How Forests Store Carbon

This article offers an introduction to how forest store carbon. It describes how forests impact the carbon cycle, and how forests can be used to help combat climate change.

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A mature white oak (Photo credit: Calvin Norman)

The threat of climate change due to increases in carbon dioxide (CO_2) and other pollutants in the atmosphere from human sources has caused some people to become interested in carbon capture and sequestration technology. This includes pumping CO_2 underground into old coal mines and aquifers. While these technologies may work, they are unproven, expensive, and for the most part theoretical.

Fortunately, the best carbon capture technology has already been created: trees and forests. According to the US Forest Service, America's forests sequester 866 million tons of carbon a year, which is roughly 16% of the US annual emissions (depending on the year). Forests sequester or store carbon mainly in trees and soil. While they mainly pull carbon out of the atmosphere—making them a sink—they also release carbon dioxide. This occurs naturally, such as when a tree dies and is decomposed (thereby releasing carbon dioxide, methane, and other gases). The movement of carbon and other gases within forests and soils occurs on a cycle. Forest management can influence these cycles and enhance carbon capture.

Trees

Trees are without a doubt the best carbon capture technology in the world. When they perform photosynthesis, they pull carbon dioxide out of the air, bind it up in sugar, and release oxygen. Trees use sugar to build wood, branches, and roots. Wood is an incredible carbon sink because it is made entirely of carbon, it lasts for years as a standing tree, and takes years to break down after the tree dies. While trees mainly store carbon, they do release some carbon, such as when their leaves decompose, or their roots burn sugar to capture nutrients and water.

Let's look at a real example, a white oak can live for 200 years; all that time it is pulling carbon out of the air and storing it. After several anthracnose outbreaks the tree dies, but it takes decades for the tree to rot. While it is slowly breaking down, the rotten tree is still keeping carbon out of the atmosphere.

Forests capture and store different amounts of carbon at different speeds depending on the average age of the trees in the stand and the number of trees in the stand. Young forests have many trees and are excellent at capturing carbon. Young trees grow quickly and are able pull in carbon rapidly. Not every small sapling becomes a large tree due to competition for light, resources, and growing space, but when they die and decompose little carbon is released. The trees that remain continue to grow and sequester more carbon as the forest matures.

Established or mature forests are made up of "middle-aged trees", which are medium to large, healthy, and have a large root system. Middle-aged trees grow slower than young trees, but the amount of carbon captured and stored is relatively greater. Some of large trees occasionally die, but they are quickly replaced by younger trees who take advantage of the new space. Since more trees are growing compared to those that are dying, the overall net productivity (how many trees grow versus how many die) is positive and carbon capture is enhanced.

Old-growth forests have a more fixed, or less dynamic, carbon cycle within live and dead trees and the soil. In old growth forests, large trees dominate by shading out small saplings, so recruitment of young trees and net productivity is zero. Still, the carbon is well contained within the big trees, slowly rotting logs, thick leaf litter and soil. Large individual trees may take up as much carbon as an individual middle-age tree, but since there are fewer trees in an old growth stand, the total additional carbon capture is often lower.

Soil

The carbon that is sequestered in forests comes in many forms. For example, forest soils contain plant roots, leaf litter, and other dissolved organic material. The amount of carbon stored in forest soils is variable, and how much carbon soil can sequester is dependent on many local factors like local geology, soil type, and vegetation. In some forests, like in Canada by the tundra, the soil holds more carbon than the trees, but in other forests, like the rain forest, the soil holds relatively little carbon and the trees store more carbon. This is because some soil types, like clay soils, can bind up a large amount of carbon, whereas sandy soils are not able to bind much carbon. Soils with more organic material (bits of wood, decaying leaves, or dead creatures) can store more carbon because organic material easily binds loose carbon molecules and the organic material itself is stored carbon. Soils that are frozen for a good part of the year or have a high-water table can also store large amounts of carbon because decomposition is slow.

Permanence

Besides capturing large amounts of carbon, forests are good at storing it for a long time. However, like all things natural, carbon in forests ultimately gets released into the atmosphere through decomposition, respiration, or other methods. Some places are better at storing carbon for long periods than others; this is called permanence. The carbon that makes up a center of a mature white oak remains bound up for a long time. It has been pulled out of the atmosphere a hundred or more years ago, and it will remain bound up until the tree dies and is decomposed. That process can take decades to centuries depending on how long the tree is alive. Carbon captured by a small trillium has little permanence. Trilliums are annual plants, so the aboveground plant dies annually and rapidly decomposes or they are commonly eaten by deer.

