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This activity was selected for the On the Cutting Edge Exemplary Teaching Collection

Resources in this top level collection a) must have scored Exemplary or Very Good in all five review categories, and must also rate as "Exemplary" in at least three of the five categories. The five categories included in the peer review process are

- Scientific Accuracy
- Alignment of Learning Goals, Activities, and Assessments
- Pedagogic Effectiveness
- Robustness (usability and dependability of all components)
- Completeness of the ActivitySheet web page

For more information about the peer review process itself, please see https://serc.carleton.edu/teachearth/activity_review.html.

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Forest Management and the Carbon Cycle

This activity is part of the community collection of teaching materials on climate and energy topics.

These materials were created by faculty as part of the CLEAN Climate Workshop, held in May, 2012 and are not yet part of the CLEAN collection of reviewed resources.
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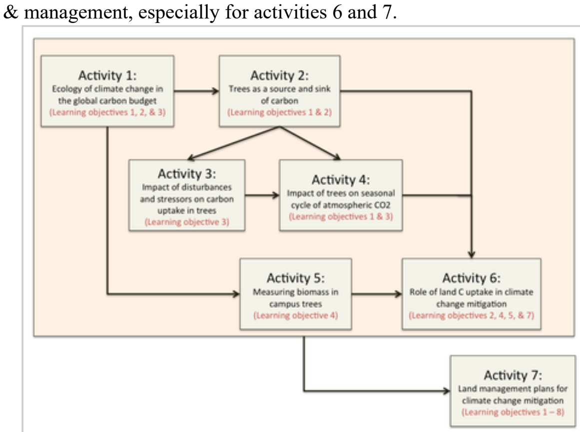
Climate Literacy application: This activity addresses**Climate Literacy Principle 2:** Climate is regulated by complex interactions among components of the Earth system; **Fundamental Principle D:** The abundance of greenhouse gases in the atmosphere is controlled by biogeochemical cycles that continually move these components between their ocean, land, life, and atmosphere reservoirs. The abundance of carbon in the atmosphere is reduced through seafloor accumulation of marine sediments and accumulation of plant biomass and is increased through deforestation and the burning of fossil fuels as well as through other processes.

Topic: Carbon sequestration in forests and trees: What is the role of forests and trees in mitigating climate change?

Course Type: Introductory-level college course in environmental science, climate science or ecology, especially for activities 1-5.
OR
Upper-level college course in environmental science, climate science, ecosystem ecology, or forest ecology & management, especially for activities 6 and 7.

Summary

Students begin this activity by using the IPCC4, carbon diagram to distinguish natural and anthropogenic carbon. (A point that students may need to have clarified is that CO_2 from natural and anthropogenic sources is the same molecule.). Students begin with Activity 1 , calculating the overall carbon transfer for a year, followed by an examination of the role of forests in the carbon cycle. This suite of activities includes 7 parts, and the selection of additional activities depends upon the discretion of the instructor and focus of the class. Activity Diagram (Acrobat (PDF) 319kB May16 12) (a larger version of file to the right)



Activity Diagram

Goal

Students should be able to explain the role of forests as an example of the complex interactions between the atmosphere and biosphere.

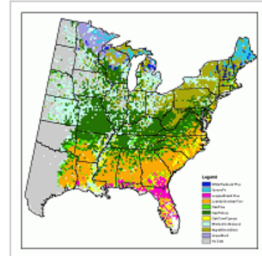
Objectives

Students should be able to do the following:

1. DISTINGUISH between natural and anthropogenic processes that contribute to the flux within the global carbon cycle
2. EXPLAIN the role of forests in the global carbon cycle and global climate change
3. ESTIMATE the impacts of forest biomass loss (deforestation, fires) and gain (reforestation, afforestation) to the global carbon cycle
4. QUANTIFY the fraction of carbon contained in terrestrial ecosystems

