Lamont-Doherty Earth Observatory
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Is the Hudson a River or an Estuary?

Lesson Plan created by:
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This lesson plan is a teacher's guide to four activities that work in conjunction with the presentation *is the Hudson a River or an Estuary?* The activities in this lesson plan includes and overarching development of a model and then three separate but connected investigations to query and refine that model.

- *Investigation 1: Let's Check in with the Hudson Residents,*
- *Investigation 2: Let's Check the Salinity of the Water in Different Parts of the Hudson,*
- *Investigation 3: Let's Check the Water Depth of the Hudson*.

Discussion questions follow each activity and are intended to engage the students in deeper critical thinking and then be discussed as a class. We have included important talking points written in blue for the teachers to facilitate discussions.

We are happy to answer any questions via email at lzaima@ldeo.columbia.edu and/or mtk@ldeo.columbia.edu

Subject: Life Science

Suggested Grade Level: Middle School/High School

Time Required:

Day 1 (30-40 minutes, slide deck 1: 14 slides):

- Students Locate their Watershed Address and Consider the Role of Watersheds
- Students Develop Models of What Defines a River and an Estuary with Critical Components, Diagrams and Illustrations
- Laying the Groundwork for Investigation #1 with Introduction of Tools
- Introduction to Seining
- Introduction to a Dichotomous Key
- Practice Identification Using a Dichotomous Key

Day 2 (40 minutes, slide deck 2: 25 slides)

- *Investigation #1:* Let's Check in with the Hudson Residents!
- A Look at 3 Different Species of Killifish
- Begin with review of the 3 different species of killifish in the investigation
- An abundance comparison of the three species of killifish
- Where Do Different Species of Killifish Live in the Hudson?
- Review the Estuary/River Concepts covered
- Review killifish species and the differences between an estuary and a river
- *Investigation #2: Introduction to Salinity*
- What tools can we use to measure salinity? Why would we use different tools?
- Let's Check the Salinity of the Water in Different Parts of the Hudson
- Mark the marine, brackish, and fresh sections on the map according to the data/key
- Compare the killifish species vs. salinity vs. location.
- Can you draw conclusions about each species preference range?
- Review the Estuary/River Concepts covered

Day 3 (40 minutes, slide deck 3: 10 slides)

- Review the killifish species vs. salinity vs. location and the estuary/river concepts that have been covered
- What tools can we use to measure water depth? Why would we use different tools?
- *Investigation #3*: Let's Check the Water Depth of the Hudson
- Review the student collected water level change at Piermont over a 4.5 hour period
- Using the Hudson River Environmental Conditions Observing System (HRECOS), what do you observe about the water level change at West Point vs. Pier 84, NYC? Similarities? Differences?
- Now observe the HRECOS data from the Mohawk River at Lock 8 vs. Mohawk River at Rexford vs. West Point, NY. Similarities? Differences? What does this data tell us?
- Review the Estuary/River Concepts covered
- From these three investigations, is the Hudson a river or an estuary?
- Take a deeper dive and consider what kind of estuary the Hudson is?

Learning Objectives:

- Understand the importance of watersheds and learn our own water addresses
- Develop and refine a model around what constitutes an estuary versus a river
- Learn the definition of an estuary and the definition of a river.
- Understand how to use a dichotomous key.
- Compare different scientific tools used to measure and observe the natural world.
- Complete an investigation using different areas of evidence to form and support hypotheses
- Understand that the environment impacts species diversity and that species have preferred environments.
- The role student collected data can play in active research.

Necessary Materials:

- PowerPoint provided here – you will want to use it in 3 parts
- Online Dichotomous Key http://clearwater.org/fishkey/

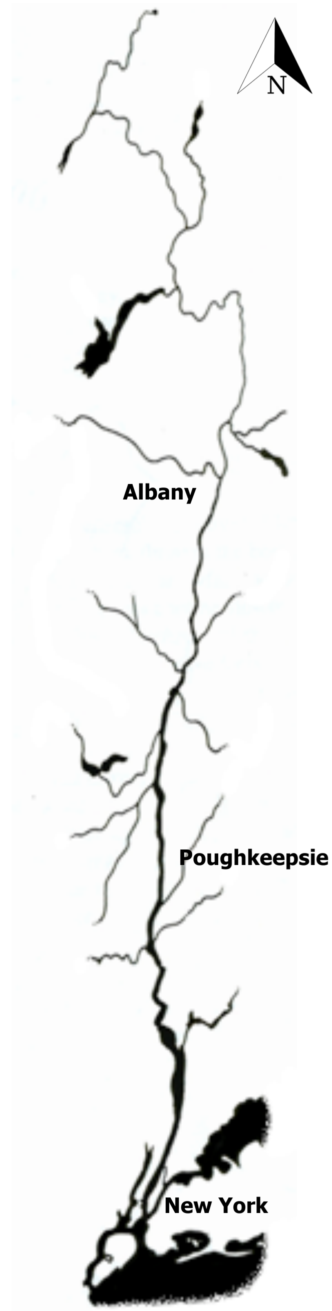
Additional Materials available to support and extend your use of this activity:

- EI LIVE: STEM on the Hudson – Video and resources
    - Video of Lamont Educators Giving the Lesson Online
- Killifish and Salinity Abundance Graphs Shown in PowerPoint (Google folder)
- NYS DEC Banded Killifish Distribution in New York State
- NYS DEC Mummichog Distribution in New York State
- LDEO's Hudson River Field Station website
- Day in the Life of the Hudson and Harbor Program- Data, lessons, and additional resources that have been collected and developed since 2003:
    - A Day in the Life of the Hudson 2019: Fishing Student Worksheet
    - A Day in the Life of the Hudson River 2019: Fishing Teacher Worksheet
    - A Day in the Life of the Hudson River 2019: Salinity Student Worksheet
    - A Day in the Life of the Hudson River 2019: Salinity Teacher Worksheet
- A Day in the Life of the Hudson River Salinity Mapping Activity Teacher Notes:
    - 2008 Salinity Map
    - 2009 Salinity Map

The Background

Each of us has a *water address*. No matter where you reside on land, you are a part of a watershed. A *watershed* is a geographic area whose rainfall, snowmelt, streams, and rivers all flow or drain into a common body of water, such as an ocean, lake, river, stream, estuary, or reservoir. Ultimately, most watersheds eventually drain into the ocean.

At Lamont-Doherty Earth Observatory's Field Station, we are a part of the Hudson River watershed, one of particular importance as it expands across approximately a third of New York State and even into New Jersey, Vermont, Massachusetts and Connecticut! The freshwater input of the Hudson River starts at any location within the watershed. One drop of rainwater in the watershed could contribute towards the freshwater of the Hudson River, eventually draining into the Atlantic Ocean. The highest point of our watershed is at Mount Marcy in the Adirondacks. While the entire Hudson River spans an impressive 315 miles from Lake Tear of the Clouds to the Atlantic Ocean, our investigation will focus on the 153 miles stretch between the Troy Dam and the Atlantic Ocean.



In three activities, we will be investigating whether this section of the Hudson is an estuary or a river using the principles outlined by the National Oceanic and Atmospheric Administration (NOAA). We will use fish species diversity, salinity ranges, and water level change to help us in our investigation.

Above is an image of Bear Mountain Bridge looking north onto Manitou Marsh, an important nursery area for several Hudson River fish including striped bass.

TEACHER DIRECTIONS:

Using the PowerPoint, you will take the students through the slides. Begin by introducing the terms 'watershed' and 'water address'. Ask the students to describe their own water addresses - what is the nearest water body to their homes? Do they know what watershed they are apart of? Share the colorful intricate map of watersheds in the United States. Discuss how the rivers and streams are visually similar to arteries and veins of the human body, and like arteries and veins are moving nutrients through our blood, streams and rivers are moving nutrients through the water that are essential for life! This activity focuses on the Hudson River watershed, which is large and covers areas in 5 states. Review key facts about the Hudson River watershed and a map for spatial reference. An important take away from this activity is that water is not limited by state or city boundaries.

Some call the Hudson a river, while other call the Hudson an estuary… but which is it? What are the differences between a river and an estuary? Students will create a model of each that they will refine as the lesson evolves.

ON THE LEFT YOU WILL CREATE A MODEL OF WHAT DEFINES AN ESTUARY.
- **In your model you will include the critical pieces that make a body of water an estuary.**
- **Be sure to annotate how the pieces relate to each other**

ON THE RIGHT YOU WILL CREATE A MODEL OF WHAT DEFINES AN RIVER.
- **In your model you will include the critical pieces that make a body of water a river?**
- **Be sure to annotate**

Write down your thoughts using this chart and then discuss as a class! You can include phrases, diagrams and drawings but only use one color for your first drawing!

