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Do you want teachers to contact you with questions / opportunities for classroom visits? Yes

Title: Under pressure! Building a coral reef under climate change and human impacts

Abstract: Corals turn seawater into massive coral reef structures that we can see from space. These structures protect our shorelines, provide habitat for fish, and are culturally significant for hundreds of millions of people around the planet. Recent news has highlighted the death of coral reefs, but can coral reefs really die? In this lesson plan, students will play a game to "build" a coral reef in 1950 and 2050 to understand how climate change and human impacts make it more difficult for coral reefs to build their calcium carbonate structures. Students will use this game to think more critically about the role of disturbances in building a coral reef and how climate change increases those disturbances to potentially change coral reef ecosystem states. At the end of the lesson, students can apply what they've learned to formulate hypotheses about how climate change may affect the more local kelp forest ecosystems in San Diego and propose solutions to improve coral reef and kelp forest health.

What standard(s) does this address?

NGSS Performance Expectation	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. (HS-LS2-2), (HS-LS2-6) • Moreover, anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species. (HS-LS2-7)
Common Core Math *(found w/ NGSS)*	**MP.2** Reason abstractly and quantitatively. (HS-LS2-7) **N-Q.1-3** Reason quantitatively and use units to solve problems. (HS-LS2-2) **S-ID.1** Represent data with plots on the real number line (dot plots, histograms, and box plots). (HS-LS2-6)
Common Core English *(found w/ NGSS)*	**RST.11-12.7** Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-LS2-6) **RST.11-12.8.a–e** Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. (HS-LS2-6)

Keywords: *coral reef, ecosystem, resilience, climate change, disturbances, remote learning*

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Learning Objectives: After completing this lesson, students will be able to:

- Integrate how local and global impacts affect the resilience and stability of coral reef (and kelp forest) environments through videos and the coral reef growth simulation game

- Reason abstractly about the role of probability in coral reef resilience—on average, simulated coral reef growth declined under increased human impacts but not all reef simulations experienced the same changes

- Construct and evaluate hypotheses regarding the growth of coral reef ecosystems under climate change and other human impacts

- *(Optional) quantitatively represent class-level data into plots and perform statistics to more rigorously test their hypotheses with the coral reef simulation game data*

Lesson plan outline:

Learning E	**Teacher Does / Says**	**Student Does**
Engage How can I get students interested in this?	Provide students link to video before class	Watch 8-minute video clip: "How dead is the Great Barrier Reef?" https://youtu.be/BO44JlAElXM
	Ask students what they think will happen to coral reef growth under climate change?	Students respond with some ideas about coral bleaching = less corals = less coral reef growth under climate change based on the video (5 mins)
	Have students formulate those ideas into a hypothesis that they will "test" in the simulation game	Students write hypotheses about how they think climate change will impact reef growth (5 mins)
Explore What tasks / questions can I offer to have students puzzle through this?	How did coral reefs grow in 1950 game simulation?	Students play 1950 version of the coral reef growth game. The probability of the game will on average drive coral reef growth in the 1950 simulation. (10 mins)
	How did coral reefs grow in 2050 game simulation?	Students play 2050 version of the coral reef game. The probability of the game will on average drive coral reef loss in the 2050 simulation. (10 mins)

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Explain How can I help students make sense of their observations? - let them try to explain first	Each student has simulated the growth of a coral reef for 1950 and 2050. In general, the results will show positive reef growth in 1950 and negative reef growth in 2050, but each student will have different results. **See key terms from game simulations in the appendix.** The 1950 game simulates a resilient reef that this able to respond to small overfishing + pollution events and keep growing. The 2050 game simulates a less resilient reef that experiences both more intense overfishing + pollution events and climate-change induced coral bleaching events, shifting the reef to a less stable state that is unable keep growing.	Poll: Which coral reef simulation ended with the greatest number of reef blocks: 1950 vs. 2050? Students use breakout rooms to discuss key differences between game simulations. What is the major difference between the two game simulations? The students should be able to see that coral bleaching events had much larger impacts that made it more difficult for the reefs to recover and continue to build structures. However, the severity of the impacts depends on frequency of bleaching events too! **Ocean warming is the #1 threat to global coral reefs** (5 mins).
	In the real world, the growth and loss of coral reef structures is much more complex, but these simplified scenarios nonetheless provide some context for some of the major drivers of reef change. Globally, corals have declined in many reefs in recent decades but there are some reefs that have maintained high proportions of corals. This is because some reefs have *resisted* the disturbances that have degraded reefs, some reefs have *escaped* the disturbances that degraded reefs, and some reefs have *recovered* from disturbances that have degraded reefs.	Poll: How many students had positive reef growth in 1950? Poll: How many students had positive reef growth in 2050? This provides a space for the students to discuss the role of probability in driving changes to individual reefs while overall 2050 reef growth declined relative to 1950 reef growth due to coral bleaching and human impacts. (10 mins) *Optional: Aggregate the data from every student into a spreadsheet to make plots and do basic statistical tests to further explore trajectories of reef building (slope of reef blocks vs. # of turns) for each of the 1950 and 2050 games or a student's T-test to see if final reef blocks were greater for all 1950 simulations than 2050 simulations. (20-30 mins)*

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Elaborate How can my students apply their new knowledge to other situations?	If disturbances increase in frequency and or intensity, ecosystems are more likely to change. In this case, increased ocean warming and human impacts are coupled with decreased coral growth and recruitment in the 2050 game resulting in less stable reef building. **See appendix for additional info on the intermediate disturbance hypothesis and coral reefs.**	This is somewhat analogous to disturbance frequencies as part of the intermediate disturbance hypothesis. Students can watch a brief video clip (2.5 mins) on intermediate disturbance hypothesis to see how disturbances shape other ecosystems too: https://youtu.be/UVj6oFKADOc
	Can students apply their knowledge from the coral reef game and the intermediate disturbance video to think of any examples of marine environments in San Diego that may be impacted by human impacts and ocean warming?	After some discussion time brainstorming various ecosystems that may be impacted (5 mins), watch the video clip (5 mins) to tie in the coral reef growth game to the kelp forests of San Diego: https://youtu.be/GRBhNK4j_V4
Evaluate How can I help my students self-evaluate and reflect on their learning?	If ocean warming and human impacts are making it more difficult to build coral reefs and kelp forests, what are potential solutions to reduce disturbances in these ecosystems? *Reducing global climate change and ocean warming is the #1 way to improve the future functioning of global coral reefs and kelp forests. Coral reefs and kelp forests that are also facing intense fishing pressure and/or land-based pollution will also benefit from removing those local factors, but this must be accompanied by reducing rates of climate change too!*	Students journal about their hypotheses and whether or not their reef simulation games supported or failed to support those hypotheses. Importantly, students can qualitatively (*or see optional quantitative section*) discuss how their reef grew compared to the class average. Students can then reflect on ways to reduce rates of warming from limiting climate change and overfishing + pollution events to reduce the negative effects of disturbances occurring on coral reefs/kelp forests. While climate change requires GLOBAL action, reducing overfishing + pollution requires LOCAL action. Reducing both is necessary, but the scales of solutions can often make LOCAL actions more feasible than GLOBAL actions. (20 mins)

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Simplified explanations of the terms from the coral reef game

Overfishing + Pollution: Overfishing can reduce the abundance of herbivores (fish that eat algae), resulting in more algae on reefs that can outcompete corals for space. Increasing pollution such as sedimentation from land-use change and nutrients in wastewater and/or runoff from agriculture can negatively impact coral reef growth in three main ways:

(1) Increasing sedimentation can actively smother and kill corals to reduce reef growth.
(2) Increased nutrients can increase rates of calcium carbonate dissolution, which is literally the dissolution of the rock structures and is analogous to dissolving a sugar cube in water.
(3) Increased nutrients can favor growth of macroalgae over corals, which can outcompete corals for space and do not build calcium carbonate structures. Some types of algae can also dissolve calcium carbonate as they put their “roots” into rocks to grow.

These factors increase in intensity from 1950 to 2050 so the number of blocks removed increases from the 1950 game to the 2050 game too.

Growth: Calcification is the building of calcium carbonate skeletons by corals as they grow. Corals build much of the calcium carbonate on coral reef environments:

(1) Quick Growth: Corals of the genus *Acropora* tend to be the corals that grow the fastest but also the most sensitive to disturbances. *As a result, they are present in 1950 simulations as “quick growth” but absent in the 2050 simulations as they are expected to decrease in populations owing to their susceptibility to coral bleaching.*
(2) Growth: Other non-*Acropora* corals tend to grow slower but resist or recover more readily from coral bleaching events. *These corals are present in both the 1950 and 2050 simulations but are the only corals present in 2050 because they are generally expected to become more dominant on coral reefs under future environmental change.*

Coral recruitment: Coral recruitment is when new coral polyps settle on the reef and increase reef growth through increasing the amount of corals that build calcium carbonate skeletons.

(1) Strong coral recruitment: Many corals recruit to the reef through the provisioning of coral polyps from neighboring reef sites with high coral cover and favorable conditions for the corals to settle on the reef.
(2) Weak coral recruitment: Few corals recruit to a reef either because fewer coral polyps are supplied to the reef from neighboring sites with lower coral cover or because the conditions are less favorable for the coral to settle on the reef.

Coral recruitment has declined in recent decades so 1950 is strong and 2050 is weak recruitment.

Coral bleaching: Coral bleaching is the breakdown of the symbiosis between coral and the symbiotic algae that lives in its tissues, providing much of the daily energy needed for the coral to survive. When seawater temperatures become too warm, this symbiosis breaks down and the symbiotic algae leaves the coral. Corals can recover following bleaching, but corals may die if the seawater temperatures are too warm for too long. The loss of corals associated with coral bleaching events greatly decreases the growth potential of coral reefs.

Global coral bleaching events observed in 1998, 2010, and 2014-2017 so only in 2050 game.

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Instructions for the 1950 and 2050 coral reef growth games

In the 1950 coral reef growth game, we will start with 10 initial building blocks and add or remove building blocks depending on the number of heads generated by our coin flips. In each year, corals can decline following overfishing and pollution disturbances or increase owing to growth, quick growth, and/or coral recruitment. In this game, each turn simulates one year of reef growth (or loss). For each turn number, write down the number of blocks in your pile.

1. Start with 10 blocks.
2. Flip 3 coins or use (https://www.random.org/coins/?num=3&cur=60-usd.0100c-anthony) and count the number of heads.
    a. If 0 of the coins are heads → overfishing + pollution → remove 2 blocks.
    b. If 1 of the coins is heads → corals grow → add 1 block.
    c. If 2 of the coins are heads → corals grow quickly → add 2 blocks.
    d. If 3 of the coins are heads → strong coral recruitment → add 3 blocks.
3. If you reach 0 blocks before completing 10 turns, there are no corals to grow but you can still add 3 blocks with a strong coral recruitment event.
4. Calculate reef growth = # of Blocks at End – # of Blocks at Start.

Turn	Start	1	2	3	4	5	6	7	8	9	End	Growth
Blocks	10											

In the 2050 coral reef growth game, we will start with the same number of initial building blocks. However, climate change and increasing human impacts increase disturbances (remove more blocks) while corals grow and recruit more slowly (add fewer blocks). In this game, each turn simulates one year of reef growth (or loss). For each turn number, write down the number of blocks in your pile.

1. Start with 10 blocks.
2. Flip 3 coins or use (https://www.random.org/coins/?num=3&cur=60-usd.0100c-anthony) and count the number of heads.
    a. If 0 of the coins are heads → coral bleaching event → remove 5 blocks.
    b. If 1 of the coins is heads → overfishing + pollution → remove 3 blocks.
    c. If 2 of the coins are heads → corals grow → add 1 block.
    d. If 3 of the coins are heads → weak coral recruitment → add 2 blocks.
3. If you reach 0 blocks before completing 10 turns, there are no corals to grow but you can still add 2 blocks with a weak coral recruitment event.
4. Calculate reef growth = # of Blocks at End – # of Blocks at Start.

Turn	Start	1	2	3	4	5	6	7	8	9	End	Growth
Blocks	10											

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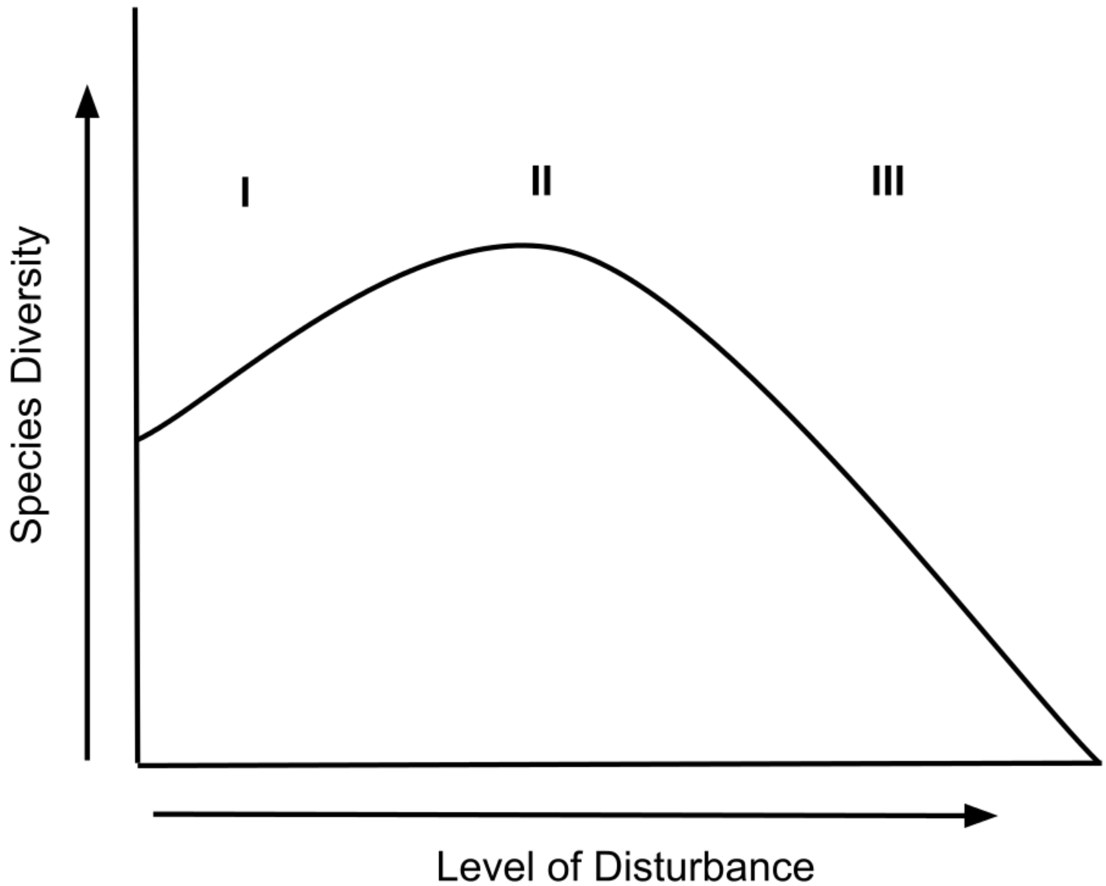
Materials needed: There are no required materials for this game. Students may use a deck of cards as the reef blocks and coins to play the simulation games. Alternatively, students can use addition/subtraction and/or the random coin flip link to virtually build their coral reefs without the use of any materials.

Intermediate disturbance hypothesis diagram:



I: This scenario is highly unlikely for most coral reef environments because there are naturally occurring physical disturbances (e.g., swell events, hurricanes, etc.) that generate disturbances on coral reefs and in part explain the high diversity on coral reefs!

II: This is essentially the 1950 game simulation where the intermediate disturbance intensities maintain a highly diverse, actively growing coral reef ecosystem composed of both rapidly growing species that are less resistant to disturbances and more slowly growing coral species that are more resistant to disturbance (i.e., highest coral diversity).

III: This is essentially the 2050 game simulation where ocean warming has increased the disturbance intensities on coral reefs by generating coral bleaching events. The reefs lose the fastest growing coral species and become dominated by slower growing corals that are able to resist and/or recover from these increased disturbances (i.e., lowest coral diversity).

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STEM researcher biography: Travis Courtney, PhD


Photo by Andreas Andersson, PhD

I grew up in coastal North Carolina and was always fascinated by the local beaches and how they changed throughout the seasons and years as storms moved sand around. I particularly enjoyed watching documentaries about the natural world that depicted the ability of small coral polyps to build massive coral reef structures we can see from space. I also learned that coral reefs were being negatively impacted by climate change and that this could negatively impact the shoreline protection, fisheries, and cultural significance that coral reefs provide to humanity. These motivations led me to pursue a research career to better understand how environmental change is affecting the growth and maintenance of coral reef structures.