Photo by Babs McDonald.

Everything but the Carbon Sink:

Carbon Storage in the Southern United States

What Kinds of Scientists Did This Research?

plant ecologist: This scientist studies the relationship of plants with one another and with other organisms in the environment.

plant pathologist: This scientist studies plant diseases.

systems ecologist: This scientist studies the way an ecosystem functions as a whole. An ecosystem is a community of plant and animal species interacting with one another and with the nonliving environment.

systems modeler: This scientist uses an understanding of relationships to construct models illustrating those relationships. Models are simple versions of more complex things. Some examples are model cars or airplanes. Models can also be built with mathematics, words, and maps.

Meet the Scientist

Hanqin Tian,
SYSTEMS ECOLOGIST AND MODELER:

My favorite science experience is discovering how ecosystems work. I study how energy is transferred from the Sun to **producers** and then to **consumers**. I am also interested in how the carbon cycle interacts with other cycles, and how ecosystems develop over time and space. In the photo, I am showing that grasses in my backyard produce three to four times more root **biomass** than aboveground biomass. Grass roots, therefore, keep carbon on earth, which may help slow climate warming.

Thinking About Science

Environmental scientists are interested in how the natural environment works. The natural environment includes all of the living and nonliving things found naturally in an area. Some of these scientists are interested in how the natural environment responds to change. In this research, scientists wondered about change occurring over a span of more than 100 years. To study this change, the scientists used data that had been collected over that many years.

The scientists entered the data into a computer program called a model. The computer model included mathematical equations. The scientists observed changes recorded over a 100-year period. They then developed equations based on the recorded changes. For example, a scientist may observe that the water level in a forest stream drops 1.10 centimeters for every 2 weeks without rain. With this knowledge, the scientist can create an equation that will predict the stream's water level for any number of weeks without rain.

In this research, the scientists were interested in whether an area of land and forests absorbed more carbon than it released into the atmosphere. With the use of a computer model, the scientists were able to identify a pattern over more than 100 years.

