Management of Forest Carbon Stocks

Preparers

Maria Janowiak, Northern Institute of Applied Climate Science, US Forest Service, Houghton, MI.
Chris Swanston, Northern Institute of Applied Climate Science, US Forest Service, Houghton, MI.
Todd Ontl, Northern Institute of Applied Climate Science, US Forest Service, Houghton, MI.

Forest carbon stocks are closely tied to forest biomass, so factors that increase tree growth rates will subsequently increase rates of carbon storage within forests (1, 2). For example, nitrogen deposition from industrial and agricultural activities has increased soil nitrogen availability, allowing trees to more effectively increase carbon capture and contributing to the capacity of existing forests to sequester carbon (3). Additionally, higher atmospheric CO_2 levels, changes to patterns of temperature and rainfall, and changing forest management strategies all contribute to higher rates of carbon storage in existing forests (4-6). There is some uncertainty, however, surrounding the capability of forests to continue to assimilate additional CO_2 with additional changes in the climate (7). Forest management activities can be used to increase the amount of carbon that is sequestered in forests, as well as the amount of carbon stored in wood products (8). The amount of additional carbon that can be sequestered depends greatly upon the condition of the forest (e.g., forest type, age, health) and the forest management practice in question, making it important to take into account change to carbon stocks across the entire system to assess trade-offs between different pools (fig. 7). The forest management practices described below generally reduce carbon losses from forests or increase carbon gains in forests and wood products, although many practices have the potential to do both.

Decrease Forest Carbon Loss

Decreasing the intensity of forest harvest is one way to decrease carbon losses to the atmosphere (1, 2). Across diverse forest systems, the “no harvest” option commonly produces the highest forest carbon stocks (9-11). Managed stands typically have lower levels of forest biomass than unmanaged stands, even though the annual rate of sequestration may be higher in a younger forest. In managed forests, reducing harvest intensity, lengthening harvest rotations, and increasing stocking or retention levels will generally increase the amount of carbon stored within forest ecosystem carbon pools in the absence of severe disturbance (1, 12-15). One study in the Pacific Northwest modeled different levels of harvest in Douglas-fir/hemlock forest and found higher levels of residual forest carbon under less-intense management regimes (16). Another study in the Northeast United States looked at both even- and uneven-aged management practices in northern hardwood forests and found that less-frequent harvests and greater levels of structural retention (e.g., residual trees) resulted in increased forest carbon stocks (11), which is consistent with observations in experimental studies (17, 13).

Carbon losses can also be reduced by limiting emissions associated with management, which can come from a number of sources. Forest harvest can cause disturbance to the ground, releasing carbon from soils and the forest floor (18). This effect is generally transitory, but varies with the degree of disturbance (18). Mechanical treatments to thin forest stands can cause disturbance that leads to additional soil carbon losses through increased erosion (19, 20). Forest harvest also creates emissions from the operation of machinery used to implement forest harvest; these emissions vary widely based upon the size and type of machinery, as well as the specifics of silvicultural treatments. Operations such as tree harvesting, planting, fertilization, and trucking produce greenhouse gas emissions from the fossil fuel used to carry out these activities (21). For example, one study that compared the carbon effects associated with different types of harvest found that the type of skidding machinery (e.g., grapple skidder, cable skidder, etc.) used to haul wood was more predictive of the net carbon flux of forest management activities than the primary silvicultural treatment (22).

Forest management may also be able to reduce carbon losses associated with disturbances. Wildfire in particular is an increasingly substantial source of CO_2 and other greenhouse gas emissions from U.S. forests. Annual greenhouse gas emissions from wildfires in the conterminous United States and Alaska ranged from 42 to 139 million metric tons of CO_2 equivalent during the period from 2010 to 2013 (23). Fuel reduction treatments can lower the risk of crown fires, which are more likely to lead to intense fire conditions that cause substantial carbon losses (24, 25, 20). Fuel reduction treatments lower the density of the forest stand, and, therefore, reduce forest carbon. Some studies suggest that fuel reduction treatments create carbon benefits over time by increasing the growth of the residual stand and reducing risk of catastrophic fire (1, 26, 27). The results of studies to date, however, are divided as to whether this benefit can be realized. Prescribed fires also result in the release of greenhouse gas emissions, which need to be accounted for when considering the relationship between fire and carbon (28, 29). Additionally, carbon emissions from prescribed fire, the machinery used to conduct treatments, or the production of wood for bioenergy may reduce or negate the carbon benefit associated with fuel treatments, especially when treatments are repeated (30-32). Further, there are uncertainties in predicting the actual occurrence of wildfire and its impacts on forests due to an incomplete scientific understanding of ecological response to fire, of fire behavior response to treatments, and inability to predict fire occurrence at the stand level (1, 33).

