Are forests helping in the fight against climate change?

Featured scientist: Bill Munger from Harvard University
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Research Background:

As humans drive cars and use electricity, we release carbon in the form of carbon dioxide (CO_2) into the air. Because CO_2 helps to trap heat near the surface of the earth, it is known as a **greenhouse gas** and contributes to climate change. However, carbon is also an important piece of natural ecosystems, because all living organisms contain carbon. For example, when plants **photosynthesize**, they take CO_2 from the air and turn it into other forms of carbon: sugars for food and structural compounds to build their stems, roots, and leaves. When the carbon in a living tree's trunk, roots, leaves, and branches stays there for a long time, the carbon is kept out of the air. This **carbon storage** helps reduce the amount of CO_2 in the atmosphere. However, not all of the CO_2 that trees take from the air during photosynthesis remains as part of the tree. Some of that carbon returns to the air during a process called **respiration**.

Another important part of the forest carbon cycle happens when trees drop their leaves and branches or die. The carbon that the tree has stored breaks down in a process called **decomposition**. Some of the stored carbon returns to the air as CO_2, but the rest of the carbon in those dead leaves and branches builds up on the forest floor, slowly becoming soil. Once carbon is stored in soil, it stays there for a long time. We can think of forests as a balancing act between carbon building up in trees and soil, and carbon released to the air by decomposition and respiration. When a forest is building up more carbon than it is releasing, we call that area a **carbon sink**, because overall more CO_2 is "sinking" into the forest and staying there. On the other hand, when more carbon is being released by the forest through decomposition and respiration, that area is a **carbon source**, because the forest is adding more carbon back into the atmosphere than it is taking in through photosynthesis.

In the 1990s, scientists began to wonder what role forests were having in this exchange of carbon in and out of the atmosphere. Were forests overall storing carbon (carbon sink), or releasing it (carbon source)? Bill is one of the scientists who decided to explore this question. Bill works at the Harvard Forest in central Massachusetts, a Long-Term Ecological Research site that specializes in setting up big experiments to learn how the environment works. Bill and his team of scientists realized they could measure the CO_2 coming into and out of an entire forest. They built large metal towers that stand taller than the forest trees around them and use sensors to measure the speed, direction, and

CO_2 concentration of each puff of air that passes by. Bill compares the CO_2 in the air coming from the forest to the ones moving down into the forest from the atmosphere. With the CO_2 data from both directions, Bill calculates the **Net Ecosystem Exchange (or NEE for short)**. When more carbon is moving into the forest than out, NEE is a negative number because CO_2 is being taken out of the air. This often happens during the summer when trees are getting a lot of light and are therefore photosynthesizing. When more CO_2 is leaving the forest, it means that decomposition and respiration are greater than photosynthesis and the NEE is a positive number. This typically happens at night and in the winter, when trees aren't photosynthesizing but respiration and decomposition still occur. By adding up the NEE of each hour over a whole year, Bill finds the total amount of CO_2 the forest is adding or removing from the atmosphere that year.

Bill setting up a large metal tower in Harvard Forest in 1989, used to measure long-term CO_2 exchange.

Bill and his team were very interested in understanding NEE because of how important it is to the global carbon cycle, and therefore to climate change. They wanted to know which factors might cause the NEE of a forest to vary. Bill and other scientists collected data on carbon entering and leaving Harvard Forest for many years to see if they could find any patterns in NEE over time. By looking at how the NEE changes over time, predictions can be made about the future: are forests taking up more CO_2 than they release? Will they continue to do so under future climate change?

Fill in the table below with information and definitions from the Research Background.

Forest processes	**Forest is a carbon source or sink?**	**Net Ecosystem Exchange (NEE) is positive or negative?**
More carbon given off by respiration and decomposition than is taken in by photosynthesis.	carbon source	(+) positive
More carbon taken in by photosynthesis than is given off by respiration and decomposition.	carbon sink	(-) negative

 Name____________________

Scientific Question: Is the Harvard Forest a carbon source or a carbon sink, and how has the net ecosystem exchange (NEE) changed over time?