Number Crunch

▶ **How many inches is 1.10 centimeters? Multiply 1.10 by 0.3937 to find out.**

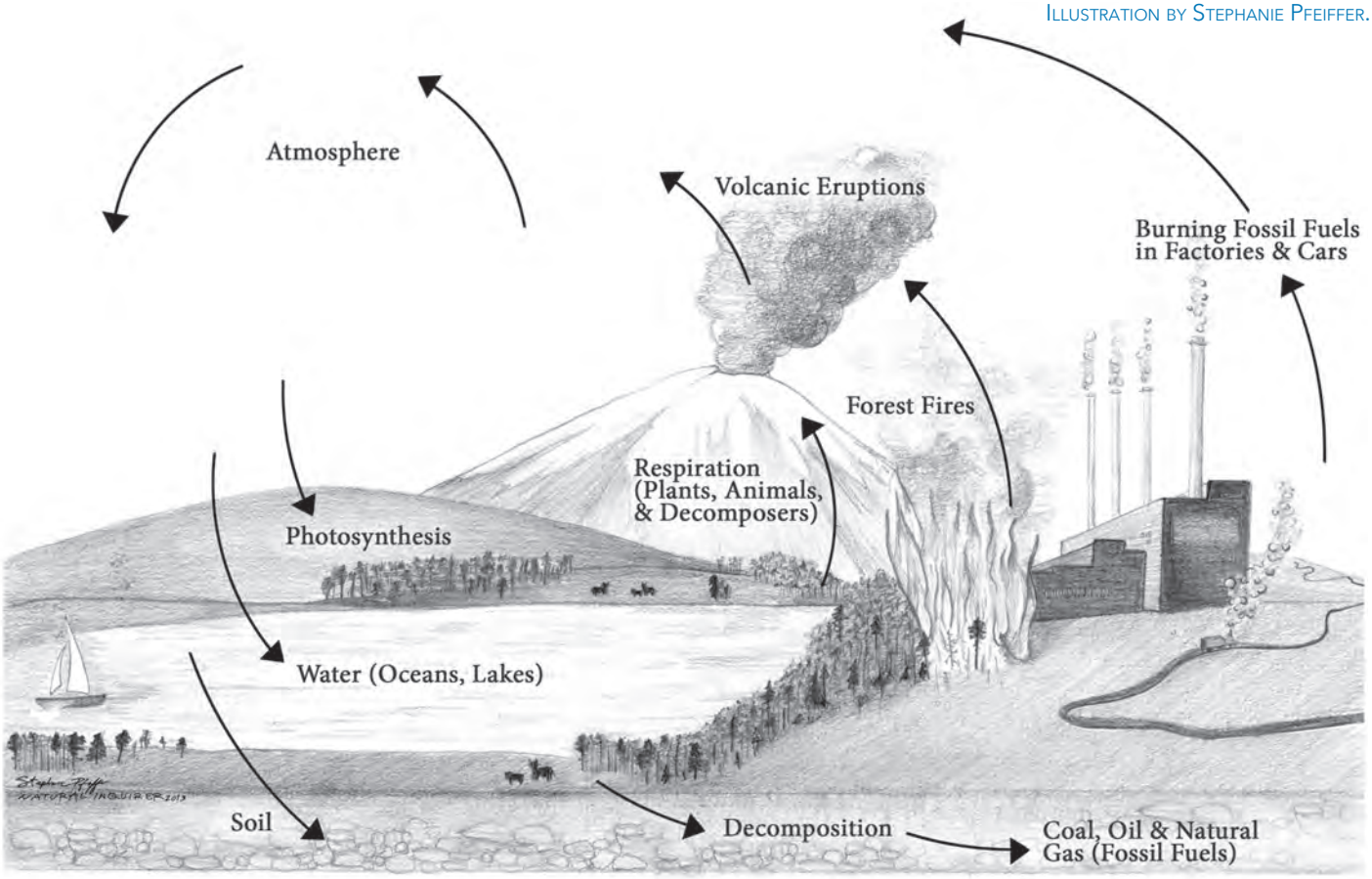
Thinking About the Environment

GLOSSARY WORDS ARE IN **BOLD** AND DEFINED ON PAGE 21.

All living and once-living matter contains the element carbon. Think about your own body. A human body contains about 18 percent carbon. The carbon in plants is produced from **atmospheric** carbon dioxide through **photosynthesis**. Plants, therefore, are called producers. Humans get their carbon from eating plants and from eating animals that eat plants. Animals, including humans, are called consumers. A plant contains carbon as long as it lives, and until it completely decays or is burned. Soil and water bodies also contain carbon.

Carbon is held by plants, soil, and water bodies, but some carbon is also released back into the atmosphere. Carbon dioxide, therefore, continually cycles between the atmosphere and Earth (FIG. 1). This exchange occurs in the form of carbon dioxide. A carbon source is when more carbon is released by the environment than is produced through photosynthesis. A carbon sink is when more carbon is produced through photosynthesis than is released to the atmosphere.

FIGURE 1.
THE CARBON CYCLE.
ILLUSTRATION BY STEPHANIE PFEIFFER.



Introduction

The scientists in this study were interested in environmental changes occurring in the Southern United States (FIG. 2). The scientists were interested in changes occurring over a long time. In particular, the scientists were interested in the following environmental changes:

- Increasing atmospheric carbon dioxide
- Increasing ozone
- Increasing nitrogen on Earth
- Climate change (Climate change is the long-term change in global weather patterns, especially increases in temperature, storm activity, and **precipitation**)
- Changes in land use (FIG. 3)

