Overview

Tropical forests under a changing climate and innovations in tropical forest management

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Global change and innovations

The future of tropical forests and the global climate are inextricably linked. Many tropical forest ecosystems and the people that depend on them are especially vulnerable to rapid shifts in the climate regime [1-4]. Potential consequences range from changes in tropical weather patterns, species distributions, and ecological function, to the modification of human communities and livelihoods. Together, these effects of global climate change could ultimately result in reduced or highly modified tropical forest cover. Recent studies demonstrate that intact tropical forests account for half of the total terrestrial sink for anthropogenic carbon dioxide (CO_2) emissions [e.g. 5]. At the same time, a substantial fraction of global CO_2 emissions comes from the conversion of tropical forest to other land uses [6], suggesting that deforestation, carbon emissions, and climate change may form a positive-feedback loop that could prove difficult to break. Despite sustained efforts to combat global deforestation, tropical forest management that provides for both human livelihoods and conservation remains an elusive goal in many parts of the globe [7]. Addressing these seemingly intractable problems will require creative problem solving, knowledge-sharing, and new approaches to tropical forest management at multiple levels of governance. All are key to finding lasting solutions.

Recent innovations in tropical forest management include new community engagement strategies, market-based and contract-based methods for reducing agricultural encroachment, and new financing for sustainable management via international climate change mitigation schemes. With an increased international focus on tropical forests as carbon stores, and the continued urgent need to find solutions for high deforestation rates and attendant biodiversity loss, the field of tropical forest management is currently a hotbed of new ideas.

On February 11-13, 2010, shortly after the 16th Conference of Parties of the United Nations Framework Convention on Climate Change, the Yale Chapter of the International Society of Tropical Foresters (ISTF) convened its annual symposium, titled "Tropical Forests Under a Changing Climate: Linking Impacts, Mitigation, and Adaptation". This symposium explored the potential ecological and socio-economic impacts of climate change on tropical forest countries, as well as the role that tropical forest management can play in climate change mitigation and adaptation. The following year, on January 27-29, 2011, the Yale Chapter of ISTF organized another symposium, titled "Communities, Commodities, and Carbon: Innovations in Tropical Forest Management". This symposium further explored recent ideas and successes in tropical forest conservation, including the regulation of agricultural supply chains and new initiatives in community-based forest management.

Prior to each conference, Yale ISTF widely distributed a call for papers, inviting submissions from practitioners and researchers from government, academia, communities, and environmental and development organizations. Both conferences featured keynote lecturers, Yale faculty moderators, and invited panelists representing tropical regions in Central and South America, Asia, and Africa. Due to common themes running through both conferences and the substantial overlap in topic areas covered in the conference papers, these proceedings feature contributions from select speakers at both symposia.

This overview article ties together the specific issues discussed at these symposia. First, we briefly review the current state of knowledge concerning the interactive effects between climate and intact tropical forests, the role of tropical land cover in the carbon cycle, potential feedback interactions, and possible forest management interventions that could facilitate adaptation of forests by decreasing their vulnerability to hotter, dryer climates. This review serves as a backdrop for the conference papers summarized thereafter, which cover topics ranging from community-level approaches to climate change mitigation and adaptation; the potential synergy between forest carbon finance and sustainable timber extraction; to efforts at reducing deforestation through cooperation between civil society, government, and agricultural producers.

Tropical forests in a changing climate

Tropical forests interact with the local and global climate in several ways. Globally, unlike other biomes, tropical forests lower air surface temperatures and enhance regional precipitation by maintaining high rates of evapotranspiration [reviewed in 5]. Tropical forests also have low albedo, which increases surface warming, but this is more than offset by the evapotranspiration effect. General circulation modeling also suggests that the climatic influence of these forests may affect precipitation in regions beyond the tropics via hydroclimatological teleconnections [8]. As tropical forests have an impact on climate, climate change in turn has an impact on forest health. Global climate change is expected to increase the likelihood of higher temperatures, reduced precipitation, and prolonged drought conditions, which exacerbate the risk of catastrophic wildfire, itself a major source of greenhouse gases [9; 10]. Additionally, tree mortality linked to drought and heat stress has been documented in African, Asian, and South and Central American tropical forests, even in ecosystems such as moist forests which are not usually considered water-limited [reviewed in 11]. However, scientific understanding of the proximate physiological and mechanistic causes of climate-related forest die-off is still in its infancy, with relatively few tropical forest tree species and ecosystems rigorously studied thus far [11]. Recent research suggests that slight increases in drought stress can create trapped gas emboli in tree xylem, which permanently reduces the ability of afflicted plants to supply water to leaves, resulting in desiccation and mortality [12].