Scientific Data:

Use the data below to answer the scientific question:

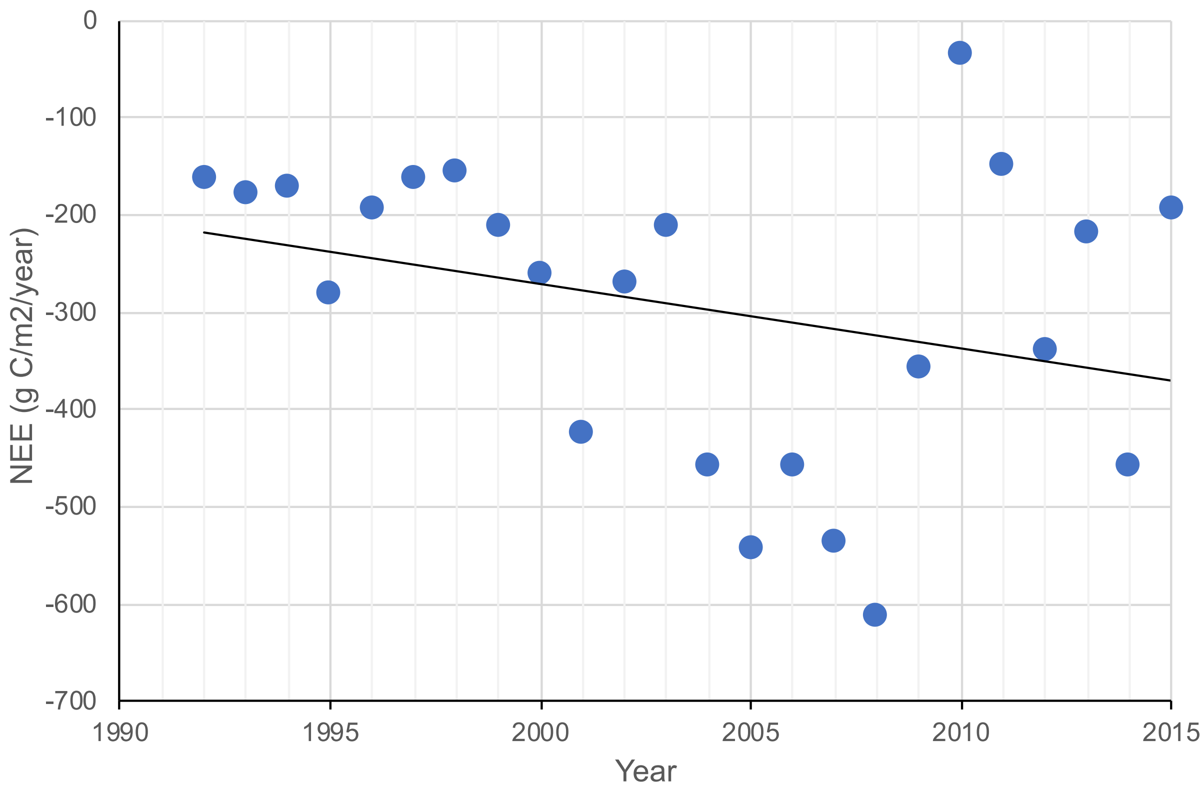
Year	NEE (grams carbon/ meters2/year)
1992	-164
1993	-179
1994	-173
1995	-282
1996	-194
1997	-163
1998	-157
1999	-213
2000	-261
2001	-426
2002	-270
2003	-212
2004	-458
2005	-543
2006	-458
2007	-537
2008	-612
2009	-358
2010	-36
2011	-150
2012	-339
2013	-218
2014	-459
2015	-194

What data will you graph to answer the question?

Independent variable: year

Dependent variable: NEE (grams C/meters^2/year)

Draw your graph below: Identify any changes, trends, or differences you see in your graph. Draw arrows pointing out what you see, and write one sentence describing what you see next to each arrow.



> **Teacher Note:** After students have drawn their graphs, have a class discussion on value of long-term data. What is the importance of long-term data collection? Is it really necessary to collect data for so long? Could we learn this same information by collecting data for a shorter time span? As an exercise, have students look at the data only five years at a time by covering up portions of their graphs. Would students make the same claim with only five years of data as opposed to 23?

Interpret the data:

Make a claim that answers the scientific question.

The Harvard Forest acts as a carbon sink. There is a general pattern of NEE becoming more negative over time, meaning that the forest is becoming a stronger carbon sink over time.

What evidence was used to write your claim? Reference specific parts of the table or graph.

NEE has been negative at Harvard Forest every year in the data series (1992-2015), with a range of -36 to -612. There is a negative trend in the graph as well, shown by the negative slope of the line of best fit.

Explain your reasoning and why the evidence supports your claim. Connect the data back to what you learned about how the processes of photosynthesis, respiration, and decomposition influence the carbon cycle in forests.

The consistent negative NEE is strong evidence that suggests that the forest acts as a carbon "sink": each year, it removes more CO_2 from the air than it produces. This means that more CO_2 is being removed from the atmosphere via photosynthesis than is returning via decomposition and respiration. Over the last 25 years, there has been a general pattern of NEE becoming more negative (although there is lots of variability, especially in more recent years). This means that the forest is becoming a larger sink and removing more CO_2 from the atmosphere over time. These long-term data suggests that forests are helping to reduce the total CO_2 in the atmosphere.