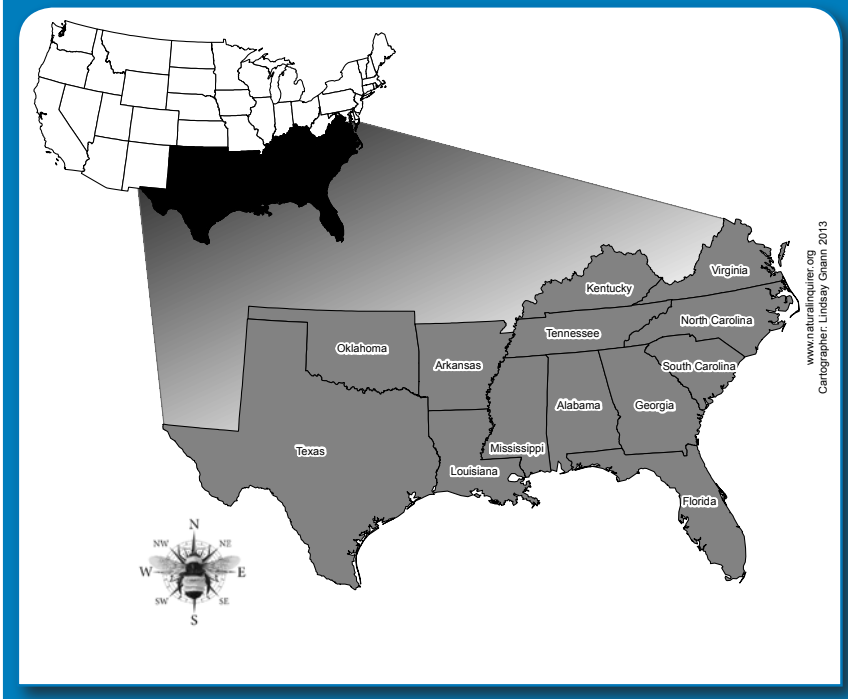


FIGURE 2. THE FOREST SERVICE DESCRIBES THE SOUTHERN UNITED STATES AS CONSISTING OF 13 STATES.
MAP BY LINDSAY GNANN.

PHOTOS BY BABS MCDONALD.

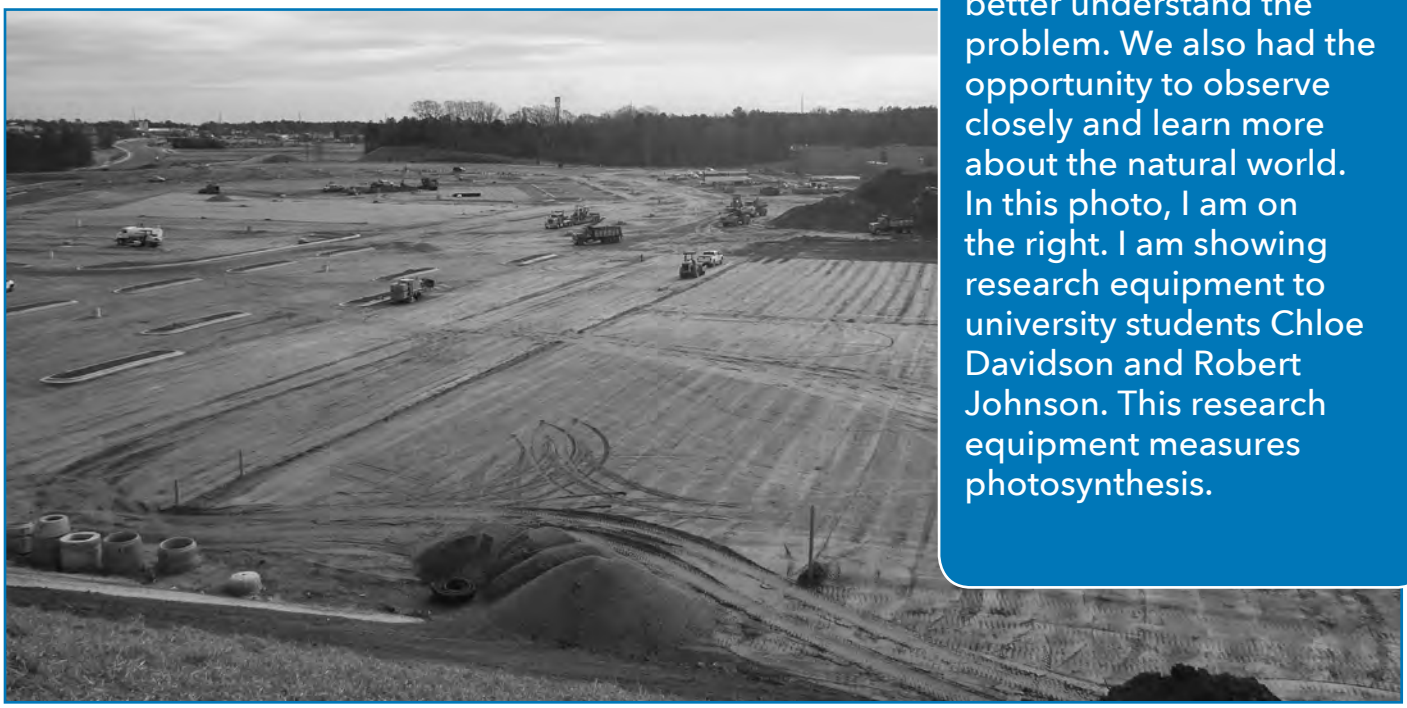
FIGURE 3. LAND USE IS THE TYPE OF COVER THAT IS FOUND ON ANY GIVEN PART OF EARTH'S SURFACE. LAND USE EXAMPLES INCLUDE FORESTS, FARMS, SHOPPING CENTERS, CITIES, HOMES, ROADS, AND WATER BODIES. WOULD YOU CALL YOUR SCHOOLYARD OR BACKYARD A TYPE OF LAND USE? WHY?

