# Robomussels: How Organisms Experience Climate (Answer Key)

## [Link to the visualization](https://huckley.shinyapps.io/ClimateBiology/)

## [Link to TrEnCh-Ed](https://trench-ed.github.io/#)

## Objectives

* Students will be able to analyze data about temperature fluctuations impacting mussel populations along the Pacific Coast of the U.S.
* Understand the temporal and spatial scales that single organisms (here mussels) “feel” temperature variations and extremes
* Students will be able to analyze how these temperature fluctuations could impact mussel populations, biodiversity and food webs.
* Students will be able to research how mussels maintain homeostasis and design an experiment for how to measure homeostasis in mussels.

## Cross-cutting concepts -- *Next Generation Science Standards*

* Scale, proportion, and quantity
* Energy and Matter
* Stability and Feedback
* Patterns
* Cause and effect
* Systems and system models
* Structure and function

## Cross-cutting concepts -- *Other*

* Change vs variability
* Data reasoning

## Standards

Life Science Standards (LS)

|  |  |
| --- | --- |
| HS-LS1-3 | Feedback (negative or positive) can stabilize or destabilize a system. Plan and conduct an investigation to provide evidence that feedback mechanisms maintain homeostasis. |
| HS-LS2-2 | Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. Use mathematical representations to support and revise explanations about factors affecting biodiversity and populations in ecosystems of different scales. |
| HS-LS2-4 | Energy cannot be created or destroyed - it only moves between one place and another place, between objects and/or fields, or between systems. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem. |
| HS-LS-2.6 | Much of science deals with constructing explanations of how things change and how they remain stable. Evaluate claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem. |

## Instructions

The readings and data visualizations below will allow students to understand how predicting an organism’s response to climate change can be complex. By looking specifically at mussels, students will use data visualizations to infer how temperature fluctuations could impact mussel populations in different locations and what this could mean for mussel populations along the west coast of the U.S.

### Part A. Robomussel Data Visualization

Now, we will explore real data that scientists have been busy collecting about how a shifting climate is impacting mussels off Washington’s coast and in many other places around the world.

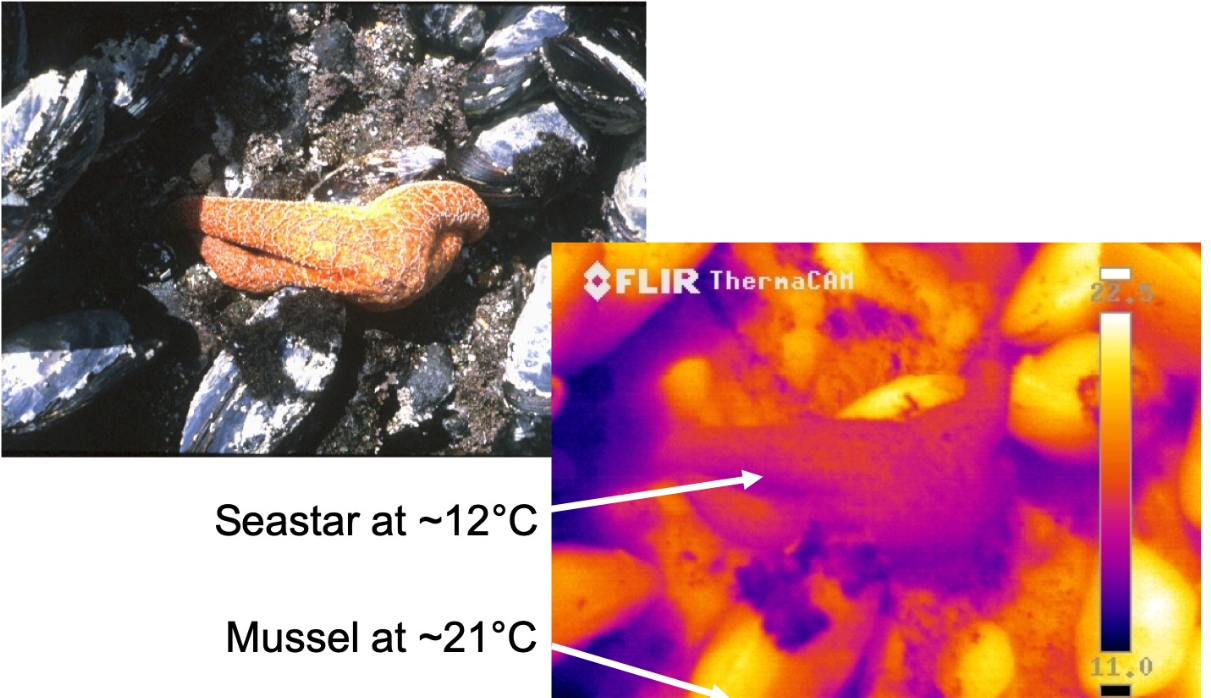
Go [here for “How Organisms Experience Climate – A Case Study”](https://huckley.shinyapps.io/ClimateBiology/)

