Lesson 4: Carbon Pools and Fluxes in Changing Ecosystems

Overview

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NOTE: This lesson introduces a quantitative model of carbon pools and fluxes, then uses that model to explain how ecosystems change over time. This is challenging content that addresses *NGSS* High School Performance Expectations. You may want to skip it with middle school classes.

In Lesson 2, students identified the pattern of organic matter distribution (the organic matter pyramid) in a meadow ecosystem. In Lesson 3, they explained why that pattern exists by tracing matter and energy and connecting scales. In Lesson 4, students explain changes in ecosystems by keeping track of carbon pools and carbon fluxes. Carbon fluxes are the rates (mass/time) at which carbon transforming processes occur.

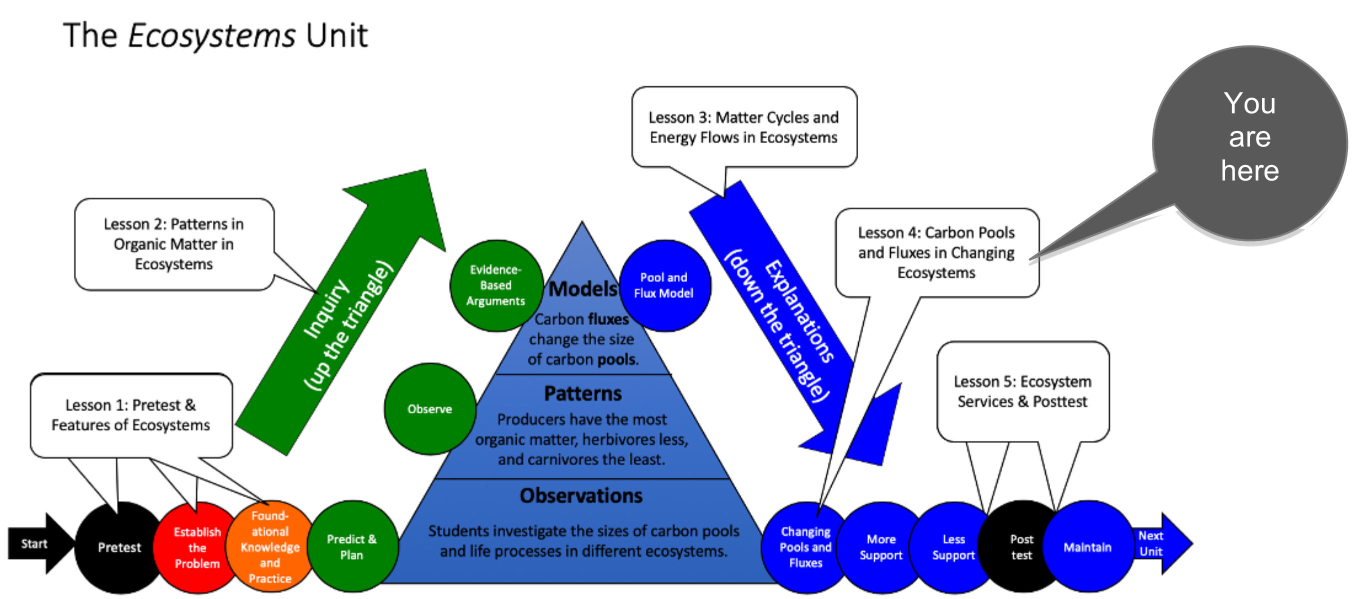
Guiding Question

How and why do carbon pools in ecosystems change over time?

Activities in this Lesson

- Activity 4.1: Tiny Pool and Flux Game (30 min)
- Activity 4.2: Carbon Pools and Constant Flux Simulation (30 min)
- Activity 4.3: How Fluxes Change and Photosynthesis Limits (40 min)
- Activity 4.4: Seasonal Changes and Ecosystem Disturbances (40 min)

Unit Map



Learning Goals

Target Performances

Activity	*Target Performance*

Lesson 4 – Carbon Pools and Fluxes in Changing Ecosystems (students as explainers)	
Activity 4.1: Tiny Pool and Flux Game	Students describe the relationship between pools and fluxes in a physical model: changes in pool sizes depend on balance among fluxes.
Activity 4.2: Carbon Pools and Constant Flux Simulation	Students describe the relationship between pools and fluxes in an online computer model: changes in pool sizes depend on balance among fluxes.
Activity 4.3: How Fluxes Change and Photosynthesis Limits	Students use an online computer model to describe how changes in carbon pools over time depend on the maximum possible rate of photosynthesis in an ecosystem.
Activity 4.4: Seasonal Changes and Ecosystem Disturbances	Students use an online computer model to describe how seasons and disturbances affect an ecosystem.