The world's remaining tropical forests contain roughly one-quarter of all the carbon in the terrestrial biosphere and absorb significant amounts of carbon annually [5]. Intact tropical forests sequester about one-half of the approximately three billion tons of anthropogenic atmospheric carbon absorbed by global total net forest growth each year, the equivalent of 15% of emissions from fossil fuel combustion and net deforestation [5; 6]. Hence, removal of tropical forests for other, primarily agricultural, uses not only releases greenhouse gases into the atmosphere but also reduces the capacity of the biosphere to sequester atmospheric carbon. After fossil fuel combustion, land use change (LUC) in the tropics, mainly deforestation, is the second greatest anthropogenic source of global carbon emissions [13]. From 1990 to 2005, net carbon emissions from predominantly tropical LUC were 1.5±0.7 Pg C yr^{-1}, though this rate has since decreased dramatically [13]. The relative contribution of tropical LUC to total anthropogenic carbon emissions was 20% in 1990-2000, but decreased to 12% in 2008 due to both decreased deforestation rates (e.g., as documented in Boucher et al. [this volume]) and increased global fossil fuel consumption [13].

Increasing tropical reforestation, which sequestered on average 1.64±0.52 Pg C yr^{-1} from 1990 to 2007, has also helped offset the 2.94±0.47 Pg C yr^{-1} in gross emissions from tropical LUC during the same period [14]. However, there is considerable uncertainty over the magnitude of terrestrial carbon fluxes from the tropics due to inconsistent but rapidly evolving measurement methodologies [15]. Moreover, tropical biomass burning releases aerosols that have multiple, complex, and countervailing effects, with the net impact on global climate still under investigation [e.g. 16; 17].

The combination of deforestation and global climate change threatens to create a positive feedback loop that perpetuates both phenomena. Deforestation reduces evapotranspiration, which in turn reduces local rainfall and increases the risk of wildfire and its attendant greenhouse gas emissions, particularly within forest fragments with dry, fire-prone edges [reviewed in 18; 19]. As noted above, even tropical areas where forests are in less danger of clearing will be more prone to catastrophic wildfire due to global climate change. Once burnt, some forests, especially those not adapted to periodic fires, become prone to further burns, particularly if grasses are allowed to establish in the forest understory and provide a renewable source of fuel [reviewed in 20]. The positive feedback loop is further perpetuated when land managers take advantage of drought conditions to burn large forest tracts in order to convert them to cattle pastures or agricultural plantations [reviewed in 21]. Moreover, even absent changes in rainfall, higher temperatures alone could substantially increase evapotranspiration rates in some areas, causing a substantial shift from forest to savanna vegetation better adapted to less soil water by the end of the 21st century [3]. A decrease in resilience caused by a combination of climate change and deforestation may push forest biomes beyond an unstable threshold and produce a self-propagating shift to savanna over a range of rainfall levels, as tropical forest regions tip from one steady-state equilibrium to another [1].

Concerted management will be necessary to diminish these positive feedback interactions and limit the adverse effects on tropical forests. Limiting deforestation below resilience thresholds should be the principal goal, especially in ways that maintain primary forest, connectivity and migration corridors, riparian buffer zones, and other areas that can serve as humid refugia at multiple scales [20; 22]. Additionally, adopting forest management practices aimed at limiting wildfires could enhance resilience to climate change [10]. Without such management, atmospheric carbon mitigation achieved via international financing for reduced emissions from deforestation and degradation (REDD, see Hodgdon et al. [this volume], Long [this volume] and Griscom and Cortez [this volume]) would likely be partially negated by wildfires occurring in areas included in such programs [10; 23].

