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Interactions of Forests, Climate, Water Resources, and Humans in a Changing Environment: Research Needs

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Authors' contributions

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Editorial

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ABSTRACT

The aim of the special issue "Interactions of Forests, Climate, Water Resources, and Humans in a Changing Environment" is to present case studies on the influences of natural and human disturbances on forest water resources under a changing climate. Studies in this collection of six papers cover a wide range of geographic regions from Australia to Nigeria with spatial research scale spanning from a tree leaf, to a segment of forest road, and large basins with mixed land uses. These studies clearly show the strong interactions among forests, global climate change, water quantity and quality, and human activities at multiple scales. Understanding the underlying processes of response of natural ecosystems and society to global climate change is essential for developing actionable science-based climate change mitigation and adaptation strategies and methodologies. Future research should focus on feedbacks among forests, climate, water, and disturbances, and interactions of ecohydrologic systems, economics and policies using an integrated approach.

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1. INTRODUCTION

Over one third of the Earth's land surface is covered with forests that are vital to human's very existence [1]. Forests have been increasingly recognized as a key player in global climate moderation [2], streamflow regulation and purification [3], erosion control [3], carbon sequestration [4], and many other ecosystem services that humans need [1]. Indeed, human civilizations originate from forests and water. However, forest and fresh water resources are increasingly threatened by ongoing global climate and land cover changes [5]. Fresh water scarcity is becoming more problematic across the planet due to increasing population growth, land use change such as deforestation, and climate change variability [6]. Global change has resulted in a series of chain reactions in both natural ecosystems and human-dominated systems. Growing concerns over watershed degradation, water scarcity, poverty, and social sustainability due to global change require new approaches to manage forests and water resources. Currently there is little science-based guidance for resource managers and policy makers to adapt to the novel and ever changing environment in the 21st century [7]. Global change sciences centered on water science (e.g. ecohydrology) are rapidly developing to meet this urgent demand [8]. Understanding the interactions among forests, climate, water resources, and human activities is essential in advancing actionable sciences and developing robust climate change mitigation and adaptation strategies and methodologies.

2. INTERACTIONS OF FORESTS, CLIMATE, WATER, AND HUMANS

Forests, climate, water, and humans interact to form a complex network of global change (Fig. 1). The distribution, structure, productivity, and functions (e.g. clear water supply and carbon sequestration) of natural forests are largely controlled by climate [9]. It is also well known that water distribution and timing is closely related to precipitation and evaporative potential (PET) [10]. Thus, it is easy to understand that global climate change has profound impacts on forest and water resources [5]. Less is known about the feedbacks of forest and water changes to climate change [2]. Natural or human disturbances such as deforestation converting forestlands to crops or urban use may dramatically alter the land surface properties such as albedo and soil infiltration capacity. The increase of albedo and loss of plant transpiration due to deforestation has profound effects on energy redistribution by decreasing net radiation, decreasing latent heat, and increasing sensible heat especially in regions where water is limited [11]. Impacts on forest energy balances directly translate to changes in local water balances and watershed hydrology through the evapotranspiration processes. Large scale forest changes can impact regional climate through altering the sources of water vapor supply and wind speed [12]. Thanks to the century-long forest hydrologic research [13], the forests' influences on water cycle at the watershed scale are well established: deforestation generally increases streamflow while reforestation decreases it[14]. The absolute and relative magnitude of effects is closely related to local climate (precipitation and PET) [15]. Climatic feedbacks of urbanization such as 'urban heat island' are well documented [16]. Global warming is projected to increase water use for irrigation [17], and studies suggest that alteration of water systems such as groundwater use for irrigation and reservoirs also have influences on local climate [18].

