Carbon's Trip Through Earth's Spheres

Monica Cohen

Introduction

St. Georges Technical High School is one of four public vocational-technical high schools in New Castle County, Delaware. The students represent diverse backgrounds – urban Wilmington, suburban Newark, and rural Middletown. The unique draw for a technical high school like ours is the ability for students to study a trade and graduate with a certification or license with the opportunity to delve directly into the workforce. Our students apply to St. Georges for a variety of reasons: learn a family trade, learn in a safer school environment when compared with a feeder high school, or earn a certification to join the workforce instead of continuing to a post-secondary school. With each graduating class, approximately fifty percent of students directly enter the workforce, an apprenticeship, or post-secondary trade school. The remaining fifty percent continue on to a four-year college/university, or a branch of the military.

The technical trades school environment offers students a distinctive high school experience. Each student earns a certificate or license in their field of study upon graduation. The trades offered to our students are as diverse as the students themselves; ranging from nursing to carpentry, web design to culinary, automotive technology to early childhood education, and a dozen other options. Students study their chosen career path in addition to the state-mandated academic courses offered within St. Georges. I am one of the science instructors within the building; teaching biology to sophomores. This unit has been developed for biology, a required course for graduation by the state of Delaware. The topics covered in this course are as follows: ecology, cell biology, genetics, and evolution. This unit is intended to be incorporated into the ecology section of the course where nutrient cycles and the conservation of matter are studied.

As a fully-inclusive school, students of all ability levels, both regular education and special education students, are placed in the same class and therefore it is important for the instructor to differentiate each lesson. Following the blended learning educational model, this unit provides students with several choices in how they learn, express their knowledge, the pace at which they learn, and utilize technology to enhance their overall learning experience. Within the blended model, the teacher becomes a facilitator while the student becomes the gatherer, organizer, and applier of information. My role as a facilitator is to provide students with appropriate resources and experiences to extract information and scaffold the lesson.

The unit is modified to match a remote learning setting where all activities are converted into electronic resources; however, some activities can be modified to allow student movement around a classroom with the use of stations. All activities have been altered to be independent learning experiences to accommodate the remote setting, with the ability for student collaboration in the classroom. The unit is also shorter than the time typically allotted due to time constraints and limited access between student and instructor. It is important that the teacher carefully identifies multiple modes of formative assessment throughout the unit to ensure all students are able to display their full understanding of the content. The consistent formative assessment of student comprehension is extremely important in a remote setting because there are fewer opportunities to explore and explain misconceptions.

The state of Delaware has adopted the Next Generation Science Standards (NGSS) and is currently implementing them into the high schools. There has been an increase in the number of standards being taught in tenth-grade biology; therefore, the amount of depth able to reach is limited. The goal is to increase student engagement and motivation into their own learning through the exploration of skills. Beginning with a phenomenon, students create their own questions, cultivating their own interest in Biology. The main skills assessed in this unit are investigating scientific concepts, supporting claims using evidence, and developing models.

Rationale

This unit is designed for students to investigate ways in which humans positively and negatively impact the natural carbon cycle by exploring the flow of carbon atoms through Earth's systems. It is intended to supplement the current curriculum as ecology encompasses almost half of the course. Many ecology concepts are built off of the student's understanding of the carbon cycle and conservation of matter. In this unit, students create and analyze models and make predictions based on the movement of carbon atoms in carbon's varying forms for multiple real-world scenarios. Students use maps while investigating the phenomena of Toronto, Canada's tree planting ordinance. The city of Toronto's policy is designed to combat climate change by positively impacting the carbon cycle. At the end of the unit, students apply their knowledge of the carbon cycle and human impacts to a unique scenario; deforestation taking place in the Amazon rainforest. The carbon cycle unit is the Biology course's avenue to teach the concept of conservation of matter. It is intended to be an overview of the movements of carbon, while subsequent ecology units delve deeper into the specific processes of photosynthesis and cellular respiration (see my previous unit from DTI, "Where did the light go?" for more details). The goal of this unit is to incorporate authentic examples by having students analyze area maps and carbon data, as it relates to human impacts into climate change and the overall cycling of carbon.