The four themes reviewed above—interactions between climate and tropical forests, the role of tropical forests in the global carbon budget, positive feedback effects, and active management for adaptation—are relevant to the articles presented here. The papers summarized below touch upon these themes in various ways, and the subsequent section highlights the common and contrasting ideas that run throughout these conference proceedings.

A question of resilience

This collection begins with a contribution from Ariel Lugo, Director of the International Institute of Tropical Forestry at the United States Forest Service, based on his keynote address at the 2010 ISTF conference. Lugo has worked on a wide range of tropical and sub-tropical ecosystems, including hardwood forests, mangroves, floodplain wetlands, sand pine forests, prairie lakes and palm wetlands. His current research assesses the role of tropical forests in global processes and compares tropical tree plantations with natural forests. Here, he argues that tropical forests and their attendant species—capable of recolonization, succession, and adaptation—are more resilient to human encroachment and other anthropogenic disturbances such as climate change than the fragile portrait of extreme biodiversity loss that many scientists and conservationists have depicted. Lugo argues that this misperception, as well as others, has occurred due to the over-extrapolation of earlier scientific studies in the tropics that were limited in disciplinary scope, spatial scale, time, and hence broader applicability. Moreover, a failure to recognize the diversity of tropical forest types has led to the perception that all tropical forests are under the same degree of dire threat. Drawing from examples in Puerto Rico and elsewhere, Lugo also notes that forest cover tends to rebound in countries following periods of deforestation as countries industrialize and urbanize, resulting in unique species assemblages. These "novel forests" have conservation value, as they are capable of developing into ecosystems as biodiverse, as ecologically robust, and as functionally valuable as primary forest.

As evidenced by Thomas Lovejoy's introduction to this collection, not all scientists agree with Lugo's optimistic scenario, and the issues he raises remain the subject of intense scientific debate. For example, Lugo's logic suggests that forests are more resilient and less prone to climate-related positive feedback mechanisms than suggested by the studies referenced above. However, Lugo's counterintuitive ideas and unique perspective represent a style of innovative thinking which is necessary to address persistent, seemingly intractable problems such as deforestation, not to mention new, rapidly evolving potential crises such as climate change. In the following sections, selected contributors to the ISTF conferences present examples of groundbreaking changes in rural community resource management, carbon finance, and commodity supply-chain governance which strive to address these challenges.

Community level innovations for addressing climate change

Recent years have seen the gradual decentralization of authority and implementation of tropical forest management away from state agencies and towards local communities [reviewed in 24; 25]. Consequently, the responsibility of implementing strategies to mitigate and adapt to climate change often has fallen upon local communities as well, particularly those reliant on forest goods and services for their livelihoods. In this collection, Sushant, a doctoral student at the Indian Institute of Forest Management, documents the effect of climate-induced changes to local natural resource production on tribal livelihoods within the central Indian state of Madhya Pradesh. Following a case-study approach, Sushant utilizes rural appraisal techniques, group consultations, semi-structured interviews, household surveys, and personal observations to explore the responses of tribal villages to perceived climate change, as well as their attempts to adapt.

Increasingly unpredictable rainfall and other climatic changes have enhanced the risks associated with traditional livelihood activities, such as rice cultivation and non-timber forest product (NTFP) collection. In response, and often with educational and financial support from local non-governmental organizations (NGOs), tribal villages have endeavored to adopt new agronomic techniques meant to reduce water usage and help plants better resist drought and winds, while also experimenting with more diverse sources of income such as commercial-scale vermi-composting, horticulture, and vegetable cultivation. Villagers have also implemented new community-based management of common forested land to adjust to increasingly scarce livestock fodder and fuelwood. However, these small-scale attempts to innovate beyond traditional practices have not all yielded successes, and their occasional failures highlight not only the precarious circumstances that climate change places upon these villagers, but also the continuing need to find creative ways to adapt.