The scientists were interested in how these five changes will affect the carbon cycle of the Southern United States (See fig. 1).

Carbon dioxide continually cycles between Earth and the atmosphere. In the past, this cycling created an average balance over time between atmospheric carbon dioxide and carbon on Earth. Over the past 100 years, however, human activities have increased the amount of carbon dioxide released to the atmosphere. Carbon dioxide is released when trees are removed for development (fig. 4) and when **fossil fuels** are burned for energy.

Human activities have caused other changes. **Tropospheric** ozone, another gas, helps protect Earth from the Sun's **ultraviolet radiation** (fig. 5). When fossil fuels are burned, however, too much ozone is produced near Earth's surface. This ozone contributes to creating a kind of air pollution called smog.

Figure 4. When trees are removed and burned to make room for urban development, the carbon in the trees is released into the atmosphere. In this example, the carbon balance and land use are affected. Besides tree removal, identify one more source of atmospheric carbon dioxide in this photo.



Photos by Babs McDonald.

Meet the Scientist

Dafeng Hui,
Plant Ecologist:

My favorite science experience is working with students to collect experimental data in the field. It is always a pleasure to **stimulate** students' interests and bring new students to this research area. When students work on real-world issues, they learn quickly and better understand the problem. We also had the opportunity to observe closely and learn more about the natural world. In this photo, I am on the right. I am showing research equipment to university students Chloe Davidson and Robert Johnson. This research equipment measures photosynthesis.

Another long-term change involves nitrogen. Human activities have caused an increase in nitrogen on Earth's surface. Nitrogen is released when fossil fuels are burned for energy. Much of this nitrogen returns to Earth. Nitrogen is also used as a crop fertilizer. Over time or in large amounts, nitrogen adds too much acid to plants, soil, and water bodies. In the short term or in smaller amounts, nitrogen can cause an increase in plant growth. This growth occurs because the plants are able to use nitrogen as a **nutrient**.

The scientists were interested in land use changes over the past 100 years. Over time, for example, forests have been cut and regrown. Farms have been **cultivated** and abandoned. Land developed for buildings and roads is one type of land use change that is not usually reversed (FIG. 6).

FIGURE 5. THE ATMOSPHERE'S LEVELS. IN WHICH LEVEL IS OZONE FOUND? ILLUSTRATION BY NICKOLA DUDLEY.

