4.1 Sea-Level Rise Risk & Reward

AGE RANGE
9th—12th grade

TIME REQUIRED
70 minutes

ACTIVITY OVERVIEW
Engage: Discussion Question

Explore: SLR Risk & Reward

Explain: Reflections

Elaborate: Adaptation Pathways Reading

Evaluate: Discussion Question

MATERIALS
Dice (one per group)
Candy or tokens (>5 per student)
Group Set-Up page
Group Worksheet

BASED ON:
"Game of Futures" by Dani Boudreau Tijuana River National Estuarine Research Reserve

LESSON TOPIC: Integrating sea-level rise resilience into planning.

ACTIVITY SUMMARY: Students will play a dice game that simulates making adaptations to plan for future sea-level rise.

OBJECTIVES:

Students will be able to:

- Understand the need to plan adaptation strategies with location-specific sea-level rise information.
- Determine if adaptation strategies are effective at reducing impacts under different climate scenarios.

LESSON BACKGROUND: The dice game sets up student groups as communities. Each student makes individual choices that may impact the whole community. Through the gameplay, students decide how much they will prepare their home for sea-level rise. The future sea-level rise impact is determined by rolling the dice. As the game progresses, students pay money if their adaptation strategy did not protect their home from sea-level rise impacts, but students will also have an opportunity to update their strategy.

The game includes a version of an insurance payout. Homeowners or renters insurance covers losses and damages to an individual's residence. The individual pays a certain amount based on the value of their home to the home insurance company each month, called the premium. In return, the insurance company agrees to pay a certain amount of money to cover expenses if there is a catastrophic event. In the case of a catastrophic event, the homeowner files a claim with the insurance provider. The insurance provider sends someone to assess the damage, and after filing paperwork, the homeowner will receive a payment to cover damages.

The student reading builds off the game by introducing the concept of adaptation pathways. The reading outlines the technique used to mitigate damage from future sea-level rise impacts by utilizing multiple solutions that build on one other. These adaptation strategies are organized into a pathway that can be followed, and additional mitigation actions added as conditions change. This becomes a proactive planning tool to add policy change and mitigation actions by following the observed sea-level rise rather than projections. Adaptation strategies are not one size fits all but they can build on previously implemented strategies. By using numerical modeling of physical processes, like wind and waves, scientists can get an idea of how adaptation strategies will behave in a future climate. There is uncertainty regarding the impacts of sea-level rise, but we can still plan for the future by effectively considering the uncertainty and preparing to respond to a range of scenarios.

The dice outcomes may seem predictable in the game, and that is because some outcomes, like sea-level rise scenarios, are more likely than others. Scientifically speaking, the range of sea-level rise scenarios cover all scientifically plausible scenarios. Having a large range of sea-level rise scenarios does not mean that scientists do not know what they are doing. It shows the range of possible outcomes. There are three major reasons for the scenarios. The first is that we do not know how much carbon will be in the atmosphere because the rate of global carbon emissions changes with policies put in place by different governments. The second is the natural variability built into the scenarios. The third is that scientists are still studying ice sheet melt, and the models used to measure the volume of ice sheets and their rate of melting is relatively new and getting more accurate constantly. With these reasons in mind, the range of sea-level rise scenarios shows the range of scientifically possible scenarios for future sea-level rise with low scenarios following a low-end range of natural variability and an extreme scenario following catastrophic ice melt. *The Module 3 lesson 3.2 Assets at Risk involves a discussion on sea-level rise projections that can be connected to this lesson.*

Just as with the dice, is it helpful to plan for sea-level rise by considering scenarios based on their probabilities of occurring. The likelihood of each sea-level rise scenario depends in part on the amount of carbon gas in the atmosphere. Carbon emission scenarios, also known as Representative Concentration Pathways or RCPs, represent different potential futures based on policies and actions of people globally. The table below explores the probability of each sea-level rise scenario under three different RCPs: RCP2.6 is a dramatic reduction of carbon currently in the atmosphere; RCP4.5 is a modest decrease in global carbon emissions; and RCP8.5 is continuing on the current global emissions trajectory. As stated above, the scenarios, low through extreme, cover the range of scientifically plausible scenarios. Probabilities help us understand the likelihood of each scenario occurring. For example, under RCP8.5, it is 100% likely that we will exceed the Low scenario by 2100, while there is a very low probability (0.1% chance) that we will exceed the Extreme sea-level rise scenario by 2100.