The unit is introduced using Toronto, Canada's Every Tree Counts program. Students are familiarized with Toronto's goal of increasing their tree canopy cover from 17-20% to 30-40% over a 50-year time span.[1] Using maps of the city and tree sequestering data, students are making observations and developing questions (notices and wonders) that are used to predict explanations for how planting trees positively impacts climate change. Throughout the unit, students create and analyze models, manipulate simulations, use maps to observe change, and use case studies to explore human impacts. Students are assessed in their ability to apply their knowledge and understanding to a new phenomenon. Students implement the knowledge and skills from this unit towards other topics studied throughout the course. Skills reinforced in this unit include, analysis of data, using data to make predictions, and using writing to communicate thoughts and ideas. The unit is able to be conducted in a remote setting as well as in collaborative groups.

As a result of completing the curriculum unit, students are able to explain the carbon cycle and predict how human activities impact the movement of carbon by analyzing maps and data. Students are able to incorporate knowledge of conservation of matter and the carbon cycle into their written and verbal responses supporting explanations of factors affecting climate change. This unit provides students a foundation to analyze any human impact as it relates to global warming and climate change. It also lays the foundation for the subsequent units that delve deeper into specific areas of the carbon cycle and correlate the conservation of matter to the conservation of energy. By the end of the unit, students have a greater understanding of the carbon cycle and both positive and negative ways in which humans influence the cycling of carbon.

Content Objectives

With the completion of this unit, students will be able to:

- Explain how human activities influence the movement of carbon through Earth's spheres.
- Use map analysis to inform explanations about changes in ecosystems.

Background Content

Earth's Spheres

Earth is divided into four spheres, excluding a new category to include human actions: atmosphere, hydrosphere, biosphere, and geosphere. The atmosphere is the gaseous layer above Earth's surface. Students typically think of this layer as air. This unit focuses on two gases within this layer, carbon dioxide and methane. The hydrosphere consists of any water found on Earth's surface. The biosphere includes all living organisms; both terrestrial and aquatic. It is important to distinguish the difference between the biosphere and hydrosphere because students confuse organisms inhabiting the oceans as being part of the hydrosphere, when in fact, these organisms are considered part of the biosphere who happen to live in the hydrosphere. The geosphere is the largest composed of all Earth's rocks and soil.

Cycling of Carbon

Carbon is constantly in flux as it moves between Earth's spheres. There are numerous pathways that a carbon atom can travel as it cycles between reservoirs. Depending on carbon's location, atoms have been rearranged to create various organic and inorganic molecules through chemical processes. Plants convert carbon dioxide from the atmosphere into glucose by the process of photosynthesis. An average mature tree is capable of absorbing forty-eight pounds of carbon dioxide annually.[2] The glucose produced as a result of photosynthesis is a form of sugar and is either stored within the parts of a plant or broken down and used during cellular respiration. For a more in-depth look at the processes of photosynthesis and cellular respiration, visit my unit "Where did the light go?". Please note that this unit specifically focuses on the movement of and transformation of carbon atoms and therefore does not introduce the other inorganic molecules involved in specific chemical reactions nor does it discuss the energy flowing through the system. Once carbon has been acquired by plants, both terrestrial and aquatic photosynthetic organisms, the glucose produced is used in the chemical process of cellular respiration converting carbon atoms back into carbon dioxide. This production of carbon dioxide is released back into the atmosphere. Cellular respiration is a life process required by all living organisms. The glucose stored in plants has the potential to be consumed by other organisms. During consumption, glucose is broken down and rebuilt into other organic molecules required by the specific organism, including being rebuilt into other glucose molecules. Similar to trees, the glucose can be stored to grow and develop an organism or it can be released back into the atmosphere during cellular respiration.