Estuary	River

How do the students' answers relate to the estuary and river concepts outlined by NOAA? Have the students discuss the 'Estuary VS. River Models' that they have developed.

The drone video was taken by Mahopac High School students in Verplanck, NY @ RM 41. Based on the estuary vs. river concepts, can you tell by this video whether the Hudson is a river or an estuary? Ask the students if they see any evidence in the video? In fact it is quite hard to tell just by visual observation. It seems that we will need to conduct a more thorough investigation of the Hudson to uncover our answer! However, there are marinas, barges, quarries and communities that line the waterfront, evidence suggesting that humans rely on the Hudson.

Investigation #1: Let's Check in With the Hudson Residents!

The biology of the Hudson can tell us a little more about whether the Hudson is a river or an estuary based on the environmental preferences/tolerances of the species that we catch. In order to catch fish in the Hudson, we suggest a couple of different fishing tools. If a site has access to the waterfront or beach, a *seine net* is a perfect tool to catch smaller fish by walking a net through the water and pulling your catch up on the beach. A *fish trap* is a great fishing tool if your site has a dock or pole to tie down the fish trap. *Rod and reel* is a more expert method of fishing that requires practice and skill, but has the ability to catch larger species of fish.

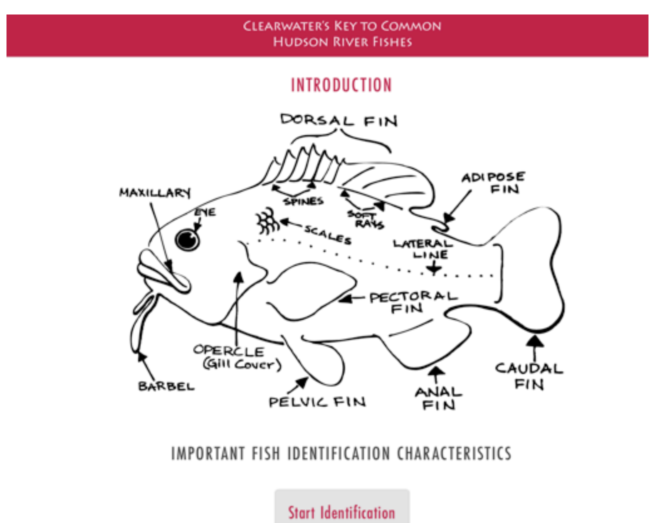
MATERIALS:

- Worksheet/packet
- Writing utensil
- Access to the internet and the Digital Version of Clearwater's Key to Hudson River Fishes via phone, computer, or iPad

Investigation #1:

Part 1: How can we tell what is caught in the Hudson River?

We can use a dichotomous key! Based on a series of questions about the species, this tool helps scientists or fishers identify the species that have been caught. Below are some key external anatomy features that the dichotomous key is based on. Each page in the key provides two options, A or a B, that describes a characteristic to examine and determine which option best describes what is being looked at. Based on these features, the key can narrow down to the genus, or in some case, the species.



Use the dichotomous key to identify the fish below. Record your answers on your worksheet to keep track of your pathway to identification.

Let's start with the first question for the key:

A. Eyes on same side of head; body lies flat on bottom
B. Eyes on opposite sides of head

For this fish, the eyes are on opposite sides of the head so we would click B.

A. Tiny mouth at tip of tube-like snout; bony rings around body
B. Mouth not at end of tube-like snout; no bony rings around body

A. Pelvic fins absent
B. Pelvic fins present

A. Long whisker-like barbels at corners of mouth and on chin
B. Barbels absent or present only on chin or at corners of mouth, not both places

A. One barbel on chin
B. Barbels lacking or located in places other than on chin
=
A. Single dorsal fin with soft rays and no more than one stiff spin (if any)
B. Spines on back, separate or as spiny rays in dorsal fin

A. Snout long or shaped like duck's bill
B. Snout not long or like duck's bill

A. Tail rounded or squared off
B. Tail distinctly forked

Answer: Killifish, but what killifish is it? Mummichog? Banded Killifish? Striped Killifish?
Point out to the students that the three species all have the same genus: Fundulus.

THIS IS THE END OF LESSON #1

TEACHER DIRECTIONS: DAY 2

The Hudson is home to over 200 species of fish, but we will focus on three types of **killifish**:

The **banded killifish** (Fundulus diaphanous) is the most slender of the three species with a squared tail and a head that is somewhat flattened on top. It has a small mouth that is turned up for surface feeding and they spawn in aquatic plant beds. During mating males will develop a bright blue patch and female eggs have adhesive threads to hold onto plants. Banded killifish live for 2-3 years and are 2-4 inches long.

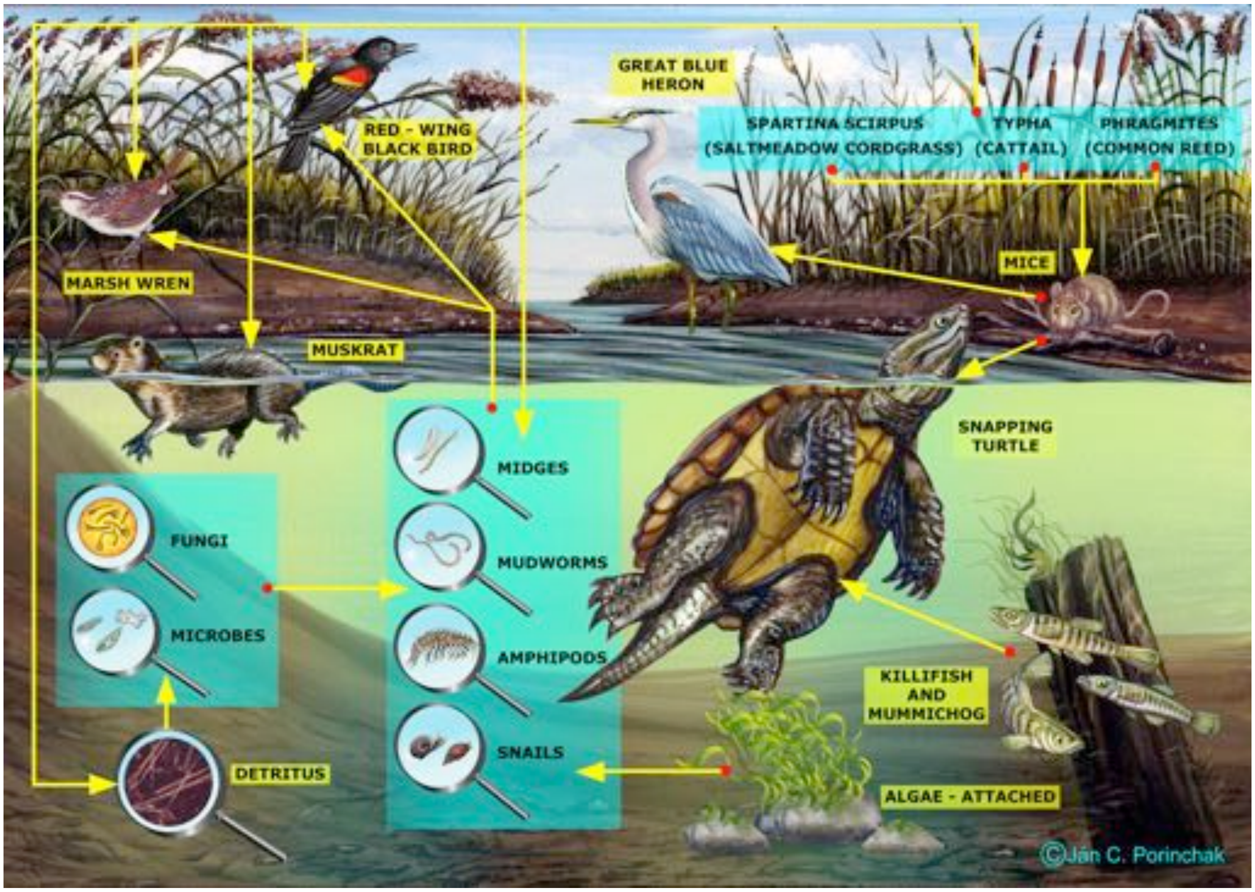
The **striped killifish (**Fundulus majalis) has a round head and a tail with rounded corners. They are more tolerant of sandy environments than the other killifish species. During mating, the males will have black sides with golden orange and bright yellow fins. The average lifespan is 3-5 years and are 6-8 inches long.

The **mummichog** (Fundulus heteroclitus) is a killifish whose name is from the Algonquian Native American tribe meaning going in crowds. This species eats up to 2,000 mosquito larvae a day and are great for mosquito control. A plump fish with a rounded tail that burrows in mud and sediment, it is very tolerant of low oxygen environments. During mating the males will have yellow pectorals and belly, with blue and orange markings, sometimes with a bull's-eye on the dorsal fin. Mummichogs can live up to 3 years and are 5-6 inches long. This species of killifish has been sent to space and have a tremendous jumping ability!