NGSS Performance Expectations

High School

- Chemical Reactions. HS-PS1-7. Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.
- Interdependent Relationships in Ecosystems. HS-LS2-1. Use mathematical and or computational representations to support explanations of factors that affect carrying capacity of ecosystems and different scales.
- Interdependent Relationships in Ecosystems. HS-LS2-2. Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems at different scales.
- Matter and Energy in Organisms and Ecosystems. HS-LS2-4. Use mathematical representations to support claims for the cycling of matter and flow of energy among organisms in an ecosystem.
- Matter and Energy in Organisms and Ecosystems. HS-LS2-5: Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.
- Earth's Systems. HS-ESS2-6. Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

Middle School

- Matter and Energy in Organisms and Ecosystems. 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.
- Interdependent Relationships in Ecosystems. MS-LS2-2. Construct an explanation that predicts patterns of interactions among organisms across multiple ecosystems.
- Matter and Energy in Organisms and Ecosystems. MS-LS2-3. Develop a model to describe the cycling of matter and flow of energy among living and nonliving parts of an ecosystem.
- Matter and Energy in Organisms and Ecosystems. MS-LS2-4. Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.

- Matter and Energy in Organisms and Ecosystems. MS-LS1-6. Construct a scientific explanation based on evidence for the role of photosynthesis in the cycling of matter and flow of energy in and out of organisms.
- Earth's Systems. MS-ESS2-1. Develop a model to describe the cycling of earth's materials and the flow of energy that drives this process.
- Human Impacts. ESS3-4. Construct an argument supported by evidence for how increases in human population and per-capita consumption of natural resources impact Earth's systems.

Background Information

Three-dimensional Learning Progression

In Lesson 4, students explain carbon movement in ecosystems in terms of pools and fluxes. A pool size is constant when the fluxes into and out of it are the same or balanced – i.e., when the net flux is zero. Pool sizes change when in and out fluxes are not balanced. High school students explain how photosynthesis limits the maximum, steady state amount of organic matter an ecosystem can support. When an ecosystem reaches its photosynthesis limit, the rate of photosynthesis and cellular respiration are essentially the same. Students explain how different types of disturbances affect pool sizes and flux rates.

Key Ideas and Practices for Each Activity

Activity 4.1 introduces students to a 2-carbon pool model of an ecosystem where organic carbon is in organic matter and inorganic carbon is in the atmosphere in the form of carbon dioxide. The hands-on activity uses a very simple system to introduce students to the effects of fluxes on pool sizes. They discover that balanced fluxes, that is situations where the net flux is zero, result in unchanging pool sizes. Through graphing exercises, students associate the value on the y-axis (the amount of carbon) with pool size and the slope of the line (carbon movement per unit of time) with flux rates.

In Activity 4.2, students use a computer simulation of a larger 2-pool system to find that the rules still hold. When the net flux into and out of a pool is zero, the pool size does not change and conversely, when the net flux is not zero, the pool size will change.

In Activity 4.3, students use a more sophisticated model of carbon pools and fluxes where the ecosystem has a maximum photosynthesis rate. In this model, the flux rates of cellular respiration and photosynthesis, rather than being constant, depend on the size of the organic carbon pool.

In Activity 4.4 students use the 2-pool simulation to explore the effects of various disturbances on ecosystems. Press disturbances are long-term changes to the environment that may affect an ecosystem's photosynthesis limit. Pulse disturbances are one-time events that ecosystems often recover from.

Key carbon-transforming processes: photosynthesis, cellular respiration, combustion

Content Boundaries and Extensions

Activity 4.1: Tiny Pool and Flux Game (30 min)

Overview and Preparation

Target Student Performance

Students describe the relationship between pools and fluxes in a physical model: changes in pool sizes depend on balance among fluxes.