Increase Forest Growth and Carbon Stocks

Many forest management actions may be used to increase the amount of carbon sequestered in forests and in wood products (1, 2). Similar to the management activities described above that reduce losses of carbon from forests, carbon gains can be made in forests by increasing the rate of accumulation of new biomass, as well as by increasing the total amount of biomass. The ability of different management practices to increase forest growth will vary greatly by region and by forest type, and the increase in carbon will generally be proportional to increases in growth rates (2). For example, plantations of southern pine can have increased yields through the combined use of improved seedlings, control of competing vegetation, and use of fertilizers (2). Fertilization and irrigation of southeastern tree species can increase biomass growth by more than 100 percent (34, 35), but the carbon accumulation from enhanced growth would need to be balanced with the high levels of emissions associated with fertilizer production (24).

Forest managers who are working to enhance forest carbon sequestration by managing forests for increased growth also need to consider the relationship between carbon stored in the forest and carbon that is harvested to create wood products or energy, which are discussed in more detail in the next section. Increasing carbon stocks within the forest may or may not be great enough to balance the associated loss of carbon from harvested wood that may have been stored in long-lived wood products or avoided fossil fuel emissions through bioenergy (1, 21). It is also important for forest managers to consider the interactions between an increase in biomass and increasing risk of fires, insect damage, and disease, which can negatively impact multiple goods and services, including carbon.

How to cite

Janowiak, M.; Swanston, C.; Ontl, T. 2017. Management of Forest Carbon Stocks. (June, 2017). U.S. Department of Agriculture, Forest Service, Climate Change Resource Center. https://www.fs.usda.gov/ccrc/topics/management-forest-carbon-stocks

Recommended Reading

Martin, K.L.; Hurteau, M.D.; Hungate, B.A.; Koch, G.W.; North, M.P. 2015. Carbon tradeoffs of restoration and provision of endangered species habitat in a fire-maintained forest. Ecosystems. 18(1): 76-88.

McKinley, D.C.; Ryan, M.G.; Birdsey, R.A.; Giardina, C.P.; Harmon, M.E.; Heath, L.S.; Houghton, R.A.; Jackson, R.B.; Morrison, J.F.;Murray, B.C.; Pataki, D.E.; Skog, K.E. 2011. A synthesis of current knowledge on forests and carbon storage in the United States. Ecological Applications. 21(6): 1902-1924.

Millar, C.I.; Skog, K.E.; McKinley, D.C.C.; Birdsey, R.A.; Swanston, C.W.; Hines, S.J.; Woodall, C.W.; Reinhardt, E.D.; Peterson, D.L.; Vose, J.M. 2012. Adaptation and mitigation. In: J. M. Vose, D. L. Peterson and T. Patel-Weynand, eds. Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the U.S. forest sector. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 125-192.

Ryan, M.G.; Harmon, M.E.; Birdsey, R.A.; Giardina, C.P.; Heath, L.S.; Houghton, R.A.; Jackson, R.B.; McKinley, D.C.; Morrison, J.F. 2010. A synthesis of the science on forests and carbon for U.S. forests. Issues in Ecology. 13: 1-16.

U.S. Climate Change Science Program. 2007. The first state of the carbon cycle report (SOCCR): the North American carbon budget and implications for the global carbon cycle. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Asheville, NC: National Oceanic and Atmospheric Administration, National Climatic Data Center. 242 pp.

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 (seeContributors).

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 Ecoi-Tree Streetsi-Tree Vuei-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.

References

1. McKinley, D.C.; Ryan, M.G.; Birdsey, R.A.; Giardina, C.P.; Harmon, M.E.; Heath, L.S.; Houghton, R.A.; Jackson, R.B.; Morrison, J.F.; Murray, B.C. 2011. A synthesis of current knowledge on forests and carbon storage in the United States. Ecological Applications. 21(6): 1902-1924.

2. Ryan, M.G.; Harmon, M.E.; Birdsey, R.A.; Giardina, C.P.; Heath, L.S.; Houghton, R.A.; Jackson, R.B.; McKinley, D.C.; Morrison, J.F.; Murray, B.C. 2010. A synthesis of the science on forests and carbon for US forests.