Probabilities of occurrence help determine which scenario best supports your risk tolerance in planning. For example, although the High scenario has a low probability of occurring, you may want to plan for it when protecting long-term investments with low risk-tolerance. For instance, a military base or water treatment facility would have a low risk-tolerance because they serve critical functions to a large number of people, have interdependent systems with other critical services, and cannot be easily moved or adapted to future conditions once built

Likelihood of sea-level rise scenarios:

Global Sea Level Rise Scenario	RCP2.6 dramatic reduction of carbon emissions	RCP4.5 modest reduction in carbon emissions	RCP8.5 no change in carbon emissions
Low	94%	98%	100%
Intermediate low	49%	73%	96%
Intermediate	2%	3%	17%
Intermediate-high	0.4%	0.5%	1.3%
High	0.1%	0.1%	0.3%
Extreme	0.05%	0.05%	0.1%

Source: Collini et al, 2018

VOCABULARY:

Adaptation	The process of adjusting to new (climate) conditions in order to reduce risks to valued assets.
Adaptation Planning	Preparing a natural or urban area for the effects of climate change with the intention of reducing risk or exposure.
Adaptive Capacity	The ability of a person, asset, or system to adjust to a hazard, take advantage of new opportunities, or cope with change.
Critical Facilities and Services	Man-made structures/improvements which, because of their function, size, service area, or uniqueness, are paramount to day-to-day function (e.g., hospitals, power plants, wastewater treatment facilities, emergency response, etc.).

Risk Communication	Process of informing people about potential hazards to their person, property, or community.
Social Vulnerability	Risk that a community will lose its ability to maintain social interactions, cultural institutions, and/or a standard of living. Negative impacts on communities due to stresses on human physical, mental, or cultural health, which consider socioeconomic factors like poverty level, access to transportation, and living conditions.

ENGAGE:

Ask students: What do you think about when making an important decision? Is it important to know the possible outcome(s) when you are planning? Would they want to know future sea-level rise when building a beach house?

EXPLORE:

Students will play the Sea-Level Rise Risk & Reward game.

Game Procedure:

1. Divide class into groups of 5. In a group of 5, one player will act as scorekeeper and the others will each get one turn to roll the dice.
    - Note: If you do not use dice in your classroom you can have students use a phone or computer to "roll the dice" by asking Siri to "roll two dice" or the teacher can pre-roll numbers.
2. Each student is given 5 pieces of candy or tokens. This represents the total money an individual has to repair, maintain, or modify the adaptation strategy as climate change is experienced.
3. Each student in a group will choose an adaptation strategy (below) to implement. They are planning to protect their home for approximately the next 30 years, through 2050.

    ADAPTATION STRATEGIES:
    You own your house on the coast. To make your home resilient to sea-level rise you can choose from the following possible options in the short term. Pay the candy/tokens to the bank.

    A. Do nothing (cost = 0 candy)
        - **Teacher talking point:** in this strategy the home is left as is.

B. Nourish the beach in front of your home to accommodate scenario 1 (cost = 1 candy)
  - **Teacher talking point:** nourishing the beach in front of the home replaces sand lost from erosion and this land will act as a barrier to sea-level rise.

C. Build a dune in front of your house to accommodate scenarios 1 & 2 (cost = 2 candy)
  - **Teacher talking point:** a dune with dune grasses will offer protection to the home from erosion and water inundation

D. Elevate your house to accommodate scenarios 1,2 & 3 (cost = 3 candy)
  - **Teacher talking point:** elevating the home raises it above base flood elevation (or higher) and will allow water to come underneath but not impact the home

E. Relocate your house inland to accommodate scenarios 1, 2, 3 & 4 (cost = 4 candy)
  - **Teacher talking point:** the home will be relocated away from the water but still within the community. This allows the home to be protected from sea-level rise impacts but also maintain community social connections and contribute to taxes.




Images: Top left, beach renourshiment; top right, sand dunes; bottom left, elevated house; bottom right, relocation.

4. Player One rolls two dice, once. Determine the scenario outcome (Step 5). Player One's roll affects all students in their group.
    - The probability of the dice sum outcome is linked to the probability of future sea-level rise scenarios for the northern Gulf of Mexico (Mississippi, Alabama, and NW Florida).