5. QUANTIFY the flux of carbon into and out of these systems (DETERMINE the source and sink contributions of the terrestrial component of the global carbon cycle)
6. CALCULATE C-sequestration/tree/year from diameter at breast height measurements (dbh)
7. PREDICT how forest ecosystem biodiversity will change under different CO2 and climate change scenarios.
8. DEVELOP a forest management plan using present and projected species distributions

Assessment



Students will be evaluated based on their ability to do the following, as corresponding to the activities and goals of the exercise:

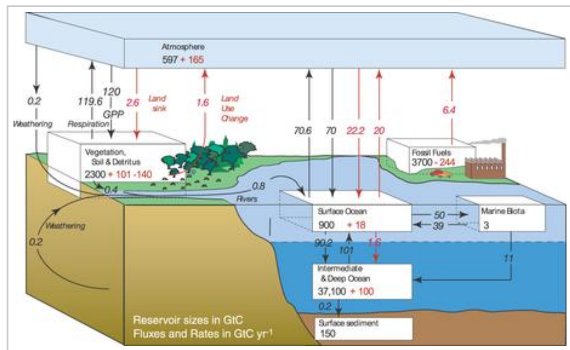
1. Determine the contributions of the terrestrial component of the Global C-Cycle
2. Determine the impacts of human activities on the Global C-Cycle
3. Describe the role of trees (sink & source) in the Global C-cycle
4. Describe the vulnerability of regional tree species/forests to present and future climate change?
5. Develop land-use strategies/plans to maximize tree's/forests role as a carbon sink
6. Predict how forest ecosystem biodiversity will change under different CO_2 and climate change scenarios.
7. Model the direct effect of elevated CO_2levels, along with accompanying changes in climate, on forest ecosystems

This assessment will take place in two phases, with the first phase related to the assessment of comprehension of the global carbon cycle and climate change, and the second phase assessing the ability of students to apply this knowledge and related concepts to the prediction, modeling, and application of the GCC to forest ecosystems and biodiversity. In the first phase of assessment students will be required to complete a written evaluation of the human and terrestrial components of the global carbon cycle, and in the second, a blended assessment of instructor evaluation and student presentations to peers/classmates will be used.

Building Blocks

Background knowledge for the module:*In a Forest's Breath, Deciphering Climate Clues*

Part 1. Ecology of climate change in the global carbon budget



The different components and flows of Earth's carbon cycle.

The total amount of carbon on Earth is constant, but the amount in different reservoirs can change. The carbon cycle diagram shows the amount of carbon that is stored in different reservoirs and the arrows show the movement of carbon between reservoirs. This is called a flux or rate of exchange. Black arrows are the natural flux and red arrows are the flux that is caused by human activity. The amount of of carbon in flux is given in gigatons per year. (From IPCC Figure 7-3).

A gigaton = 1 billion tons. Since a Prius weighs about 1.5 tons, this is the weight of 670,000 Priuses. If this number of Priuses were lined up they would extend from Atlanta, Georgia to New York City.

Ecology of Climate Change, a video from the American Museum of Natural History, shows scientists studying impacts of climate change in the northern hemisphere boreal forest (Alaska). They estimate how much light is absorbed by the trees and their CO_2 fluxes; and discuss changes related to feedbacks and fire. Between 4:10 and 8:07 minutes (the end) the video focuses on permafrost changes and might not be appropriate for this exercise. There is an accompanying, one page pdf with some teaching suggestions and a link to a figure that shows how/why carbon is absorbed and released from different reservoirs.

Through this activity, students will identify the size of different carbon sources and sinks and will calculate the imbalance within the Carbon Cycle.

Carbon Sources:

- List the natural sources of carbon (upward black arrows) to the atmosphere. Calculate (in Gigatons) the total amount of carbon provided to the atmosphere by natural sources for one year.
- List the anthropogenic sources (upward red arrows) to the atmosphere).
- Calculate (in Gigatons) the total amount of carbon provided to the atmosphere by anthropogenic sources for one year.