The process of consumption is considered decomposition when the organism that is doing the consuming are decomposers, such as worms, maggots, fungi, and other microorganisms. Decomposers break down dead organisms to recycle the matter to the soil, atmosphere, or aid in their own growth and development. Since they too are living organisms, they also complete the process of cellular respiration, returning carbon to the atmosphere in the form of carbon dioxide. Carbon cycled into the geosphere has the potential to become a fossil fuel over millions of years. Fossil fuels are considered coal, oil, and natural gas; each able to be refined into usable energy by humans. Prior to the industrial revolution, this carbon reservoir was unable to be accessed and thus fossil fuels are considered a carbon sink – the ability to store carbon for long periods of time. This notion of human impact on the carbon cycle is discussed in an upcoming segment of the Background.

Carbon dioxide from the atmosphere is constantly being exchanged with the carbon dioxide in the oceans. As carbon dioxide reacts with the water, carbonic acid is produced. Earth's oceans absorb approximately 30% of the carbon dioxide in the atmosphere.[3] The increase in carbonic acid has acidified the oceans, causing damage to ecosystems and coral reefs. The increase in acidity is largely caused by human activities and is discussed further in the Human Impact section below.

Although carbon atoms are constantly in flux between Earth's four spheres, the total number of carbon atoms does not change as explained by the law of conservation of matter. Matter is unable to be created or destroyed, yet atoms can be rearranged into new molecules. As carbon continues to increase in the atmosphere and hydrosphere, there are a number of ways that carbon is decreasing in both the biosphere and geosphere. Students are familiar with the law of conservation from previous science courses, typically as it pertains to balancing equations of energy. Students struggle with comprehending the law of conservation on a global scale so utilizing data is helpful to make this concept more tangible. As carbon from the atmosphere dissolves into the oceans, the amount of carbon in the hydrosphere increases. Humans are decreasing the amount of carbon in the geosphere reservoirs through the process of combustion, adding 37.1 billion metric tons of carbon globally to the atmosphere in 2018.[4] Using available data, students are able to calculate the total amount of carbon in gigatons on Earth before and after the Industrial Revolution. Noticing that the total amount of carbon does not change as reservoirs fluctuate over time, students understand the idea of conservation of matter on a global scale.

Human Impact

Prior to the Industrial Revolution that took place in Europe in the mid-1700s, human civilizations did not disrupt the natural cycling of carbon any more than returning carbon dioxide to the atmosphere through cellular respiration. However, the Industrial Revolution allowed humans to mass produce goods in factories which required more energy than simple machines that harnessed natural energy, such as wind and water. Humans turned toward fossil fuels as easy and cheap energy. With increased ability to access coal, oil and natural gas, humans are depleting these natural carbon sinks faster than they are able to be restored. After mining and drilling for these reserves, the fossil fuels are subsequently burned through the process of combustion and converted into energy for the electrical grid and other needs. The carbon that was once stored in the geosphere as fossil fuels is being released into the atmosphere as carbon dioxide. After the Industrial Revolution, societies became increasingly reliant on the energy quantities produced by fossil fuels, propelling the redistribution of carbon from the geosphere to the atmosphere.

Since the only two ways for carbon dioxide to naturally be removed from the atmosphere is through photosynthesis and oceanic absorption, it has become increasingly difficult for these reservoirs to continue balancing out the amount of carbon dioxide introduced to the atmosphere from combustion of fossil fuels. Unfortunately, large forests such as the Amazon are being burned, deforested, and converted into crop land and agricultural land. Analyzing false-colored satellite images, it is clear to distinguish the slight variations in land cover – areas converted to croplands, pastures, or newly exposed soil.[5] The using bright colors allows the viewer to identify the smallest differences in land-use that would otherwise be difficult to differentiate between in true color. Carbon once stored in trees, as glucose, is returned to the atmosphere as carbon dioxide when forests are burned or when trees are taken down followed by their burning for energy. The global vegetation is calculated to absorb twenty percent of fossil fuel emissions; however, the accuracy of this number is debated due to constant land use changes.[6] Deforestation is the process by which trees are cleared in vast forests making room for urbanization or agricultural land. There is conflicting data reported pertaining to deforestation and forest loss. Global Forest Watch analyzes satellite data to determine approximately 72.6 million acres of tree cover were lost in 2017.[7] However this data does not include forest regrowth that potentially occurred after a naturally-occurring wildfire or other temporary reduction in forest, accounting for seventy-three percent of the 72.6 million lost acres.[8] When considering global regrowth, it is estimated that 12.4 million acres of forest have been permanently destroyed and converted into agricultural sites.[9] The permanent destruction of forests prevents carbon dioxide from being removed from the atmosphere, and if the trees are burned, for example, in a wildfire, additional carbon dioxide is added to the atmosphere.

