How Does Climate Change

Affect Primary Producers?

DESCRIPTION

Students play the roles of water-intensive and drought-tolerant plants to understand the impacts of climate change on water, primary producers, and the food web.

GRADE LEVEL
6 – 12

OBJECTIVES

Students will:

- Model the uptake of resources by plant structures
- Analyze the effects of limited resources on plant populations
- Synthesize understanding of resource availability, survival, and energy transfer to determine the effects on a food web

TIME
40 MINUTES – 1 HOUR

COMMON CORE STATE STANDARDS

English Language Arts Standards » Science & Technical Subjects » Grade 6-8
CCSS.ELA-LITERACY.RST.6-8.4
Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 6-8 texts and topics.

CCSS.ELA-LITERACY.RST.6-8.7. Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).

English Language Arts Standards » Science & Technical Subjects » Grade 9-10
CCSS.ELA-LITERACY.RST.9-10.4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics.

CCSS.ELA-LITERACY.RST.9-10.7. Translate quantitative or technical information expressed in words in a text into visual form (e.g., a table or chart) and translate information expressed visually or mathematically (e.g., in an equation) into words.

English Language Arts Standards » Science & Technical Subjects » Grade 11-12
CCSS.ELA-LITERACY.RST.11-12.4. Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics.

Grade 7 » Statistics & Probability
CCSS.MATH.CONTENT.7.SP.B.3. Informally assess the degree of visual overlap of two numerical data distributions with similar variabilities, measuring the difference between the centers by expressing it as a multiple of a measure of variability.

NEXT GENERATION SCIENCE STANDARDS

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.

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

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

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. [Extension Activity]

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

HS-LS4-4. Construct an explanation based on evidence for how natural selection leads to adaptation of populations. [Extension Activity]

BACKGROUND

Plants are an important component of the water cycle and affect the movement of water through Earth's systems. Plants release water to the atmosphere through the process of transpiration. **Transpiration** occurs when water is absorbed by the roots and carried up through the stem to the leaves. Some of this water is used in photosynthesis and some is released as water vapor through the stomata, which are pores on plant surfaces that regulate gas exchange.

Because transpiration rates vary with climatic conditions, plant response to climate change can have a large impact on plant populations and soil moisture. Transpiration rates increase as temperature increases, and transpiration rates increase as humidity decreases. As temperatures increase and water availability declines under climate change conditions in the US Southwest, plant transpiration rates will likely increase. Some plant species are drought tolerant and are adapted to warm, dry conditions. Under climate change conditions in the US Southwest, drought-tolerant plants may be more likely to survive than plants that do not have the same adaptations. Drought-tolerant plants include cacti and creosotebush throughout the continental desert Southwest and ifit trees, native on islands throughout the Indian and South Pacific Oceans.

How plants react to climate change may affect the entire ecosystem. If plant populations decline, there will be less food available to primary consumers, and their populations may also decline. These effects may be felt throughout the food web and could be especially detrimental in species with limited ability for resource switching.

MATERIALS

- *Ready, Set, Grow* handout [1 per student]
- Drought-Tolerant plant nametags, copied onto cardstock, cut and strung with a piece of ribbon or string long enough to be worn as a necklace [1 per every 1-2 students] (Figure 1)
- Water-Intensive Plant nametags, copied onto cardstock, cut and strung with a piece of ribbon or string long enough to be worn as a necklace [1 per every 1-2 students] (Figure 1)
- Carbon dioxide resource cards, copied onto colored cardstock and cut (Figure 2)
- Water resource cards, copied onto colored cardstock (preferably a different color than the carbon dioxide resource cards) and cut (Figure 2)
- Game Graph, Excel file **OR** hand-drawn graph on board or large piece of paper
- *Ready, Set, Grow* instructional video, optional introduction to the game for the educator
- Computer and projector (if using Excel graph)
- Set of four different colored pencils [1 set per every 2-4 students]

Figure 1. Drought-Tolerant and Water-Intensive Plant nametags

Figure 2. Carbon Dioxide and Water resource cards

PREPARATION

1. If possible, watch the *Ready, Set, Grow* instructional video for an introduction to the game.
2. Locate a suitable space in a classroom or outside area and scatter resource cards throughout the area. The space can be a room with surfaces like benches or tables, where students can quickly move through the area without hazards, or a suitable outdoor spot. Refer to table 1 for the recommended starting resource card numbers for round 1 based on class size.
3. Place drought-tolerant and water-intensive nametags and water and carbon dioxide resource cards in an accessible location for the educator.
4. Draw the Game Graph from page 1 of the *Ready, Set, Grow* handout on the board/large piece of paper or prepare to show it with a document camera or computer and projector. In the legend on hand-drawn graphs, indicate four colors that you will use to display the number of drought-tolerant plants, water-intensive plants, carbon dioxide resource cards, and water resource cards.

Table 1. Recommended resource card numbers based on class size

	20 STUDENTS		25 STUDENTS		30 STUDENTS		35 STUDENTS		40 STUDENTS	
	Water	***CO_2***	***Water***	***CO_2***	***Water***	***CO_2***	***Water***	***CO_2***	***Water***	***CO_2***
ROUND 1	45	40	55	50	65	60	75	70	80	80
SUBSEQUENT ROUNDS	Decrease by 5	Increase by 5	Decrease by 5	Increase by 5	Decrease by 5	Increase by 5	Decrease by 5	Increase by 5	Decrease by 5	Increase by 5

PROCEDURES

1. Pass out a *Ready, Set, Grow* handout to each student.
2. Ask students what plants need to survive and have them list the answers under the Focus Question on page 1 of their handout [answer: nutrients, water, sun, suitable temperature range, space, CO_2].
3. Ask students to name the limiting resource(s) in the ecosystem as climate change intensifies and circle them on their handout. Explain that limiting resources limit a population's ability to increase and/or spread out in an ecosystem. Also, climate change refers to any significant change in the measures of climate lasting for an extended period of time (e.g., global warming, precipitation patterns, severe storms). These changes in our climate are the result of increased greenhouse gases, mostly CO_2, in the atmosphere.
    a. Water: today we will focus on water as one of the largest limiting resources for plants throughout much of the Southwest.
    b. Suitable temperature range: linked to water availability. Plants can cool themselves if they have enough water.
    c. **Not** sun: stays relatively constant.
    d. Maybe soil nutrients: climate change will likely disrupt nutrient ratios in the soil. Phosphorous may increase, and carbon and nitrogen will decrease as soils dry out. This may negatively impact plant growth.
    e. Maybe CO_2: not much of a limiting factor itself for plants, but increasing CO_2 in the atmosphere affects water availability, temperature, and soil nutrient availability, which may negatively impact some plants.
4. Explain the following. Plants are part of the water cycle. Plants absorb water from the soil and move it through their structures, which allows them to have water available for photosynthesis. When a plant takes in carbon dioxide, needed for photosynthesis, it loses water to the air through microscopic openings on its surfaces called stomata (singular = stoma). This is known as transpiration, and it is the process by which plants release water vapor into the atmosphere. In this way, plants affect the movement of water through Earth's systems. However, the availability of water has a large effect on plants as well; it is a very important factor for plant survival, distribution, and population growth.

    Today, we will explore the effects of reduced water availability on plant populations because climate scientists predict that many areas of the world, including the southwestern United States, will experience increased and prolonged periods of drought. As global temperatures increase because of climate change, more water evaporates from Earth's surface. Because of this, some areas, including Alaska and other high latitudes of the Northern Hemisphere, will receive more precipitation. Many other areas, such as the US Southwest, Mediterranean, and southern Africa, will receive less annual precipitation.

PLAYING THE GAME

1. Assign 1/3 of the class as plants to begin the game. The rest of the students will wait in line for the next round. Half of the beginning students will be assigned as drought tolerant plants, and half will be water-intensive plants.

2. Begin the game by explaining the baseline conditions for each round. Each round is like a growing season, with a certain amount of water and CO_2 available for plants. Students act as plants to quickly and carefully gather resource cards to ensure survival until the next round. In reality, of course, plants do not move around to uptake resources. However, in the game, students move around to act as stomata taking up carbon dioxide and roots absorbing water.
3. At the end of every round, students will have to transpire an increasing number of water points back to the environment (Table 2). The transpiration cost for round 1 is 1 water point, and it increases by 1 water point every round. It may be helpful to draw Table 2 on the board.

Table 2. Transpiration cost for each round

ROUND	TRANSPIRATION COST
1	1
2	2
Subsequent Rounds	Increase by 1

4. At the end of each round and after transpiration, **drought-tolerant plants** must have **2 water points and 2 CO_2 points** to survive to the next round. **Water-intensive plants** must have **4 water points and 2 CO_2 points** after transpiration. It may be helpful to write this on the board. Advise students to pick up as many resource cards as they can, even if they get more than they need.
5. After ensuring that students understand the transpiration cost for the round and how many water and CO_2 points are needed, say "Ready, Set, Grow" and release students to gather as many cards as possible.
6. There is no set time for each round. In a medium-sized class, a round takes 15-20 seconds. Watch students gathering cards, and when almost all the cards are gathered, begin a 5-second countdown. Call students back to a central location to end the round.
7. Instruct students to transpire the appropriate number of water points for the current round back to the environment (Table 2).
8. After transpiration, ask how many drought-tolerant plant students have **2 water points and 2 CO_2 points**, and instruct students to show you their cards. Then ask drought-tolerant plants to return all of their resource cards back to the environment, making sure they are scattered well enough for the next round of play. The ones who had enough cards are the surviving drought-tolerant plants. The drought-tolerant plant students who did not survive this round must move to the end of the line of students waiting to play.
9. Ask how many water-intensive plant students have **4 water points and 2 CO_2 points** after transpiration, and instruct students to show you their cards. Then ask water-intensive plants to return all of their resource cards back to the environment, making sure they are scattered well enough for the next round of play. The ones who had enough cards are the surviving water-intensive plants. The water-intensive plant students who did not survive this round must move to the end of the line of students waiting to play.
10. Give each of the surviving drought-tolerant and water-intensive plant students a nametag that matches their own. Instruct these students to give the nametag to the next student in line to create a new "sprout."
11. Recap the events of round 1 as you graph the number of plants from the start of rounds 1 and 2 on the Game Graph.
    a. Graph the number of drought-tolerant and water-intensive plants at the beginning of round 1.
    b. Discuss the number of plants that survived and reproduced as you graph the number of drought-tolerant and water-intensive plants that will begin round 2.
12. Graph the number of carbon dioxide and water cards available at the beginning of round 1.
13. Tell students that climate change conditions are in effect. Ask students to predict what will happen to the amount of carbon dioxide in the environment [answer: it will increase].
    a. Explain that the number of **carbon dioxide resource cards will increase by 5** in round 2, and graph the carbon dioxide cards available for round 2 (Table 1).
14. Ask students to predict what will happen to the amount of water in the environment throughout most of the US Southwest [answer: it will decrease].
    a. Explain that the number of **water resource cards will decrease by 5** in round 2, and graph the water cards available for round 2 (Table 1).
15. Before beginning the second round, add 5 carbon dioxide resource cards to the environment, and remove 5 water cards from the environment.
16. Explain that, as conditions become drier and warmer, plants lose more water during transpiration, and the transpiration cost has gone up by 1 point. Plants will have to transpire 2 water points at the end of round 2.
17. Repeat procedures 3 – 10.
18. To begin subsequent rounds,

graph the number of drought-tolerant plants, water-intensive plants, carbon dioxide resource cards, and water resource cards at the beginning of each round.

19. Add 5 carbon dioxide resource cards to the environment, and remove 5 water cards from the environment.
20. Continue to repeat procedures 3 – 10.

ENDING THE GAME

1. Depending on the time available, end the game after any round or wait until one or both of the plant populations dies out.
2. If one or both of the plant populations dies out and there is time to conduct more rounds, restart the game.
3. At the conclusion of the game, finish the graph. Draw lines to connect the points for each of the graphed items. Discuss the trend(s) of each of the plant populations and how they relate to the amount of carbon dioxide and water available.
4. At some point during or at the conclusion of the game, instruct students to complete the Game Graph on their handout with colored pencils.

RESULTS AND CONCLUSIONS

1. Instruct students to answer the results questions on page 2 of their handout. Use the questions to elicit a discussion about the population trends over the course of the game.
2. Ask students to answer the first conclusion question on page 2 of their handout. Discuss whether plants are more or less likely to survive with limited water resources. Extend the discussion by asking students to infer from their game data which plants are better adapted to survive in drought conditions.
3. Instruct students to look over the food web and answer the associated questions. Explain that the arrows in a food web point in the direction that the energy is moving (e.g., energy moves from grasshoppers to coyotes when coyotes prey on grasshoppers).
    a. Discuss how impacts on primary producer populations affect primary, secondary, and tertiary consumers.
    b. Extend the discussion to include other species that may be affected and impacts of declining perennial grass populations (such as habitat loss and changes in biodiversity).

GAME VARIATIONS

1. In a large class, students may be left standing in the "sprout" line for too long. Here are some options to reduce the line size and/or give students tasks to complete while waiting.
    a. Reduce the line size by giving some students roles as game helpers. Ask students whether they would rather have a job as a helper or play the game. Here are possible game helper roles:
        i. A student could graph the numbers from each round on the Game Graph.
        ii. A student could add and remove carbon dioxide and water resource cards between each round.
        iii. A student could hand out plant nametags to surviving plants each round.
    b. Students waiting in line could keep the handout with them and add to the Game Graph after every round.
    c. If two educators are available, "seeds" from surviving plant students could spread to a second area to colonize it. This will require two sets of materials.
        i. In the first round, surviving plant students could be given two plant nametags that match their own. They could then give them to the next two students in the "sprout" line. The first new "sprout" student would join the current game, and the second new "sprout" student would act as a seed and move over to another area with the second educator to establish a new population and game.
        ii. Surviving plant students from each of the two games would pull students from the one "sprout" line, and the two games would continue simultaneously.
        iii. As an option, set up the second area with different resource availability (different numbers of starting water and carbon dioxide resource cards), and at the conclusion of the game, the trends in the populations from both areas could be compared.
2. If one of the populations looks like it will crash and you would like to keep playing the game without starting over, institute a wet season. A **wet season** is an adjustment round and a method for returning plant population numbers to higher levels.
    a. At the beginning of a round, increase the number of water resource cards available (instead of decreasing them).
    b. Try increasing the available water by 2 – 7 cards. Be cautious. Changing the water by a few points can dramatically change the outcome and the length of play. It may take awhile to get the feel for what works best for your group of students.
    c. If there is time, increase water conservatively and conduct more than one wet season if needed.
    d. Go on to play the round as usual after adding more water cards.

EXTENSIONS

1. Explore the concept of carrying capacity (K) by keeping resource availability constant instead of instituting climate change conditions.
   a. If students are not familiar with carrying capacity, introduce the topic. Carrying capacity is the number of individuals of a species that an area's resources can sustain. Populations that grow exponentially tend to start out slowly, grow rapidly, and then level off when the carrying capacity has been reached (Figure 3).

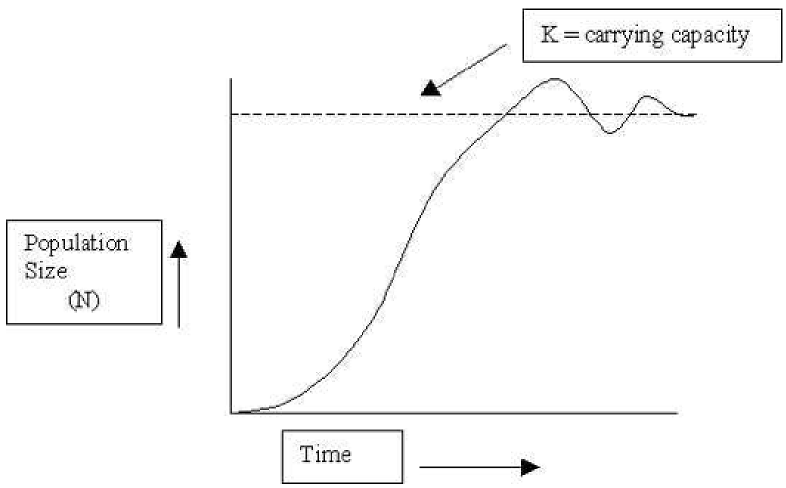

Figure 3. Graph of population size over time showing carrying capacity (K).
Source: faculty.plattsburgh.edu/thomas.wolosz/popbionote.htm

   b. Start with a fairly abundant amount of water and carbon dioxide, perhaps 5 or 10 more cards than suggested in Table 1 for your class size.
   c. Plan to play the game with only the drought-tolerant plant population, and then try it with both plant populations.
   d. Before playing, ask students to hypothesize about how the curves of population size over time will look for each version of the game (one plant population and two plant populations) when assuming a constant environment. Ask students whether they think drought-tolerant plants will have a larger or smaller carrying capacity once water-intensive plants are introduced, and ask them to draw their graphs to reflect their hypotheses.
   e. Try conducting the game with only one plant population (drought-tolerant plants); then play the game with both plant populations, and compare the graphs.
   f. Do not remove water resource cards or add carbon dioxide resource cards. Keep the environment constant.
   g. At the conclusion of both games, compare student hypotheses with the Game Graphs created while playing each version of the game (one plant population vs. two plant populations).
2. *Ready, Set, Grow* could work well in an evolution unit to demonstrate natural selection.
   a. Be creative with changing resource availability in relation to possible plant adaptations to investigate the effects on selection.
      i. For example, change the intensity of how drought tolerant or water intensive plants are in in the game by changing the amount of water they need after transpiration or how much they transpire. Survival can reflect selection for individuals of a species with favorable adaptations.

ADDITIONAL RESOURCES

1. Website with student-friendly information about transpiration:
   United States Geological Survey. Transpiration–The Water Cycle. Published 15 Apr. 2014. Web. Accessed 24 Mar. 2015. <http://water.usgs.gov/edu/watercycletranspiration.html>.
2. Website with helpful background information about population biology and carrying capacity for educators who are interested in conducting the carrying capacity extension activity:
   Wolosz, T., State University of New York, Center for Earth and Environmental Sciences. A Brief Look at Population Biology. Web. Accessed 9 Apr. 2015. <http://faculty.plattsburgh.edu/thomas.wolosz/popbionote.htm>.