In contrast, the article from Benjamin Hodgdon, Jeffrey Hayward, and Omar Samayoa, working with the Rainforest Alliance's Training, Extension, Enterprises and Sourcing (TREES) Program, presents an example of successful community-level forest management within the 2.1 million hectare Maya Biosphere Reserve (MBR) in the Petén region of northern Guatemala. Since 1994, a growing number of forest concessions to communities living within the reserve have been a remarkable success in conservation terms. Now totaling 400,000 hectares, over 86% of these community concessions are certified as sustainable by the Forest Stewardship Council. Moreover, not only have certified concessions exhibited deforestation rates twenty times lower than adjacent protected areas, they have also boosted local incomes and employment while constituting a funding source for healthcare, education, forest protection, and other social projects. The granting of concessions from the government to forest communities has been successful in no small part due to committed engagement from local and international NGOs, which assisted community coalitions in organizational and technical capacity-building and forest management planning. Funding from international development banks and aid agencies was also instrumental to the program's success.

These civil society, government, and international organizations continue to play an outsized role in improving the community concession model, notably through the development of a new initiative, GuateCarbon, aimed at capitalizing on the current global movement towards international financing of forest carbon sequestration (i.e., REDD+). These groups have employed an innovative collaborative framework in order to lay the groundwork for MBR community concessionaires to receive carbon finance. The Rainforest Alliance has played a facilitating role among government, community, and international agencies to undertake baseline emissions assessments, estimate potential carbon credits, analyze legal and regulatory issues, and create a distribution mechanism for financial benefits. While some of these activities, such as baseline assessments, follow previously established guidelines, others have required more creatively negotiated, ad-hoc approaches that impart early lessons and intellectual spillover from the subnational MBR project to Guatemala's national REDD readiness plan. For example, the mechanism for apportioning payments for carbon credits, currently being negotiated for GuateCarbon, will likely eventually apply at the national level. Thus, though forest management is implemented at the community level, a complex web of stakeholders at multiple levels of governance, representing frequently competing interests, is nonetheless invested in the success of this initiative.

The community-level activities presented in these contributions by Sushant and Hodgdon et al. underscore the importance of assistance from external groups, government, and civil society in the successful formulation and implementation of innovative land management strategies. External agents are sources not only of new ideas, but also of funding and other institutional support. Thus, involvement and collaboration among multiple stakeholders can help reduce the risk that would have been borne by a rural community attempting to execute a new initiative on its own. NGOs in particular can play useful roles in oversight, quality control and coordinating cooperation among the public and private sectors, as well as between international, national, and sub-national governance agencies. Moreover, some strategies, such as REDD, are potentially so complicated that they involve external engagement by necessity. The papers in the next section further explore the potential for active forest management to influence the implementation of REDD financing and vice-versa.

Incorporating improved tropical timber management into carbon finance

Noting that multilateral environmental agreements have generally failed at promoting sustainable forest management to date, Andrew Long, Assistant Professor of Law at the Florida Coastal School of Law, suggests in his article for this collection that the explicit incorporation of adaptation and sustainable forestry practices into REDD accounting would strengthen forest carbon sequestration programs. REDD has been more promising than past attempts at international forest governance due to its adherence to the principle of common but differentiated responsibilities, while its voluntary, contract-based design alleviates national sovereignty concerns. However, Long argues that REDD, as presently conceived, is focused primarily on carbon storage, while the welfare of local communities most directly affected is a secondary concern. As the climate changes and communities highly dependent on extracting local natural resources become increasingly vulnerable, emissions mitigation and adaptation will constitute interdependent and simultaneous endeavors. REDD, as the primary international policy strategy for addressing the mitigation of forest-based carbon emissions, ought therefore to explicitly incorporate adaptation as well.