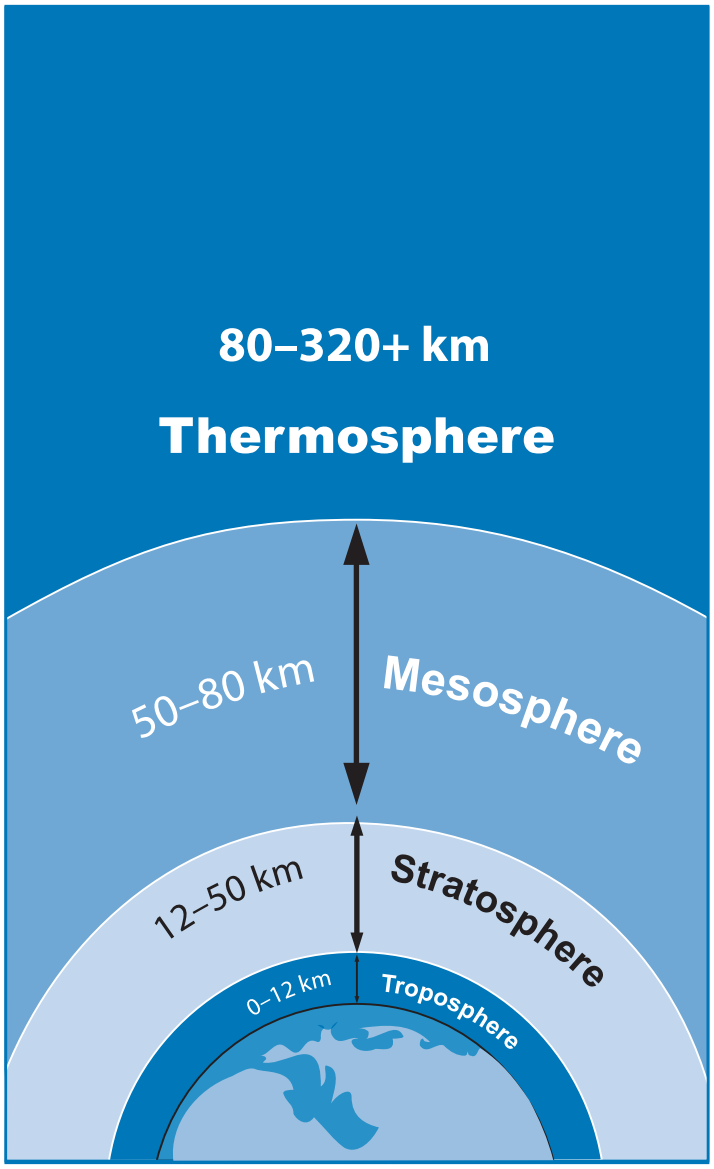


FIGURE 6. SOME KINDS OF LAND USES ARE MORE EASILY CHANGED THAN OTHERS.

PHOTOS BY BABS MCDONALD.

The scientists were also interested in the changing climate. Over the past 100 years, the average yearly temperature has been rising around the world. This average rising temperature may have an effect, for example, on where and how much rain falls.

The scientists in this study wanted to know how these environmental changes have affected how land in the Southern United States holds carbon or releases it to the atmosphere. The scientists wondered if the Southern United States has been a carbon source or a carbon sink over the past 100 years. A carbon source is when more carbon is released by the environment than is produced through photosynthesis. A carbon sink is when more carbon is produced through photosynthesis than is released to the atmosphere.

Reflection Section

- What was the question the scientists wanted to answer? Be specific about what the scientists were studying.
- What is one of the primary reasons for many of the changes studied by the scientists in this study?

Meet the Scientist

Art Chappelka,
Plant Pathologist:

My favorite science experience is studying how plants respond to pollutants and to a changing climate. Plants continually respond to their environment in ways that we can see and also in ways that we cannot see. Plants cannot move away from unfavorable conditions. Because they cannot move, plants have developed complex ways to respond when conditions are not favorable.

What Is Net Carbon Exchange?

A carbon sink or carbon source is measured by the amount of carbon absorbed or released over a period of time. The measurement does not include the carbon already present in the plant, soil, or water body.

Think about your own body. Each time you take a breath, you breathe in an amount of oxygen. You also expel an amount of carbon dioxide. Your body, however, contains additional amounts of each gas. The **volume** of oxygen coming in could be compared with the volume of carbon dioxide going out.

Scientists compare the amount of carbon dioxide absorbed in an area with the amount being released. Any excess amount determines whether an area is a carbon sink or source. Scientists measure the excess quantity over time. This quantity is called net carbon exchange or NCE. A positive NCE value indicates a carbon sink. A negative NCE value indicates a carbon source. By measuring NCE, scientists observe and record changes in carbon storage over time.

Methods

The scientists were interested in studying environmental changes that have occurred over the past 100 years. They used data that were collected between 1895 and 2007 across the Southern United States (FIG. 7).

The scientists divided the Southern United States into a grid of blocks 8 kilometers by 8 kilometers in size (FIG. 8). A value for each **variable** in figure 7 was calculated and assigned to each block.

FIGURE 7. THE SCIENTISTS USED THE FOLLOWING DATA THAT WERE COLLECTED BY OTHER SCIENTISTS BETWEEN 1895 AND 2007. THESE DATA ARE CALLED VARIABLES, BECAUSE THEIR VALUE CAN CHANGE OR VARY.

The amount of carbon dioxide in the atmosphere
The amount of ozone in the atmosphere
The amount of nitrogen fertilizer being used for agriculture
The amount of acid in the soil
The amount of nitrogen released on Earth's surface through burning fossil fuels
The average yearly temperature
Minimum and maximum yearly temperatures
The amount of yearly rainfall and snowfall
The amount of land in acres in various land use categories in certain years, including forests, farmland, and urban land
Net Carbon Exchange (NCE, for short): This is a measure of the amount of carbon produced through photosynthesis, minus the amount of carbon dioxide released into the atmosphere from various sources.

