion and rate of sea level rise that threatens marshes. Vertical accretion is simulated by adding Lego blocks vertically and building a larger “marsh” while the rate of sea level rise is controlled by how much water they pour into the container. They will run this simulation under three scenarios initially: low, moderate, and high sea level rise scenarios. After graphing their observations, students will calculate the time that their marshes drowned (when elevation=sea level). From this, students will see that marshes drowned under every simulation of sea level rise. The end of the worksheet then brings up the fact that there are some marshes that are hundreds and thousands of years old and asks the students how this might be the case. This is the transition to the second part of the activity where students repeat the same simulations but with dynamic vertical accretion.

## Procedure

- Split the class into groups (of 3 or 4)
- Explain to the class that each group will receive a worksheet that explains vertical accretion and some of the factors that control it. Also, on the same worksheet, it provides a chance for students to design their own marsh and see how it might survive sea level rise (Design Your Marsh worksheet). Groups should be given ~5 minutes to complete the worksheet followed by any questions before the activity begins.
- Explain that students will be recording marsh elevation and water level using a simulation with Lego blocks and water they pour into the container
- Walk through the first two or three timesteps of the first trial on the worksheet (Vertical Accretion Worksheet) and record their observations in the provided table together
- After the groups have recorded their observations for the first trial, have them graph that trial on the first graph provided.
- Once groups complete the first worksheet (Vertical Accretion worksheet; 20 minutes) hand out the second worksheet (Dynamic Vertical Accretion worksheet; 20 minutes).
- Graphing and questions following the simulation portion of the worksheet should be completed as groups, but can also be done individually if preferred.

## Evaluation

- Suggested wrap up questions and answers:
  - Revisiting the discussion questions from the Background Information PowerPoint will likely be helpful in addition to the questions below.
  - On the first worksheet, how did sea level rise affect when the marsh drowned?
    - Answer: The quicker the rate of sea level rise, the quicker the drowning.
  - Why might this not be realistic?
    - Answer: Vertical accretion is not constant, instead it interacts with sea level so that accretion is higher when sea levels are higher
  - Describe how vertical accretion is dynamic.
    - As sea levels rise, the duration and amount of water that floods the marsh increases. As the water flows into the marsh, the velocity of the water slows,

meaning that it can't carry as much suspended sediment in the water. This causes the sediment to drop out and add material to the marsh surface. Additionally, root growth is maximized under a certain amount of inundation. As the marsh becomes more flooded and approaches this level of inundation, root growth increases and further raises the marsh elevation. Therefore, we can see that marsh elevation is dynamic in response to sea level rise from sediment trapping and root growth.

- If a migratory goose were to come in and eat up all the shoots of the marsh grass, how might this affect vertical accretion?
  - Answer: You'd have a lot less sediment trapping and possibly less vertical accretion. Because the goose just ate the shoots, vertical accretion would still benefit from root growth, but this may also be limited if the grazing from the goose was severe enough.
- What are some ways in which humans affect vertical accretion?
  - Many possible answers for this question
  - If humans develop the land, then vertical accretion will be impossible due to the destruction of the marsh
  - If humans increase the rates of sea level rise through global anthropogenic effects or local processes like subsidence, then the marsh may still drown. There is a limit to how fast a marsh can respond to sea level rise. At some point, even with dynamic vertical accretion, the plants begin to drown and the marsh dies.
  - If humans change the amount of sediments in the water, decreasing them with damming or increasing them through construction and land conversion, this changes the vertical accretion rate.
  - Also acceptable are answers that talk about how humans influence the growth of plants or the animals that live in salt marshes.

Have students work through the questions at the end of the worksheet either in class as a group or individually as homework

### 13. Assessment

Students will be assessed based on their performance on the data table, graphs, and follow up worksheet questions.

## Designing Your Marsh Worksheet

Name \_\_\_\_\_

Date \_\_\_\_\_

**Background Information.** Rising sea levels are constantly threatening to drown salt marshes. Luckily, marshes have unique interactions with their environment that allows them to gain height allowing them to survive rising sea levels. We call the ability for marshes to increase their height, or elevation, **vertical accretion**.

Vertical accretion is driven by a number of different components and is necessary for continued marsh survival in the face of rising seas. Generally, vertical accretion can be categorized into belowground and aboveground components.

Marshes gain elevation belowground when the roots of the grasses that makes up the marsh grow. As the roots grow, they physically expand the soil making the elevation of the marsh rise. A similar process happens in terrestrial plants! This is what happens when trees along sidewalks have roots that break through the pavement and rise above the surface.

Marshes also gain elevation by taking soil out of muddy water and adding that soil to the marsh surface. The water that floods marshes has sediment, similar to dirt, within the water; these sediments are often what makes muddy water look muddy. As that water enters the marsh, it slows down. This is due to the fact that all of the grass in the marsh prevents the water from flowing at its normal speed. It's similar to how you can run down an empty hall quicker than you can run down a hall full of people. Fast moving water is able to carry more sediment than slow moving water so as the water slows down, the sediment that was in the water begins to fall out of the water and settles on the marsh surface. This adds height to the marsh surface and allows for the marsh to survive rising sea levels.

Therefore, a number of factors control vertical accretion in salt marshes and how these salt marshes try to survive sea level rise.

**Activity:** Your job in the worksheet below is to, as a group, select aspects of salt marshes to design a salt marsh that will survive sea level rise the longest.

### Part 1: Marsh Design

Muddiness of the water: What degree of sediment will result in the longest living marsh?