1. After reading “Two Meters is Too Tall”, what is the challenge for biologists in assessing organisms’ environmental conditions?

Generally, air temperature data available to the scientists are given by a stable sensor a couple of meters above the ground. A challenge for biologists studying organisms near ground is that the climate at the sensor is nothing like the climate experienced at the ground level especially when the organisms also move between shade and sun.

1. After reading “Robomussels to the Rescue”, what solution did marine ecologist Brian Helmuth devise for getting a more accurate picture of mussels’ actual environmental conditions? **Elaborate on how this solution works in at least three sentences.**

He created biomimetic sensors that are scaled exactly like mussels. The sensor was embedded inside artificial shells that are morphologically similar to mussel shells and recordings were made every 10 to 30 minutes to capture minute changes in the environment. These features represent the spatial scale and temporal scale of the mussels more accurately.



1. Looking at these pictures again, make the case for why a Robomussel is essential in understanding an organism’s lived experience (why would the Seastar’s experience be different from the mussel’s, even though they are literally right beside one another?)

Sea stars and mussels have different colors.

Sea stars are colored lighter than mussels, which absorb less solar radiation and keeps them cooler. The robomussels enable the researchers to capture this difference to provide accurate environmental conditions that mussels experience, which would otherwise be dismissed.

Navigate to the sites selector and corresponding map. Select “Alegria, CA,” “Cattle Point, WA,” and “Strawberry Hill, OR.”

1. Read “Extreme Mussel Environments” to understand what is being shown in the graph below.
2. What is the x-axis showing?  
     
   Day of the year.
3. What is the y-axis showing?  
     
   Maximum daily temperature.
4. What do the different colors on each graph represent?  
     
   Robomussels placed in different subsites that experience different tidal levels.
5. Why is the measurement of “maximum temperatures”, like we are seeing in these graphs, a useful tool for biologists wanting to predict how mussel populations could be impacted by a warming climate?

We can predict the impacts of climate change the best by observing how the mussels respond to the most extreme conditions.

1. Comparing the graphs from CA, WA, and OR:  
   1. What is similar between graphs?  
        
      The maximum daily temperatures fluctuate a lot in all three graphs.
   2. What looks different between graphs?  
        
      The average and maximum temperatures look different between the graphs.
   3. Which graph has the biggest variation (tallest peaks) in maximum temperatures? Any guesses as to why this could be true?  
        
      Cattle Point, WA has the biggest variation.

This might be the influence of experiencing a less stable climate compared to the locations further away from the pole.

* 1. Which graph has the smallest variation (smallest peaks) in maximum temperatures? Any guesses as to why this could be true?  
       
     Alegria, CA has the smallest variation, potentially because of its closeness to the tropics.
  2. The furthest south site is CA and the furthest north is WA. Is the CA site the hottest? Is the WA site the coolest?  
       
     No, the robomussels in Washington hit the greatest maximum temperature. The robomussels in Oregon experienced the lowest temperatures.
  3. If it’s not, what else could influence the temperature trends we observe in the graphs besides being further north/south?

Hours of sunlight, hours of exposure, mussel bed substrates, wind speed, proximity of the mussel beds to water, ocean temperature.

1. Below, graph how you think the maximum temperature variation will change at one of these sites as the climate warms and changes.  
     
   Graphs should look something like a sine graph with the median steadily increasing. The peaks are increasing more than the troughs.
2. Explain your thinking – why did you make the graph look this way?  
     
   The climate is warming, but not consistently. We also see that the summers are warming more quickly than the winters.

### Part B. Mussels and bivalves in Puget Sound, WAMachine generated alternative text: ty Chm cf '•t•f/d/ife

Let’s take some time to learn a little bit more about mussels (also known more generally as bivalves) and the role they play in the ecosystem. We will focus on mussels/bivalves in Puget Sound so we understand their role better close to our home.

