Forest Ecology and Management 355 (2015) 83–90

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Review and synthesis

Trends in management of the world's forests and impacts on carbon stocks ☆,☆☆

Richard Birdsey [a,*], Yude Pan [b]

[a] USDA Forest Service, 11 Campus Blvd Suite 200, Newtown Square, PA 19073, United States
[b] USDA Forest Service, United States

ARTICLE INFO

Article history:
Received 23 January 2015
Received in revised form 22 April 2015
Accepted 27 April 2015
Available online 28 May 2015

Keywords:
Forest management
Carbon cycle
Land-use change
Climate change

ABSTRACT

Global forests are increasingly affected by land-use change, fragmentation, changing management objectives, and degradation. In this paper we broadly characterize trends in global forest area by intensity of management, and provide an overview of changes in global carbon stocks associated with managed forests. We discuss different interpretations of "management" and highlight some important accounting and analysis issues. The area of global forests has declined by 3% since 1990 but the area of planted forest has increased in all regions of the world and now accounts for almost 7% of global forest land. The area of primary forest, which is typically defined as lacking direct human influence, is about 34% of all forest land according to country reports, but the area is declining especially in South America and Africa because of human-caused habitat fragmentation and degradation. Concurrently, the area of naturally regenerated forest that is not classified as primary forest has declined. As a result of increasing management intensity, the area of unmanaged forest, typically defined as land lacking protected status or a management plan, dropped significantly since 1990 and now comprises only 21% of global forests. There have been significant increases in areas of forest used for non-wood forest products such as protection of soil and water, conservation of biodiversity, and provision of social services. Globally, timber production has been relatively stable since 1990, but increasing areas of forest used for non-wood forest products indicates that harvesting is taking place on a smaller proportion of the total forest area. Based on trends in the area of managed forest and regional studies, it is clear that historical and current forest management has been a very significant determining factor of current carbon stocks. Established forests currently offset about 30% of global emissions of CO_2 from fossil fuel use, and there are mitigation opportunities involving forests that could increase the gross terrestrial C uptake from roughly 4.0 to 6.2 Pg C annually. However, our results suggest that a diversifying use of forest land may have significant consequences for maintaining or increasing the current rate of terrestrial carbon sequestration. In the future, indirect human influences such as increasing atmospheric CO_2 and climate change, along with the direct effects of land management and projected increasing demand for wood biofuel, are likely to become increasingly important elements that influence land management strategies and the role of forests in the global carbon cycle.

Published by Elsevier B.V.

Contents

☆ Review Paper prepared for Special Issue of Forest Ecology and Management titled "Carbon, Water, and Nutrient Cycling in Managed Forests" edited by Noormets et al.
☆☆ This article is part of a special issue entitled "Carbon, water and nutrient cycling in managed forests".

* Corresponding author. Tel.: +1 610 557 4091; fax: +1 610 557 4095.
E-mail addresses: rbirdsey@fs.fed.us (R. Birdsey), ypan@fs.fed.us (Y. Pan).

http://dx.doi.org/10.1016/j.foreco.2015.04.031
0378-1127/Published by Elsevier B.V.

1. Introduction

Global forests are increasingly affected by land-use change, fragmentation, changing management objectives, and degradation. At the same time all forests, no matter how remote, are responding to changes in atmospheric composition especially increasing concentration of CO_2 and climate change. How these concurrent factors will affect future forests is a critical question not only for the sustainability of the many traditional services provided by forests such as timber production and watershed protection, but also for the continuation of the role of forests in removing emitted CO_2 from use of fossil fuels. If the global carbon sink in established forests that currently absorbs about 30% of fossil fuel CO_2 emissions (Pan et al., 2011a) is reduced or eliminated, global efforts to mitigate climate change will require even more emissions reductions than currently envisioned (IPCC, 2014). Because the concept of forest management takes on different meanings around the world in different contexts, and because changes in forest management are often considered to be a significant component of climate change mitigation, the purpose of this paper is to highlight some of the different interpretations of forest management and reveal some of the major trends in forest management that are likely to affect the many services of forests in the future. We broadly characterize global forest area by intensity of management, and provide an overview of changes in global carbon stocks associated with managed forests. We highlight some of the important accounting and analysis issues associated with assessments of managed forests and carbon stocks. We conclude with comments about accounting for the full impacts of forest management on the concentration of CO_2 in the atmosphere, taking consideration of harvested wood and associated indirect effects such as substitution of wood for other material.

"Managed forest" may take on different meanings in different contexts, but generally refers to forests that have been directly impacted by human activities, excluding deforestation which is distinguished from forest management since it is a change in land use according to the most commonly used definition (Foley et al., 2005). In some contexts, a forest may be defined as managed even without obvious direct human impacts, for example, areas that have been set aside or protected by administrative statute.

Forest management is related to goals defined by the landowner or responsible management entity, and there are typically specific management practices that support the defined goals. Tree plantations and natural forests managed for wood products are obvious examples of "managed forests", and for these examples, applied practices leading to the goal of producing timber may include thinning, harvesting, and regeneration treatments. Forests with other management objectives may not be considered managed since the direct influence of human activity is minimal. For example, a wilderness area is by some definitions managed for its biodiversity values, but direct human impacts may be limited to maintenance of hiking trails and low-impact camping sites. Indirect human impacts such as increasing atmospheric CO_2 and climate change may significantly affect forests no matter how remote, even if the cause of these effects originates elsewhere.

To help frame the concept of managed forests, Table 1 includes some common forest classification terms arranged in an approximate hierarchy of management intensity. In this paper we focus on the forest land classifications, but also give some consideration to those forests or areas with tree cover that may not meet some definitions of forest, and are often classified as areas with "trees

Table 1
Land management classifications and definitions of key terms, roughly organized by intensity of management from lowest to highest. Categories are not all mutually exclusive.

Classification	Description
Land classifications	
Wildland	Land with little to no evidence of direct human impact as evidenced by occurrence of population density, land transformation, accessibility, and infrastructure (Sanderson et al., 2002)
Intact land	An unbroken expanse of natural ecosystems showing no signs of significant human activity, and large enough that all native biodiversity, including viable populations of wide-ranging species, could be maintained (adapted from Potopov et al. (2008))
Protected areas	Areas especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means (FAO, 2010). Direct human impacts may be allowed by administrative statute
Forest land[a] *classifications*	
Primary forest	Naturally regenerated forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed (FAO, 2010)
Protected forest	Forest area within formally established protected areas, regardless of the purpose for which the protected areas were established (FAO, 2010)
Unmanaged natural forest	Forest land without protected status that does not have a documented management plan. Some areas may be actively managed or there may be direct human impacts such as occasional tree harvesting
Managed natural forest	Forest area that has a long-term (ten years or more) documented management plan, aiming at defined management goals, which is periodically revised (FAO, 2010). Excludes forest plantations and managed forests without a documented management plan
Planted forest	Forest predominantly composed of trees established through planting and/or deliberate seeding (FAO, 2010). Plantation forests may be used for timber production or other purposes such as erosion control
Land with trees outside forests	
Other wooded land	Land not classified as "forest", spanning more than 0.5 hectares; with trees higher than 5 m and a canopy cover of 5–10%, or trees able to reach these thresholds *in situ*; or with a combined cover of shrubs, bushes and trees above 10%. It does not include land that is predominantly under agricultural or urban land use (FAO, 2010)
Agroforestry	A collective name for land-use systems and technologies where woody perennials (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence (Lundgren and Raintree, 1982)
Settlements	All developed land with trees, including transportation infrastructure and human settlements of any size, unless already included under other categories (IPCC, 2003)

[a] Land spanning more than 0.5 hectares with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds *in situ*. Forest lands that are temporarily treeless because of harvest or disturbance are included. Forest does not include land that is predominantly under agricultural or urban land use, even though such land may have some tree cover. Tree plantations are included (FAO, 2010).