Climate change is expected to increase the vulnerability of tropical forests to fires, extreme precipitation events, droughts, and shifts in species' ranges, as well as to exacerbate poverty and governance problems, often the root causes of deforestation. These factors endanger the successful implementation of REDD itself, and a REDD program that neglects ecological and socioeconomic needs among local communities runs a high risk of failure. According to Long, the incentivization of sustainable forestry principles within REDD —designed in part to maintain income flows from timber resource management while preserving ecological and social benefits to local communities—will not only help communities meet adaptation needs but also bolster the long-term security of REDD carbon mitigation. Ultimately, this modified REDD strategy would require innovations in polycentric governance. International frameworks creating the appropriate positive incentives for national and subnational levels of governance could implement verifiable carbon storage while enhancing the ability of forests to sustainably meet local needs.

In the subsequent paper, Bronson Griscom, Director of Forest Carbon Science at the Nature Conservancy, and Rane Cortez, REDD advisor to the Nature Conservancy, explore in greater detail the sustainable forestry practices mentioned by Long, presenting a mechanistic rationale for their incorporation into REDD schemes. Using the alternative term improved forest management (IFM), Griscom and Cortez describe three types of practices relevant to the selective logging operations prevalent in the tropics: harvesting with greater timber recovery but reduced ecological impacts and waste; identification and protection of special conservation zones; and silvicultural treatments to ensure regeneration and maintenance of native tree diversity and commercially exploitable species. Nascent research on IFM suggests that it could lower carbon emissions compared with conventional logging, has less potential for leakage than logging bans, and could alleviate the risk of non-permanence by reducing the likelihood of fires, all while maintaining or enhancing both local employment and biodiversity. Moreover, where implemented by local communities IFM can engender a stakeholder constituency with economic incentives to avoid deforestation.

However, the incorporation of IFM into REDD still needs to overcome several obstacles, such as perennial transparency, corruption and tenure issues; the disjointed nature of existing forest management and carbon storage verification standards; gaps in current scientific knowledge; and up-front development, adoption and certification costs. Financing from REDD agreements could offset cost barriers and catalyze IFM adoption, particularly among small-scale community-based forest managers less likely to have access to other sources of capital. However, the resolution of the other challenges listed above will require innovations not only in governance as indicated by Long, but also in certification schemes, scientific knowledge, and technological capability. Griscom and Cortez highlight in particular the need for economically feasible, dependable and scalable methods for measuring, reporting, and verifying emissions reductions. Aside from the need to integrate the existing certification schemes for sustainable forest management and carbon emissions reductions, they identify three additional research gaps: quantification of emissions reductions from specific IFM practices; refinement of monitoring methods such as remote sensing; and quantification of the post-harvest net carbon flux.

Together, the contributions by Long and Griscom and Cortez present a cohesive case for incorporating improved forest management into REDD. They not only thoroughly explore the feasibility of capturing IFM emissions reductions via REDD, but also highlight the potential benefits to both the long-term success of a REDD regime as well as to the community-based recipients of financing. However, there are still major obstacles both in the governance of such a program and in its technical implementation, which will require further innovation and integration of international policymaking, verification schemes, national and subnational governance reforms, not to mention further scientific research and community-level outreach. The final selection of conference papers highlights how such an integrated approach was employed to successfully reduce the rate of deforestation in the Brazilian Amazon.

Integrated supply-chain approaches to reducing deforestation in the Amazon

Though persistent, the deforestation rate in the Brazilian Amazon has decreased dramatically in recent years, to one-third of its average during the decade from 1996 to 2005, and one-fourth of its high point in the mid-2000s. In their article, Doug Boucher, Sarah Roquemore, and Estrellita Fitzhugh of the Union of Concerned Scientists' Tropical Forest and Climate Initiative attribute this reduction—which occurred despite continuing deforestation pressures from high export prices for agricultural commodities—to a combination of action by civil society, Brazilian political leadership favorable to conservation, resultant policy changes and rigorous enforcement, and external international funding for carbon sequestration. Forest clearing, primarily for cattle ranches and soybean farms, accelerated since the early 1990s to reach over 27 thousand square kilometers cleared during the 2003/2004 cropping season alone.

However, since that peak the annual deforestation rate has exhibited a relatively steady decline, despite increased cattle and soy production, due to the confluence of several factors. First, in the latter 2000s, NGOs produced several reports excoriating soy and cattle producers for their role in Amazonian deforestation, focusing on major targets such as multinational corporations that sourced their soy from Brazil and the large companies among which cattle processing and distribution are concentrated. These actions, combined with civil society campaigns, helped convince major companies situated along the soy and cattle processing and exporting supply chains to enact moratoria on purchases of soybeans and cattle from newly deforested lands.