Teacher Note: There are many things that can cause variability in NEE over time. Initially, Bill and other scientists thought that forests would tend to be carbon sinks when they were young and growing rapidly, but eventually the NEE would be neutral, or close to zero, as they aged. On the other hand, other factors such as changes in climate, the length of the growing season, or CO_2 concentration in the air might boost photosynthesis compared to decomposition and respiration, resulting in negative NEE. The key to understanding NEE is that it is the result of three processes: photosynthesis, respiration, and decomposition. Therefore, variability can come from many, sometimes unexpected, places. One illustration of this is light: changes in light levels (say due to cloudiness) will change photosynthesis a lot, but hardly affect decomposition or respiration at all.

You may also notice that the variability in NEE from year to year seems to have increased over this time period. Bill and his colleagues are still not sure why this might be happening. One idea they have is that photosynthesis might respond much more quickly to things like changing weather or disturbances than decomposition does. This could mean that some years those two processes get out of sync. Another idea they have is that the length of the growing season (the season when plants can photosynthesize!) is changing due to climate change. This could also cause variability in NEE from year to year, depending on how long that year's growing season was. There are lots more reasons why this could be happening though, so it is still a work in progress!

Your next steps as a scientist:

Science is an ongoing process. What new question do you think should be investigated?

There are a number of possibilities for thoughtful answers to the following questions. See the following Teacher Note.

> **Teacher Note:** One natural next step in this process has been to try and figure out: 1. Why is the forest a carbon sink? 2. Why is the forest storing gradually more carbon over time (ie why NEE is becoming more negative)? These questions are currently under investigation by scientists at the Harvard Forest and elsewhere. One hypothesis is that as CO_2 concentrations increase in the atmosphere, trees can increase how quickly they photosynthesize and grow (because trees use the CO_2 to grow, this is similar to providing more "food" for the trees). Alternative hypotheses include other factors that might increase growth and photosynthesis, such as warmer and wetter weather, or changes to the amount of dead wood and its decay rate.

What future data should be collected to answer your question?

Independent variable(s): temperature, precipitation, CO_2 concentration, etc.

Dependent variable(s): NEE (grams C/ meters^2/year)

For each variable, explain why you included it and how it could be measured.

Because we would like to isolate the *mechanism* driving the pattern we observed in the long-term data, we should try to follow a two-step process. First, we can look through the observational data for clues. For example: was there a general increase in CO_2 concentration over the same time period that the NEE was getting more negative? Were the years that had the most negative NEE the warmest, or the wettest? Once we find a likely suspect in our observational data, the next step is to design an experiment. Experiments help us to isolate individual factors in a way that help us understand which ones might be responsible for the response we see. For this type of question, scientists have set up large scale manipulations: large pieces of forest that get altered in some way. For example, there are several experimental forests where scientist have set up systems that increase the CO_2 levels in the air in a patch of forest. By comparing the tree growth in the parts of the forest receiving extra CO_2 to the parts that are not receiving any extra, we can determine if increased CO_2 levels in the air is (in part) responsible for the pattern we see in NEE!

At the Harvard Forest, scientists have also been investigating what happens to forests as the temperature changes. By experimentally warming the soil, scientists are testing how decomposition and respiration in soil might respond to a warmer climate. In this case, increases in temperature might cause the forest to become less of a carbon sink, as warmer temperatures might accelerate decomposition and respiration.

What hypothesis are you testing in your experiment? A hypothesis is a proposed explanation for an observation, which can then be tested with experimentation or other types of studies.

Example hypothesis: Increasing CO_2 concentration causes trees to photosynthesize and grow more, which removes more carbon from the atmosphere. This helps explain the general pattern we see in NEE over time at the Harvard Forest.

Additional teacher resource related to this Data Nugget:

For more information on this research, check out the Harvard Forest page on their long-term carbon exchange research:
http://harvardforest.fas.harvard.edu/major-research-topics/major-research-topics/forest-atmosphere-exchange

A PowerPoint to accompany this Data Nugget with images of Bill and his research in Harvard forest, and diagrams of NEE and carbon sources and sinks:
http://datanuggets.org/wp-content/uploads/2018/08/Harvard-Forest-NEE-powerpoint.pptx

Do your students want to get involved with research monitoring carbon cycles in forests? Check out "Our Changing Forests", a hands-on field investigation led by a team of Ecologists at Harvard Forest. Students can contribute to this study by monitoring a 20 meter by 20 meter plot in a wooded area near their schools.
http://harvardforest.fas.harvard.edu/Our_Changing_Forests

There are several publications related to the data included in this activity. PDFs of all papers can be found at http://harvardforest.fas.harvard.edu:8080/exist/apps/pubs/pb-pdf.html

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