3. Nadelhoffer, K.J.; Emmett, B.A.; Gundersen, P.; Kjonaas, O.J.; Koopmans, C.J.; Schleppi, P.; Tietema, A.; Wright, R.F. 1999. Nitrogen deposition makes a minor contribution to carbon sequestration in temperate forests. Nature. 398(6723): 145-148.

4. Ainsworth, E.A.; Rogers, A. 2007. The response of photosynthesis and stomatal conductance to rising [CO2]: mechanisms and environmental interactions. Plant, Cell & Environment. 30(3): 258-270.

5. Cole, C.T.; Anderson, J.E.; Lindroth, R.L.; Waller, D.M. 2010. Rising concentrations of atmospheric CO2 have increased growth in natural stands of quaking aspen (Populus tremuloides). Global Change Biology. 16(8): 2186-2197.

6. Franks, P.J.; Adams, M.A.; Amthor, J.S.; Barbour, M.M.; Berry, J.A.; Ellsworth, D.S.; Farquhar, G.D.; Ghannoum, O.; Lloyd, J.; McDowell, N.; Norby, R.J.; Tissue, D.T.; von Caemmerer, S. 2013. Sensitivity of plants to changing atmospheric CO2 concentration: from the geological past to the next century. New Phytol. 197(4): 1077-94.

7. Bellassen, V.; Luyssaert, S. 2014. Carbon sequestration: Managing forests in uncertain times. Nature. 506(7487): 153-155.

8. Birdsey, R.; Alig, R.; Adams, D. 2000. Chapter 8: Mitigation Activities in the Forest Sector to Reduce Emissions and Enhance Sinks of Greenhouse Gases. In: L. A. Joyce, R. Birdsey and (eds.), eds. The impact of climate change on America's forests: a technical document supporting the 2000 USDA Forest Service RPA Assessment. Fort Collins, CO: Rocky Mountain Research Station, USDA Forest Service.

9. Perez-Garcia, J.; Lippke, B.; Comnick, J.; Manriquez, C. 2007. An assessment of carbon pools, storage, and wood products market substitution using life-cycle analysis results. Wood and Fiber Science. 37: 140-148.

10. Creutzburg, M.K.; Halofsky, J.E.; Halofsky, J.S.; Christopher, T.A. 2015. Climate Change and Land Management in the Rangelands of Central Oregon. Environmental Management. 55(1): 43-55.

11. Nunery, J.S.; Keeton, W.S. 2010. Forest carbon storage in the northeastern United States: net effects of harvesting frequency, post-harvest retention, and wood products. Forest Ecology and Management. 259(8): 1363-1375.

12. Harmon, M.E. 2001. Carbon sequestration in forests: addressing the scale question. Journal of Forestry. 99(4): 24-29.

13. D'Amato, A.W.; Bradford, J.B.; Fraver, S.; Palik, B.J. 2011. Forest management for mitigation and adaptation to climate change: Insights from long-term silviculture experiments. Forest Ecology and Management. 262(5): 803-816.

14. Taylor, A.R.; Wang, J.R.; Kurz, W.A. 2008. Effects of harvesting intensity on carbon stocks in eastern Canadian red spruce (Picea rubens) forests: An exploratory analysis using the CBM-CFS3 simulation model. Forest Ecology and Management. 255(10): 3632-3641.

15. Harmon, M.E.; Marks, B. 2002. Effects of silvicultural practices on carbon stores in Douglas-fir western hemlock forests in the Pacific Northwest, U.S.A.: results from a simulation model. Canadian Journal of Forest Research. 32(5): 863-877.

16. Harmon, M.E.; Moreno, A.; Domingo, J.B. 2009. Effects of partial harvest on the carbon stores in Douglas-fir/western hemlock forests: a simulation study. Ecosystems. 12(5): 777-791.

17. Powers, M.; Kolka, R.; Palik, B.; McDonald, R.; Jurgensen, M. 2011. Long-term management impacts on carbon storage in Lake States forests. Forest Ecology and Management. 262(3): 424-431.

18. Nave, L.E.; Vance, E.D.; Swanston, C.W.; Curtis, P.S. 2010. Harvest impacts on soil carbon storage in temperate forests. Forest Ecology and Management. 259(5): 857-866.

19. Schwilk, D.W.; Keeley, J.E.; Knapp, E.E.; McIver, J.; Bailey, J.D.; Fettig, C.J.; Fiedler, C.E.; Harrod, R.J.; Moghaddas, J.J.; Outcalt, K.W.; Skinner, C.N.; Stephens, S.L.; Waldrop, T.A.; Yaussy, D.A.; Youngblood, A. 2009. The national Fire and Fire Surrogate study: effects of fuel reduction methods on forest vegetation structure and fuels. Ecological Applications. 19(2): 285-304.