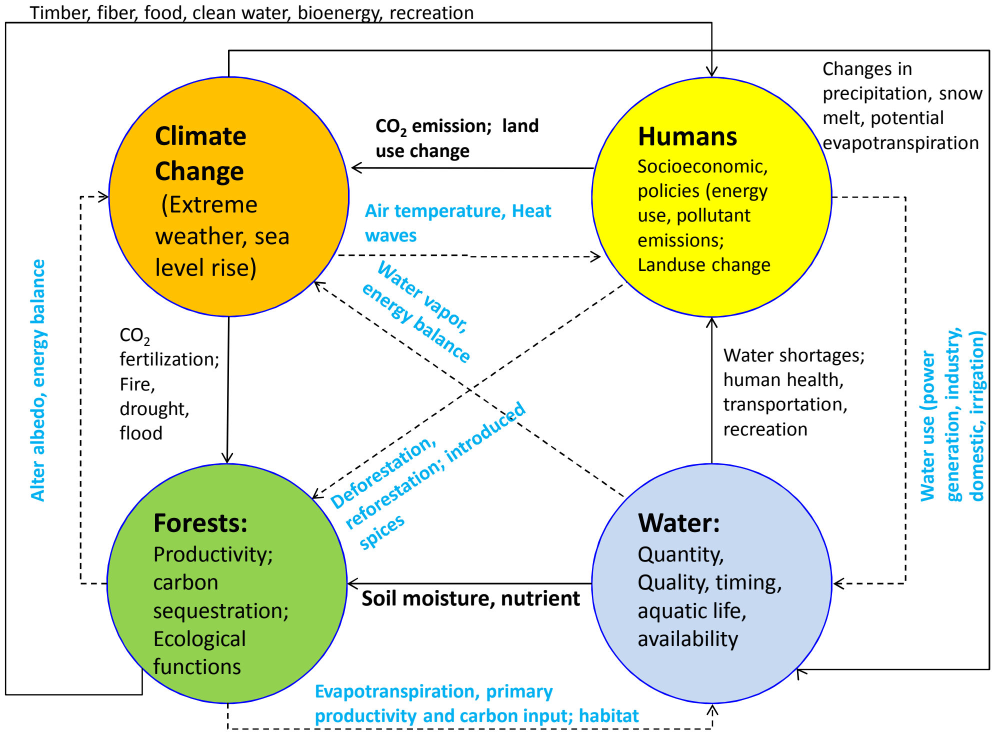

Fig. 1. Interactive processes among forests, climate, water, and human systems

2. RESEARCH NEEDS

Quantifying the complex interactions among forests, climate, water resources, and human disturbances is challenging. Our current knowledge about the interactive relationships among the underlining processes is incomplete. For example isolating the effects of climate change from the effects of land cover change, human water use, or from the changes caused by vegetation response to past disturbance is difficult [19]. We have identified the following knowledge gaps that require attention of the research community for addressing modern global change threat issues:

First, many global change processes occur at a spatial and temporal scale beyond traditional empirical field experiments, and thus are difficult to verify. For example, forest hydrologists know about the influences of forest on streamflow through small watershed manipulation experiments. We also know a great deal about the climatic control on forest micrometeorology, tree growth, vegetation distribution, and ecological functions, but we know little about the influences of vegetation and land use/land cover change on local, regional, and global climate [11]. Debates remain on forest functions in regulating water resources among scientists, engineers, and policy makers [12,14]. We have much understanding of the response of individual tree to climate change and variability [20], but we have less knowledge of ecosystem-level response to multiple stressors [21].

Second, the interactive processes are often non-linear and involve physical, biological, ecological, and socioeconomic mechanisms. For example, recent long term monitoring studies in North America that climate warming may not necessarily result in an increase in actual evapotranspiration due to plant active adaptation to a changing climate [21] Due to the various addition or subtraction processes, the end results may vary depending on which factors dominate the entire systems. For example, an increase in atmospheric CO_2 concentration is like to increase tree water use efficiency thus reduce plant transpiration rate [22], but increased productivity and biomass due to climate warming and CO_2 fertilization effects may increase total water use at the ecosystem scale as a whole [23]. Similarly, in some regions, land use change [24] or human activities such as damming or irrigation practices may cancel or aggravate the climate change signals in terms of water availability and temporal distribution [21,25,26].