Examples

Let's look at how forest growth and soils affect the permanence of forest carbon. The Amazon rainforest appears to be a good place for carbon sequestration because it is full of big trees that grow rapidly. But research has found the Amazon is a poor carbon sink because there is little permanence. Whole trees rapidly decompose in the hot humid climate, the soils are not able to store a lot of carbon.

The near constant rain also helps to break down organic material and wash away soil and nutrients. In contrast, the spruce forests of Alaska are excellent carbon sinks. The spruce grow large, decomposition is slow due to the cold, and the soil is able to lock up carbon in permafrost. Unfortunately, the growth rates in these forests is relatively slow due to the cold temperatures and limited growing season. Changes in global climate are also melting the permafrost, releasing much of the captured carbon. Pennsylvanian forests offer an ideal middle of the road solution. The trees grow well and are long-lived, decomposition occurs at a mild rate, and the soil stores a moderate amount of carbon. This means our forests have great potential to serve as an effective carbon sink and provide long-term carbon storage.

Management Strategies

While carbon capture in trees is a natural process, there are ways to encourage trees to sequester more carbon through forest management. The most important strategy is to keep forests as forests. When forests are converted to other types of land uses, carbon is released and the land loses its potential to store carbon. This does not mean that clear cutting (where silviculturally appropriate) must be stopped. Clear cutting simply resets the forests age and can in fact accelerate carbon capture by growing younger trees. The best way to enhance carbon capture without cutting is to increase forest cover. This can be done by planting old fields with a mix of native trees or restoring old mine sites.

Controlling invasive plant species is another important strategy for enhancing carbon capture. While many non-native/invasive plant species can grow rapidly and appear to be a good carbon sink, they are not. Invasive species disrupt native ecosystems, change the makeup of the local soil microbes, and prevent tree regeneration, all of which interferes with a forest's ability to sequestration carbon. Native trees and plants are adapted to thrive in local conditions and tend to function better as carbon capture mechanisms. Native plants also provide other important benefits such as wildlife habitat.

Practicing sustainable silviculture is essential for ensuring forests remain healthy and can also help enhance carbon capture. Harvesting is considered sustainable when decisions are based on silvicultural knowledge and follow a long-term management plan. Professional foresters are also important for helping owners meet multiple management objectives while maintaining the value of their stands.

Forests that maintain their value are more likely to remain as forests in the future when ownership changes.

Uneven aged stands offer the best carbon capture services, as well as other benefits (e.g., wildlife habitat). In an uneven aged stand, there is continuous recruitment of younger trees, but older trees also remain and help hold carbon for long periods. Uneven aged stand management requires harvesting to occur through single tree or group selection. However, removing individual trees disturbs the soils in the local area. These soils also hold carbon and frequent disturbance over time can turn soils from a carbon sink to a carbon source. To help prevent soil disturbance in these stands it is important to extend the rotation period. For example, a hardwood forest that has been traditionally thinned every 10-15 years should be thinned ever 20-25 years, so the soils have time to recover between entries. In comparison, the rotation of even-aged forests do not need to be extended. In Pennsylvania, these harvests tend to occur every 80 to 100 years, which means the soils can remain undisturbed for long periods.

There are several other best practices you can adopt today for enhancing carbon storage in trees and soils. When harvesting, it is important to reduce damage to the soil. This can be done by putting slash on skid trails, not harvesting in the rain, harvesting in the winter, and using forwarders instead of whole-tree skidding. Harvesting trees that are slowly growing can also contribute to carbon sequestration. Instead of letting mature trees die and decompose, they can be removed and cut into products like 2x4s, flooring, or cabinets which go into homes and buildings and that could be around for centuries. The Liberty Bell is a great example of how high-quality wood products can help store carbon. The wooden yoke of the Liberty Bell is made from American elm harvested in the 1770s (there is some disagree on how old the beam is). Instead of decomposing in a forest centuries ago, the carbon in that wood is still around today holding up the Bell.

Closing Remarks

Forests are an important carbon sink, as both trees and forest soil are able store large amount of carbon for a long time. However, carbon management is not just about deciding which trees to cut, but also where harvesting and planting occurs on the landscape. It is important to maintain a mix of tree ages and forest types with a focus on young and established forests, as these forests capture and sequester the most carbon. However, this does not mean old-growth forest should be sacrificed to create more young forests. This could release large amounts of carbon, and a new forest would take decades to sequester as much carbon as currently stored in the old-growth forest. The key is to use planning and management strategies that help capture additional carbon while minimizing losses of stored carbon. Professional foresters can help you understand the potential of your land and forests for enhancing carbon capture through forest management, while maintaining the value and health of your forests.