Global Carbon

Preparers

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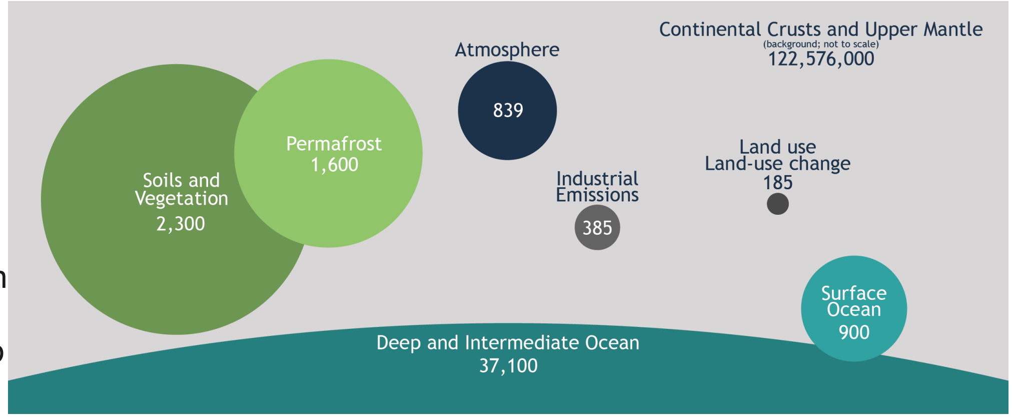
Background

Carbon is one of the most important elements found on Earth. The carbon cycle supports all life by transferring carbon between living things and the environment. Plants take up carbon dioxide (CO_2) and release oxygen (O_2) during photosynthesis, which transfers carbon to their stems, roots, and leaves as they grow. When leaves fall and decompose or when plants die, the carbon that was stored in plants is released through respiration or combustion and transferred back to the atmosphere or to the soil. Because of these processes, forests and other natural ecosystems can store considerable amounts of carbon and act as an important global carbon sink. Carbon stored in U.S. forests and associated wood products increased by more than 600 million metric tons in 2014, offsetting a substantial amount of U.S. greenhouse gas emissions from burning fossil fuels (1).

Across the globe, carbon is stored in different places and in different forms. The amount of carbon stored in a particular system is called a "stock" or a "pool". The Earth's largest carbon stock is found within the continental crusts and upper mantle of the Earth, a large portion of which is sedimentary rock formed over millions of years (2). Oceanic carbon is the next largest stock; over 95% of oceanic carbon is mainly present in the form of inorganic dissolved carbon, although only 900 gigatons of carbon (GtC) is available for exchange in the surface ocean. The atmosphere, although a relatively smaller carbon stock containing 839 GtC, still plays a very important role as it contains carbon mainly in the form of carbon dioxide, a greenhouse gas. Soils store approximately 1,325 GtC in the top few feet and perhaps as much as 3,000 GtC in total when deeper depths are included (3). In addition, permafrost (frozen soil) stores a large pool of carbon that is climatically protected from decomposition (4)(5), although more and more of this pool is becoming available as the average global temperature rises (6)(7).

Figure: Global carbon stocks (carbon stored in pools), shown in gigatons.

Forests take up carbon through photosynthesis and this carbon is subsequently allocated above and belowground, contributing to the global forest stock. Forests account for 92% of all terrestrial



biomass globally, storing approximately 400 GtC (8), but this is not homogenously distributed across the Earth. Different forest types store different amounts of carbon, and much of this variation is related to the climate found in a particular part of the world. Warm tropical regions tend to store much more carbon in the above ground components compared to belowground while the cool regions of the boreal forest have enormous belowground carbon stores.