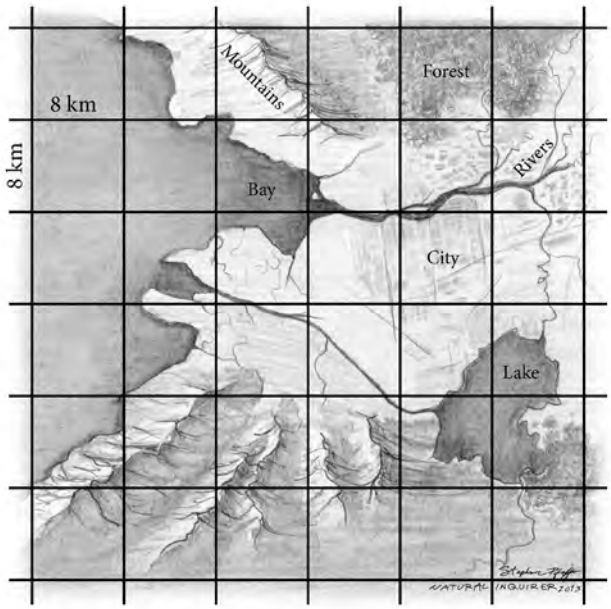


FIGURE 8. THE ENTIRE SOUTHERN UNITED STATES WAS DIVIDED INTO A GRID OF BLOCKS 8 KILOMETERS LONG ON A SIDE. THIS EXAMPLE SHOWS A LAND AREA DIVIDED INTO A GRID.

ILLUSTRATION BY STEPHANIE PFEIFFER AND LINDSAY GNANN.

The scientists entered all of the data into a computer. The scientists developed a computer program, called a model, to **analyze** the data. The model used equations to calculate NCE. The scientists then compared all combinations of variables in figure 7 with the value NCE. This process was done for each block in the grid over the entire 112 years. Then all of the data in all blocks were averaged to produce values for the entire Southern United States.

Number Crunches

- How many years of data did the scientists gather?
- How many miles across is the side of each block in the grid? Multiply the number of kilometers by 0.62 to find out.
- How many square kilometers are contained in each block?
- How many square miles are contained in each block?

Reflection Section

- What is one advantage of using data collected by another scientist?
- What is one disadvantage of using data collected by another scientist?
- Explain NCE in your own words. What would an NCE value of 0 mean?
- Which is more desirable in today's world: A carbon sink or a carbon source?

Number Crunch work area

Science Fun Fact:

What Is a Petagram?

A petagram (Pg) is a unit of measurement. A Pg is equal to 10^{15} grams, which is 10x10x10x10x10x10x 10x10x10x10x10x10 x10x10x10, which is 1,000,000,000,000,000 grams, or one quintillion grams. One Pg of carbon is equal to the weight of 25,000 elephants.

The scientists in this study estimated the amount of carbon stored in the Southern United States' plants and soil. Their estimate of total storage was 26 Pg of carbon. According to the United Nations Food and Agriculture Organization, trees store 289 Pg of carbon worldwide. The world's trees, soil, and **leaf litter** store an estimated 653 Pg of carbon.

Findings

The findings in figure 9 show values for NCE in the Southern United States over three time periods.

FIGURE 9. NET CARBON EXCHANGE (NCE) IN THE SOUTHERN UNITED STATES FROM 1895 TO 2007. A NEGATIVE VALUE INDICATES A CARBON SOURCE.

	Percent change	NCE in petagrams
1895 → 1951	4.11	-1.20
1951 → 2007	7.12	2.00
1895 → 2007	2.72	0.80

Number Crunches

▶ What percentage of the world's **terrestrial** carbon is stored by plants and soil in the Southern United States? Divide 26 by 653 to find out.

▶ How many elephants would equal the weight of all of the carbon held in the plants and soil of the Southern United States? Multiply 26 Pg by 25,000 elephants to find out.

The Southern United States was a carbon sink for the period of 1895–2007, over which there was an increase in terrestrial carbon of 0.80 Pg (SEE FIG. 9). This amount accounted for 2.7 percent of the total carbon stored across the entire Southern United States in 1895. Between 1895 and 1950, however, the Southern United States was a carbon source of 1.20 Pg. Between 1951 and 2007, the Southern United States was again a carbon sink, storing an additional 2.0 Pg of carbon. The scientists believe that the Southern United States was a carbon source

between 1895 and 1951 because many acres of forest land were cleared for agriculture. From the 1950s until the late 1900s, many of these agricultural lands were abandoned and forests grew back.

Overall, the scientists found that changes in land uses over the past 112 years have had a negative impact on carbon storage in the Southern United States. The scientists discovered that different kinds of land use stored different amounts of carbon (FIG. 10). The application of nitrogen fertilizer and an increase in nitrogen released on Earth had a positive impact on carbon storage. This positive impact is from the beneficial effects of nitrogen on plant growth. When plants grow, more carbon is stored.

Climate change, as an individual variable, appeared to have little direct impact on carbon storage in the Southern United States. However, when considering that most of the other variables studied had an impact on climate

PHOTOS BY BABS MCDONALD.