1. Read the description below and fill in the graphic organizer that follows.

This variety of geoducks, oysters, and clams feed on phytoplankton (microscopic plants) and decomposing material in the waters of Puget Sound. They are important water filterers - cleaning up the water where they are found. This can also sometimes mean that they are dangerous to eat because they can contain high levels of bacteria, and toxins from filtering the water. They are important habitat constructors - their shells form cracks and crevices along the shore and more shallow waters where many species can shelter from predators. They are also "grown" by many different farmers that sell these clams, oysters, and geoducks for money. This is a profitable industry in WA state and good for our economy, especially in rural places where good job opportunities are hard to find.

#### Data

These bivalves were abundant prior to settlers reaching the Puget Sound. As settlers set up factories and paper mills, the bivalves began to decline. Because of pollution and now climate change and ocean acidification, these species are still struggling to re-establish themselves.

Machine generated alternative text:
z 
140000 
120000 
100000 
80000 
60000 
40000 
20000 
1840 1860 1880 
W•ilapa Bay 
O Sound 
1920 1960 1980 
Figure 1. Olympia oyster harvest (1 sack is equal to approximately 4,000 individuals) in Willapa Bay 
(filled circles) and Puget Sound (open circles) from the mid 19th to mid 20th century based on 
Washington Manne Fish and Shellfish Landings (figure from White et al. 2009) (reprinted with permission 
from the Journal of Shellfish Research) 

#### Climate change and bivalves

As temperature increases, this will decrease the bivalves’ ability to reproduce as effectively. It will also increase the amount that they need to eat, but if there is a decreasing amount of food source, they will be hungry.

When the water warms, it holds less oxygen. Bivalves do not do well in low-oxygen environments. Another challenge will be ocean acidification, making it more difficult for bivalve larvae to survive and grow to become an adult. Ocean acidification will also damage the adult shells.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| SPECIES NAME | What did you learn ABOUT the species? | What would happen if this species declined (you may not have read this, but think…) | What does the DATA show about this species? | What does the DATA show us about the environment's CARRYING CAPACITY for this species? (you probably didn't read this, but think) | Connection to CLIMATE CHANGE/  OCEAN ACIDIFICATION |
| geoduck/  oyster/  clam | Feed on phytoplankton. Water filterers. Habitat constructors. Abundant before settlers. Now struggling. | Waters would become more polluted. Species that feed on these species (marine and terrestrial) would decline as a result. | These species numbers are declining to almost zero. | In Willapa Bay, the carrying capacity is at least 130,000 sacks. In Puget Sound, the carrying capacity is at least 60,000. | Along with over-harvesting, climate change and ocean acidification can speed up the decline of these species and may cause species extinction. |

#### Sources ( [1](https://www.watereducation.org/sites/main/files/file-attachments/jan_thompson.pdf?1405035289), [2](https://www.eopugetsound.org/science-review/1-bivalves) )

1. Connect what you just filled into the graphic organizer with your graph prediction of how you think maximum temperature variation will change as the climate warms (#6 above)… what do you suspect could happen to the mussel/bivalve populations? Why? Write at least THREE SENTENCES to explain your reasoning.

Over-harvesting has largely impacted the population size of mussels and bivalves in the late 1900s, and the process of regaining population requires time and stability. Climate change can cause the ocean temperature to be warmer, which decreases the oxygen available in the water. This has the potential to nullify the progress species have made and annihilate the populations.

Look at the picture below and answer the questions that follow:

Machine generated alternative text:
cling on 
Seabirds 
Quaternalf 
Consumers 
r size a 
na age. 
Salmon 
Seal 
Large quantities of nutrients are transferred from 
freshwater ecosystems into the ocean by salmon. 
As salmon die, nutrients from their carcasses are 
food for Other animals. While growing in the ocean, 
salmon also eat crustaceans and small fish. 
Orca 
Species at the top of the food chain - 
such as orca whales - can concentrate 
contaminants from their prey into higher 
levels than species lower on the food chain. Machine generated alternative text:
The Marine Food Web 
Rising earbon dioxide levels are not only driving climate change, theyare changing 
the chemistry ofour oceans. Seawater absorbs carbon from the air, causing ocean 
acidification, which is likely to have a profound impact throughout the marine food 
web. ICs another Ivason why clitnateehange action is essential. 
Primary Producer' 
M icroscopic 
Plants 
(Phytoplankton) 
Bull Kelp 
Eelgrass 
Forage fish are small 
schooling fish that are 
a critical link in the 
marine food web, 
bridging groups like 
zooplankton and 
larger fish. 
Tertian 
Consumers 
Energy flows through the 
marine food web starting from 
the sun. Primary producers 
convert the sun's energy 
through photosynthesis into 
chemical energy. 
Secondary 
consulners 
Small Forage Fish 
.JelMish 
Only about 10% Of 
the energy is passed through 
the food web from one feeding 
level to the next. 
Primary Consumer 
Sea Snails 
and SlugQs 
M icroscopic 
Anilnals 
(Zooplankton) 
M [Essels 
Seastar 
Crab 
Sea 
Cucunlber 
Some species — such as Dungeness 
crab - occupy multiple places Or play 
multiple roles in the food web 
depending on their size and age. 

1. Find where mussels are in this picture.
   1. What are the mussels predators? (*Hint: not only limited to the one connecting below bubble)*Small fish, jellyfish, sea stars, crabs, seabirds, etc
   2. What are the mussels prey?  
        
      Phytoplanktons, bull kelps, eelgrasses.
2. Without human interference, what would be keeping the number of mussels in these waters relatively stable over time? THINK OF AT LEAST TWO IDEAS.

IDEA ONE: The fluctuation in the amount of food available to them in the ecosystem.

IDEA TWO: The fluctuation in the number of predators in the ecosystem.

1. Predict – What do you think could happen to the amount of mussels because of temperature spikes due to climate change?  
   Fill in the Claim, Evidence, Reasoning table below to complete your prediction.

|  |  |
| --- | --- |
| CLAIM | I predict that the number of mussels will decrease because of a warming climate. |
| EVIDENCE | Research shows that the mussels are decreasing. |
| REASONING | The data make sense because increased temperatures decrease the bivalves’ ability to reproduce effectively. |

1. If the amount of mussels decreases over time due to a changing climate, how will this impact the overall biodiversity (amount of different species living in these waters) of these waters? LIST TWO IDEAS.

IDEA ONE: It will increase the populations of mussel prey (e.g. phytoplankton).

IDEA TWO: It will decrease the populations of mussel predators (e.g. jellyfish).

1. Imagine that humans got our act together, stopped burning fossil fuels, and in 100 years, temperatures and CO2 in the atmosphere were beginning to stabilize. What would you predict would be happening to mussel populations in that scenario? Complete the Claim, Evidence, Reasoning table below to complete your prediction.

|  |  |
| --- | --- |
| CLAIM | I predict that the number of mussels will increase because of a stabilizing climate. |
| EVIDENCE | Research shows that the mussels are increasing before settlement. |
| REASONING | The data make sense because mussels do well in water with lower acidity and lower temperature. |

### Part C. Homeostasis & Planning an Investigation

1. Remind yourself what the word HOMEOSTASIS means in terms of an organism.

Homeostasis is a condition in which organisms remain at a stable internal state in changing environments.

1. How does FEEDBACK (positive and/or negative) relate to the word HOMEOSTASIS?

Feedback loops are used to maintain homeostasis in organisms.

1. How is POSITIVE FEEDBACK different from NEGATIVE FEEDBACK?

In a positive feedback loop, the product of a reaction contributes to the increase in that reaction while in a negative feedback loop, the product of a reaction suppresses the reaction.

Mussels/bivalves cannot get up and move when they don’t like how the environment is changing. They are sedentary organisms, meaning, they cannot move. They are also cold-blooded invertebrates, meaning their internal temperature is regulated by the environment, not by their own bodies. We are going to spend some time researching how mussels work to maintain homeostasis in their bodies and then we will work in groups to come up with an investigation for how to monitor mussels doing homeostasis.