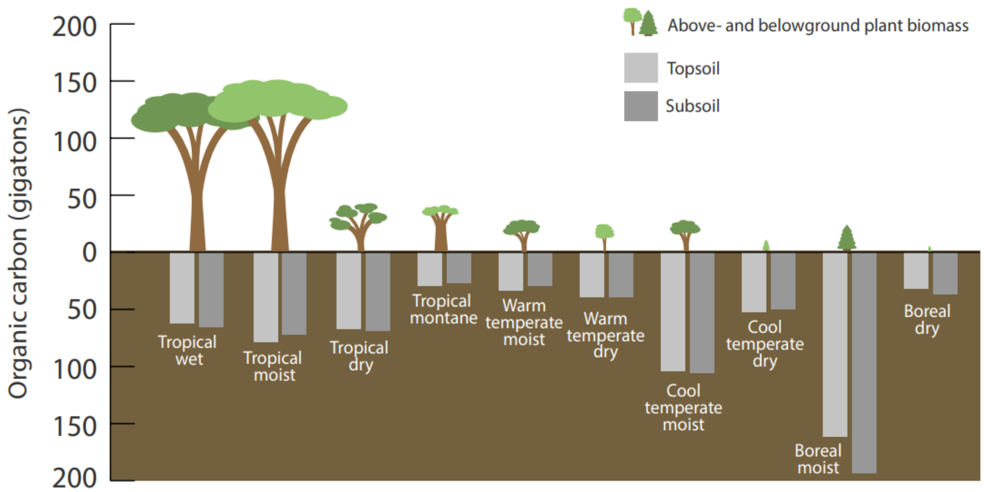


Figure: Carbon (Gt C) stored in ecosystems (based on Scharlemann et al., 2014).

Carbon is exchanged between different stocks in the land, ocean, and atmosphere. This means that carbon in many stocks, whether global or local, can be quite dynamic. Carbon that enters or leaves a stock is referred to as a flux, and the average rate at which carbon flows through a stock is called carbon turnover. The turnover of carbon within ecosystems across the globe gives an idea of where carbon might be most vulnerable to release as CO_2 to the atmosphere. Knowledge of turnover within ecosystems can inform management decisions that affect the rate of carbon turnover, ultimately influencing the flux of carbon into and out of ecosystems.

Figure: Average ecosystem turnover times (years) of different terrestrial carbon pools.

Issues

The amount of carbon stored in the Earth’s atmosphere is miniscule compared to the amount stored in oceans, soils, and geologic formations. Small additions to the atmosphere over a long time have an enormous effect on the global carbon cycle. The start of the industrial revolution nearly 300 years ago, marked the beginning of the period during which human (anthropogenic) activities moved large amounts of carbon from different terrestrial and geologic stocks to the atmosphere. Emissions from fossil fuel use and land use change have been increasing over the last three centuries and currently result in a net addition of approximately 9 GtC per year to the atmosphere. These anthropogenic fluxes have led to a 19-36% shift of carbon out of the Earth’s gas, oil, and coal reservoirs, carbon that had been essentially locked away from the carbon cycle for millions of years but is now expected to remain in the atmosphere for decades to centuries. This contribution of fossil fuel carbon to the atmosphere can be considered a *net addition* to the contemporary carbon cycle and a driver of climate change.

Figure: Global carbon cycle. Carbon pool numbers (Gt C) are denoted in (parentheses), and flux numbers (Gt C per year) are associated with arrows.

In order of fastest turnover times to slowest turnover: tropical forests, tropical savannahs and grasslands, wetlands, croplands, temperate forests, temperate grasslands and shrublands, boreal forests, tundra.

Climate Change Effects on Carbon

Climate change is already having an impact on ecosystems across the world, and many of these changes are expected to continue or accelerate in the future (10, 11). Opportunities to mitigate atmospheric greenhouse gas emissions is driving interest in managing carbon within ecosystems (12), highlighting the important role forests and grasslands play in sequestering CO_2 and providing a source of renewable energy. At the same time, changes in the Earth's climate system are altering forests in dramatic ways, which can also have consequences for the emission of carbon and other greenhouse gases.

Carbon flows from the atmosphere to the land through gross photosynthesisand carbon flows from the land to the atmosphere from total respiration and wildfire.

Warmer temperatures and extreme weather (13, 14) have the potential to directly increase the frequency and severity of many types of disturbance, including drought, wildfire, and blowdown, as well as exacerbate pests, diseases, and other agents to further increase stress on ecosystems (10, 15, 16). An example of the effect of climate on disturbance is seen in the Western United States, where climate variability drives wildfire occurrence in areas of high tree mortality from bark beetles (17, 18). Large disturbances are generally expected to increase, which could result in greater carbon releases from ecosystems (19, 20).

It is unclear whether many forests will be able to maintain their ability to sequester carbon at current rates. In many parts of the country, reforestation and the succession of young forest to older age classes has been a fundamental source of carbon uptake, and this sink may not be as strong in the future (21). Although warmer temperatures and enhanced CO_2 may maintain and even increase the growth of many forests over the next few decades (22), these benefits may be variable across the landscape and ultimately transitory (23). Boreal forests are especially vulnerable to climate change, and the decline of these systems leads to dramatic carbon emissions (24, 25). Boreal and northern species within temperate systems also face potential declines as climate conditions become less suitable in the future and biomes shift toward ecosystems more tolerant of hotter and drier conditions that typically store less carbon (26-28). While new species may shift into these ecosystems, the pace of natural species migration is expected to be substantially slower than changes in climate (29, 30).