20. Stephens, S.L.; McIver, J.D.; Boerner, R.E.J.; Fettig, C.J.; Fontaine, J.B.; Hartsough, B.R.; Kennedy, P.L.; Schwilk, D.W. 2012. The Effects of Forest Fuel-Reduction Treatments in the United States. BioScience. 62(6): 549-560.

21. Ingerson, A. 2011. Carbon storage potential of harvested wood: summary and policy implications. Mitigation and Adaptation Strategies for Global Change. 16(3): 307-323.

22. Mika, A.M.; Keeton, W.S. 2013. Factors contributing to carbon fluxes from bioenergy harvests in the U.S. Northeast: an analysis using field data. GCB Bioenergy. 5(3): 290-305.

23. U.S. Environmental Protection Agency, E. 2016. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014. Washington, DC: U.S. Environmental Protection Agency. 558.

24. Millar, C.I.; Skog, K.E.; McKinley, D.C.C.; Birdsey, R.A.; Swanston, C.W.; Hines, S.J.; Woodall, C.W.; Reinhardt, E.D.; Peterson, D.L.; Vose, J.M. 2012. Adaptation and mitigation. In: J. M. Vose,

D. L. Peterson and T. Patel-Weynand, eds. Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the U.S. forest sector. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 125-192.

25. Reinhardt, E.D.; Keane, R.E.; Calkin, D.E.; Cohen, J.D. 2008. Objectives and considerations for wildland fuel treatment in forested ecosystems of the interior western United States. Forest Ecology and Management. 256(12): 1997-2006.

26. Finkral, A.; Evans, A. 2008. The effects of a thinning treatment on carbon stocks in a northern Arizona ponderosa pine forest. Forest Ecology and Management. 255(7): 2743-2750.

27. Boerner, R.E.J.; Huang, J.; Hart, S.C. 2008. Fire, thinning, and the carbon economy: Effects of fire and fire surrogate treatments on estimated carbon storage and sequestration rate. Forest Ecology and Management. 255(8–9): 3081-3097.

28. Wiedinmyer, C.; Hurteau, M.D. 2010. Prescribed Fire As a Means of Reducing Forest Carbon Emissions in the Western United States. Environmental science & technology. 44(6): 1926-1932.

29. Hurteau, M.; North, M. 2009. Fuel treatment effects on tree-based forest carbon storage and emissions under modeled wildfire scenarios. Frontiers in Ecology and the Environment. 7(8): 409-414.

30. Loehman, R.A.; Reinhardt, E.; Riley, K.L. 2014. Wildland fire emissions, carbon, and climate: Seeing the forest and the trees – A cross-scale assessment of wildfire and carbon dynamics in fire-prone, forested ecosystems. Forest Ecology and Management. 317: 9-19.

31. Campbell, J.L.; Harmon, M.E.; Mitchell, S.R. 2012. Can fuel-reduction treatments really increase forest carbon storage in the western US by reducing future fire emissions? Frontiers in Ecology and the Environment. 10(2): 83-90.

32. Hudiburg, T.W.; Luyssaert, S.; Thornton, P.E.; Law, B.E. 2013. Interactive effects of environmental change and management strategies on regional forest carbon emissions. Environmental science & technology. 47(22): 13132-13140.

33. Thompson, M.P.; Calkin, D.E. 2011. Uncertainty and risk in wildland fire management: A review. Journal of Environmental Management. 92(8): 1895-1909.

34. Albaugh, T.J.; Lee Allen, H.; Dougherty, P.M.; Johnsen, K.H. 2004. Long term growth responses of loblolly pine to optimal nutrient and water resource availability. Forest Ecology and Management. 192(1): 3-19.

35. Coyle, D.R.; Aubrey, D.P.; Coleman, M.D. 2016. Growth responses of narrow or broad site adapted tree species to a range of resource availability treatments after a full harvest rotation. Forest Ecology and Management. 362: 107-119.

Search CCRC

Related Topics

Forest Management for Carbon Benefits

Carbon Considerations in Land Management

Carbon Benefits of Wood-Based Products and Energy

Grassland Carbon Management

Carbon and Land Management, an introduction

Importance of Forest Cover

Global Carbon

Carbon as One of Many Management Objectives

Forest Soil Carbon and Climate Change