Carbon Sinks:

- List the natural sinks for carbon (downward black arrows) from the atmosphere. Calculate (in Gigatons) the total amount of carbon removed from the atmosphere by natural sources for one year.
- List the anthropogenic sinks for carbon (downward red arrows) from the atmosphere). Calculate (in Gigatons) the total amount of carbon removed from the atmosphere by anthropogenic sources for one year.
- Calculate the net transfer of carbon to or from the atmosphere. What are the implications of this transfer?

Part 2. How trees serve as a source and sink of carbon, and how their role changes seasonally

Use the activity, Global patterns in Green-up and Green-down

Through this activity, students will:

- Explore the relationship between land cover types and vegetation vigor (i.e., growth)
- Explore the change in vegetation vigor (e.g., growing cycle) globally and for each hemisphere.

Part 3. The impacts of insects, disease, and wildfires on carbon sequestration in trees (additive stressors on trees)

As we think about the ability of forests to sequester carbon and help to lower atmospheric levels of carbon dioxide it is important to be aware of the role of disturbance processes. Forests are naturally exposed to insect attack, disease, and wildfire. Additionally humans have long affected forests with logging and clearing for agriculture and human settlements. This adds to the complexity of our task of predicting the ability of forests to sequester carbon. Furthermore, as the climate changes, trees are subject to new stresses, such as heat waves and droughts, blowdown from high winds or ice storms, changes to fire frequency and severity, and attack by insects and diseases that were formerly limited in their ranges by cold temperatures.

In this section we will read about pine beetle outbreaks in Colorado and western Canada. We will then read about the Emerald Ash Borer in Eastern United States. Finally we conclude by reading Westerling's article about the huge increase in fire frequency and severity in the Western United States, and why this is thought to be linked to climate change rather than land management and fire suppression.

Trees and forest can experience stress. These stresses may come from climate change and/or be species of insects and diseases for which they have no resistance. Once dead, the trees become a source of atmospheric carbon and begin to return the carbon stored in wood back to the atmosphere. This can happen gradually (decades) through decomposition or rapidly (days) through wildfire. Once an area has been infested, trees from that area are usually quarantined and can no longer be shipped to uninfected areas. This limits the use of the trees as a forest product.

In this section examples of stressors from introduced insects and disease are provided. Different strategies may be needed to address different insect and disease invasions and for different areas. For example, should trees that are likely to be attacked, be harvested before an invasion, so the carbon can be sequestered in the wood, which is used for building materials? Should insecticides be used?

A. Pine Beetles.

Students will complete the following two activities.

Pine Bark Beetle Outbreaks and Climate

This interactive shows the extent of the killing of lodgepole pine trees in western Canada. The spread of pine beetle throughout British Columbia has devastated the lodgepole pine forests there.

Mountain Pine Beetles

This lesson plan has students working in small groups to research the Mountain Pine Beetle in Colorado and other inter-mountain Western states. Students identify the factors that control pine beetle outbreaks.

B. Emerald Ash Borer (New threats to northeastern forest hardwoods) Students will read about the Emerald Ash Borer using this fact sheet.

May, 2012 map of emerald ash borer location in U.S.

Emerald Ash Borer (EAB)**:** The emerald ash borer (*Agrilus planipennis* Fairmaire) was first discovered in Michigan in 2002. As of May 2012 it was found in Illinois, Indiana, Iowa, Kentucky, Maryland, Minnesota, Missouri, New York, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, Wisconsin, Ontario and Quebec. It is expected to cross into Connecticut and Massachusetts by 2014. The EMB larvae attach the structure of ash (*Fraxinus spp)*trees.

Students can discuss what should be done to mitigate the effect of the EAB on northwester forests. (insecticide, removal, other?). Discussion should include costs, probability of success in reducing the infestation, and securing the necessary funds.