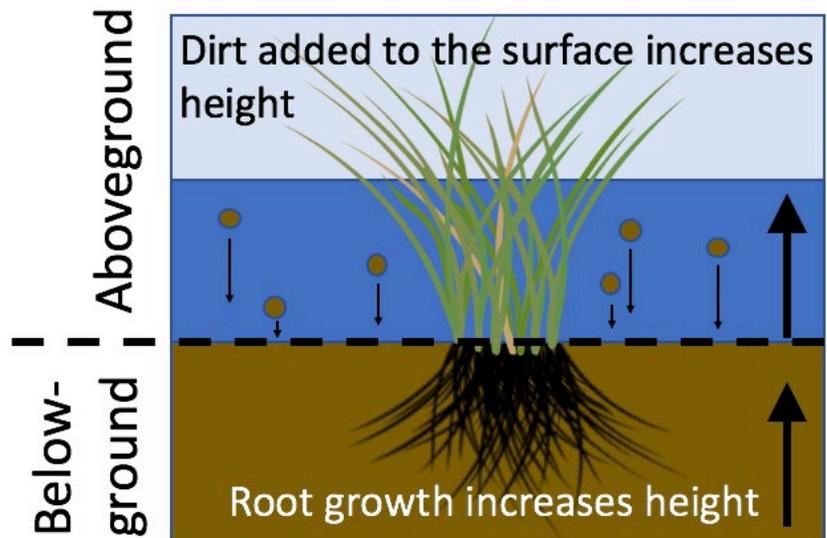
- A. Extremely Muddy      B. Clear Water      C. Slightly Muddy

Aboveground plant growth: What speed of plant growth will result in the longest living marsh?

- A. 2300 g/m<sup>2</sup>/year      B. 2500 g/m<sup>2</sup>/year      C. 1500 g/m<sup>2</sup>/year

Belowground plant growth: What speed of root growth will result in the longest living marsh?

- A. 800 g/m<sup>2</sup>/year      B. 1500 g/m<sup>2</sup>/year      C. 1000 g/m<sup>2</sup>/year



Rate of sea level rise: What rate of sea level rise will result in the longest living marsh?

- A. 2.0 mm/y                      B. 5.0 mm/y                      C. 1.2 mm/y

Initial elevation: What initial elevation will result in the longest living marsh?

- A. 100 centimeters              B. 2 meters                      C. 10 centimeters

Now that you've designed your marsh, use the below key to add up your points and grade your marsh! How'd you do?

Muddiness:

- A. 3 B. 1 C. 2

Aboveground plant growth:

- A. 2 B. 3 C. 1

Belowground plant growth:

- A. 1 B. 3 C. 2

Rate of sea level rise:

- A. 2 B. 1 C. 3

Initial elevation:

- A. 2 B. 3 C. 1

Based on your point value, what can we say about how these aspects affect marsh survival?

**5-8 points: Less than 100 years**

Unfortunately, the marsh you designed is going to be rather short lived. See how changing some of your choices will improve your marsh survival.

**9-12 points: 100-300 years**

So close! You've designed a pretty good marsh, but there are one or two areas that could make your marsh live longer, so where you might've gone wrong.

**13-15 points: Greater than 300 years**

Congratulations! You've designed a long-lived marsh, one that your great-great-great-great-great-great-great-grandkids could visit one day!