Resources You Provide

- Markers such as M&Ms or bingo chips (10 per student or pair of students)

Resources Provided

- 4.1 Tiny Pool and Flux Worksheet (1 per student)
- 4.1 Grading the Tiny Pool and Flux Worksheet
- 4.1 Tiny Pool and Flux Game Placemat (1 per student or pair of students)
- 4.1 Tiny Pool and Flux Game PPT

Setup

Open the 4.1 Tiny Pool and Flux Game PPT and project it. Prepare enough copies of the 4.1 Tiny Pool and Flux Worksheet for each student to have one. Prepare enough copies of the 4.1 Tiny Pool and Flux Game Placemat for each student or pair of students to have one.

Directions

1. Use the instructional model to show students where they are in the course of the unit.

Show Slide 2 of the 4.1 Tiny Pool and Flux Game PPT.

- Show Slide 3 and discuss Stability and Change as the main focus for this lesson. Students have been introduced to carbon pools in previous lessons. In this lesson, they will study carbon fluxes.

2. Students review the two-pools model of carbon in an ecosystem.

Use Slide 4 to remind students how the carbon in the meadow simulation can be divided into five pools.

- Use Slide 5 to show how scientists categorize organisms into particular two pools of carbon, organic and inorganic.

3. Use Slides 6-9 to define fluxes as rates (mass/time).

Show Slide 6. Explain the terms, movements and fluxes.

- Show Slide 7 to show students the two main pools.
- Show Slide 8 to show students the two main fluxes. Tell students that photosynthesis moves carbon from the inorganic to the organic pool. Cellular respiration moves carbon from the organic to the inorganic pool. Remind students that they found this during the Carbon Dice Game.
- Show Slide 9 to show the other fluxes within the organic carbon pool. Remind students that they traced their movement on this diagram in Lesson 3.

4. As a class, run through Scenario 1 of the Tiny Pool Flux Game

Handout one 4.1 Tiny Pool and Flux Worksheet to each student along with a 4.1 Tiny Pool and Flux Game Placemat and 10 markers. The game can be done by individual students or in pairs. Each student keeps their own data and graphs.

- Show Slides 10-12 to explain the game and setup.
- Show Slide 13. In this scenario, they will have 6 carbon atoms in the organic pool and 4 in the organic pool. Have students put the appropriate number of markers on placemat and starting points on the graph. Both the photosynthesis and cellular respiration rates are at 2 carbon atoms/year. Have class work through years by moving markers according to the fluxes and recording each year's result in the chart and on the graph. Students should connect the dots for the organic (green) pool with a dashed line and use a solid line for the inorganic atmospheric pool
- Have students play through year 5, recording and graphing their data as they go.
- Have students compare their results to Slide 14.

5. Have students determine other starting conditions that yield the same graph.

Show Slide 15. Have students find another set of fluxes that produce the same graph.

- Have students share their results.
- Discuss the pattern in the results. Students should find that any starting conditions with the same original pool sizes and equal flux rates will produce the same results.

6. Have students try Scenario 2.

Show Slide 16. Have students try Scenario 2 and graph the results.

- Show Slide 17. Discuss the pattern.
- Show Slide 18. Have students try to find another set of fluxes that produce the same results. Students should find that any set of fluxes that differ by the same amount should produce the same results.

7. Challenge students to find a set of starting conditions that produces a graph with crossing lines.

Use Slide 19 to challenge students to find a set of starting conditions that will make the graph lines cross.

- After the students find one set of conditions, challenge them to find another set of conditions that produce the same graph.
- Have students discuss their results and find patterns.

8. Allow students to try their own starting pools and fluxes.

Show Slide 20 to have students try their own starting pools and fluxes.

- After, have them find different fluxes that produce the same graph.
- Have students share and discuss their results.

9. Have students summarize what they found about the relationship between pool size fluxes.

Have students answer question B on the worksheet. Allow students to share their answers with a partner.

10. Introduce the idea of net flux.

Use Slide 21 to have students summarize what they found about the relationship between pool size and fluxes as a whole class. Don't show the bullet points until they are finished summarizing. • Use the bullet points to introduce the idea of net flux.
11. Have students complete an exit ticket. Show slide 22 of the 4.1 Tiny Pool and Flux Game PPT. • Conclusions: How do carbon fluxes change the size of carbon pools? • Predictions: How are real ecosystems and the tiny ecosystem alike and different? • On a sheet of paper or a sticky note, have students individually answer the exit ticket questions. Depending on time, you may have students answer both questions, assign students to answer a particular question, or let students choose one question to answer. Collect and review the answers. • The conclusions question will provide you with information about what your students are taking away from the activity. Student answers to the conclusions question can be used on the Driving Question Board (if you are using one). The predictions question allows students to begin thinking about the next activity and allows you to assess their current ideas as you prepare for the next activity. Student answers to the predictions question can be used as a lead into the next activity.

Assessment

This activity introduces the idea of net flux, which will be important throughout the rest of the unit. Be sure students understand the ideas on the final slide before moving on to the next activity. Use the 4.1 Grading the Tiny Pool and Flux Worksheet to grade students' work.

Differentiation & Extending the Learning

Differentiation

- Identify locations in the room as the two carbon pools, then have students play the role of carbon atoms moving between the two pools.
- Project the graphs onto a white board and demonstrate how to fill them in after each move.
- Have students work in pairs and fill out one worksheet for each pair.

Modifications

Activity 4.2: Carbon Pools and Constant Flux Simulation (30 min)

Overview and Preparation

Target Student Performance

Students describe the relationship between pools and fluxes in an online computer model: changes in pool sizes depend on balance among fluxes.

Resources You Provide

- Computers with internet access (1 per student or pair of students)

Resources Provided

- 4.2 Carbon Pools and Constant Flux Simulation PPT
- Constant Flux Simulation https://carbontime.bscs.org/sites/default/files/simulations/pool-flux-simulation-updated/index.html
- 4.2 Computer Model for Constant Flux Worksheet (1 per student)
- 4.2 Grading the Computer Model for Constant Flux Worksheet

Setup

Open the 4.2 Carbon Pools and Constant Flux Simulation PPT and project it. Print one copy of 4.2 Computer Model for Constant Flux Worksheet for each student. Prepare computers for each student or pair of students to run the simulation.

Directions

1. Use the instructional model to show students where they are in the course of the unit.

Show Slide 2 of the 4.2 Carbon Pools and Constant Flux Simulation PPT.

2. Review the patterns found in Activity 4.1.

Show Slide 3 of the 4.2 Carbon Pools and Constant Flux Simulation PPT.

- Have students discuss the patterns they found in Activity 4.1 and review the idea of net flux.

3. Introduce the Constant Flux Simulation.

Show Slide 4 of the 4.2 Carbon Pools and Constant Flux Simulation PPT. Pass out a 4.2 Computer Model for Constant Flux Worksheet to each student.

- Have students read until #1 for an overview of the simulation.
- Show Slide 5 and open the simulation. Show students how to move the sliders and run an example. Point out the graphs and how they can slide the line of the graph to get data for a particular point in time.

4. Students run the simulation.

Display slide 6. Have students follow the instructions to run the simulation. Students should record their data in the table on their worksheet.

- (Optional) Use slide 7 and 8 to discuss Run 1 and Run 2 as a class.

5. Students consider patterns in their results. When students have completed the table, have students work individually and then with a partner to answer questions 6 and 7 on 4.2 Computer Model for Constant Flux Worksheet. • (Optional) Use slide 9 to complete the table as a class.
6. Discuss the patterns. Show Slide 10 of 4.2 Carbon Pools and Constant Flux Simulation PPT. Have students share and discuss their answers to questions 6 and 7.
7. Review the patterns. Show slide 11. Discuss with students how the rules from Activity 4.1 in the tiny system also are true of the larger system in the simulation.

Assessment

During the discussion after the simulation, be sure that students recognize that the patterns are the same as in Activity 4.1 even though there is a larger number of atoms in the system. Use 4.2 Grading the Computer Model for Constant Flux Worksheet to grade students' work.

Differentiation & Extending the Learning

Differentiation

- Have students work in pairs, with each pair using one computer and one worksheet.

Modifications

Activity 4.3: How Fluxes Change and Photosynthesis Limits (40 min)

Overview and Preparation

Target Student Performance

Students use an online computer model to describe how changes in carbon pools over time depend on the maximum possible rate of photosynthesis in an ecosystem.