TEACHER DIRECTIONS:

Using the PowerPoint review the three types of killifish in the Hudson- considering how each is different, but also alike!

By looking at the illustration of the Hudson River food web, have your students identify commonalities that all killifish share for Question 1? In reviewing the specifics of each species, have your students complete Question 2. Question 3 tests understanding.



A depiction of a Hudson food web. By Ján C. Porinchak

In observing the Hudson River food web and listening to the PowerPoint, answer the following questions:

1. **What are the similarities between these killifish?**
    1. **Their place in the food web**
    2. **They live close to shore (less than 100 feet)**
    3. **They all have counter shading.**
    4. **They all have disruptive camouflage**
    5. **They all have similar mouth and eye positioning**
    6. **They all have coloration difference between the males and females**
    7. **They are all native to the Hudson**

2. **How many centimeters are each killifish on average?**
    1. **Banded killifish 5-10cm**
    2. **Striped killifish 15-20 cm**
    3. **Mummichog 13-15 cm**
3. **Notes about *banded killifish*:**

4. **Notes about *mummichogs*:**

5. **Notes about *striped killifish*:**

6. **Notes about *striped killifish*:**

Investigation #1:

Part 2: Where do Different Species of Killifish Live in the Hudson?

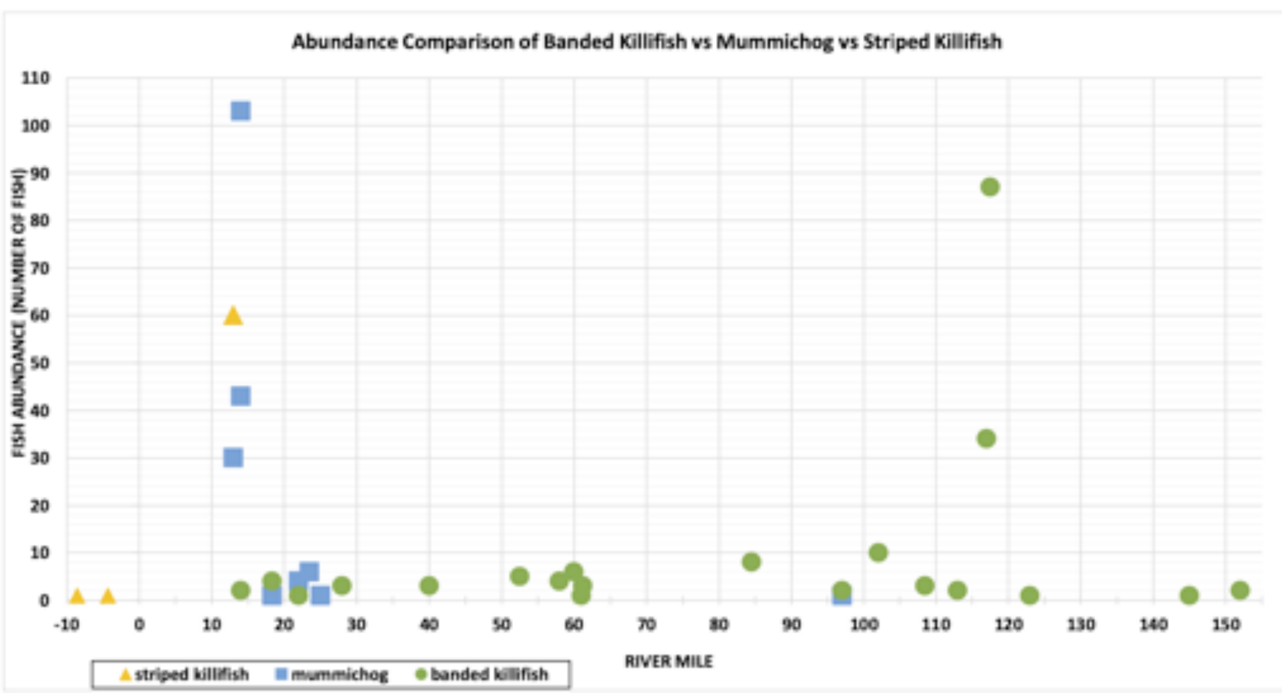
MATERIALS:
- Piece of paper
- Writing utensil

TEACHER DIRECTIONS:
Let the students complete Investigation 1 Part 2 on their own or in groups. Use the PowerPoint to review the answers as a class and to spark discussion. Then review the Hudson habitat slides with students to conclude Investigation 1.

We are going to look at where the different killifish live throughout the Hudson. The Hudson is broken up into different River Miles (RM) with RM 0 located at the southern tip of the Battery in Lower Manhattan in the New York Harbor. We start the Hudson RM count at this point with RM numbers increasing as you travel northward. We begin by looking at the abundance of each killifish species caught at the noted RMs during a set of sampling events.

DIRECTIONS:

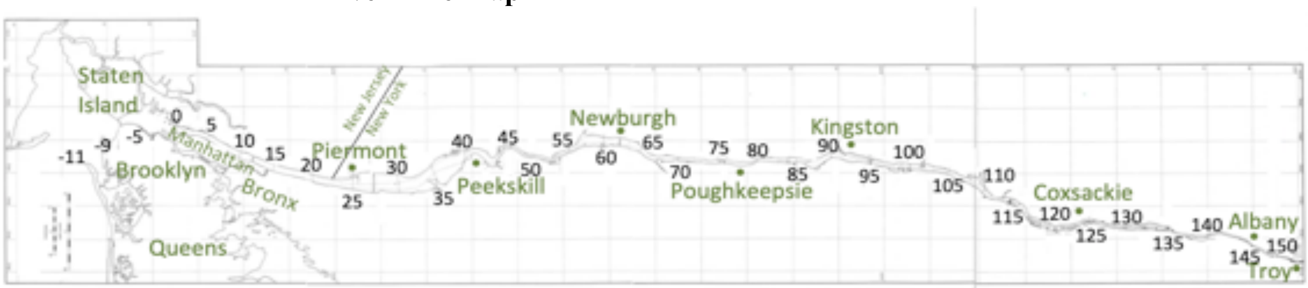
Look at the graph below. Based on the data provided in the Killifish Species Graph below, identify the range shown for each of the killifish species netted during our event. Next you will use the River Mile Map on the next page to show the species ranges shown in the data below.



Killifish Species Graph

Use the map and draw a line that represents the extent of the range of each Killifish species. Be sure to use a different color for each species. Then use the data to make observations, answering the questions below.

River Mile Map



Questions:

1. **Which species was found in the most locations?**
   a. **Banded Killifish**
2. **Between what river miles did we find Striped Killifish?**
   a. **River mile -10 to river mile 15**
3. **Between what river miles did we find Mummichog?**
   a. **River mile 15 to river mile 98**
4. **Between what river miles did we find Banded Killifish?**
   a. **River mile 15 to river mile 155**
5. **Why do you think these fish are found in different areas of the Hudson?**
   a. **Just like all animals and plants, different species of killifish prefer different types of habitats, and there are a variety of different habitats found throughout the Hudson!**
      i. **Near river mile 9 there is Canarsie Pier, a sandy area with a few rocks.** ***Remember: Striped Killifish prefer sandy bottom habitats.***
      ii. **Near mile 15 you have Inwood, a very protected and located where the Harlem River and Hudson River meet. A marshy environment that is very mucky with a lot of mud and sediments.** ***Remember: Mummichogs get the nickname mud minnows because they love marshy environments and can bury themselves in the mud.***
      iii. **Near mile 25 there is Piermont Pier, the seining location that is protected by the pier structure. This is also a very marshy environment with a lot of mud and sediments.**
      iv. **Between mile 60 and 65 there is Denning's Point, a sandy beach protected by a peninsula with some shrubbery near the water's edge.**
      v. **By mile 120 there is Coxsackie, a sandy/rocky beach with quiet waters and a lot of protection.**
      Banded killifish seem to span a large part of the upper estuary. There must be something more that we can learn about them…let's move onto the next investigation!

Remembering the estuary and river concepts, which ones have we covered so far?

Look at your model on page 2. Using a different colored pen/pencil, update your model or annotate it with the new information we have talked about!

Highly complex with varied habitats and people rely on them for the many things they provide are the two concepts that have been covered so far in Day 1.

Begin with a refresher of the principles of the estuary/river material and killifish range information. Ask the students to update their own model with anything that might have turned up in Day #1 (completed version is below for reference). The students should use a different color pen/pencil to annotate and update their model.