Management Options

It is increasingly important to consider the current and long-term effects from climate change, where land management seeks to maintain or increase carbon stocks or to provide a source of renewable energy. Adaptation actions, which work to reduce a system's vulnerability to a changing climate, can help support beneficial carbon outcomes. Adaptation and mitigation are not alternatives to one another, but rather are part of an overall strategy to lessen the severity of climate change impacts. For example, increasing soil organic matter enhances soil carbon while also improving the water-holding capacity of soil and reducing the vulnerability of forests to more frequent intense drought. Management actions that serve to adapt forests and grasslands to changes in climate are critical for maintaining existing carbon pools and reducing losses of ecosystem carbon to the atmosphere.

More information and specific examples for carbon management can be found in the CCRC topic pages on Forest Management for Carbon Benefits, Carbon and Land Management, Forest Soil Carbon, and Grassland Carbon and Management.

How to cite

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Related Links

USFS Forest Service: National Forest Carbon Assessments

Carbon Dioxide Information and Analysis Center

The Global Carbon Project

US Environmental Protection Agency: Inventory of U.S. Greenhouse Gas Emissions and Sinks

US Geological Survey: Land Carbon

Tools

COLE (Carbon OnLine Estimator)

COLE is a versatile and appropriate tool to use for a wide range of carbon estimation needs. COLE draws from Forest Inventory and Analysis (FIA) data to provide basic carbon inventory and growth-and-yield estimates for a particular forest, region, or state.

ecoSmart Landscapes

This tool can help members of the public, cities and other organizations estimate the carbon and energy impacts of trees. The online tools provide quantitative data on carbon dioxide sequestration and building heating/cooling energy savings afforded by individual trees. Results can be used to estimate the greenhouse gas benefits of existing trees, to forecast future benefits, and to facilitate planning and management of carbon offset projects.

First Order Fire Effects Model (FOFEM)

FOFEM is a model that predicts first-order fire effects including tree mortality, fuel consumption, emissions (smoke) production, and soil heating caused by prescribed burning or wildfire.

Forest Inventory Data Online (FIDO) and EVALIDator

FIDO and EVALIDator applications both draw from US Forest Service FIA (Forest Inventory and Analysis) data to produce estimates with associated sampling errors for user selected forest attributes. Carbon estimates can be produced for several carbon pools, including total forest carbon, above and belowground carbon in live trees, standing dead trees, and live seedlings shrubs and bushes; litter; soil; and stumps, roots and woody debris.

Forest Planner

The Forest Planner enables landowners to visualize alternative forest management scenarios for their properties. It compares user selected areas to forest stands from a national database to estimate management outcomes including timber stocking and yields, harvest costs and revenues, carbon storage, and fire and pest hazard ratings. The tool does NOT account for the effects of projected climate change on future timber and carbon estimates.

Forest Vegetation Simulator (FVS)

Natural resource managers are increasingly interested in the effects of planned management activities on carbon stocks. The Forest Vegetation Simulator (FVS) is a family of forest growth simulation models that allow a user to explore how silvicultural treatments may affect growth and yield (and, therefore, carbon stocks). "Suppose" is the name for the graphical user interface for FVS.

Fuel and Fire Tools (FFT)

Fuel and Fire Tools (FFT) is a software application that uses fuels data classified as fuelbeds to let users perform a variety of calculations related to fire behavior and emissions. These include predicting surface and crown fire behavior, fuel consumption, pollutant emissions (including carbon emissions), and heat release. The FFT integrates several tools that were previously stand-alone into a single user interface (including the FCCS).

Global Carbon Atlas

The Global Carbon Atlas gives audiences a number of ways to visualize carbon dioxide emissions and flux data, and to compare between countries and regions over time (1960 – 2012). Its products are grouped into three main categories that are intended for users with varied technical backgrounds. All products are based on current datasets and models contributed by scientists and research institutions (see Contributors).

i-Tree

i-Tree consists of several different applications focused on quantifying the benefits of local trees for neighborhoods and communities. Each application has a unique focus, however several calculate the carbon sequestration and/or energy savings benefits of urban trees, including i-Tree Eco, i-Tree Streets, i-Tree Vue, and i-Tree Design (beta).

NASA - CASA Global CQUEST - Carbon Query and Evaluation Support Tools

This application from NASA provides datasets and a viewer for geographic data that support large-scale carbon inventory. The datasets combine NASA remote sensing technology, ecosystem process modeling, and field-based measurements to characterize impacts on the carbon cycle.

USGS LandCarbon Visualization Tools

The LandCarbon application provides data download and visualization tools for terrestrial carbon and land-use datasets from the USGS National Assessment of Biologic Carbon Sequestration.

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