C. Wildfire in the American West.

Westerling Fire Severity (TIFF 372kB May16 12)

Students will read the article Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity, by A.L. Westerling, H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. Published in Science Express on July 6, 2006. Science. Available from http://www.sciencemag.org.

Answer the following questions:

- How has fire frequency and severity increased in the American West since the 1980s?
- What elevations have seen the most increase in fire?
- Why are early snowmelt years linked to increased frequency and severity of fire?

D. Summary question for the Building Block 3: What future factors might influence the ability of forests to sequester carbon and thus mitigate human emissions of fossil fuels?

Students could write a short essay (3-5 pages) summarizing what they have learned from the readings and activities in Building Block 3. Alternatively, the instructor can lead an active discussion around this broad question.

Part 4. Seasonal cycle of atmospheric CO_2 concentrations
Use the activity, Seasonal cycle of atmospheric CO_2 concentrations

Global patterns in green-up (i.e., bud burst) and green-down (i.e., senescence) causes annual fluctuations in the atmospheric CO_2 concentrations. Plants take up CO_2 from the atmosphere through photosynthesis and release CO_2 back to the atmosphere through respiration.

Have students work through this activity to explore how green-up and green-down impact atmospheric CO_2.

Potential modifications to this activity:

- Have students pick measurement sites in land cover regions identified in activity (2) above (e.g., tundra, desert, tropical forests).
- Questions to explore when examining the seasonal cycle of CO_2 measurements at these different sites:
    - Do you notice any patterns in the atmospheric CO_2 measurements at each measurement location? If yes, what does this pattern represent?
    - Do the relative maximum and minimum concentrations align for each data set or measurement location? If not, why do you think they are different?
    - Why is the decline in atmospheric CO_2 concentrations (in northern hemisphere) so much faster than the rise?
    - How do the amplitudes of the seasonal cycles differ between measurement stations (e.g., station in northern versus southern hemisphere)? Which sites exhibit the greatest seasonal variability? Can you explain the differences?

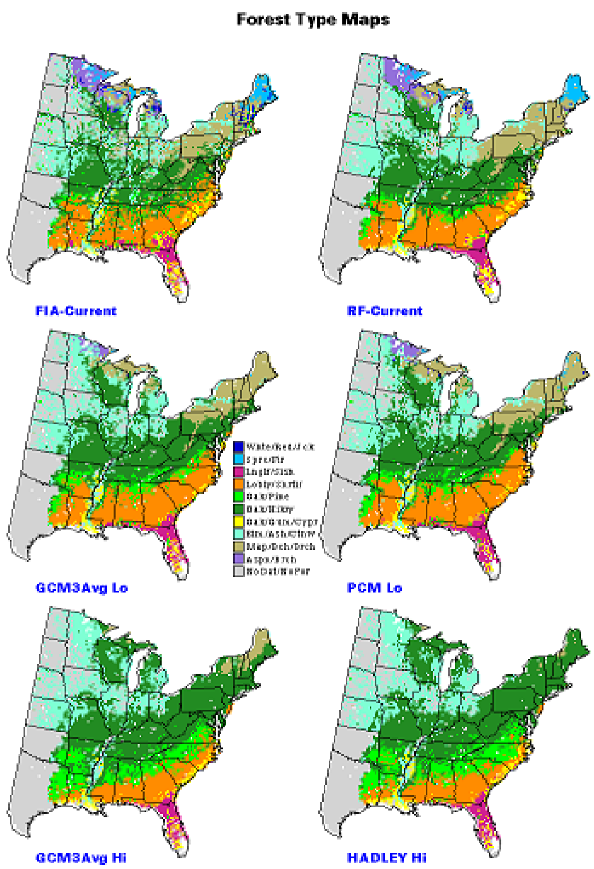
Part 5. Carbon sequestration in campus trees

Using an allometric approach, this activity has students use a set of calculations to determine the net carbon sequestration in a set of trees. It builds on the knowledge gained in activities 1-3 above and helps students explore the amount of carbon stored by different tree species.

Part 6. Scope of land use management for climate change mitigation
[Wisconsin carbon budget tool]

Students use an interactive model of carbon dioxide concentrations to determine the total amount of carbon that would need to be sequestered in trees and soils in order to lower atmospheric CO2 to 350 ppm, assuming fixed fossil fuel emissions. They can then calculate the total biomass of trees that would represent.

Part 7. Fifty year forest management plan for eastern USA forest ecosystems based on climate model projections, [USDA Forest Service Climate Change Tree Atlas]



[NOTE: This part of the lesson plan is still under development]

This project serves as a capstone activity for the Carbon Sequestration in Forests module.
Students develop land-use strategies or plans to maximize a forests role as a carbon sink integrating species composition, habitat preferences, reforestation, afforestation, and tree age class information into their plans.

Time Frame: Semester-long project, to be submitted near the end of the semester (preferably with enough time for students to present their forest management plans to the rest of the class using a science symposium format)

Learning Goal: Students develop a management plan for a forest ecosystem in the eastern U.S. projecting 50 years into the future.

Investigation Questions:

1. What is the vulnerability of regional tree species and forests to present and future climate change?
2. What is the direct effect of elevated CO2 levels, along with accompanying changes in climate, on forest ecosystems (e.g., altered ecosystem structure, potential stimulation of net primary productivity)?

Students will:

- Use the USDA Forest Service Climate Change Tree Atlas to construct models that compare current and projected tree distributions in a national forest or national park
- Visualize current tree species distribution maps and projected suitable habitats using Google Earth
- Describe several abiotic limiting factors (climate, soil, elevation) for the distribution of selected tree species
- Assess habitat suitability for selected trees species distributions based on six climate model scenarios
- Explain the assumptions and of the six climate models
- Evaluate the effectiveness of the habitat suitability models to predict habitat suitability for specific tree species
- Synthesize current and projected habitat suitability data and models to develop a forest management plan that includes suggested species to plant with in the next 50 years to retain maximum tree species diversity

Background Reading:

- In a Forest's Breath, Deciphering Climate Clues: http://cleanet.org/resources/42816.html
- Intergovernmental Panel on Climate Change. 2007. Synthesis Report. [IPCC AR4 Synthesis Report, 2007] (Acrobat (PDF) 5.4MB May16 12)

- Reliability of Climate Models used in the IPCC Report. 2007. FAQ 8.1 IPCC 2007 FAQ 8.1 Climate Models Reliability (Acrobat (PDF) 141kB May16 12)

References

CLEAN activities used in this module

- In a Forest's Breath, Deciphering Climate Clues: http://cleanet.org/resources/42816.html
- Ecology of Climate Change, http://cleanet.org/resources/42811.html
- Global patterns in Green-up and Green-down, http://cleanet.org/resources/41847.html
- Pine Bark Beetle Outbreaks and Climate, http://cleanet.org/resources/42874.html
- Mountain Pine Beetles, http://cleanet.org/resources/42733.html
- Seasonal cycle of atmospheric CO_2 concentrations, http://cleanet.org/resources/42680.html
- Carbon Sequestration in Campus Trees, http://cleanet.org/resources/43158.html
- Global Carbon Budget 1960 – 2100, Wisconsin carbon budget tool: http://cleanet.org/resources/43024.html

Additional resources

- Emerald Ash Borer Information, http://www.emeraldashborer.info
- Emerald Ash Borer Fact Sheet http://www.emeraldashborer.info/files/Multistate_EAB_Insecticide_Fact_Sheet.pdf
- Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity, by A.L. Westerling, H.G. Hidalgo, D.R. Cayan, and T.W. Swetnam. Published in Science Express on July 6, 2006. Science. Available from www.sciencemag.org.
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- USDA Forest Service Climate Change Tree Atlas, http://www.nrs.fs.fed.us/atlas/tree