Concurrently, Brazil benefited from political leadership at the federal level, which was committed to reducing the country's greenhouse gas emissions from deforestation, and enacted legislation creating a framework for monitoring and verification of emission reductions. On the ground, federal and state governments also began to more rigorously enforce forest protection laws, reducing illegal logging, confirming legal protection for indigenous lands, and promoting sustainable development. Finally, these commitments to reduce emissions were incentivized by pledges from the Norwegian Climate and Forest Initiative of up to $1 billion for Brazil's Amazon Fund, which have been implemented via multilateral funding platforms and are contingent upon verified progress in reducing deforestation. Brazil's reduction of Amazonian deforestation rates has thus occurred largely under the aegis of innovative polycentric governance similar to the kind espoused by Long: its tentative success is due to innovative, integrated efforts at multiple levels of governance—international, federal, and local—and among wide ranging interest groups, e.g., international NGOs, Brazilian civil society, indigenous groups, commodity producers, and state and federal governments.

The final paper of this collection, by Nathalie Walker and Sabrina Patel of the National Wildlife Federation and Kemel Kalif of Amigos da Terra Amazônia Brasileira, further explores the cattle commodity production and supply chains that have for decades contributed to Amazon deforestation in Brazil. In particular, this paper investigates the range of products and markets supplied by Amazonian cattle herds; the commodity markets driving further expansion of ranches into forested lands; and the potential for the demand for environmentally sustainable products, by both intermediate purchasers and end consumers, to influence the Brazilian cattle industry's behavior concerning deforestation. Utilizing data on cattle raised and slaughtered, production of a range of specific commodities and end-products, as well as export and import statistics, the authors show that, from 1994 to 2009, a rapid expansion of Amazonian herds occurred alongside increased exports of live animals, beef, leather, and cattle co-products. Walker et al. also estimate the size of the illegal, essentially unregulated clandestine sector of cattle commodities production, finding that from 2002 to 2009, the total number of registered slaughters was less than three-fourths of the total estimated based on hide production. This discrepancy suggests that over one-quarter of all cattle slaughters are unregistered and, thus, illegal.

Finally, Walker et al. research the cattle supply chain from ranch to slaughterhouse via literature review and field visits. They find that while many major beef and leather producers have committed to the deforestation moratorium described in detail by Boucher et al., these producers are responsible for only one-third of the Amazonian export supply. The moratorium does not cover processors who purchase unregistered carcasses, nor does it cover producers of co-products such as tallow. Moreover, by the illegality of their actions, processers who participate in the clandestine market are unlikely to modify their behavior based on semi-governmental initiatives like the cattle moratorium. Reducing deforestation by those currently not bound by the moratorium will require further innovative action on the part of government, civil society, financiers, multilateral institutions, and consumers. Therefore, while Boucher et al. show that notable strides have been made in reducing the rate of Amazonian deforestation through the polycentric implementation of multiple, integrated strategies, Walker et al. demonstrate that continued effort in generating new solutions will likely be necessary for this success to continue.

The future of forests

Collectively, these papers suggest that there is good reason for the kind of optimism espoused by Lugo. Through innovations in governance, technology, and cooperative action among multiple stakeholders, alarming rates of deforestation can be slowed while concurrently allowing continued economic growth. Similarly, with external assistance, local communities highly dependent upon tropical forests can not only adapt to climate change but can also contribute to the mitigation of greenhouse gas emissions. Nonetheless, the urgency expressed by Lovejoy is well-founded, since these challenges should by no means be considered adequately met. While the scholarly and policy worlds of tropical conservation are awash with innovative ideas, many are far from the implementation stage and will require extensive testing and refinement in the field. For the foreseeable future, climate change and deforestation will persistently advance, creating new, unexpected problems ecologically, economically, and politically, which will require our continued creativity to address.

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