Oceans absorb a large percentage of carbon dioxide in the atmosphere creating an increasingly acidic environment for living organisms that inhabit these areas. As carbon continues to diffuse into the oceans, the shells of invertebrates have a difficult time developing and calcifying. Coral reefs undergo coral bleaching and eventually lead to the death of reefs. Even the 0.1% decrease in pH has had great impact on the fragile ecosystems.[10]

Even though humans have dramatically altered the location where carbon molecules are stored through negative activities, there recently have been positive actions taken by communities. For example, students are introduced to the unit by the actions Toronto is undertaking by planting trees as a way to absorb more carbon dioxide from the atmosphere to alleviate climate change. Studies have shown that focusing on reforestation and preventing further deforestation is extremely important in order to prevent a two-degree Celsius increase in global temperature.[11] There has been a surge in electric automobiles that do not require fossil fuels in order to run. Many cities and towns have begun to access alternative forms of energy as a way to provide power to its citizens. The unit does not focus on positive human actions with the exception of explaining if Toronto's tree policy will be successful over time.

Toronto's Every Tree Counts program was initiated in 2007 with a goal to increase the amount of forest cover to thirty-five percent in the city over fifty years.[12] It was initially calculated that the majority of forest cover is found in the parks. Prior to the start of the program, local parks had the most stable forest cover at forty-four percent, while industrial and commercial forest cover was at four and five percent respectively.[13] With approximately twenty percent of tree coverage, it is estimated that Toronto's trees are able to store 1.1 million metric tons of carbon annually, and sequester an additional 46,000 metric tons of carbon per year.[14] The amount of carbon stored refers to the amount of carbon in the tree's biomass: its trunk, bark, roots, and branches; while the amount a tree is able to sequester is the carbon absorbed during photosynthesis and used for cellular processes, much of this is used and not stored. Younger trees grow more rapidly and therefore sequester more carbon than store, in contrast to older trees that store more carbon than they sequester; it is maintaining a balance between the varying tree maturity that can optimize the forest benefits.[15] In the first few years of the program, approximately eighty-four thousand trees were planted annually; however, between 2008 and 2018 an average of 120 thousand trees were planted annually.[16] [17] The continuous planting of new trees will lead to the additional removal of carbon dioxide from the atmosphere.

Importance of Maps

Satellite data has become increasingly important for monitoring forest cover changes since the early 1970s. Deforestation in the Amazon has been precisely monitored by satellite systems beginning in 1998, with an additional satellite system added in 2004 after the Brazilian government ordered the protection of the rainforest ecosystem.[18] DETER, the second satellite system, provides daily coverage of the forests and are able to notify local authorities with deforestation alerts within a day.[19] After Brazil's ordinance in 2004, forest clearing decreased by nearly eighty percent by 2012; however, within this time frame, forest clearing dramatically increased in Columbia and Peru.[20] The maps have been falsely-colored and overlayed to distinguish the amount of forest loss each year.[21] It is this constant monitoring that has made forest management at the large scale possible. As technology improves, microwave signals are currently being used to observe subtle land changes to see through the cloud cover in these areas.[22] Analysis of satellite data has uncovered that more than half of the potential to restore global tree cover can be found in six countries: Russia, USA, Canada, Australia, Brazil, and China.[23] These countries have the most potential to restore tree cover, due to the largest removals of tree cover.[24] Having the capability to observe changes in tree cover and land use, increases the potential to mitigate current climate problems.