FIGURE 10. WHICH LAND USE STORES THE MOST AMOUNT OF CARBON?

change, some of the change in carbon storage can be **indirectly** related to climate change.

Although the Southern United States was a carbon sink over the past 112 years, many factors influenced carbon storage positively and negatively. Some factors related to climate change had a negative effect, for example, but were **offset** by increased nitrogen and the application of nitrogen fertilizer. Land use change had a negative effect, but was offset by an increase in the amount of forest land in the Southern United States.

Reflection Section

- Land use in the Southern United States is changing, with more land developed for homes, shopping centers, roads, and office parks. If this trend continues, do you think the Southern United States will remain a carbon sink or will it once again become a carbon source? Why?
- Think about the finding that even though the Southern United States was a carbon sink over the past 112 years, many factors influenced carbon storage positively and negatively over this time period. This finding highlights that scientists do not always get absolute answers to their questions. Pretend that you are one of the scientists on this study. How would you explain to the press the importance of discovering that both positive and negative factors influence carbon storage?

Discussion

The scientists found that an increase in atmospheric carbon dioxide and nitrogen created a carbon sink over the time period. Increases in ground-level ozone, urban development, and a changing climate contributed most to carbon losses.

The scientists noted that the list of variables they considered was incomplete. Forest management, for example, could affect NCE but was not included in the model. Hurricanes, fires, and other natural disturbances were also not included in the model. If these variables were included, NCE estimates might be different.

The scientists said that additional research is needed to better understand how changes on the planet contribute to the carbon balance between Earth and the atmosphere.

Photos by Babs McDonald.

Reflection Section

- How might an increase in atmospheric carbon dioxide help create a carbon sink?
- What is the paradox of an increase in atmospheric carbon dioxide helping to create a carbon sink? A paradox is a situation that is unexpected because it defies logic or reason.
- Why is it important to understand how human-caused changes contribute to NCE?

Adapted from Tian, H., Chen, G., Zhang, C. [and others]. 2012. Century-scale responses of ecosystem carbon storage and flux to multiple environmental changes in the Southern United States. Ecosystems. 15: 674-694. http://www.srs.fs.fed.us/pubs/ja/2012/ja_2012_tian_002.pdf

Glossary

analyze (**a** nə līz): To study or examine carefully.

atmospheric (at mə **sfēr** ik): Of, relating to, or occurring in the atmosphere. The atmosphere is the whole mass of air surrounding Earth.

biomass (**bī** ō mas): Living matter.

consumer (kən **sü** mər): A person or thing that consumes or uses something. In this case, consumers are animals that eat plants and other animals.

cultivate (**kəl** tə vāt): Prepare for planting.

fossil fuel (**fä** səl **fyü(-ə)**l): Fuel, such as coal, petroleum, or natural gas, formed from the fossilized remains of plants and animals.

indirect (**in** dī rekt): Not straightforward and open; not directly aimed at.

leaf litter (**lēf li** tər): The top layer of dead and decaying leaves, small sticks, and twigs that lay on the forest floor.

nutrient (**nü** trē ənt): A substance that plants, animals, and people need to live and grow.

offset (of **set**): To serve as a counterbalance for or to compensate for.

photosynthesis (**fō** tō **sin(t)** thə səs): The process by which green plants use sunlight to form sugars and starches from water and carbon dioxide.

precipitation (pri **si** pə **tā** shən): Rain, hail, snow, mist, or sleet.

producer (prō **dü** sər): An organism (such as a green plant) viewed as a source of living matter that can be consumed by other organisms.

stimulate (**stīm** ü lāt): To excite to activity, greater activity, or growth.

terrestrial (tə **res** t(r)ē əl): Of or relating to land as opposed to air or water.

tropospheric (trō pə **sfēr** ik): Of or relating to the part of the atmosphere, measured from the surface of the planet to about 6 miles.

ultraviolet radiation (**əl** trə **vī** (ə-)lət **rā** dē **ā** shən): Light waves located beyond the visible spectrum at its violet end and having a wavelength shorter than those of visible light but longer than those of X-rays.

variable (**ver** ē ə bəl): Something that is able or apt to vary.

volume (**väl** yüm): The amount of a substance.

Accented syllables are in **bold.** Marks and definitions are from http://www.merriam-webster.com.