## Part 2:

### Vertical Accretion worksheet

Name \_\_\_\_\_

Date \_\_\_\_\_

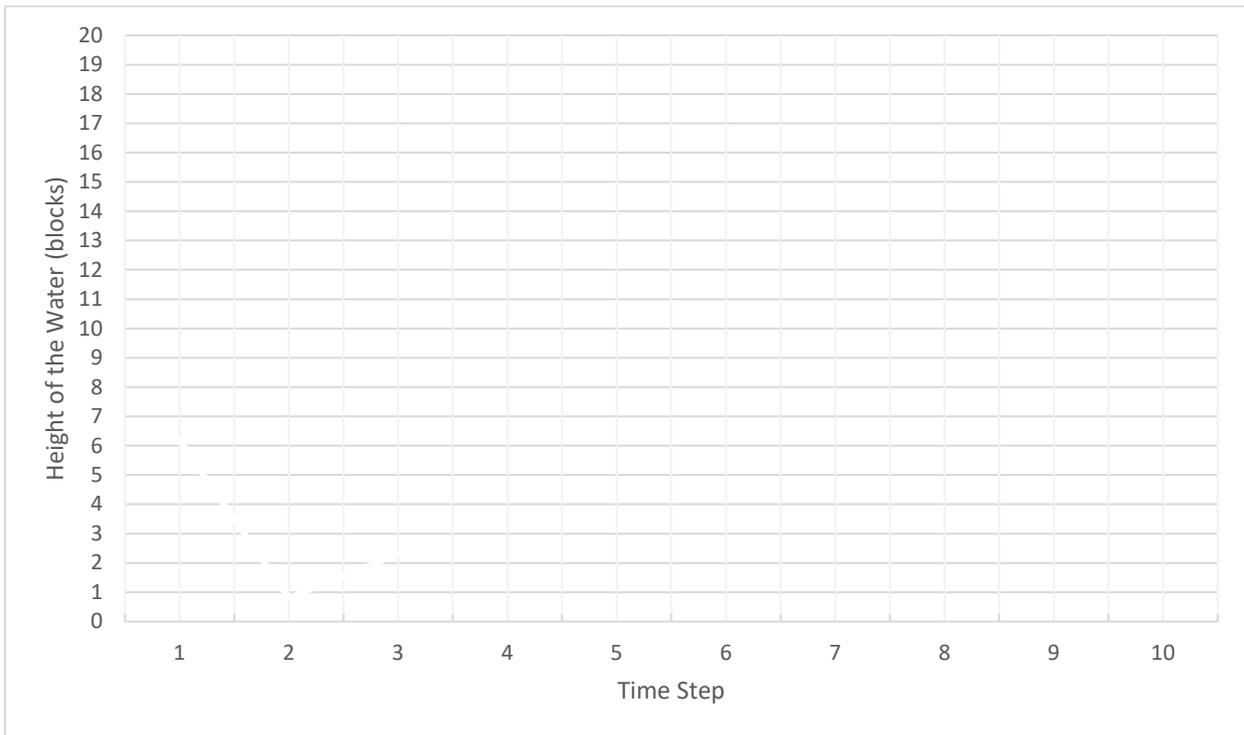
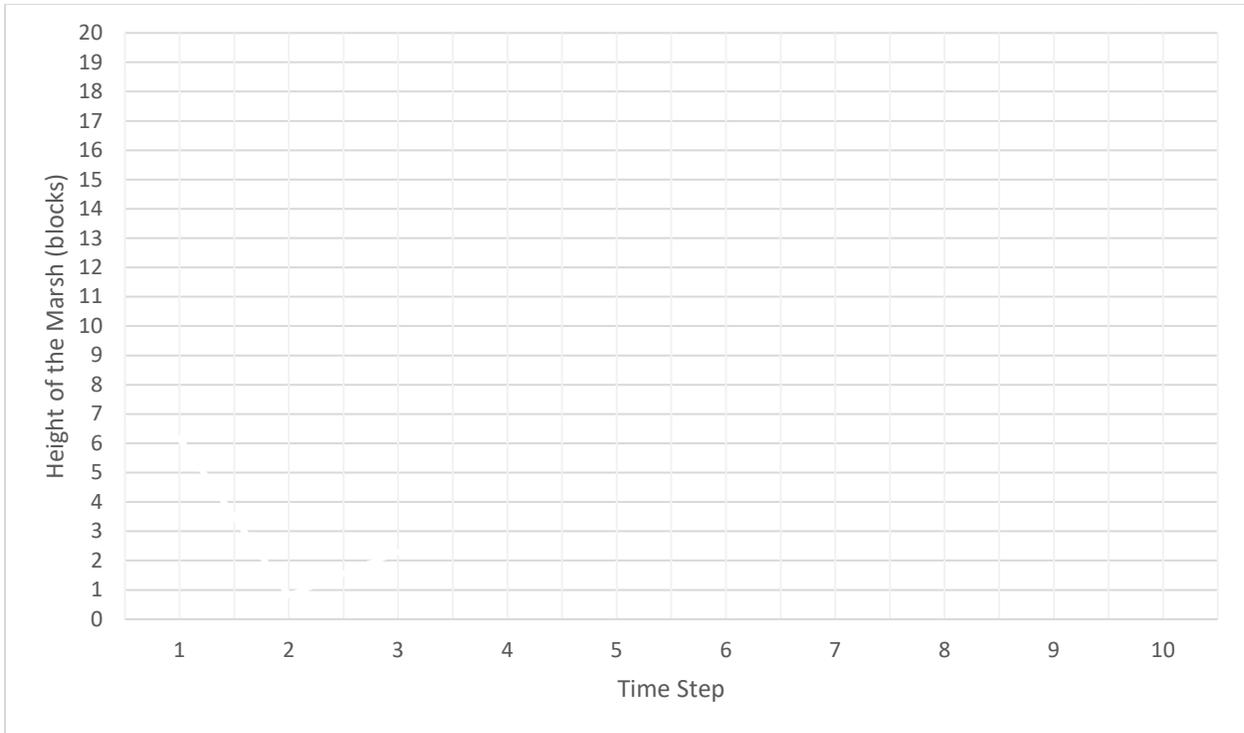
#### Instructions

- With your group, you'll be simulating vertical accretion and sea level rise.
  1. To start, stack 6 blocks vertically on top of each other. These blocks will represent your marsh elevation.
  2. Stack those blocks in the waterproof container provided.
  3. Now, record the heights of the blocks and the water that you've set up in the table below at time 0 in the column under trial 1. Since there's no water in the container yet, the height of the water is 0.
  4. Add 1 block to your marsh. This represents vertical accretion. Your stack should be 7 blocks high.
  5. Add 3 blocks of water – fill the container with water slowly until it reaches the top of the third block. For the first trial, you'll add 3 blocks of water after you add a block to your marsh. This means at time 1, the water will be 3 blocks high and at time 2 the water will be 6 blocks high and so on.
  6. Count the number of blocks in your marsh and measure the height of the water level in blocks and record the new height of the marsh and water level in the table at time 1. *You should have 7 blocks of marsh and 3 blocks of water at time 1.*
  7. Repeat this last step for all of the time steps (adding 1 block to your marsh and increasing the water level) and record your heights in the table until trial 1 is complete! **If the water level becomes equal to the height of the marsh, stop adding blocks to the marsh and water to the sea level. When this happens, the marsh has drowned and is no longer able to vertically accrete.**
- Once trial 1 is complete, empty the container of water and make your marsh 6 blocks tall and repeat this process for trial 2 and 3 but with the new sea level rise numbers (in the top of the table below). For trial 2, step 5 above should be 2 blocks of water for each block of marsh added. For trial 3, 4 blocks of water should be added for each block of marsh added. Vertical marsh accretion will always be 1 block added throughout this entire simulation.

Fill out the Data Table as you complete your water level and vertical accretion simulations.