Teaching Strategies

This unit focuses on the Next Generation Science Standards which are developed to create a three-dimensional learning experience. This unit focuses on multiple Crosscutting Concepts: cause and effect, the cycling of matter, and stability and change. The Scientific and Engineering Practices that the unit highlights include: developing and using models; analyzing and interpreting data; and obtaining, evaluating, and communicating information. The third dimension, Disciplinary Core Ideas, is solely focused on conservation of matter. The intention behind these standards and this unit are for students to develop a scientific understanding of the world around them and be able to apply the knowledge to new scenarios.

A Notice and Wonder activity is a strategy currently used in science classrooms when engaging with introductory phenomena. Students are asked to make observations (notices) and ask questions (wonders) about phenomena to drive their learning in a unit. This tool helps students to better engage with text, data sets, graphs, and images because they become more adept at observing and making connections and are then able to incorporate prior knowledge to the scenario.

Modeling allows students to display their understanding of a topic with few to no parameters. Models in this unit are used in various contexts. Some models are developed for students to analyze and make observations. Other models act as scaffolds in student learning where students are asked to complete the model with their current understanding of the content. In the final assessment of the unit students develop their own model based upon data and text provided to explain what is occurring in the Amazon rainforest with deforestation.

Simulations are an integral part of this unit and are completed electronically or through the use of stations. With remote learning, all stations were converted into electronic simulations for students to experience and complete independently, however in a typical classroom setting, half of the simulations are designed as stations while others are electronic. Simulations allow students to channel their "inner carbon atom" and travel to different carbon reservoirs to learn what happens as carbon moves. For this unit, simulations have students explore the many possibilities for carbon to travel between Earth's spheres. Some simulations are better at representing the many possible movements of carbon, while others are better at reinforcing the idea that carbon can become stuck or trapped in some reservoirs and easily accessed in other reservoirs. It is important that the lesson includes both types of simulations to best explain the idea of carbon flux.

Classroom Activities

Notice and Wonder Class Discussion

Students are presented with data about Toronto's tree planting initiative. Students observe data and images ranging from aerial views of Toronto streets, graph of number of trees planted annually, and carbon storage versus sequestration data, all of which are available in *Every Tree Counts* document.[25] Students are asked to view the data for a few moments in silence and are reminded that "Notices" are simple observations of the data, and they are not to make inferences about what the data means. Students are prompted to either type their notices into the chat box, or the instructor may opt to call on individual students. I prefer to have students type directly in the chat and this way all students have the opportunity to share ideas in a relatively short amount of time. The teacher reads aloud some of the observations made by students.

After students have the opportunity to make observations about the data, students are asked to "wonder" about the data. These "wonder" questions propel student learning for the unit. Wonder questions are inferences about the data and what the images are trying to explain. Students might wonder why there is a difference in the amount of carbon stored versus carbon sequestered, or why planting trees would make a difference to Toronto, or how can tree cover be measured using satellite images. These questions are revisited throughout the unit so students can try and answer the questions posed before any learning took place.

Carbon Cycle Game

Students explore the movement of a typical carbon atom through Earth's spheres. In a remote setting it is important to model all aspects of this activity – station movement and drawing a model – during a Live video session prior to students attempting the activity. All materials that would typically be stations are converted into electronic resources. Students are introduced to the terms carbon sink and carbon source because at the end of the activity, they will be asked to identify what type of carbon reservoir they spent the longest time in. The game begins by individual students choosing a carbon reservoir to commence their journey; it is advised that students do not begin their journey at the fossil fuel station or the deep ocean station because they are carbon sinks and there are few opportunities for students to leave the station once they arrive. After choosing one of the available stations, students roll the electronic die and read the scenario for what happens to the carbon atom and to what sphere they travel to next. The process of rolling a die and moving between stations continues for at least twelve rolls, providing students enough time to move through multiple locations while not being too repetitive. The instructor can opt to have students complete more stations if they desire; however, it should not be expected that students make it to every reservoir.