ESTUARIES	RIVERS
Connect directly to the ocean so water is both salty & fresh	A large body of fresh flowing water
Flow two ways due to tides	Flow one way –from higher to lower elevation
Depth determined by tides	Depth determined by flow
Ocean connection makes them very dynamic	Generally consistent water conditions
Highly complex with varied habitats	Less complex with fewer habitats
Species include freshwater, saltwater & estuarine (brackish)	Species are freshwater
People rely on them for the many things they provide	People rely on them for the many things they provide

Investigation #2: Let's Check the Salinity of the Water in Different Parts of the Hudson

MATERIALS:
- Worksheet/packet
- Writing utensil

TEACHER DIRECTIONS:
Using the PowerPoint, introduce the students to water salinity and the different tools used to measure it. Let the students complete Investigation 2 activity on their own or in groups. Use the PowerPoint to review the answers as a class and to spark discussion.

A big difference between salt water and fresh water is the amount of dissolved salts or salinity of the water. Both salt and freshwater have salt, but the amount of salts in saltwater are significant higher. The amount of salt also influences the density of the water. Saltwater has a higher density than freshwater. That's why you can float or are more buoyant in saltwater than freshwater. Fresh water is water with a salt concentration of less than 0.01 percent as opposed to salt water that has an average salinity of 3.5 percent.

The amount of salt in a body of water, also known as the ***salinity**,* helps define the type of water we are looking at. In the Hudson, we have fresh, brackish, and marine sections. The **freshwater region** is defined as having < **100 ppm** (parts per million) salinity. The **brackish water** section has a salinity range that is **> 100 ppm and < 18,000 ppm (18 ppt). Marine waters** are defined as having a salinity that is **> 18,000 ppm (18 ppt).** For reference, the open ocean has approximately 35,000 ppm (35 ppt). The instrument that is used to measure salinity depends on your location on the Hudson.

Salinity is measured using *(from left to right)* a hydrometer, a refractometer, or quantabs.

A *hydrometer* is an instrument that measures salinity based on density. A hydrometer determines specific gravity by operating on Archimedes principle or the *principle of floatation* that states a solid suspended in a liquid/fluid will be buoyed up with a force that equals the weight of the fluid it displaces. In small plastic hydrometers like the one shown above it measures the buoyancy of the plastic lever/arrow as a way to find the relative density of a liquid. The lever will sink further into water with lower density (freshwater) than water with high density (salty or brackish water).

A *refractometer* is a tool that determines the concentration of a substance (salinity) in a given solution (water) based on the principle of refraction. When the rays of light pass from one medium into another, they are bent either toward or away from a normal line between the two media. Salinity causes light to scatter or refract. Therefore, the refractive light can be used to determine the sodium chloride (NaCl), concentration of salinity, in a solution. For each percent salinity value, there is a corresponding angle of refraction, and the angle of refraction is converted to percent salinity.

Salt is an ionic compound, with the majority of ions in seawater being sodium (Na^+) and chloride (Cl^-). *Quantabs* measure the amount of chloride in the water. When the quantab is placed in the sample of river water the fluid moves up the strip by capillary action. Each quantab contains a strip of silver ions, and when combined with chloride, a white column of silver chloride forms in the strip. The length of the white column is marked and proportional to the chloride ion concentration. The reading is then easily converted the total salinity.
A simple calculation can provide the total salinity from the chloride concentration (total salinity (ppm) = 1.8066 * Cl^- (ppm or mg/L)).

DIRECTIONS:

Identify the Marine, Brackish, and Fresh sections

HIGH SCHOOL VERSION:
Recall that levels of salinity are used to identify whether water is Marine, Brackish or Freshwater. (You may want to go back to the start of this investigation if you need a refresher.) Examine the Salinity Graph below to see what salinity readings the samplers recorded. Then on the River Mile Map below the graph, mark on or above the map, the ranges where the samplers found the marine section, brackish section, and fresh water sections of the Hudson. Use different colored lines as you did for the fish ranges in Investigation #1.

Hint: It might be useful to add some salinity concentrations from the graph on the map to visualize how the salinity changes with river mile.

Hint Hint: You might want to start by identifying the salinity breaking points where the sections move from marine to brackish and brackish to fresh.

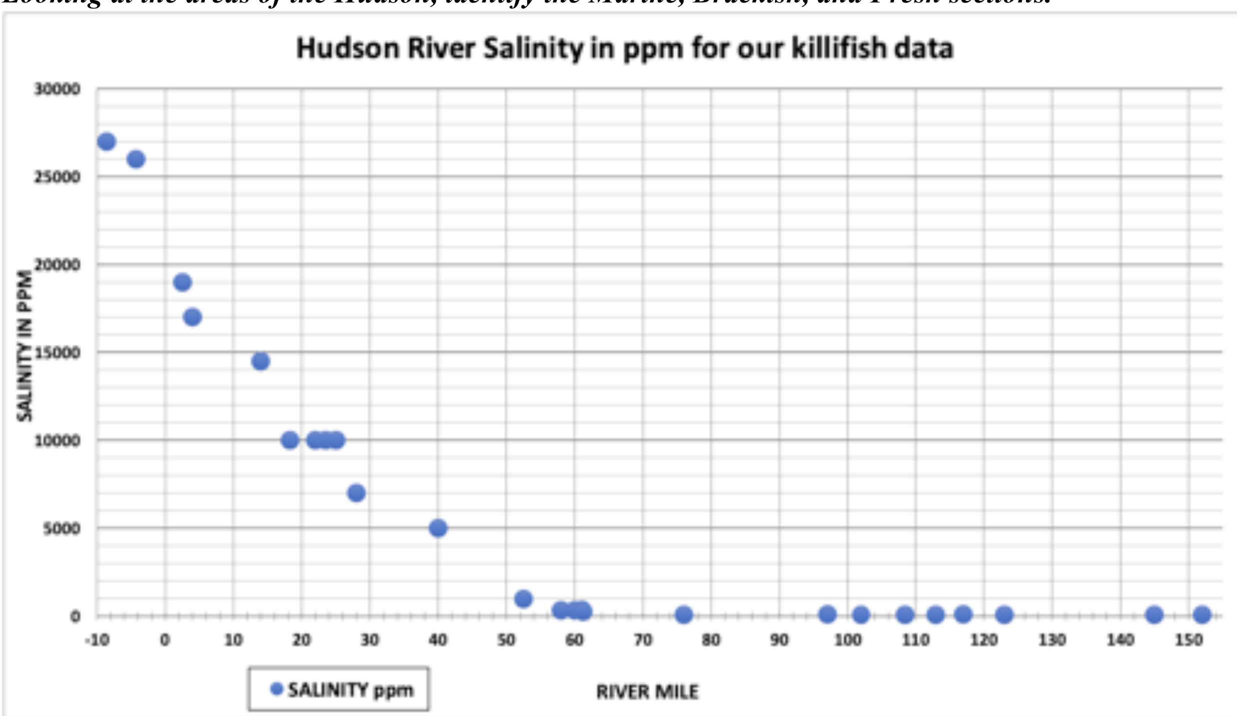
MIDDLE SCHOOL VERSION:
(This version has arrows added to the River Mile Map that students can use to add some different salinity data straight onto the map. For the High School there is a second Hint that suggests they may want to do this on their own.)

This activity will use both images below. On the top is a graph of the different salinity readings that were collected by groups while they were sampling. Below that is a map with RMs listed along the river every 5 miles. You will see red arrows at 10 different locations on the map.

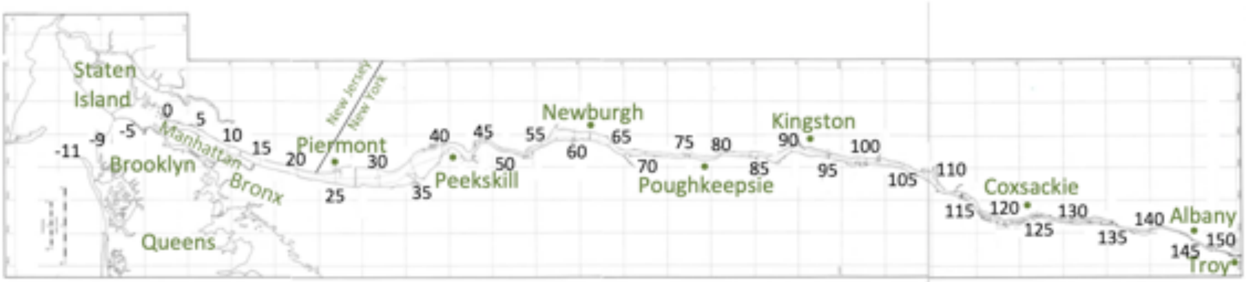
Recall that levels of salinity are used to identify whether water is Marine, Brackish or Freshwater. (You may want to go back to the start of this investigation if you need a refresher.) Examine the Salinity Graph below to see what salinity readings the samplers recorded. Use that information to add the salinities at each river mile with a red arrow. Then, use different colored markers to identify the ranges of the marine section, brackish section, and fresh section of the Hudson given this data. Mark out these sections on or above the map.

