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Editorial: Climate-smart solutions for tropical mountain environments

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Editorial on the Research Topic
Climate-smart solutions for tropical mountain environments

This article is an Editorial of the Frontiers in Forests and Global Change in the Research Topic "*Climate-smart solutions (CSS) for tropical mountain environments*." Tropical mountain ecosystems in the tropics are important for the provision of ecosystem services but are under pressure including a loss of diversity and native tree species in the overstory layer thus losing its adaptive capacity. The CSS in the context of tropical mountain environments is a framework that aims to assist communities to withstand extreme events and maintain productivity, increase adaptive capacity (i.e., implement effective response options) and develop opportunities to reduce emissions from the ecosystems. Agroforestry is one example of CSS which collectively stands for a dynamic, natural resource management system that either integrates trees on farms and in agricultural landscapes or introduces agricultural products in forests. Agroforestry has been practiced in East African landscapes as a traditional approach to cultivation in varying forms across the tropical mountains. By integrating perennial trees into agriculture systems, it is possible to create multiple ecosystem services and adaptation benefits, such as improved soil fertility, reduced erosion risk, better protection against landslides, and carbon sequestration. This Research Topic addresses the interconnected problems of understanding socio-ecological dynamics in mountain ecosystems to meet emerging local and international sustainable development and conservation goals. Recent international agreements highlight the need to develop and support the implementation of ambitious approaches and programmes at national and regional levels anchored in the Paris Agreement and other multilateral climate change agreements. This Research Topic identified an opportunity for the research community to generate information that will contribute to effectively implementing these agreements and guiding conservation action. The five contributions of this Research Topic integrate and report evidence from natural and social sciences to support a community-led change in sustainable land management in mountain socio-ecological systems (SES). The evidence challenges practitioners in mountain ecosystems to address hindrances from (1) gaps between the evidence bases of different disciplines and (2) the implementation of science-based recommendations. This editorial presents summaries of three original

research, one perspective and one review article to provide a conceptual framework for explaining desirable solutions to face SES challenges in mountain ecosystems, particularly in the Global South. The results place evidence from the mountain ecosystems in the context of policy needs and provide an updated roadmap for how to observe ecosystem and landscape change in a way that supports climate and conservation actions through attribution science.

The study of Meya et al. attempted to quantify, the amounts of stover transported from maize-based fields in the drier lowlands on the volcanic footslopes of Mount Kilimanjaro, Tanzania to the humid highlands of the region to produce animal protein and manure. The nutrient flows and balances between these two agroecosystems were documented. The central question was how banana and milk production in the highlands is linked to maize-based farming systems of the lowlands. The findings demonstrated that Maize (Zea mays) stover produced in the lowlands serves as an important additional fodder for smallholder zero-grazed dairy cattle farming in the highlands. The obtained cattle manure is used to replenish nutrients and manage soil fertility in the banana-based homegardens of the highlands, which contributes significantly to sustaining crop production, thus food security and the livelihoods of the community. The results revealed further that maize stover yield, related positively to mineral nutrient uptake by maize plants, implying that any determination to increase stover transfer will increase nutrient flows to the banana-based homegardens. However, mineral nutrient removal by the stover alone exceeded inputs and is expected to deplete soils in the maize-based fields of the lowlands.

Kimaro et al. investigated the salient features and ecosystem services (ES) of tree species in mountainous indigenous agroforestry systems (AGF) of the North-Eastern Mountains in Tanzania. This study describes four different types of AGF, the tree species diversity and the farmers' perceptions of the ES they provide. The article's approach to using four contrasting AGF is of practical interest to understanding the relationship between the choice of overstory tree species and the ES farmers require. The study collected data on the structure, tree species composition, diversity, and associated ES provision in the four AGF. The findings revealed notable differences in the salient features of the studied systems, with the *Kihamba* system having the highest number of native tree species and the largest diversity in species used for provisioning services. On the other hand, non-native species were used in the Miraba or Mixed spices agroforestry. The results imply that policies to increase resilience and restore the native tree species cover of the AGF can only be successful if knowledge of the ES potential of native tree species is increased, and interventions are tailored to each system's ES needs for conservation as well as livelihood.

The third article, Kamamia et al. coupled the Soil and Water Assessment Tool (SWAT) model with a genetic algorithm to identify land-use/management configurations with minimal trade-offs between environmental objectives (reduced sediment load, increased stream low flow) and the crop yields of maize and soybean in Nyangores catchment, Kenya. The findings revealed that a combined measure implementation strategy (agroforestry on certain sites and conservation agriculture on other sites within the catchment) proved to be superior to single measure implementation strategies. The study revealed further that the largest impact of land-use change on catchment hydrology can be linked to deforestation. Such changes are driven by exponential population growth and intensified food and industrial production. The study demonstrated that a spatially targeted implementation strategy for different conservation management practices can remarkably improve environmental sustainability with only marginal trade-offs in crop production at the catchment level. Incentive policies such as payments for ecosystem services (PES), could offer a practical way to effect these changes.

The perspective article, Rüegg et al., presents a modeling framework to evaluate the net effect of forest management for a key ES of flood protection. A case study in the upper Rhone catchment, applied for the first Swiss Federal Forest law (1876) is given a case example, which was established to protect mountain forests against natural hazards, particularly floods. The perspective revealed that environmental laws and policies are rarely evaluated, often because the environmental services are part of a complex socio-ecological system. The insight is therefore relevant to global water and forest discourses bridging the synergies between policies and implementation, often receiving little scientific attention.

The review paper by Langston et al. proposes embedded science as a method to generate knowledge related to local forests and forest management options for achieving positive outcomes for local and non-local stakeholders. This is so because there is a global shift of forest management to local levels to better reconcile local livelihoods and biodiversity conservation. The paper revealed that science can contribute to local learning and adaptation within landscape contexts. However, complexity and power relations have hampered scientists' efforts to engage with the people who use and influence the use of resources at landscape scales. Therefore, landscape approaches present an opportunity for science to help steer local management to address local contexts.

The collective findings of the five papers have highlighted the overarching research problem when viewed collectively. The articles have provided evidence across disciplines for addressing challenges and generating opportunities for the socio-ecological nexus in tropical mountains and their ecosystems. For example, the papers that analyzed nutrient flows in maize-based fields on Mount Kilimanjaro, ecosystem services in Tanzanian agroforestry systems, land-use management strategies in Kenya, a modeling framework for flood protection in Swiss forests and the concept of embedded science in forest management, each have offered a unique perspective for understanding the CSS for tropical mountain environments. The findings corroborate that the choice of CSS is closely linked to communities' ES needs, livelihood strategies and the features of each ecosystem.

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