After virtually traveling between stations, students create a model of their travels. Scientific models include an image, arrows, and appropriate labels. This part of the activity is modeled at the beginning of the lesson and a copy of the sample model is made accessible to students on a learning management platform to go back to and view. Each student drawing is unique because the carbon pathway experienced varies between students. I would recommend using a "media album" for student submissions – available on Schoology. This type of submission allows students to upload their own drawings, with the ability to view their classmate's work.

With access to their peer's drawings, students complete a modified gallery walk. A remote-style gallery-walk entails students viewing each other's work and completing a graphic organizer to identify patterns. The instructor should preview the work prior to another Live virtual session to provide discussion opportunities surrounding the idea that there are multiple smaller cycles within the carbon cycle.

Culminating Application Assignment

Students analyze provided data and maps of the Amazon Rainforest to determine how changes in the ecosystem impact the overall carbon cycle. Global Forest Watch's interactive map provides geographic information of tree cover gain and loss between 2001 and 2019, allowing for exploration into deforestation and land use.[26] NASA's Earth Observatory project has mapped the Amazon with more detailed explanations of land use; what areas have been cleared for cattle and areas cleared for cropland.[27] Students are able to explain that deforestation prevents carbon dioxide in the atmosphere from moving into the biosphere and cycling through Earth's systems. A decrease in carbon dioxide removed from the atmosphere through photosynthesis consequently leads to an increase, or build up, of carbon dioxide in the atmosphere. This increase in atmospheric carbon dioxide impacts the changes in global climate.

As a component of the assignment, students are asked to create a model to explain how the change in the Amazon biosphere impacts the cycling of carbon. Based on the data and their understanding of the carbon cycle, students represent a decrease in the amount of carbon dioxide leaving the atmosphere. This representation is in the form of the thickness of arrows. In a remote setting, students create their models, snap a photograph, and upload their images to a submission location. This assignment includes a verbal or written explanation of the model depicted.

Appendix A: Implementing District Standards

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.

This unit focuses on the student's ability to develop a model and illustrate their understanding of carbon atoms moving through Earth's spheres. Students are exposed to the concepts of photosynthesis and cellular respiration, but delve deeper into the specific chemical changes in a future unit.

Appendix B

This unit is written with a remote learning setting in mind; however, with minor modifications the unit can be altered to support both a hybrid and in-person learning settings. With all three learning scenarios, a learning management system, such as Schoology, is used as a place to house assignments and resources. My traditional teaching style models that of a blended learning model; students work at their own pace and have choice in their learning. Another focus of this teaching style is to provide students with the opportunity to work individually as well as in collaborative groups.

The introductory Notice and Wonder activity is written to take place in a face-to-face manner, whether over video conference or in-person. The goal is to allow students to make observations about data and develop questions that future activities help them answer. In a virtual setting, the instructor may choose to call on students to share or have them write in the available chat feature as participation opportunities. For both hybrid and traditional classrooms, this activity would have students taking turns and sharing ideas in a classroom. The teacher records student notices and wonders to refer back to throughout the unit.

Modeling for this unit can take place in a variety of ways conducive to all learning scenarios. Students may opt to develop their own individual model electronically, through such programs like Google Drawings or Google Slides, or on paper and upload a photograph of their model to the learning management system for classmates to view and comment. However, this can also be completed in a traditional learning environment where groups of students create models in the form of posters and have the opportunity to present to their peers. This activity is ideal for students to accomplish as groups in a traditional classroom setting where student proximity is not limited; however, having students develop individual models gives greater insight into their understanding. In a hybrid scenario, it is best to continue having students work as individuals, yet there is greater opportunity for students to explain their thinking to each other.