Third, the Earth is entering into a new era of Anthropocene. Modern environmental issues such as climate change, watershed ecosystem degradation, regional water scarcity, are all coupled with human activities [27]. Indeed, our observed environmental changes are results of combined effects of both nature and humans, the so called Coupled Nature-Human Systems [28]. Population growth and landuse change can have more impacts on water availability and stress than climate change [6,29]. Reforestation practices do not always achieve the desire ecohydrologic functions when such ecological restoration policies are poorly implemented [30]. A recent study in China suggests that there remains large uncertainty about the effects of policy-driven large scale ecological restoration on the sustainability of ecological rehabilitation performance and ecosystem service enhancement [31]. Therefore, an adaptive management approach to regional ecological rehabilitation policy should focus on the dynamic interactions between people and their environments in a changing world.

The six papers collected in this special issue highlight some of the research needs identified above. One study from Greece [32] observed that that man-made engineering works, such as large dams for power generation, irrigation and water supply, artificial river diversion projects seriously affected the environmental balance (e.g., reduced sediment delivery) of inland and coastal ecosystems (forests, wetlands, lagoons, Deltas, estuaries and coastal areas) in many Mediterranean countries. Their studies suggest that the creation of artificial lakes in forest areas contributes to increase emissions of CO_2 and other greenhouse gases. The geomorphological evolution of some coastal zones in Greece was dramatically impacted by anthropogenic activities in addition to sea level rise. Forests provide the best water quality among all land uses. However, unsealed roads and tracks may cause sediment pollution in forested catchments due to road to stream connectivity via gullied pathways as well as via diffuse overland flow. A study conducted in Australia [33] examined how to design road drainage spacing based on road slope by surveying 11 km segment of roads in seven coastal catchments near Coffs Harbour on the sub-tropical New South Wales (NSW), mid north coast in Australia. They concluded that to prevent sediment loading to forest streams, in addition to preventing erosion of the road surface, gully formation, and connectivity with streams via diffuse overland flow should be prevented. This requires factoring in contributing area, hillslope gradient at drain outlets and distance to the nearest stream. Climate change is not just about changes in temperature and precipitation. Other climatic variables such as wind, radiation, and humidity can be important in altering hydrology through the evapotranspiration processes. Using the wind tunnel technique, a detailed transpiration study [34] evaluated the responses of sap flow to wind speeds under steady and unsteady wind conditions for coniferous and broad-leaved trees in Taiwan. This study suggested that neither hydraulic system nor leaf shape differences between coniferous and broad-leaved trees was an ultimate factor affecting the transient response of tree sap flux and transpiration to wind speed. Instead, stomata conductance played an important role in transpiration regulation in response to wind speed. Climate change can also alter forest ecosystems by affecting the microbial soils community associate to the symbiotic processes between fungal species and tree root systems (mycorrhizal association). A review study [35] highlights these effects and the need for a holistic view for studying the effects of climate change on forested ecosystems. The changes in soil physical and chemical properties in a timber sawmill dumpsite in Abakaliki, Nigeria were examined in another paper [36]. They found that continuous dumping sawmill waste significantly improve physical and chemical properties of soil in terms of bulk density, total porosity, moisture content, organic matter, total and exchangeable Mg and pH. Although heavy metals increased their concentration were within normal range. Therefore, the dumpsites improved overall soil fertility and productivity. Social choices in managing natural resources are also greatly shaped by the climatic context. One study [37] assessed the determinants of choice of indigenous climate related strategies by farmers in Northern Ghana. They analyzed data collected during focus group discussions and household surveys and found that the presence of a market, informal credit from friends and relatives, farmer-to-farmer extension, location of farmer, notion of climatic change (i.e decrease in rainfall or increase in temperature) influence the choice of indigenous climate related strategies. Their study recommended creating more awareness about the phenomenon of climate change highlighting changes in rainfall and temperature in order to facilitate the adoption of both indigenous and introduced climate related strategies.

3. SUMMARY

Large uncertainty exists on the feedbacks between climates, forest management, water quantity and availability, and human systems. Landscape managers are facing increasing challenges of balancing a wide range of multi-sectorial forest benefits without detriment to water resources and ecosystem function and services. There is increasing and diverse needs from forests including timber, carbon and water in the 21st century, and thus we need to explore how lands are managed optimally and sustainably at landscape level to achieve this goal. Contemporary forests, climate, water, and societal issues have brought ample opportunities for foresters, ecologists, climatologists, hydrologists, managers, and policy makers to work together to find the best approach to confronting emerging global environmental change problems.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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