Resources You Provide

- Computers with internet access (1 per student or pair of students)

Resources Provided

- 4.3 How Fluxes Change and Photosynthesis Limits PPT
- Changing Flux Simulation (https://carbontime.bscs.org/sites/default/files/simulations/pool-flux-simulation-updated/index.html)
- 4.3 Computer Model for Changing Fluxes Handout (1 per student)
- 4.3 Computer Model for Changing Fluxes Worksheet (1 per student)
- 4.3 Grading the Computer Model for Changing Fluxes Worksheet

Setup

Print a copy for each student of 4.3 Computer Model for Changing Fluxes Handout and 4.3 Computer Model for Changing Fluxes Worksheet*.* Set up a computer and projector for 4.3 How Fluxes Change and Photosynthesis Limits PPT.

Directions

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1. Use the instructional model to show students where they are in the course of the unit.

Show Slide 2 of the 4.3 How Fluxes Change and Photosynthesis Limits PPT.

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2. Review the Constant Fluxes Model and introduce the Changing Fluxes Model.

Show Slide 3.

- Pass out the 4.3 Computer Model for Changing Fluxes Handout to each student.
- In partners or as a whole class, have students read the handout.
- Discuss how the Constant Flux and Changing Fluxes Models are different.
- Review the idea from Activity 2.4 that different ecosystems have different amounts of organic carbon and relate it to the photosynthesis flux.

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3. Show students how to use the simulation.

Show Slide 4 and open the simulation.

- Show students how to move the sliders and run an example. Point out the graphs and how they can slide the line of the graph to get data for a particular point in time.

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4. Students run the simulation.

Pass out the 4.3 Computer Model for Changing Fluxes Worksheet to each student.

- Have students follow the instructions to run the simulation. Students should record their data in the tables.

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- (Optional) Use Slides 5-13 to discuss Run 1, 2, and 3 as a class. Students can complete the tables on Slides 5, 8, and 11 on their worksheets. Results from example runs are shown in both graph and table form.

5. Students consider patterns in their results.

When students have completed the tables, have students work individually and then with a partner to answer the questions in Part B on 4.3 Computer Model for Changing Fluxes Worksheet.

6. Discuss the patterns.

Show Slide 14. Have students share and discuss their answers to questions.

7. Have students complete an exit ticket.

Show slide 15 of the 4.3 How Fluxes Change and Photosynthesis Limits PPT.

- Conclusions: Why do ecosystems with unbalanced fluxes often stabilize?
- Predictions: What can cause stable ecosystems to become unstable?
- On a sheet of paper or a sticky note, have students individually answer the exit ticket questions. Depending on time, you may have students answer both questions, assign students to answer a particular question, or let students choose one question to answer. Collect and review the answers.
- The conclusions question will provide you with information about what your students are taking away from the activity. Student answers to the conclusions question can be used on the Driving Question Board (if you are using one). The predictions question allows students to begin thinking about the next activity and allows you to assess their current ideas as you prepare for the next activity. Student answers to the predictions question can be used as a lead into the next activity.

Assessment

Use 4.3 Grading the Computer Model for Changing Fluxes Worksheet to grade students' work and get a sense of how they are understanding the pool and flux model.

Differentiation & Extending the Learning

Differentiation

- Have students work in pairs, with each pair using one computer and one worksheet.

Modifications

Activity 4.4: Seasonal Changes and Ecosystem Disturbances (40 min)

Overview and Preparation

Target Student Performance

Students use an online computer model to describe how seasons and disturbances affect an ecosystem

Resources You Provide

- Computers with internet access (1 per student or pair of students)

Resources Provided

- 4.4 Seasonal Changes and Ecosystem Disturbances PPT
- Seasonal Changes and Disturbances Simulation (https://carbontime.bscs.org/sites/default/files/simulations/pool-flux-simulation-updated/index.html)
- 4.4 Computer Model for Seasons and Disturbances Handout (1 per student)
- 4.4 Computer Model for Seasons and Disturbances Worksheet (1 per student)
- 4.4 Grading the Computer Model for Seasons and Disturbances Worksheet
- (Optional) 4.4 Fire Reading (1 per student)

Recurring Resources

- Large Scale Four Questions Handout with Checklist (1 per student)
- Learning Tracking Tool for Ecosystems (1 per student)
- Assessing the Learning Tracking Tool for Ecosystems
- Questions, Connections, Questions Student Reading Strategy

Setup

Print a copy for each student of 4.4 Computer Model for Seasons and Disturbances Handout and 4.4 Computer Model for Seasons and Disturbances Worksheet. If you choose to use it, print one copy of 4.4. Fire Reading for each student. Set up a computer and projector for 4.4 Seasonal Changes and Ecosystem Disturbances PPT.