- This sea-level rise scenario outcomes in this game are representative of likelihoods with no change in carbon emissions. You may choose to share this with your students when they are selecting Adaptation Strategies.
    1. **100%** Low 0.8ft (~0.2m)
    2. **96%** Intermediate-Low 1.0ft (~0.3m)
    3. **17%** Intermediate 1.5ft (~0.5m)
    4. **1.3%** Intermediate high 2.0ft (~0.6m)

5. The sum of the two dice determines what scenario they are in.

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Year 2050	7	6 or 8	4, 5, 9, 10	2, 3, 11, 12

   Payout!
   a. If students adequately protected their home from the scenario they rolled, they keep their candy/token and get 2 bonus candy/token. The bonus candy/token reflects homeowners saving income.
   b. If students did not adequately protect their home from the scenario they rolled, they pay the bank with 1 candy/token for each level of scenario of difference. (Ex: If they protected to Scenario 1 but rolled Scenario 2, they pay 1 candy/token. If they protected to Scenario 1 but rolled Scenario 4, they pay 3 candies/tokens.)
6. Repeat with Player Two rolling the dice.
7. Before Player Three rolls there is an opportunity for an Insurance Payment. If any of the players lost candy/tokens due to the scenario outcome in Round One, they get to collect one less candy/token than they lost. (Ex: If they paid 1 candy/token, they would not collect insurance. If they paid 3 candy/token, they would collect 2 candy/token from insurance.) This represents the process of insurance payments, where partial damage is covered through insurance and it happens months-years after the damage.
8. Repeat Step 4 with Player Three rolling the dice.
9. There is an opportunity at this point in the game for students to change their original Adaptation Strategy to one of the other 5 choices. **Discuss with students**: Is my strategy effective?
    - Is everyone's strategy still effective with the sea-level rise scenarios?
    - What strategies are successful in the new scenario? Why or why not?
    - If not successful, can it be altered to be effective in the scenario?
10. Repeat Step 4 with Player Four rolling the dice.
11. Players count their remaining candy/tokens.

EXTENSION: There are two game extension opportunities to add to the game. RESOURCE VULNERABILITY starts the game off with each individual having different resources. This option would work well for 1) classes playing a second round or 2) for teachers to use the first time with an advanced class. HIGH-TIDE FLOODING COMMUNITY IMPACT is a game option that allows teachers to add an element into the game while it is currently being played. There are three real life scenarios for teachers to select from.

RESOURCE VULNERABILITY

When the game is played with Resource Vulnerability, individuals in the community start the game with different resources. To determine which players will have limited resources each player will roll one die. The die outcome is the number of candy/tokens that player starts the game with. (Ex: If they rolled a 1, they only get 1 piece of candy/token.)

Social vulnerability is a combination of factors that determine how resilient a community is when confronted by external stresses, potentially from a hazard like sea-level rise. The Social Vulnerability Index (SVI) employs U.S. Census Bureau data to identify communities at higher risk. The SVI ranks on 15 social factors, including poverty, disability, minority status, lack of vehicle access, and crowded housing. These are then grouped into four themes: socioeconomic status, household composition, race/ethnicity/language, and housing/transportation. Our game will rank students randomly and is used as a starting point for discussion of resource vulnerability. The SVI fact sheet can be found online: https://svi.cdc.gov/factsheet.html

HIGH-TIDE FLOODING COMMUNITY IMPACT

When the game is played with High-Tide Flooding Community Impact, the community group must work together to fund infrastructure improvements. This extension can be introduced to the game at any point by the teacher to heighten game-play and stimulate community-level conversations. There are three real-life simulated options below for the teacher to select from. Each of the following community impacts affect everyone regardless of their chosen Adaptation Strategy. The community cost for each improvement is 10 candies/tokens, and this can be divided across individuals however each community group decides, for example, communities may decide that everyone contributes an equal share. In the case that some individuals do not have enough money the community may decide that other individuals cover the difference.

Road Access: The main road to enter the community is inaccessible for one third of the year due to high-tide flooding. Since the flooding blocks access for the whole community, the community must collectively raise the funds to elevate the road.

Storm Water Infrastructure: The storm drains along community roads no longer drain rainwater away fast enough during thunderstorms. Sometimes the storm drains back up with water during a high tide even without a rainstorm. The outflow pipe directs water from the streets into the bay. This system needs to be improved so that the exit point is not covered by water during the tidal cycle.

Power Station: The facility that provides power for the community is vulnerable to storm surge inundation and needs to be relocated. Moving the power station will allow the community to be more resilient to future storms. This relocation will be a partnership between the power company and the community, so the community will help pay a portion of the relocation cost.

EXPLAIN:

Wrap-up and reflections

Begin by determining who the individual and group "winners" are. If multiple people or groups seem to have been successful, begin a discussion around why those individuals/groups were successful.

Discuss with students what lessons were learned throughout the process.

- If you did not choose an expensive adaptation when you had the resources, how did that impact you later in the game? Would you change your strategy if you did it again?
- What strategies seemed to be the most resilient?
- Community vs. individual successes?
- What did you struggle with throughout the game?
- Is the adaptation to relocate an easy choice in real life?
- Was there one scenario that seemed to be particularly difficult for individuals or community?
- Who has the most candy left and why? Even though relocation protects against all scenarios, it also cost the most and may not even have been necessary.
- Do the outcomes seem a little predicable? Is sea-level rise predictable?
    - With this final discussion topic remind them that we have the sea-level rise projections for the range of scenarios from Low to Extreme. We can use this information to make plans for our homes and communities.

Connect to facts:

- Every $1 spent on mitigation funding can save the nation $6 in future disaster costs.
  - National Institute of Building Sciences. Natural Hazard Mitigation Saves: 2017 Interim Report
- For every $1 a private property owner spends installing a living shoreline instead of a bulkhead they will save $6 in avoided maintenance, replacement, and storm repair costs over 60 years.
  - Sicangco, Camille, et al. *Cost-Benefit Analysis of a Small-Scale Living Shoreline Project*. MASGP-21-054
- As sea-level rises, the benefits for installing a living shoreline also rise. Rising seas decreases the lifespan of bulkheads, increasing maintenance cost and replacement frequency.
  - Sicangco, Camille, et al. *Cost-Benefit Analysis of a Small-Scale Living Shoreline Project*. MASGP-21-054

The Sea-Level Rise Risk & Reward game allows students to start thinking about how planning now prepares individuals and communities for future conditions.

ELABORATE:

Students read the excerpt about adaptation strategies. This mirrors the game-play, because as conditions change you can follow the adaptation pathway and make the largest/most expensive adaptations only when they are needed, yet preliminary planning and investment is required for these approaches to work.

Excerpt from Smallegan S. M., Irish, J. L., and van Dongeren, A. R. (2017) Developed barrier island adaptation strategies to hurricane forcing under rising sea levels. Climate Change.

EVALUATE:

Ask students: What is an adaptation pathway? Why is it important to have a mitigation plan that might change?

FUTURE SCENARIO NARRATIVES:

1. Low: 0.8ft (~0.2m)
2. Intermediate-Low: 1.0ft (~0.3m)
3. Intermediate: 1.5ft (~0.5m)
4. Intermediate-High: 2.0ft (~0.6m)

ADAPTATION STRATEGIES:

You own your house on the coast. To make your home resilient to sea level rise you can choose from the following possible options in the short term. Pay the candy/tokens to the bank.

A. Do nothing (cost = 0 candy)
B. Nourish the beach in front of your home to accommodate scenario 1 (cost = 1 candy)
C. Build a dune in front of your house to accommodate scenarios 1 & 2 (cost = 2 candy)
D. Elevate your house to accommodate scenarios 1,2 & 3 (cost = 3 candy)
E. Relocate your house inland to accommodate scenarios 1, 2, 3 & 4 (cost = 4 candy)

GAME-PLAY

SEA-LEVEL RISE SCENARIOS:

The sum of the two dice determines what scenario you are 30 years into the future:

	Scenario 1 - Low	Scenario 2 – Intermediate-Low	Scenario 3 - Intermediate	Scenario 4 – Intermediate-High
Year 2050	7	6 or 8	4, 5, 9, 10	2, 3, 11, 12

ROUND PAYOUT:

a. If students adequately protected their home from the scenario they rolled, they keep their candy and get 2 bonus candy.
b. If students did not adequately protect their home from the scenario they rolled, they pay the bank with 1 candy for each level of scenario of difference. (Ex: If they protected to Scenario 1 but rolled Scenario 2, they pay 1 candy. If they protected to Scenario 1 but rolled Scenario 4, they pay 3 candy.)

INSURANCE PAYOUT:

If any of the players lost candy/tokens due to the scenario outcome in Round One, they get to collect one less candy/token than they lost. (Ex: If they paid 1 candy, they would not collect insurance. If they paid 3 candy, they would collect 2 candy from insurance.)

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	Player 1: *Name*	Player 2: *Name*	Player 3: *Name*	Player 4: *Name*	Player 5: *Name*
Strategy: *Check a box*	☐ A ☐ B ☐ C ☐ D ☐ E	☐ A ☐ B ☐ C ☐ D ☐ E	☐ A ☐ B ☐ C ☐ D ☐ E	☐ A ☐ B ☐ C ☐ D ☐ E	☐ A ☐ B ☐ C ☐ D ☐ E
Round One Roll: ______	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*
Round Two Roll: ______	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*
Insurance Payment If you lost $$ in Round One *Check a box*	☐ No ☐ Yes +______	☐ No ☐ Yes +______	☐ No ☐ Yes +______	☐ No ☐ Yes +______	☐ No ☐ Yes +______
Round Three Roll: ______	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*
Strategy change? *Check a box*	☐ No ☐ Yes: _______	☐ No ☐ Yes: _______	☐ No ☐ Yes: _______	☐ No ☐ Yes: _______	☐ No ☐ Yes: _______
Round Four Roll: ______	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*
Final Count:	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*	*Write # of candy*

Adaptation Pathway - Sequential implementation of adaptation strategies as a policy pathway

Due to the uncertainty in future climate conditions, including the amount of sea-level rise and coastal response to those conditions, and due to relative effectiveness of individual strategies for different rates of sea-level rise, it is important to develop a strategic plan that is also adaptive. Haasnoot et al. (2013) describes dynamic adaptive policy pathways: a set of possible actions that may be implemented sequentially and in response to changing conditions. When the current action is no longer able to meet the intended objective, which in this study is to lessen the damage to a coastal community from a hurricane and rising seas, a tipping point is reached and a new action must be chosen.

Using the sea-level rise scenarios and adaptation strategies analyzed in this study, a policy pathway is created for Bay Head (Fig. 5). According to computer modeling simulations, strategy A reduces erosion (i.e., improves habitability) for sea-level rise = +0.2 m but not for sea-level rise = +1.0 m and higher. Strategy A is also the least expensive option in terms of initial costs based on the amount of sediment required to raise the beach (Fig. 2). However, a tipping point is reached as sea levels rise from +0.2 to +1.0 m, and a new strategy must be chosen. The preferred pathway routes to strategy B (Fig. 5) such that, as sea levels rise above +0.2 m, both the beach and dune must be nourished to offer protection from future storms at higher sea levels. Since there is more sediment available on the beach and dunes for transport (Fig. 2), erosion is reduced, island habitability is improved, but initial costs are higher due to the additional sediment required to build the dune. Also, the larger dunes only protect against ocean-side waves and surge, and the back barrier remains vulnerable to flooding and erosion by bay-side surge.

As sea levels continue to rise, back-barrier vulnerability becomes too large and another tipping point is reached. Strategy D is required to continue protection of the island for sea-level rise greater than +1.0 m. Although raising the island is an extreme adaptation strategy, it was implemented in Galveston, TX, USA, a developed barrier island located on the Gulf of Mexico. After a devastating hurricane in 1900, Galveston built a 16-km-long seawall and raised the island by up to 4 m (Bartee 2001). Over the last century, Galveston has survived several strong tropical storms including Hurricane Ike (2008), which has been largely attributed to the seawall and grade raising (Bartee 2001). As sea-level rise increases above 1.0 m in Bay Head, strategy D is the only option considered here that prevents complete erosion of the back barrier for extreme sea-level rise. Although it has the highest initial costs, a life cycle cost analysis for each strategy may reveal that periodic renourishment over several decades of sea-level rise could have greater costs than the initial cost of strategy D. Additionally, the analyses may reveal that it makes more sense to strategically relocate some of the infrastructure and aspects of the community.

Excerpt from Smallegan S. M., Irish, J. L., and van Dongeren, A. R. (2017) Developed barrier island adaptation strategies to hurricane forcing under rising sea levels. Climate Change.