Hint: You might want to start by identifying the salinity breaking points where the sections move from marine to brackish and brackish to fresh.

Looking at the areas of the Hudson, identify the Marine, Brackish, and Fresh sections.



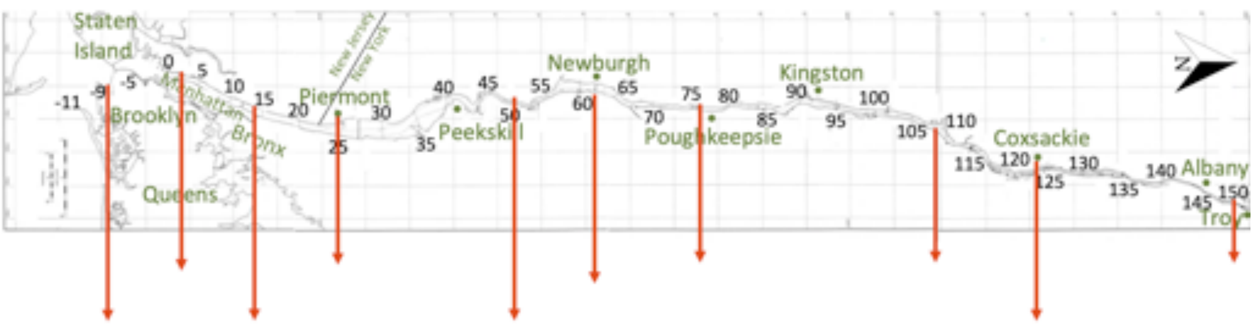
Salinity Graph



River Mile Map (High School)

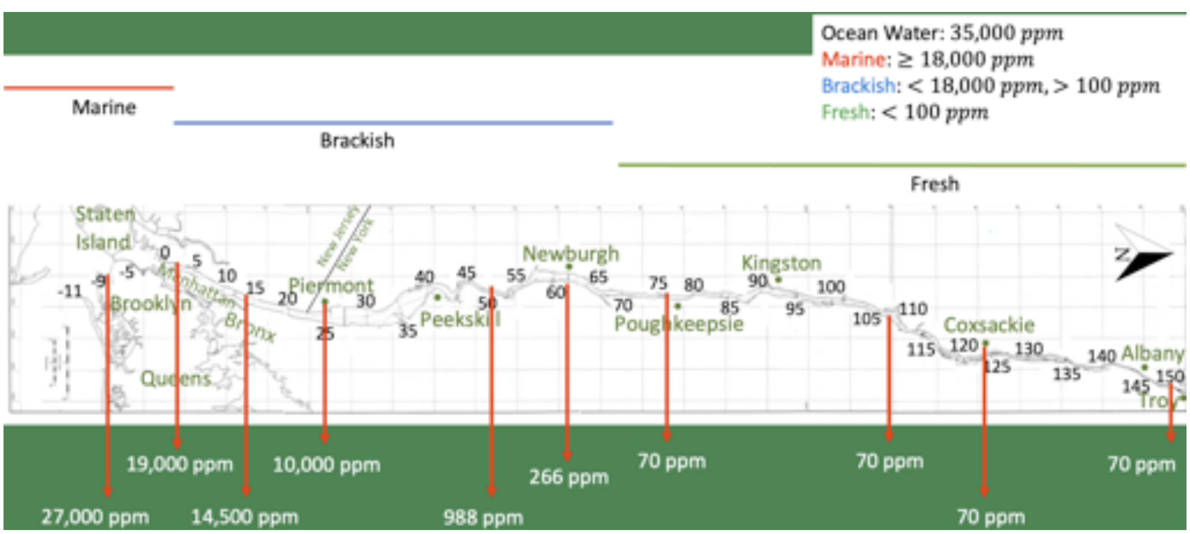
NOTE FOR THE HIGH SCHOOL VERSION:

Based on the students' graph reading abilities, the graph with the red arrows already labeled can be used if students' need assistance.



River Mile Map (Middle School)

TEACHER COPY ANSWER KEY:



Using the map and the corresponding river mile, you can see that at mile -9, the water's salinity is measured around 27,000 ppm, with a classification of marine water. At approximately river mile 2, the water transitions from marine to brackish water. The brackish range continues through approximately river mile 58. From river mile 58 and above, the water is fresh.

REMEMBER, THE HUDSON IS A DYNAMIC WATER BODY!

The marine, brackish, and fresh sections of the Hudson vary daily, weekly, seasonally, and yearly based on tides, rain, snowmelt, and climate change. We are labeling the marine, brackish, and fresh sections of the Hudson based on the data collected in 2015 from the 'Day in the Life of the Hudson and Harbor' program.

Questions:

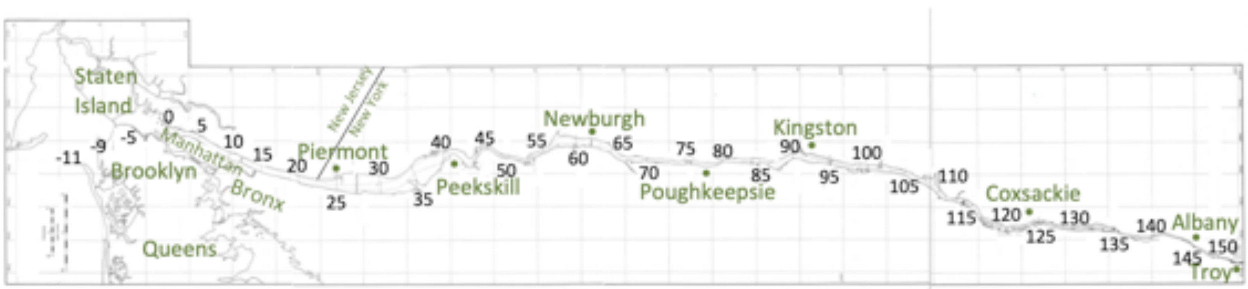
1. **Based on this data set, where are the marine sections in of the Hudson?**
   River mile -9 to 2

2. **Based on this data set, where are the brackish sections of the Hudson?**
   River mile 2 to 58

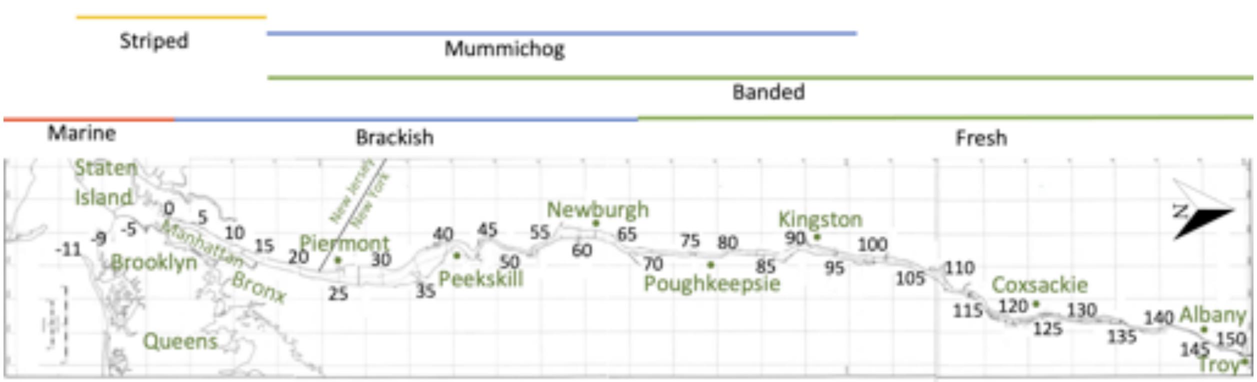
3. **Based on this data set, where are the fresh sections of the Hudson?**
   River mile 58 to 155

Let's put the biological and the chemical data on the same map!

On the River Mile Map below combine the killifish ranges identified in *Investigation #1* with the salinity sections identified in *Investigation #2*. Now let's make some observations. Are there any correlations?