Pick one area of focus to research. This topic will guide your investigation. Fill in the table after you read the research.

|  |  |
| --- | --- |
| **TEMPERATURE** ([Source](https://jeb.biologists.org/content/210/17/2999))  Temperature, due to its impact upon all levels of biological organization, is a crucial determinant of the biogeography and physiological characteristics of poikilotherms. Indeed, temperature alters the velocity of chemical and enzymatic reactions, rates of diffusion, membrane fluidity and protein structure ([Hochachka and Somero, 2002](https://jeb.biologists.org/content/210/17/2999#ref-27)). The thermal sensitivity of membrane processes is due to the strong effect of temperature on the physical properties of membrane lipids, which in turn have a major influence on associated proteins. A decrease in temperature usually reduces membrane fluidity, which can lead to membrane dysfunction. Poikilotherms usually counteract this temperature effect by remodelling membrane lipids, a process known as homeoviscous adaptation (HVA), *via* changes in phospholipid headgroups, fatty acid composition and cholesterol content that compensate for the effect of temperature on membrane structure ([Sinensky, 1974](https://jeb.biologists.org/content/210/17/2999#ref-52); [Hazel, 1995](https://jeb.biologists.org/content/210/17/2999#ref-25)). Many intertidal organisms, which commonly withstand variations in temperature of 20–30°C on a daily basis and encounter even wider thermal ranges on a seasonal basis, are able to regulate membrane fluidity in response to thermal change. For example, the mussel *Mytilus californianus* exhibits strong seasonal variations in membrane fluidity that are consistent with HVA ([Williams and Somero, 1996](https://jeb.biologists.org/content/210/17/2999#ref-62)). Similarly, membrane fluidity in gill phospholipids of the sea scallop *Placopecten magellanicus* is positively correlated with 20:5n-3 and negatively correlated with acclimation temperature, presumably helping to maintain membrane function at low temperatures ([Hall et al., 2002](https://jeb.biologists.org/content/210/17/2999#ref-24)). Finally, a major remodelling of lipids consistent with HVA occurs in hard clams *Mercenaria mercenaria* exposed to a gradual cooling from ∼24°C to 0°C and acclimatisation at <0°C ([Pernet et al., 2006b](https://jeb.biologists.org/content/210/17/2999#ref-46)). | **SUMMARIZE WITH YOUR GROUP** – How do mussels maintain homeostasis when the environment’s temperature changes?  Mussels use HVA that adjusts the membrane lipids, which allows them to maintain membrane fluidity in variable temperatures. |
| **MOISTURE** ([Source](https://en.wikipedia.org/wiki/Bivalvia))  When buried in the sediment, burrowing bivalves are protected from the pounding of waves, desiccation, and overheating during low tide, and variations in salinity caused by rainwater. They are also out of the reach of many predators.[[60]](https://en.wikipedia.org/wiki/Bivalvia#cite_note-BCO-60) Their general strategy is to extend their siphons to the surface for feeding and respiration during high tide, but to descend to greater depths or keep their shell tightly shut when the tide goes out.[[60]](https://en.wikipedia.org/wiki/Bivalvia#cite_note-BCO-60) They use their muscular foot to dig into the substrate. To do this, the animal relaxes its adductor muscles and opens its shell wide to anchor itself in position while it extends its foot downwards into the substrate. Then it dilates the tip of its foot, retracts the adductor muscles to close the shell, shortens its foot and draws itself downwards. This series of actions is repeated to dig deeper.[[61]](https://en.wikipedia.org/wiki/Bivalvia#cite_note-61) | **SUMMARIZE WITH YOUR GROUP** – How do mussels maintain homeostasis when the tide goes out and they are no longer covered by water?  They bury themselves in the substrate when the tide goes out. |