FACTivity

Time Needed
30–40 minutes

Materials

- Photo sheets and answer sheets provided in this FACTivity
- Pencil
- Blank paper or science notebook (optional)

In this research, you learned about carbon sinks and carbon sources. You learned about different land uses and whether they are more likely to be a carbon sink or source. The questions you will answer in this FACTivity are: What are the characteristics of an area identified as a carbon sink? What are the characteristics of an area identified as a carbon source?

Methods

You may work individually, in pairs, or in small groups. Examine the two photo sheets provided in the next section. Identify whether you believe each photo shows an area that is a carbon sink or a carbon source. Your teacher may make copies of the answer sheet, or you may use the one in this journal.

On the answer sheet, indicate whether each photo is a carbon sink or a carbon source. Then, explain what makes the area a sink or a source by writing one or two complete sentences. Recall that a carbon sink is an area that absorbs more carbon through photosynthesis than it releases. A carbon source is an area that releases more carbon than it absorbs through photosynthesis. Then, rank all of the photos from one to eight. Rank the photos from the most powerful carbon sink to the most powerful carbon source.

On your own, write a short paragraph describing the main characteristics of a carbon sink. Write a short paragraph describing the main characteristics of a carbon source. These paragraphs should be based on your photo observations and evaluations. Use complete sentences with proper grammar and punctuation.

Your teacher will lead a class discussion about what makes an area a carbon sink or a carbon source. As a class, discuss your rankings. Did everyone agree and if not, why not? As a class, determine whether the area around your school is a carbon sink or source. To do this, your class must first agree on how large an area you will consider. Then, identify three opportunities to improve the area's status as a carbon sink. Write these three ideas in complete sentences and develop a plan to implement them in the area around your school.

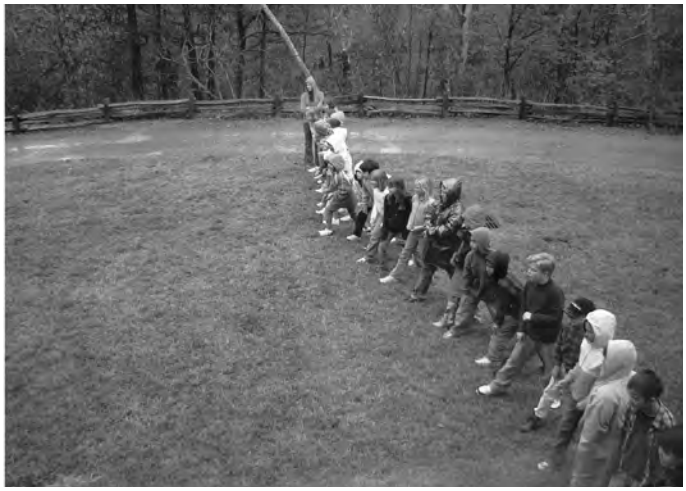
Carbon sink or carbon source?

1

2

Photos by Babs McDonald.

3



4

Carbon sink or carbon source?

5

6

Photos by Babs McDonald.

7

8

NOTE: 1 is most powerful carbon sink, 8 is the most powerful carbon source.

Photo	Carbon sink or source?	Why is this area a carbon sink or a carbon source? (1–2 sentences)	Rank order from 1-8
1			
2			
3			
4			
5			
6			
7			
8			

Describe the obvious visual characteristics of a carbon sink.	Describe the obvious visual characteristics of a carbon source.	Three ways to improve our schoolyard's status as a carbon sink are:

FACTivity Extension

To complete this extension, you must have either a smartphone or a digital camera. Using your smartphone or camera, take five photos of areas around your community that are carbon sinks. Take five photos that are carbon sources. Share your photos with the class and describe why you think the area is a carbon sink or source. As a class, identify ways to move the carbon source areas toward carbon sinks.

Web Resources

A Student's Guide to Global Climate Change by the U.S. Environmental Protection Agency
http://www.epa.gov/climatestudents/

Climate Kids: NASA's Eyes on the Earth
http://climatekids.nasa.gov/

NOAA Climate Change for Students
http://www.education.noaa.gov/Climate/

Pachamama: Our Earth--Our Future
http://www.grida.no/publications/other/geo2000/pacha/

U.S. Environmental Protection Agency Ozone Web site
http://www.epa.gov/glo/

An Article about Fossil Fuels and the Nitrogen Cycle
http://news.mongabay.com/2009/0604-hance_nitrogen.html

✱"Everything but the Carbon Sink" is taken from the saying "Everything but the kitchen sink." This saying means that nearly everything possible is being included, usually when someone is taking items from a place.

If you are a trained Project Learning Tree-educator, you may use *Our Changing Climate* or *Our Changing World* as additional resources.