Simulations in science are extremely important for student engagement and understanding. This unit modified a carbon cycle game where traditionally, students would travel about the classroom to simulate the movement of carbon. The activity was converted to meet the needs of a remote or hybrid environment that does not allow students to use common materials or be in close proximity with one another. Students are provided the stations, an electronic copy of the worksheet, and a link to an electronic die. In a traditional setting, the stations would be placed around the room and students would roll dice to inform their travels between stations. Students are asked to create a drawing to represent their unique travels through Earth’s systems and submit them electronically. If students were in-person with each other, whether hybrid or traditional, a gallery walk could be conducted or student samples could be shared using a document camera.

Teacher Resources

Ceven, Jennifer. n.d. *The Carbon Cycle Game.* Accessed December 23, 2020. https://climatechangelive.org/img/fck/file/carbon_cycle_game.pdf.

This is a sample Carbon Cycle Game complete with stations and activity sheet. The instructor has the ability to convert this activity into either physical stations for in-person learning or electronic materials for remote or hybrid learning.

Global Forest Watch. 2016. Accessed December 6, 2020. https://www.globalforestwatch.org/map/?map=eyJjZW50ZXIiOnsibGF0IjotMC45NDUyMzkyNTIyOTEzMzgyLCJsbmciOi00OC4xMTcxODc0OTk5OTc1OH19.

This interactive map students access during the culminating application assignment. Students manipulate the map layers to visualize tree cover gain and tree cover loss.

NASA. 2019. *Tracking Amazon Deforestation from Above.* December 20. Accessed December 6, 2020. https://earthobservatory.nasa.gov/images/145988/tracking-amazon-deforestation-from-above.

The satellite images within the article are used for student analysis during their culminating application assignment. The article focuses on the importance of satellite imagery in monitoring the Amazon and has images, both still and time-lapse, for students to observe.

Bibliography

Birminghan, University of. 2017. *Role of terrestrial biosphere in counteracting climate change may have been underestimated.* Accessed October 11, 2020. www.sciencedaily.com/releases/2017/01/170130110930.htm.

This resource provides data on the amount of carbon dioxide the biosphere is able to absorb annually.

Global Forest Watch. 2016. Accessed December 6, 2020. https://www.globalforestwatch.org/map/?map=eyJjZW50ZXIiOnsibGF0IjotMC45NDUyMzkyNTIyOTEzMzgyLCJsbmciOi00OC4xMTcxODc0OTk5OTc1OH19.

This resource is an interactive map that the students are accessing during the culminating application assignment. Students manipulate the map layers to visualize tree cover gain and tree cover loss.

Harvey, Chelsea, and E&E News. 2018. *CO2 Emissions Reached an All-Time High in 2018.* December 6. Accessed October 11, 2020.

https://www.scientificamerican.com/article/co2-emissions-reached-an-all-time-high-in-2018/.

This website provides recent data on carbon dioxide levels being released into the atmosphere from the combustion of fossil fuels.

Leahy, Stephen. 2019. *How to erase 100 years of carbon emissions? Plant trees—lots of them.* July 4. Accessed December 6, 2020. https://www.nationalgeographic.com/environment/2019/07/how-to-erase-100-years-carbon-emissions-plant-trees/.

National Geographic identifies the six countries that have the potential to restore half of the lost tree coverage. It was accessed as background information.

NASA Earth Observatory. 2019. *Mapping the Amazon.* September 27.

This resource provides background information on deforestation in the Amazon rainforest. Many of the images are able to be used in class to promote discussion.

—. 2019. *Tracking Amazon Deforestation from Above.* December 20. Accessed December 6, 2020. https://earthobservatory.nasa.gov/images/145988/tracking-amazon-deforestation-from-above.

This resource provides background information on deforestation in the Amazon rainforest. Many of the images are able to be used in class to promote discussion. The article focuses on the importance of satellite imagery in monitoring the Amazon.

National Oceanic and Atmospheric Administration. 2020. *Ocean Acidification.* April. Accessed October 10, 2020. https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification.

This resource provides background information on ocean acidification and the effects it is having on the local ecosystems. NOAA has updated data as it relates to the interaction between the atmosphere and hydrosphere.