| **SALINITY** ([Source](https://www.nature.com/articles/s41598-018-26706-9))  Valve closure is a common behavioural response of bivalves to sudden changes in salinity which allows them to reduce salt lost from the mantle cavity fluid[4](https://www.nature.com/articles/s41598-018-26706-9#ref-CR4),[5](https://www.nature.com/articles/s41598-018-26706-9#ref-CR5),[25](https://www.nature.com/articles/s41598-018-26706-9#ref-CR25),[61](https://www.nature.com/articles/s41598-018-26706-9#ref-CR61),[62](https://www.nature.com/articles/s41598-018-26706-9#ref-CR62) avoiding osmotic shock for short periods of time. During valve closure physiological activity is depressed (bradycardia, reduced respiration, etc.) and anaerobic metabolism activated[4](https://www.nature.com/articles/s41598-018-26706-9#ref-CR4),[5](https://www.nature.com/articles/s41598-018-26706-9#ref-CR5),[6](https://www.nature.com/articles/s41598-018-26706-9#ref-CR6),[7](https://www.nature.com/articles/s41598-018-26706-9#ref-CR7), therefore longer exposures below their lethal tolerance result in mass mortality events as has been extensively documented for cockles at salinity below 15[8](https://www.nature.com/articles/s41598-018-26706-9#ref-CR8),[9](https://www.nature.com/articles/s41598-018-26706-9#ref-CR9),[25](https://www.nature.com/articles/s41598-018-26706-9#ref-CR25). As the lethal threshold is exceeded, acclimation processes are triggered. Avoidance of osmotic shock and oxidative stress are energetically expensive, and are usually accompanied by reductions of feeding activity and energy acquisition[4](https://www.nature.com/articles/s41598-018-26706-9#ref-CR4),[5](https://www.nature.com/articles/s41598-018-26706-9#ref-CR5),[6](https://www.nature.com/articles/s41598-018-26706-9#ref-CR6),[7](https://www.nature.com/articles/s41598-018-26706-9#ref-CR7),[5](https://www.nature.com/articles/s41598-018-26706-9#ref-CR5). Feeding activity was resumed for drifters after 2 days of exposure at salinity 15 and progressively increased with salinity (Fig. [1A](https://www.nature.com/articles/s41598-018-26706-9#Fig1)) indicating the activation of the acclimation processes at day 2. However, sedentary settlers kept CR close to zero at salinity 15 even after 7 days of exposure (Figs [1B](https://www.nature.com/articles/s41598-018-26706-9#Fig1) and [2B](https://www.nature.com/articles/s41598-018-26706-9#Fig2)) sustaining an on/off response instead of acclimation. Reductions in feeding activity during acclimation to hyposmotic environments have been reported for many bivalves species[6](https://www.nature.com/articles/s41598-018-26706-9#ref-CR6),[29](https://www.nature.com/articles/s41598-018-26706-9#ref-CR29),[63](https://www.nature.com/articles/s41598-018-26706-9#ref-CR63),[64](https://www.nature.com/articles/s41598-018-26706-9#ref-CR64),[65](https://www.nature.com/articles/s41598-018-26706-9#ref-CR65),[66](https://www.nature.com/articles/s41598-018-26706-9#ref-CR66),[67](https://www.nature.com/articles/s41598-018-26706-9#ref-CR67),[68](https://www.nature.com/articles/s41598-018-26706-9#ref-CR68) and might be ruled by the effect of salinity on the degree of shell gaping and siphon retraction[62](https://www.nature.com/articles/s41598-018-26706-9#ref-CR62). On/off responses have been also reported in several studies on filter feeding bivalves exposed to stress conditions and described as an energy saving strategy[6](https://www.nature.com/articles/s41598-018-26706-9#ref-CR6),[69](https://www.nature.com/articles/s41598-018-26706-9#ref-CR69),[70](https://www.nature.com/articles/s41598-018-26706-9#ref-CR70). | **SUMMARIZE WITH YOUR GROUP** – How do mussels maintain homeostasis when the salinity of the water greatly decreases or increases?  Generally, mussels will close their shells when their salinity tolerance is exceeded. During valve closure, their metabolism is slowed. When they are unable to discontinue feeding any longer, they begin to try to acclimate to the salinity slowly. |

Imagine we were going to conduct an experiment on the topic you just read about in regard to how mussels maintain homeostasis. Brainstorm with your group how we would set-up this experiment.

|  |  |
| --- | --- |
| **Question**  What is the scientific question? |  |
| **Variables**  Independent (manipulated)  Dependent (responding)  Controlled (things that must be the same) |  |
| **Hypothesis**  If \_\_\_\_\_\_\_\_ changes in the mussels environment, then the mussels will maintain homeostasis by \_\_\_\_\_\_\_\_\_\_\_\_\_ because \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |  |
| **Materials**  What materials would you need for this experimental design? |  |
| **Your Design**  Give a step-by-step outline of what you would need to do in order to test your hypothesis. |  |

1. Get some feedback from another group about your experimental design. What things should be changed or adjusted to make the experiment more complete?

### Part D. Wrap Up

1. How do you imagine this experiment could be tied to the information we learned above with climate change, temperature fluctuations, and food webs? LIST AT LEAST THREE IDEAS.

IDEA ONE:

IDEA TWO:

IDEA THREE: