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Research paper

Trees, forests and water: Cool insights for a hot world

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ABSTRACT

Forest-driven water and energy cycles are poorly integrated into regional, national, continental and global decision-making on climate change adaptation, mitigation, land use and water management. This constrains humanity's ability to protect our planet's climate and life-sustaining functions. The substantial body of research we review reveals that forest, water and energy interactions provide the foundations for carbon storage, for cooling terrestrial surfaces and for distributing water resources. Forests and trees must be recognized as prime regulators within the water, energy and carbon cycles. If these functions are ignored, planners will be unable to assess, adapt to or mitigate the impacts of changing land cover and climate. Our call to action targets a reversal of paradigms, from a carbon-centric model to one that treats the hydrologic and climate-cooling effects of trees and forests as the first order of priority. For reasons of sustainability, carbon storage must remain a secondary, though valuable, by-product. The effects of tree cover on climate at local, regional and continental scales offer benefits that demand wider recognition. The forest- and tree-centered research insights we review and analyze provide a knowledge-base for improving plans, policies and actions. Our understanding of how trees and forests influence water, energy

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Adaptation
Sustainability

and carbon cycles has important implications, both for the structure of planning, management and governance institutions, as well as for how trees and forests might be used to improve sustainability, adaptation and mitigation efforts.

1. Introduction

Billions of people suffer the effects of inadequate access to water (Mekonnen and Hoekstra, 2016) and extreme heat events (Fischer and Knutti, 2015; Herring et al., 2015). Climate change can exacerbate water shortages and threaten food security, triggering mass migrations and increasing social and political conflict (Kelley et al., 2015). Strategies for mitigating and adapting to such outcomes are urgently needed. For large populations to remain where they are located without experiencing the extreme disruptions that can cause migrations, reliable access to water and tolerable atmospheric temperatures must be recognized as stable ingredients of life. As we explain, the maintenance of healthy forests is a necessary pre-condition of this globally-preferential state.

The published work we review suggests forests play important roles in producing and regulating the world's temperatures and fresh water flows. Well recognized as stores of carbon, forests also provide a broad range of less recognized benefits that are equally, if not more, important. Indeed, carbon sequestration can, and perhaps should, be viewed as one co-benefit of reforestation strategies designed to protect and intensify the hydrologic cycle and associated cooling. Organized and conceived in this way, reduced deforestation, forest landscape restoration and forest preservation strategies offer essential ingredients for adaptation, mitigation and sustainable development.

Functions inherent to forests (Fig. 1) offer solutions to water availability and cooling (Ellison et al., 2012; Hesslerová et al., 2013; Syktus and McAlpine, 2016; Hecht et al 2016). By evapotranspiring, trees recharge atmospheric moisture, contributing to rainfall locally and in distant locations. Cooling is explicitly embedded in the capacity of trees to capture and redistribute the sun's energy (Pokorný et al., 2010). Further, trees' microbial flora and biogenic volatile organic compounds can directly promote rainfall. Trees enhance soil infiltration and, under suitable conditions, improve groundwater recharge. Precipitation filtered through forested catchments delivers purified ground and surface water (Calder, 2005; Neary et al., 2009).

Forests currently cover only about one third of Earth's surfaces (FAO, 2016). Between 2000 to 2012, urban expansion, agricultural land conversions, logging and forest fires resulted in the loss of some 1.5–1.7 million km^2 of tree cover, or approximately 3.2% of global forest cover (DeFries et al., 2010; Hansen et al., 2013; Riitters et al., 2016), and vastly more loss has occurred throughout human history (Pongratz et al., 2010).

Deforestation and anthropogenic land-use transformations have important implications for climate, ecosystems, the sustainability of livelihoods and the survival of species, raising concerns about long-term damage to natural Earth system functions (Steffen et al., 2015). Mean warming due to land cover change may explain as much as 18% of current global warming trends (Alkama and Cescatti, 2016). Deforestation exerts an influence on warming at the local scale and alters rainfall and water availability, not to mention the emission of greenhouse gases.

Though we eschew precise definitions of tree and forest landscapes herein, plantation forests and the use of some more exotic species can upset the balance of evapotranspiration regimes, possibly with negative impacts on water availability (Trabucco et al., 2008). Moreover, re- and afforestation, particularly in the context of climate change, rising temperatures and diminishing rainfall, can further reduce water availability (Liu et al., 2016; Rind et al., 1990). However, in the correct spatial settings, forest restoration can positively impact water and energy cycles and improve water availability.

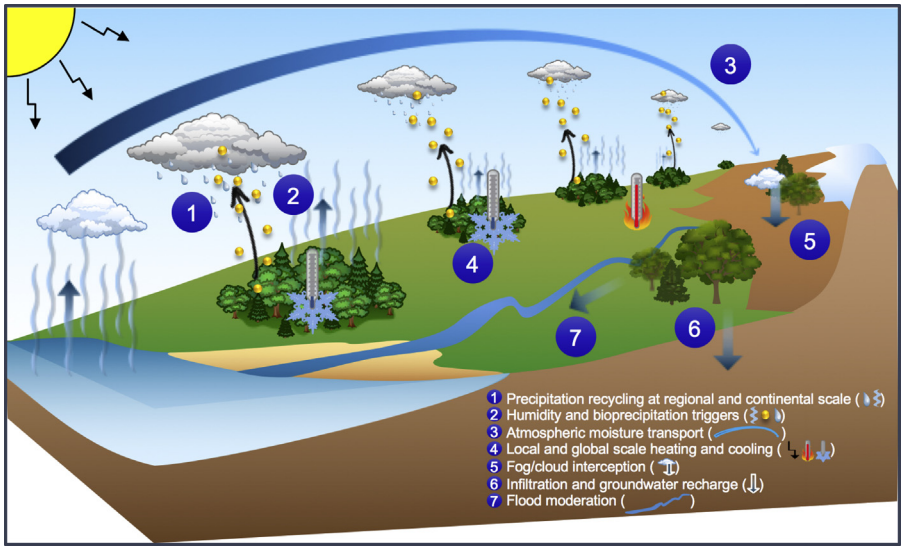

Fig. 1. Effects of forests on water and climate at local, regional and continental scales through change in water and energy cycles. (1) Precipitation is recycled by forests and other forms of vegetation and transported across terrestrial surfaces to the other end of continents. (2) Upward fluxes of moisture, volatile organic compounds and microbes from plant surfaces (yellow dots) create precipitation triggers. (3) Forest-driven air pressure patterns may transport atmospheric moisture toward continental interiors. (4) Water fluxes cool temperatures and produce clouds that deflect additional radiation from terrestrial surfaces. (5) Fog and cloud interception by trees draws additional moisture out of the atmosphere. (6) Infiltration and groundwater recharge can be facilitated by trees. (7) All of the above processes naturally disperse water, thereby moderating floods. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)