Pearce, Fred. 2018. *Conflicting Data: How Fast Is the World Losing its Forests?* October 9. Accessed October 11, 2020. https://e360.yale.edu/features/conflicting-data-how-fast-is-the-worlds-losing-its-forests.

This article focuses on deforestation and provides relevant background information and data. The article includes a map of the world color-coding the reasons for forest loss.

Stancil, Joanna Mounce. 2019. *The Power of One Tree - The Very Air We Breathe.* June 3. Accessed December 2020.

https://www.usda.gov/media/blog/2015/03/17/power-one-tree-very-air-we-breathe.

This article provides data on the amount of carbon that a single tree is able to absorb in a year. It also identifies the amount of oxygen a single tree releases.

Toronto Urban Forestry. 2020. "Canopy to Toronto." Accessed December 6, 2020. https://www.toronto.ca/legdocs/mmis/2020/ie/bgrd/backgroundfile-141367.pdf.

This is the updated information from Richard Ubbens' Every Tree Counts document that was collected after ten years of the program being in place. Data tables embedded within this article are appropriate for student discussion.

Ubbens, Richard. n.d. "Every Tree Counts: A Portrait of Toronto's Urban Forest." Accessed November 2020. https://www.itreetools.org/documents/349/Toronto_Every_Tree_ Counts.pdf.

This website includes information about Toronto's Every Tree Counts project in addition to relevant data sets used during the Notice and Wonder activity. Sections of the document can be accessed to provide students with background knowledge on the project.

Notes

[1] Ubbens, Richard. n.d. "Every Tree Counts: A Portrait of Toronto's Urban Forest." Accessed November 2020. https://www.itreetools.org/documents/349/Toronto_Every_Tree_ Counts.pdf.

[2] Stancil, Joanna Mounce. 2019. *The Power of One Tree - The Very Air We Breathe.* June 3. Accessed December 2020. https://www.usda.gov/media/blog/2015/03/17/power-one-tree-very-air-we-breathe.

[3] National Oceanic and Atmospheric Administration. 2020. *Ocean Acidification.* April. Accessed October 10, 2020. https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification.

[4] Harvey, Chelsea, and E&E News. 2018. *CO2 Emissions Reached an All-Time High in 2018.* December 6. Accessed October 11, 2020. https://www.scientificamerican.com/article/co2-emissions-reached-an-all-time-high-in-2018/.

[5] NASA Earth Observatory. 2019. *Tracking Amazon Deforestation from Above.* December 20. Accessed December 6, 2020. https://earthobservatory.nasa.gov/images/145988/tracking-amazon-deforestation-from-above.

[6] Birminghan, University of. 2017. *Role of terrestrial biosphere in counteracting climate change may have been underestimated.* Accessed October 11, 2020. www.sciencedaily.com/releases/2017/01/170130110930.htm.
[7] Pearce, Fred. 2018. *Conflicting Data: How Fast Is the World Losing its Forests?* October 9. Accessed October 11, 2020. https://e360.yale.edu/features/conflicting-data-how-fast-is-the-worlds-losing-its-forests.
[8] (Pearce 2018)
[9] (Pearce 2018)
[10] (National Oceanic and Atmospheric Administration 2020)
[11] (Birminghan 2017)
[12] (Ubbens n.d., 49)
[13] (Ubbens n.d., 45)
[14] (Ubbens n.d., 9)
[15] (Ubbens n.d., 56)
[16] (Ubbens n.d., 10)
[17] Toronto Urban Forestry. 2020. "Canopy to Toronto." Accessed December 6, 2020. https://www.toronto.ca/legdocs/mmis/2020/ie/bgrd/backgroundfile-141367.pdf.
[18] (NASA Earth Observatory 2019)
[19] (NASA Earth Observatory 2019)
[20] (NASA Earth Observatory 2019)
[21] (NASA Earth Observatory 2019)
[22] (NASA Earth Observatory 2019)
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