	Trial 1 Sea Level Rise= 3 blocks		Trial 2 Sea Level Rise= 2 blocks		Trial 3 Sea Level Rise= 4 blocks	
	Marsh	Water	Marsh	Water	Marsh	Water
Time 0		0		0		0
Time 1						
Time 2						
Time 3						
Time 4						
Time 5						
Time 6						
Time 7						
Time 8						
Time 9						
Time 10						

Graph the marsh data as a line graph in the first graph and graph the water level data as line graph in the second graph. Time will go on the x-axis and height of the marsh and water (in number of blocks) will go on the y-axis. Each trial will be a separate line. If your marsh drowned, only graph from time 0 to the point where the marsh drowned. Graph trial 1 in blue, trial 2 in red, and trial 3 in black.



**Complete the questions below after graphing.**

1. During which time step did your marshes drown during the simulations?

Trial 1:

Trial 2:

Trial 3:

2. If each time step was 10 years and each block was equal to 10 cm in height, when (how many years) and how tall (in cm) were the marshes when they drowned?

Trial 1:

Trial 2:

Trial 3:

3. Calculate the rate of change of the lines you've graphed with both your water level and your marsh elevation data using the following steps. I calculate the rate of change for water level in trial 1 below, follow these steps for water level in trial 2 and trial 3 and the marsh elevation. If your marsh drowned, calculate the rate of change before the point where it drowned.

Step 1)

Write down your data from Time 0 and Time 2 as a sentence.

Ex: At time 0, the water level was 0 blocks high. At time 2, the water level was 6 blocks high.

**YOUR DATA**

Marsh Elevation:

Water Level Trial 2:

Water Level Trial 3:

Step 2)

Because time is on the x-axis (the bottom, horizontal line of the graph) and height is on the y-axis (the left, vertical line of the graph), we can rewrite our values in the form of data points. Data points are always written (x,y) and in our worksheet x is time and y is height. So we write our data points as (time, height).

Ex: (0,0) and (2,6)

For your data points, use the height data from time 0 and time 2. Make sure that the numbers you're plugging in are coming from the same time, we don't want to mix up our data from time 0 and time 2.

### YOUR DATA

Marsh Elevation:

Water Level Trial 2:

Water Level Trial 3:

Step 3)

Next, we'll calculate the rate of change or slope. The rate of change describes how quickly something happens or changes. If the rate of change is high, this is quickly changing, and if the rate of change is low, then this changing slowly.

We calculate the rate of change by subtracting the y-value from the first data point from the y-value of the second data point.

Data Points: (0,0) and (2,6)

$$6-0=6$$

### YOUR DATA

Marsh Elevation:

Water Level Trial 2:

Water Level Trial 3:

Step 4)

Then do the same thing with the x-values

Data Points: (0,0) and (2,6)

$$2-0=2$$

The order of subtraction is very important in these steps. If we accidentally do this step wrong, we may get a negative number, which would mean that the water level was decreasing. We know that the water level was increasing because we were adding water to our containers, so we subtract the smaller number from the bigger number.

### YOUR DATA

Marsh Elevation:

Water Level Trial 2:

Water Level Trial 3:

Step 5)

Finally, calculate the rate of change by dividing the number you got from subtracting your y-values by the number you got from subtracting your x-values

$$6/2=3$$

This is the rate of change! We see that the rate of change of the water level is 3, but what does this mean? It means that after every x-value (time) the y-value (height) increases by 3. Now, calculate the rate of change for the marsh elevation and the water level in trial 2 and 3.

#### YOUR DATA

Marsh Elevation:

Water Level Trial 2:

Water Level Trial 3:

4. Describe the different rates of change you calculated for the water levels. Which water level was changing the fastest? Which water level was changing the slowest? Use your data to support your answer.

5. Look at the marsh age you calculated for each trial in Problem 2 above. Compare that to the ages of marshes in the table provided. Based on that comparison, do you think the simulations were realistic? Why or why not?

#### Less than 100 years

Unfortunately, this marsh is going to be rather short lived.

#### 100-300 years

A pretty good marsh, but there are marshes that can live much longer

#### Greater than 300 years

A long-lived marsh, one that your great-great-great-great-great-great-great-grandkids could visit one day!

**Part 3:**

**Dynamic Vertical Accretion worksheet**

Name \_\_\_\_\_

Date \_\_\_\_\_

**Introduction:**

Marshes throughout the world can be hundreds if not thousands of years old, but with sea levels rising how can this be? Marshes are able to survive because vertical accretion is dynamic – it changes over time! In part 2, you added one block to your marsh each time, but that is not the way it works in a real marsh. Instead of simply remaining one value over time, vertical accretion **increases** the closer the sea level comes to the surface of the marsh. As sea levels rise, more water is over the marsh for a longer amount of time. As the water flows into the marsh, the water slows down and can't carry as much sediment or dirt in the water. This causes the dirt to fall out of the water and add material to the marsh surface. That is accretion! As sea levels rise, the marsh becomes flooded longer and more often, so more and more sediment can be added to the increase marsh height. Plus, as the marsh becomes more flooded, root growth increases and raises the marsh elevation even more. Therefore, we can see that marsh elevation is dynamic in response to sea level rise from sediment trapping and root growth. We call this cycle, where one change in the ecosystem causes another, a **feedback**. In these next simulations, we'll simulate this dynamic response!

**Instructions**

- This time, with your group you'll be simulating dynamic vertical accretion and sea level rise.
1. To start, stack 6 blocks vertically on top of each other. These blocks will represent your marsh elevation.
  2. Place those blocks vertically in the waterproof container provided.
  3. Now, record the heights of the blocks and the water that you've set up in the table below at time 0 in the column under trial 1. Since there's no water in the container yet, the height of the water is 0.
  4. This time, vertical accretion changes depending on how close the water level is to the surface of the marsh. Use the table below to determine how many blocks you should add depending on the water level.

If the water level is 0 or greater than 3 blocks away	Add 1 block of marsh
If the water level is 3 blocks away	Add 2 blocks of marsh
If the water level is 2 blocks away	Add 3 blocks of marsh
If the water level is 1 block away	Add 4 blocks of marsh
If the water level is equal to marsh platform	Add 0 blocks (marsh drowned)

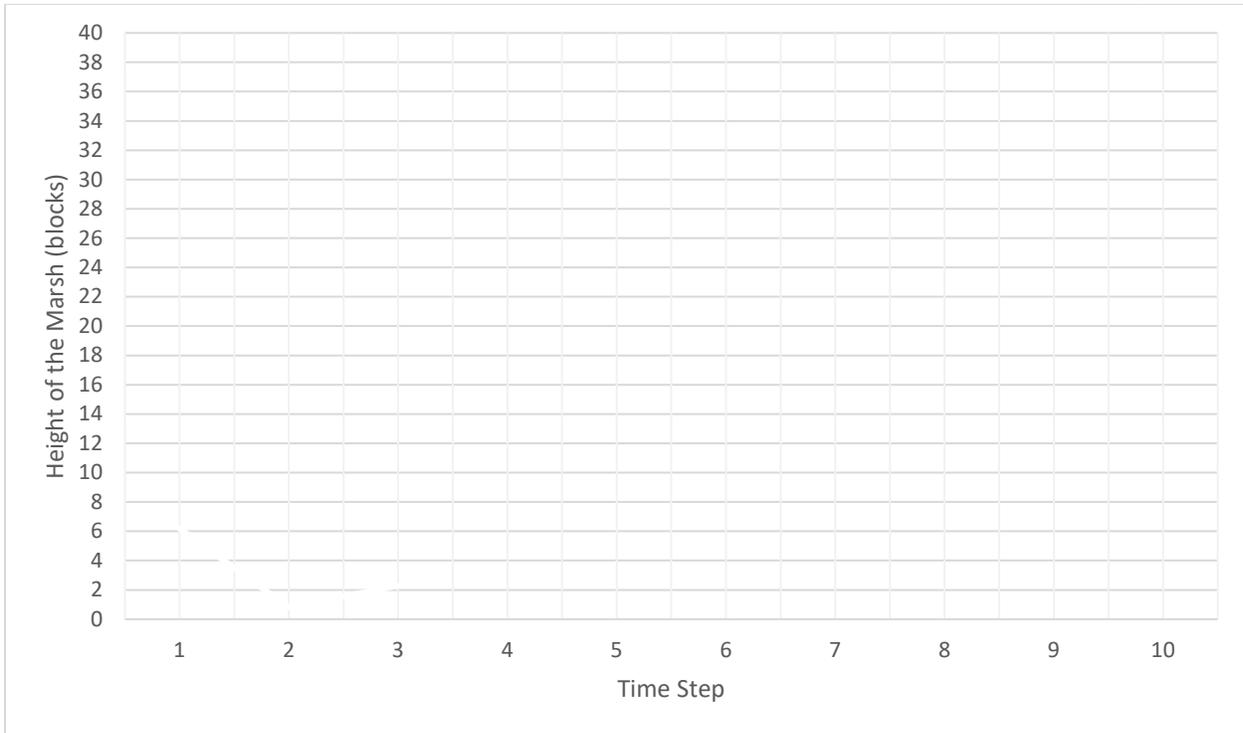
5. After you've added the block, add water the number of blocks according to your trial number. For the first trial, you'll add 3 blocks of water after you add a block to your marsh. This means at time 1, the water will be 3 blocks high and at time 2 the water will be 6 blocks high and so on.

6. After you've added the blocks to the marsh and increase the water level, count the number of blocks in your marsh and measure the height of the water level in blocks and record the new height of the marsh and water level in the table at time 1.
  
7. Repeat this last step for all of the future time steps (till time 10) and record your heights in the table until trial 1 is complete! **If the water level becomes equal to the height of the marsh, stop adding blocks to the marsh and water to the sea level. When this happens, the marsh has drowned and is no longer able to vertically accrete.**
  
- Once trial 1 is complete, empty the container of water and make your marsh 6 blocks tall and repeat this process for trial 2 and 3 but with the new sea level rise numbers.

Fill out the Data Table as you complete your water level and vertical accretion simulations.

	Trial 1 Sea Level Rise= 3 blocks		Trial 2 Sea Level Rise= 2 blocks		Trial 3 Sea Level Rise= 4 blocks	
	Marsh	Water	Marsh	Water	Marsh	Water
Time 0		0		0		0
Time 1						
Time 2						
Time 3						
Time 4						
Time 5						
Time 6						
Time 7						
Time 8						
Time 9						
Time 10						

Graph the marsh height data as a line graph after you have finished filling out the data table. Time will go on the x-axis and height of the marsh (in number of blocks) will go on the y-axis. Graph trial 1 in blue, trial 2 in red, and trial 3 in black.



**Complete the questions below after graphing.**

6. During which time step did your marshes drown in these simulations?

Trial 1:

Trial 2:

Trial 3:

7. If each time step was 10 years and each block was equal to 10 cm in height, when and how tall were the marshes when they drowned?

Trial 1:

Trial 2:

Trial 3:

8. Take Home Question: What are other factors beyond dynamic vertical accretion that may help marsh survival in the face of rising sea levels?

## Vertical Accretion worksheet

Name **Answer Key**

Date \_\_\_\_\_

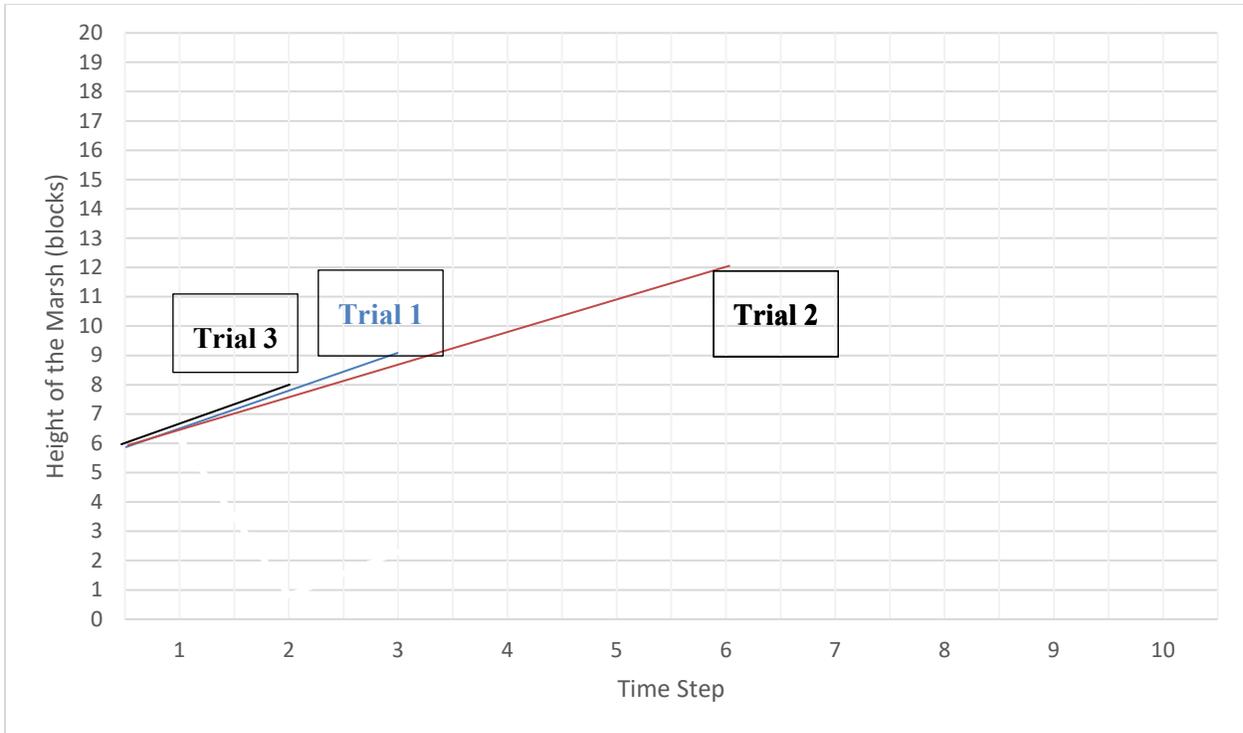
### Instructions

- With your group, you'll be simulating vertical accretion and sea level rise
- To start, stack 6 blocks vertically on top of each other. These blocks will represent your marsh elevation.
- Place those blocks vertically in the waterproof container provided.
- Now, record the heights of the blocks and the water that you've set up in the table below at time 0 in the column under trial 1. Since there's no water in the container yet, the height of the water is 0.
- Next, you'll add 1 block to your marsh. This represents vertical accretion. After you've added the block, add water the number of blocks delineated by your trial number. For the first trial, you'll add 3 blocks of water after you add a block to your marsh. This means at time 1, the water will be 3 blocks high and at time 2 the water will be 6 blocks high and so on.
- After you've added the blocks to the marsh and increase the water level, count the number of blocks in your marsh and measure the height of the water level in blocks and record the new height of the marsh and water level in the table at time 1.
- Repeat this last step for all of the time steps (adding 1 block to your marsh and increasing the water level) and record your heights in the table until trial 1 is complete!
- If the water level becomes equal to the height of the marsh, stop adding blocks to the marsh and water to the sea level. When this happens, the marsh has drowned and is no longer able to vertically accrete.
- Once trial 1 is complete, empty the container of water and make your marsh 6 blocks tall and repeat this process for trial 2 and 3 but with the new sea level rise numbers. Vertical marsh accretion will always be 1 block added throughout this entire simulation.

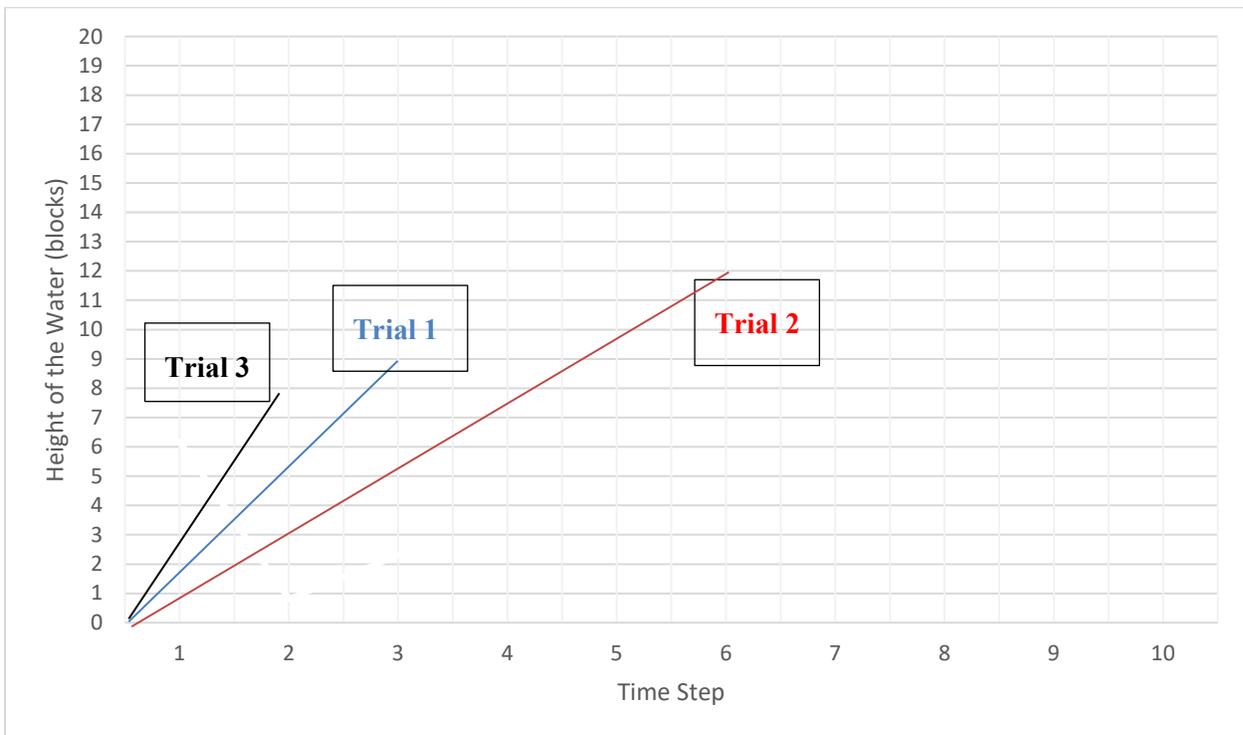
Fill out the Data Table as you complete your water level and vertical accretion simulations.

	Trial 1 Sea Level Rise= 3 blocks		Trial 2 Sea Level Rise= 2 blocks		Trial 3 Sea Level Rise= 4 blocks	
	Marsh	Water	Marsh	Water	Marsh	Water
Time 0	6	0	6	0	6	0
Time 1	7	3	7	2	7	4
Time 2	8	6	8	4	8	8
Time 3	9	9	9	6		
Time 4			10	8		
Time 5			11	10		
Time 6			12	12		
Time 7						
Time 8						
Time 9						
Time 10						

Graph the data after you have finished filling out the data table.



All of these lines will have the same slope and y-intercept, but differing lengths because of drowning at different times.



Complete the questions below after graphing.

- During which time step did your marshes drown in these simulations?

Trial 1: Time 3

Trial 2: Time 6

Trial 3: Time 2

10. If each time step was 10 years and each block was equal to 10 cm in height, when and how tall were the marshes when they drowned?

Trial 1: 30 years, 90 cm

Trial 2: 60 years, 120 cm

Trial 3: 20 years, 80 cm

11. Calculate the rate of change of the lines you've graphed with both your water level and your marsh elevation data using the following steps. I calculate the rate of change for water level in trial 1 below, follow these steps for water level in trial 2 and trial 3 and the marsh elevation. If your marsh drowned, calculate the rate of change before the point where it drowned.

Step 1)

Marsh Elevation: At time 0, the marsh elevation level was 6 blocks high. At time 2, the marsh elevation was 8 blocks high.

Water Level Trial 2: At time 0, the water level was 0 blocks high. At time 2, the water level was 4 blocks high.

Water Level Trial 3: At time 0, the water level was 0 blocks high. At time 2, the water level was 8 blocks high.

Step 2)

Marsh Elevation: (0,6) and (2,8)

Water Level Trial 2: (0,0) and (2,4)

Water Level Trial 3: (0,0) and (2,8)

Step 3)

Marsh Elevation: 2

Water Level Trial 2: 4

Water Level Trial 3: 8

Step 4)

Marsh Elevation: 2

Water Level Trial 2: 2

Water Level Trial 3: 2

Step 5)

Marsh Elevation: 1

Water Level Trial 2: 2

Water Level Trial 3: 4

12. Describe the different rates of change you calculated for the water levels. Which water level was changing the fastest? Which water level was changing the slowest?

Changing the fastest in Trial 3 and changing the slowest in trial 2.

13. Based on the ages of marshes we looked at on the Design Your Marsh worksheet, do you think these simulations were realistic? Why or why not?

No, Possible Explanation: we know that marshes can exist for hundreds of years, but all of our marshes died in less than 100.

## Dynamic Vertical Accretion worksheet

Name \_\_\_\_\_

Date \_\_\_\_\_

### Introduction:

Marshes throughout the world can be hundreds if not thousands of years old, but with sea levels rising how can this be? Marshes are able to survive because vertical accretion is dynamic! Instead of simply remaining one value over time, vertical accretion increases the closer the sea level comes to the surface of the marsh. As sea levels rise, the duration and amount of water that floods the marsh increases. As the water flows into the marsh, the velocity of the water flows, meaning that it can't carry as much suspended sediment in the water. This causes the sediment to drop out and add material to the marsh surface. As sea levels rise, the marsh becomes flooded longer and more often meaning that more sediment can be deposited on the marsh surface thereby increase marsh elevation. Additionally, root growth is maximized under a certain amount of inundation. As the marsh becomes more flooded and approaches this level of inundation, root growth increases and further raises the marsh elevation. Therefore, we can see that marsh elevation is dynamic in response to sea level rise from sediment trapping and root growth. In these next simulations, we'll simulate this dynamic response!

### Instructions

- This time, with your group you'll be simulating dynamic vertical accretion and sea level rise.
- To start, stack 6 blocks vertically on top of each other. These blocks will represent your marsh elevation.
- Place those blocks vertically in the waterproof container provided.
- Now, record the heights of the blocks and the water that you've set up in the table below at time 0 in the column under trial 1. Since there's no water in the container yet, the height of the water is 0.
- Next, you'll add 1 block to your marsh. This represents vertical accretion. After you've added the block, add water the number of blocks delineated by your trial number. In the first trial, you'll add 3 blocks of water. Now, record the new height of the marsh and water level in the table at time 1.
- This time, vertical accretion changes depending on how close the water level is to the surface of the marsh. Use the table below to determine how many blocks you should add depending on the water level.

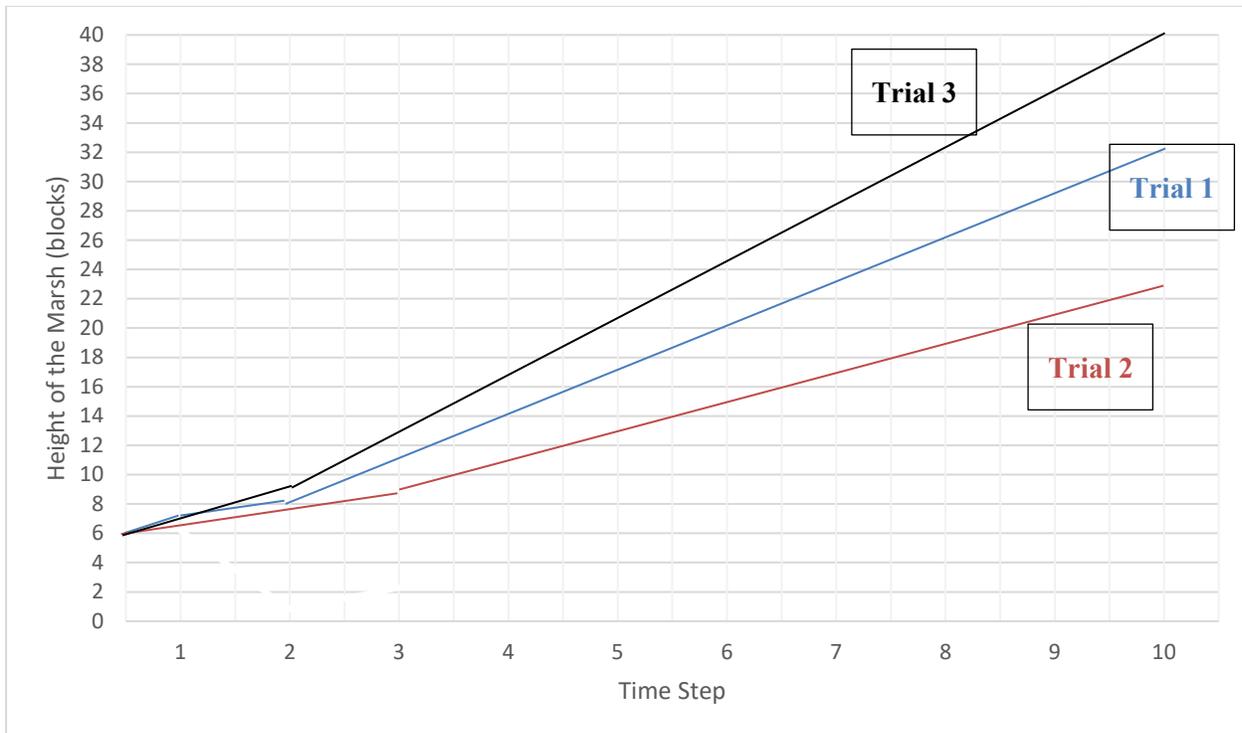
If the water level is greater than 3 blocks away	Add 1 block
If the water level is 3 blocks away	Add 2 blocks
If the water level is 2 blocks away	Add 3 blocks
If the water level is 1 block away	Add 4 blocks
If the water level is equal to marsh platform	Add 0 blocks (marsh drowned)

- Repeat this last step for all of the time steps and record your heights in the table until trial 1 is complete!
- If the water level becomes equal to the height of the marsh, stop adding blocks to the marsh. When this happens, the marsh has drowned and is no longer able to vertically accrete.
- Once trial 1 is complete, empty the container of water and make your marsh 6 blocks tall and repeat this process for trial 2 and 3 but with the new sea level rise numbers.

Fill out the Data Table as you complete your water level and vertical accretion simulations.

	Trial 1 Sea Level Rise= 3 blocks		Trial 2 Sea Level Rise= 2 blocks		Trial 3 Sea Level Rise= 4 blocks	
	Marsh	Water	Marsh	Water	Marsh	Water
Time 0	6	0	6	0	6	0
Time 1	7	3	7	2	7	4
Time 2	8	6	8	4	9	8
Time 3	11	9	9	6	13	12
Time 4	14	12	11	8	17	16
Time 5	17	15	13	10	21	20
Time 6	20	18	15	12	25	24
Time 7	23	21	17	14	29	28
Time 8	26	24	19	16	33	32
Time 9	29	27	21	18	37	36
Time 10	32	30	23	20	41	40

Graph the data after you have finished filling out the data table.



Complete the questions below after graphing.

14. During which time step did your marshes drown in these simulations?

Marshes never drowned in this simulation

15. If each time step was 10 years and each block was equal to 10 cm in height, when and how tall were the marshes when they drowned?

Marshes never drowned in this simulation

16. Based on the ages of marshes we looked at on the Design Your Marsh worksheet, do you think these simulations were realistic? Why or why not?

Possibly more realistic because we see our marshes surviving for more than 100 years! If the students catch onto the point that we expect marshes to drown at some point eventually and that these rates are in equilibrium with each other and therefore will never drown, that'd be a good point of how this simulation is not realistic.

17. Take Home Question: What are other factors beyond dynamic vertical accretion that may help marsh survival in the face of rising sea levels?



A number of different answers acceptable here. Marsh migration, conservation practices, vegetation shifts, decreasing sea levels, artificial deposition. Answers should show that they've thought about the question, not that they've necessarily landed on the right answer.