Directions

1. Use the instructional model to show students where they are in the course of the unit.

Show Slide 2 of the 4.4 Seasonal Changes and Ecosystem Disturbances PPT.

2. Review the Constant and Changing Fluxes Models and introduce the Seasons and Disturbances Model.

Show Slide 3. Review what students concluded from the Constant and Changing Fluxes Models.

- Show Slide 4. Pass out the 4.4 Computer Model for Seasons and Disturbances Handout to each student.
- In partners or as a whole class, have students read the handout until Part A.
- Discuss what students learned from the first two models and how Model 3 is different.

3. Students run the simulation.

Pass out 4.4 Computer Model for Seasons and Disturbances Worksheet to each student.

- Have students follow the directions on 4.4 Computer Model for Seasons and Disturbances Handout to complete Part A and B on their worksheet.
- (Optional) Use Slides 5-11 to go through Part A and B with the students. The questions can be completed together using the slides.

4. Students continue to run the simulation.

Have students follow the directions on 4.4 Computer Model for Seasons and Disturbances Handout to complete Part C on their worksheet.

- (Optional) Use Slide 12 to go through Part C with the students.

5. Students read about disturbances in real ecosystems.

Show Slide 13.

- Have students read the last section of 4.4 Computer Model for Seasons and Disturbances Handout about disturbances in real ecosystems.
- Have students answer Part D of their worksheet.

6. Discuss the patterns.

Show Slide 14. Have students share and discuss their answers to questions.

7. (Optional) Students read about and discuss the effects of fire as a disturbance.

Pass out the 4.4 Fire Reading.

Have student read 4.4: Fire Reading using the Questions, Connections, Questions Student Reading Strategy. See the Questions, Connections, Questions Reading Strategy Educator Resource document for information about how to engage students with this strategy.

- After pairs are finished reading, have students share with the class what they found interesting and any questions they have.

8. Have a discussion to complete the Learning Tracking Tool for this activity.

Show slide 15 of the 4.4 Seasonal Changes and Ecosystem Disturbances PPT.

- Pass out a Learning Tracking Tool for Ecosystems to each student.
- Have students write the activity chunk name in the first column, "Carbon Pools and Fluxes, Explainers"
- Have a class discussion about what students did during the activity chunk. When you come to consensus as a class, have students record the answer in the second column of the tool.
- Have a class discussion about what students figured out during the activity chunk that will help them in answering the unit driving question. When you come to consensus as a class, have students record the answer in the third column of the tool.
- Have a class discussion about what students are wondering now that will help them move towards answering the unit driving question. Have students record the questions in the fourth column of the tool.
- Have students keep their Learning Tracking Tool for Ecosystems for future activities.
- Example Learning Tracking Tool

Activity Chunk	What Did We Do?	What Did We Figure Out?	What Are We Asking Now?

Carbon Pools and Fluxes Explainer	Explain changes in ecosystems by keeping track of carbon pools and carbon fluxes.	Carbon pools are stable when fluxes are balanced and change size when fluxes are unbalanced. Seasons and disturbances cause unbalanced fluxes.	How do humans depend on and disturb ecosystems?	

Assessment

Use 4.4 Grading the Computer Model for Seasons and Disturbances Worksheet to grade students' work and get a sense of how they are understanding seasons and disturbances.

Differentiation & Extending the Learning

Differentiation

- Have students work in pairs, with each pair using one computer and one worksheet.

Modifications

Use Slides 4-11 to go through the simulation and the questions with students.

Extending the Learning

- Have students explore the Digging Deeper links at the end of 4.4 Computer Model for Seasons and Disturbances Handout.
- For more information about a specific disturbance, have students read the 4.4 Fire Reading.