(a)

Strategy (sediment volume added, m³)	Beach raised by SLR	Dune raised by SLR	Seawall raised by 0.5 m	Seawall raised by 1.0 m	Seawall raised by 2.0 m	Back barrier raised to minimum elevation
EC						
A (8,32,71)	X					
B (11, 68, 145)	X	X				
C (11, 68, 145)	X	X	X	X	X	
C1.0 (10, 67, 144)	X	X	X	X	X	
C2.0 (7, 64, 141)	X	X	X	X	X	
D (13, 128, 322)	X	X				X
E (13, 128, 322)	X	X	X			X
E1.0 (12, 127, 321)	X	X		X		X
E2.0 (9, 124, 318)	X	X			X	X

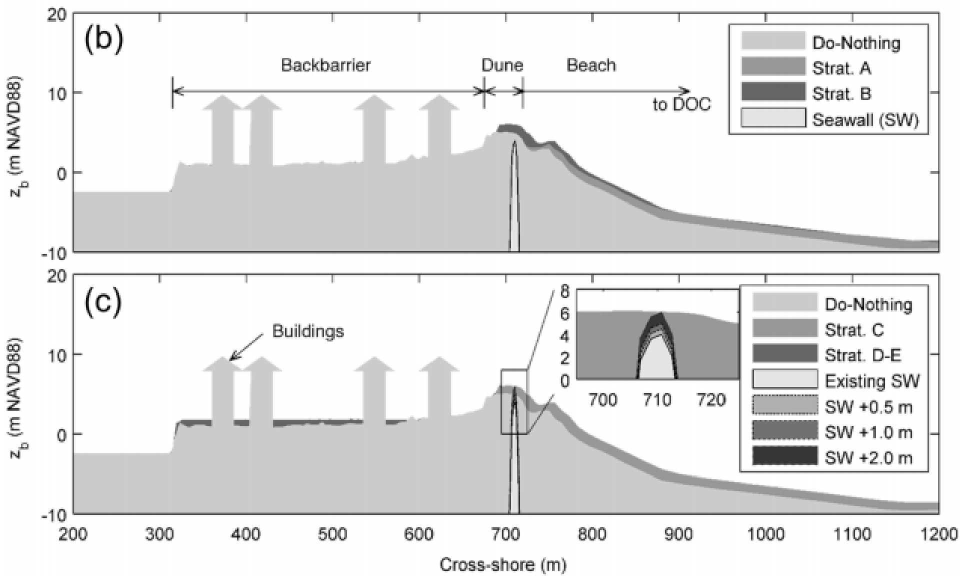

Fig. 2 Characteristics of adaptation strategies (**a**) and representative cross-shore profiles for SLR = +1.0 m: **b** EC elevation (z_b) and strategies A–B; **c** EC z_b and strategies C–E. Initial volumes are per unit width. Buildings are peaks in data and the seawall is represented by *shaded regions* at cross-shore distance 785 m. *SW* denotes seawall, and *DOC* is the depth of closure

Image: Figure 2 from Smallegan S. M., Irish, J. L., and van Dongeren, A. R. (2017) Developed barrier island adaptation strategies to hurricane forcing under rising sea levels title. *Climatic Change.*

Fig. 5 Policy pathway for Bay Head under SLR scenarios

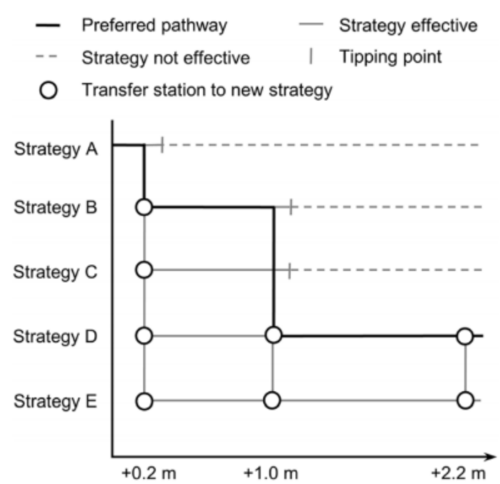

Image: Figure 5 from Smallegan S. M., Irish, J. L., and van Dongeren, A. R. (2017) Developed barrier island adaptation strategies to hurricane forcing under rising sea levels. *Climatic*

STUDENT PAGE | Sea-Level Rise Risk & Reward

DO NOW:

Describe how you currently think about sea-level rise in regards to living along the coast.

EXIT TICKET:

Why is having a mitigation plan that changes helpful for community resilience?