TEACHER: GRAPH ANSWERS



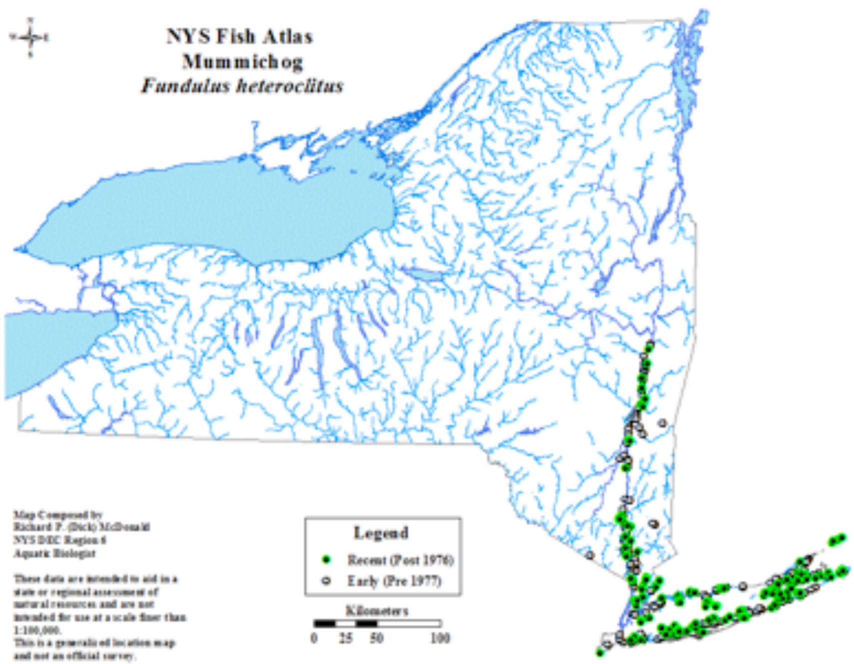
1. **Can you say anything about the preferences of STRIPED KILLIFISH?**
   They prefer marine water, but can tolerate the saltier brackish areas. They are primarily a salt loving fish. Remember, they like sandy bottom environments just like the habitat discussed at Canarsie Pier in Jamaica Bay.

2. **What about the preferences of MUMMICHOGS?**

Mummichogs are a brackish water species but are known as being *euryhaline*, meaning they have an ability to tolerate a wide range of salinities. However, you will not find them in exclusive freshwater bodies that have no connection to the ocean. In NYS, the only freshwater bodies that they are found are areas of the Hudson River estuary. In general, Mummichogs are an extremely hardy species. They can also live in a wide range of water temperatures and in extremely low oxygen environments. Remember, they were even sent to space!

With the nickname mud minnows, you may have guessed that they prefer marsh environments. They are commonly caught at Piermont and Inwood because of the presence of a marsh habitat.

3. **Hypothesize! See if you can make at least 3 additional observations that you can make about MUMMICHOGS based on this map?**

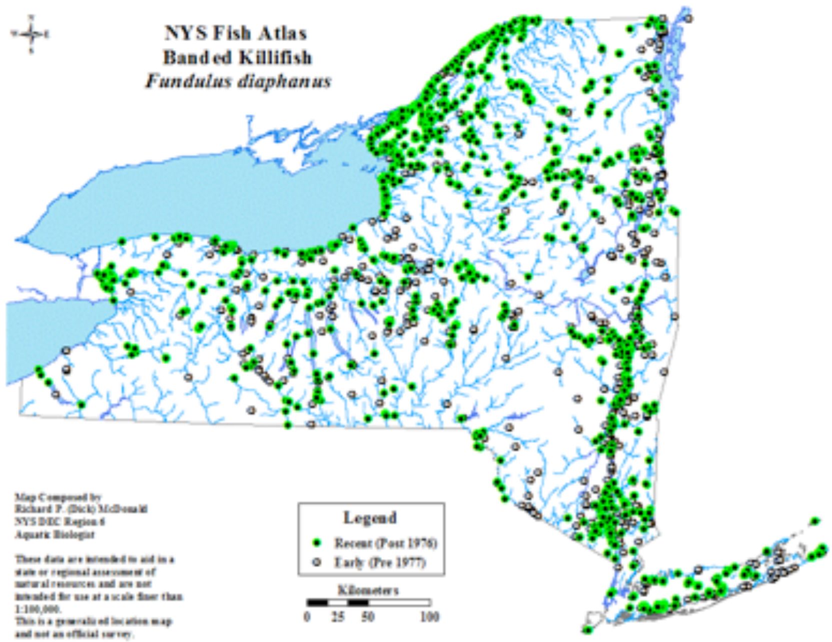


Mummichog distribution in NYS. Source: [NYS DEC]

1. Mummichogs do not live in exclusive freshwater bodies that have no connection to the ocean.
2. In NYS today, the only freshwater bodies where they are found are areas of the Hudson River estuary.
3. The range for mummichogs is primarily estuarine and marine.
4. The range from pre 1977 and post 1976 has not varied greatly

4. **What about the preferences of a BANDED KILLIFISH?**
The banded killifish prefers freshwater environments, but can tolerate brackish water. Due to the combined length of the fresh and brackish water sections, the banded killifish is found throughout the largest range of the Hudson.

5. **What are 3 additional observations that you can make about BANDED KILLIFISH based on this map?**



Banded killifish distribution in NYS. Source: NYS DEC

1. Banded killifish are found all throughout NYS
2. They can live in lakes, rivers, streams, and estuaries
3. Banded killifish do not need salt in the water- identified by their presences in lakes.
4. They can, however, be found in very salty marine waters - Long Island Sound, south shore of Long Island
5. The range from pre 1977 and post 1976 has not varied greatly

MAIN TAKE AWAY: Fish have preferences of water conditions and habitats in which they would like to live, but have a wider tolerance range! Don't be surprised if you catch a species outside of its normal preference range. It could (and has) happened!

Remembering the estuary and river concepts, which ones have we covered so far?
Look at your model on page 2. Using the information we have discovered from *Investigation #1 and Investigation #2* about the Hudson, update your model or annotate it using a different colored pen/pencil with the new information we have talked about!

After the students have individually updated their own models ask them to share. After sharing you can review the estuary/river concepts together as a class to see which ones have been covered thus far.

ESTUARIES	RIVERS
Connect directly to the ocean so water is both salty & fresh	**A large body of fresh flowing water**
Flow two ways due to tides	**Flow one way –from higher to lower elevation**

Depth determined by tides	**Depth determined by flow**
Ocean connection makes them very dynamic	**Generally consistent water conditions**
Highly complex with varied habitats	**Less complex with fewer habitats**
Species include freshwater, saltwater & estuarine (brackish)	**Species are freshwater**
People rely on them for the many things they provide	**People rely on them for the many things they provide**

1. **It connects directly to the ocean so water is both salty and fresh.**
2. **There is an ocean connection that makes them very dynamic.**
3. **It is highly complex with varied habitats.**
4. **Species include freshwater, saltwater, and estuarine (brackish).**
5. **People rely on them for the many things they provide.**

THIS IS THE END OF DAY 2

TEACHER DIRECTIONS: DAY 3

Investigation #3: Let's Check the Water Depth of the Hudson

MATERIALS:
- Worksheet/packet
- Writing utensil

TEACHER DIRECTIONS:
Using the PowerPoint, introduce the students to water level change and the different tools used to measure it. Let the students complete Investigation 3 activity on their own or in groups. Use the PowerPoint to review the answers as a class and to spark discussion.

There is one additional piece of evidence that can help us determine whether the Hudson is a river or an estuary: measuring water level change! Water level or water depth can be measured in the field in a variety of different ways depending on your site.


Water level measured *(left to right)* from the surface of the water to the bottom of the Hudson, the distance the water has changed from where it hits the shore, the water level as marked on a tide stick.

1) If your site has a pier or dock, you can measure the water level by *measuring from the surface of the water to the bottom of the river.* If you are on a dock, you will have to do a couple measurements and some simple math to calculate the water's depth. First, measure from the top of the pier/dock to the bottom of the Hudson, and then measure the distance from the top of the pier/dock to the surface of the water. The difference between these two measurements will give you the depth of the water!

2) You could also use a *tide stick*. A meter stick gets placed in the water. Periodically, check back to measure the water level change in centimeters on the tide stick.

3) If you have access to the water via shoreline or beach, you can measure changes in the tide by measuring changes in *the water line on the beach.* Periodically, mark where the water line is on the beach to observe how the water line has changed.

DIRECTIONS:

At Piermont (RM 24.5) we used method #1 and #2 to observe the water level change over a 4.5 hour period during 'Day in the Life of the Hudson and Harbor'. You will use our data and complete the chart below.

1. **Calculate the time between the measurements. Then using the change in cms recorded you will complete the rate of change column for both the tide stick measurements and the measurements from the dock.**

Piermont RM 25								
Time	Tide Stick cm	Change / cm	Rate of Change	Rising/ Falling	Measure to Water cm	Change / cm	Rate of Change	Rising/ Falling
9:00 AM	20				550			
9:30 AM	12	8	8cm/30 m	F	563	13		F
10:30 AM	25	-13	13 cm/60 m	R	555	-8		R
11:02 AM	41	-16		R	540	-15		R
11:23 AM	50	-9		R	535	-5		R
11:39 AM	60	-10		R	485	-50		R
12:30 PM	85	-25		R	436	-49		R
1:00 PM	92	-7		R	430	-6		R
1:20 PM	95	-3		R	411	-19		R

2. **Consider the two methods. Why are progressive measurements between the *Tide Stick* readings increasing, while the *Measure to the Wat*er are decreasing, yet the water level is 'rising' throughout the majority of the day?**

Another way to observe water level change is by using equipment like the Hudson River Environmental Conditions Observing System (HRECOS). HRECOS is a network of high-frequency monitoring stations that are geographically distributed along the Hudson and Mohawk River, equipped with sensors that continuously record a suite of water quality and weather parameters every 15 minutes with most stations operating year-round.

DIRECTIONS: Review the graphs and data below and answer the corresponding questions. Once the students complete these questions individually, discuss the answers as a class by using the PowerPoint.

Graph 1 shows the water level changes at West Point, NY (blue) and Pier 84, NY (orange) from August 10th, 2021 through August 17th, 2021.

Graph 1: Comparing the water level change over a week at West Point, NY in **blue** and Pier 84, NYC, NY in **orange**.

1. **List your observations about this data graph.**

- **Regular up and down pattern; oscillations**. If you count the peaks and troughs, you would identify that there are two high peaks and two low troughs per day.
- **Time offset** at the peaks and troughs between the data collected at West Point and the data collected at Pier 84
- **Different ranges** in the oscillations between the two sites. There is a greater range at the West Point, NY site which is farther away from the Hudson harbor.
- Both measurements are on the Hudson

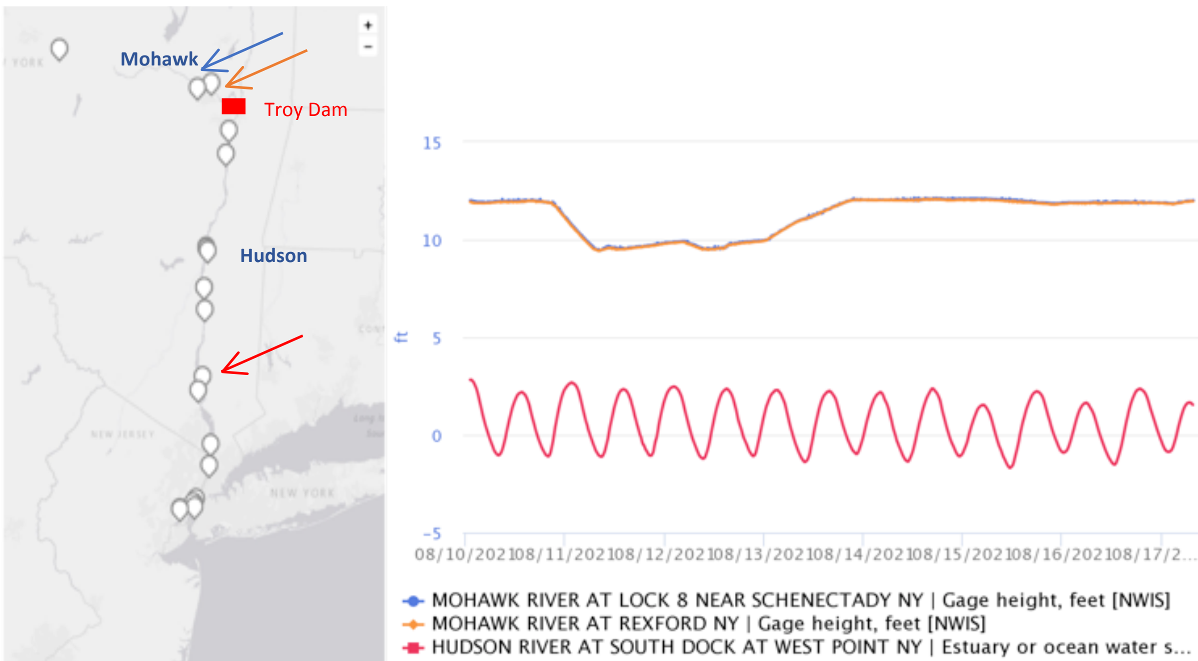
2. **What might be the driver for the pattern that you see? Tides caused by the gravitational pull of the moon and sun!** The Hudson is connected to the Atlantic Ocean, and therefore, experiences tidal force. Our specific area experiences *semidiurnal tides*, meaning two high and two low tides a day.
   For more on tides, review 'Tides and Water Levels' from NOAA or a 'Tides in the Hudson' from the Cary Institute.

3. **Why might the oscillation pattern between two sites not occur at the exact same time?**
   - **Timing offset** between the two sites because West Point, NY is farther away from the Atlantic Ocean. It takes longer for the water from the Atlantic to make its way up the river so the high tide reaches West Point a little later than it does at Pier 84.

4. **Why might the oscillation pattern between the two sites have a different range between high and low tide?**

- There is a larger difference in the tidal range at West Point than at Pier 84 because the width of the Hudson is narrower at West Point. The widest section of the Hudson is at Haverstraw bay at approximately 3 miles wide, and as you move north from this location, the Hudson narrows. The increased high to low tide range is because the same amount of water is flowing through a smaller Hudson width.

Graph 2 demonstrates the water level changes at Lock 8 near Schenectady, NY in the Mohawk River (blue), Rexford, NY in the Mohawk River (orange), and West Point, NY in the Hudson River (red) from August 10th, 2021 through August 17th, 2021.



1. **Jot down some observations from this data graph.**
   - **Measurements are relatively flat** for the Mohawk River Stations
   - Mohawk River Stations **water level change is nearly identical** over the course of 7 days.
   - Mohawk River Stations **do not have a 6 hr. oscillation**. The data represents a single directional flow and does not appear to have any tidal influence.
   - West Point data shows **oscillations being driven by tidal force**. There are two high and two low tides per day, which indicates that West Point experiences semidiurnal tides.

2. **The data collected from Lock 8 and Rexford, NY appears to follow the same pattern. Can you provide a hypothesis as to why?**
   - These two sites are both collected from the Mohawk River, and are in close proximity to one another, and thus appear to have similar influences controlling their water flow.

3. **What might be the cause of the difference in the data collected from Lock 8 and Rexford and that collected at West Point?**
   Lock 8 and Rexford have the same trajectory because they are both above the Troy Dam and thus above the influence of the tides. The Troy Dam has a large (human made) elevation change in which the tidal forces are halted. Therefore, the dam divides the Hudson: above the dam is a river and below the dam is an estuary. Lock 8 and Rexford are both above the Troy dam, and therefore, are not tidal. West Point is tidal because it is below the dam. **Students often wonder** if had the

dam not been built, would tides have continued further up the Hudson, and the answer is no. The dam was constructed to facilitate boating because of a natural elevation change. This elevation change would have stopped the tides.

4. **What do you think might drive the water level change in the Mohawk River? What about in the Hudson River at West Point**?
Lock 8 and Rexford are both above the Troy dam, and therefore, are not tidal. Their water level is driven by river flow, which can be influenced by rain, drought, snow melt, etc. West Point's water level change is driven by the tides.

CAN WE DETERMINER WHETHER THE HUDSON IS A RIVER OR AN ESTUARY BASED ON OUR 3 INVESTIGATIONS?

Look at your model on page 2. Using the information we have discovered from *Investigation #1, Investigation #2, and Investigation #3* about the Hudson, update your model or annotate it using a different colored pen/pencil with the new information we have talked about!

After the students have individually updated their own models. Review the estuary/river concepts together as a class to see which ones have been covered thus far.

Each of the estuary concepts have been covered by the 3 investigations so we can conclude that the 153 miles of the Hudson, starting from the Hudson harbor up to the Troy dam, is AN ESTUARY! This is why many people refer to the Hudson as the Hudson River Estuary!

ESTUARIES	RIVERS
Connect directly to the ocean so water is both salty & fresh	A large body of fresh flowing water
Flow two ways due to tides	Flow one way –from higher to lower elevation
Depth determined by tides	Depth determined by flow
Ocean connection makes them very dynamic	Generally consistent water conditions
Highly complex with varied habitats	Less complex with fewer habitats
Species include freshwater, saltwater & estuarine (brackish)	Species are freshwater
People rely on them for the many things they provide	People rely on them for the many things they provide

BONUS QUESTION!

There are different types of estuaries around the world that we have defined below. Considering all that you know about the Hudson River, how would you define this estuary?

CIRCLE YOUR ANSWER FROM THE FOLLOWING:

1. **Fjord-** steep walled river valleys created by glacial advance (Example: Alaska)
2. **Drowned River Valley (or Coastal Plain Estuaries)-** rising sea levels flood existing river valley (Example: Chesapeake Bay)
3. **Tectonic-** Tectonic plate collide or fold together (Example: San Francisco Bay)

4. **Bar Built-** Barrier beaches, coastal parallel island, or barrier island create this estuary (Example: North Carolina)

The Hudson is both a fjord estuary and a drowned river valley! The Hudson is a fjord estuary because the Hudson highlands and chiseled cliffs were carved out by the glaciers and Laurentide ice sheet that covered this area most recently about 20,000 years ago. However, the Hudson is also a drowned river valley because as temperatures warmed and ice sheets in the north and south of the globe began to melt around 21,000 years ago, water levels rose rapidly for ~14,000 years, until about 7,000 years ago when sea level slowed. Areas once land became flooded. The edge of the continental shelf is evidence of the flooded coastal plain! For more information, read 'Classifying Estuaries: By Geology' by NOAA.

New York State Science Learning Standards (NYSSLS)

Middle School:

MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem

Analyzing and Interpreting Data Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. Analyze and interpret data to provide evidence for phenomena.	**Interdependent Relationships in Ecosystems** Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. Growth of organisms and population increases are limited by access to resources.	**Cause and Effect** Cause and effect relationships may be used to predict phenomena in natural or designed systems.

MS-LS2-3. Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

Science & Engineering Practices		
Developing and Using Models Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. Develop a model to describe phenomena.	**Cycle of Matter and Energy Transfer in Ecosystems** Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.	**Cause and Effect** The transfer of energy can be tracked as energy flows through a natural system. ***Connections to Nature of Science*** **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** Science assumes that objects and events in natural systems occur in consistent patterns that are understandable though measurement and observation.

MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

Engaging in Argument from Evidence Engaging in argument from evidence in 6–8 builds on K– 5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world(s). Construct an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem.	**Ecosystem Dynamics, Functioning, and Resilience** Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations.	**Stability and Change** Small changes in one part of a system might cause large changes in another part.

High School:

HS-LS2-1. Use mathematical and/or computational representations to support explanations of biotic and abiotic factors that affect carrying capacity of ecosystems at different scales.

Science & Engineering Practices		
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. Use mathematical and/or computational representations of phenomena or design solutions to support explanations.	**Interdependent Relationships in Ecosystems** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. Carrying capacity results from the availability of biotic and abiotic factors and from challenges such as predation, competition, and disease	**Scale, Proportion, and Quantity** The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.

HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.

Science & Engineering Practices		
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. Use mathematical representations of	**Interdependent Relationships in Ecosystems** Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. Carrying capacity results from the availability of biotic and abiotic factors and from challenges such as predation, competition, and disease. **Ecosystem Dynamics, Functioning, and Resilience**	**Scale, Proportion, and Quantity** Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale.

phenomena or design solutions to support and revise explanations. _ ***Connections to Nature of Science*** **Scientific Knowledge is Open to Revision in Light of New Evidence** Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.	A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.	

HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in ecosystems.

Science & Engineering Practices		
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. _ ***Connections to Nature of Science*** **Scientific Knowledge is Open to Revision in Light of New Evidence** Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.	**Cycles of Matter and Energy Transfer in Ecosystems** Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.	**Energy and Matter** Energy drives the cycling of matter within and between systems.

HS-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.

Science & Engineering Practices		
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are	**Cycles of Matter and Energy Transfer in Ecosystems** Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. The chemical elements that make up	**Energy and Matter** Energy can be transferred between one place and another place, between objects and/or fields, or between systems.

created and used based on mathematical models of basic assumptions. Use mathematical representations of phenomena or design solutions to support claims.	the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved. When matter is cycled through organisms and ecosystems, some of the matter reacts to release energy for life functions, some is stored in newly made structures, and some is eliminated as waste.	

Next Generation Science Standards (NGSS)

Middle School:

MS-LS2-1. Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Analyzing and Interpreting Data Analyzing data in 6–8 builds on K–5 experiences and progresses to extending quantitative analysis to investigations, distinguishing between correlation and causation, and basic statistical techniques of data and error analysis. • Analyze and interpret data to provide evidence for phenomena.	**LS2.A: Interdependent Relationships in Ecosystems** • Organisms, and populations of organisms, are dependent on their environmental interactions both with other living things and with nonliving factors. • In any ecosystem, organisms and populations with similar requirements for food, water, oxygen, or other resources may compete with each other for limited resources, access to which consequently constrains their growth and reproduction. • Growth of organisms and population increases are limited by access to resources.	**Cause and Effect** • Cause and effect relationships may be used to predict phenomena in natural or designed systems.

MS-LS2-3. Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Developing and Using Models Modeling in 6–8 builds on K–5 experiences and progresses to developing, using, and revising models to describe, test, and predict more abstract phenomena and design systems. • Develop a model to describe phenomena.	**LS2.B: Cycle of Matter and Energy Transfer in Ecosystems** • Food webs are models that demonstrate how matter and energy is transferred between producers, consumers, and decomposers as the three groups interact within an ecosystem. Transfers of matter into and out of the physical environment occur at every level. Decomposers recycle nutrients from dead plant or animal matter back to the soil in terrestrial environments or to the water in aquatic environments. The atoms that make up the organisms in an ecosystem are cycled repeatedly between the living and nonliving parts of the ecosystem.	**Energy and Matter** • The transfer of energy can be tracked as energy flows through a natural system. - - - - - - - - - - *Connections to Nature of Science* **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** • Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation.

MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Engaging in Argument from Evidence Engaging in argument from evidence in 6–8 builds on K–5 experiences and progresses to constructing a convincing argument that supports or refutes claims for either explanations or solutions about the natural and designed world(s). • Construct an oral and written argument supported by empirical evidence and scientific reasoning to support or refute an explanation or a model for a phenomenon or a solution to a problem. - - - - - - - - - - - - - - - ***Connections to Nature of Science*** **Scientific Knowledge is Based on Empirical Evidence** • Science disciplines share common rules of obtaining and evaluating empirical evidence.	**LS2.C: Ecosystem Dynamics, Functioning, and Resilience** • Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations.	**Stability and Change** • Small changes in one part of a system might cause large changes in another part.

High School:

HS-LS2-1. Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Use mathematical and/or computational representations of phenomena or design solutions to support explanations.	**LS2.A: Interdependent Relationships in Ecosystems** • Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.	**Scale, Proportion, and Quantity** • The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.

HS-LS2-2. Use mathematical representation to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Use mathematical representations of phenomena or design solutions to support and revise explanations. - - - - - - - - - - - - - - - ***Connections to Nature of Science*** **Scientific Knowledge is Open to Revision in Light of New Evidence** • Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.	**LS2.A: Interdependent Relationships in Ecosystems** • Ecosystems have carrying capacities, which are limits to the numbers of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environments and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem. **LS2.C: Ecosystem Dynamics, Functioning, and Resilience** • A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.	**Scale, Proportion, and Quantity** • Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale.

HS-LS2-3. Construct and revise an explanation based on evidence for the cycling of matter and flow of energy in aerobic and anaerobic conditions.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Constructing Explanations and Designing Solutions Constructing explanations and designing solutions in 9–12 builds on K–8 experiences and progresses to explanations and designs that are supported by multiple and independent student-generated sources of evidence consistent with scientific ideas, principles, and theories. • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. - - - - - - - - - - - - - - - - ***Connections to Nature of Science*** **Scientific Knowledge is Open to Revision in Light of New Evidence** • Most scientific knowledge is quite durable, but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.	**LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** • Photosynthesis and cellular respiration (including anaerobic processes) provide most of the energy for life processes.	**Energy and Matter** • Energy drives the cycling of matter within and between systems.

HS-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.

Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Using Mathematics and Computational Thinking Mathematical and computational thinking in 9-12 builds on K-8 experiences and progresses to using algebraic thinking and analysis, a range of linear and nonlinear functions including trigonometric functions, exponentials and logarithms, and computational tools for statistical analysis to analyze, represent, and model data. Simple computational simulations are created and used based on mathematical models of basic assumptions. • Use mathematical representations of phenomena or design solutions to support claims.	**LS2.B: Cycles of Matter and Energy Transfer in Ecosystems** • Plants or algae form the lowest level of the food web. At each link upward in a food web, only a small fraction of the matter consumed at the lower level is transferred upward, to produce growth and release energy in cellular respiration at the higher level. Given this inefficiency, there are generally fewer organisms at higher levels of a food web. Some matter reacts to release energy for life functions, some matter is stored in newly made structures, and much is discarded. The chemical elements that make up the molecules of organisms pass through food webs and into and out of the atmosphere and soil, and they are combined and recombined in different ways. At each link in an ecosystem, matter and energy are conserved.	**Energy and Matter** • Energy cannot be created or destroyed—it only moves between one place and another place, between objects and/or fields, or between systems.