EDITORIAL

MINI FOCUS: SUSTAINABLE LANDSCAPES IN A WORLD OF CHANGE: TROPICAL FORESTS, LAND USE AND IMPLEMENTATION OF REDD+

Predicting broad-scale carbon loss and recovery in managed tropical forests

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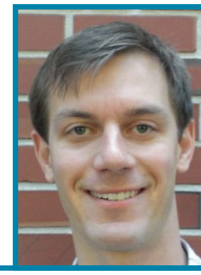

"Quantitative understanding of carbon loss and recovery from broad-scale tropical forest degradation could be furthered by the development of forest dynamics models that are simple, generalizable and constrained by data."

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Reducing carbon emissions from tropical deforestation and forest degradation, as formalized in the REDD+ framework, could substantially slow increases in atmospheric CO_2. Although REDD+ programs have predominantly focused on deforestation, tropical forest degradation from extensive selective logging affects an annual area equivalent to that converted to nonforest land use [1]. There appears to be considerable unrealized potential to reduce carbon emissions by mitigating forest degradation from unsustainable selective logging in tropical regions [2]. High expectations notwithstanding, precise assessment of this potential remains a challenge because forest degradation encompasses a range of selective logging practices, because tropical forests vary in their potential for carbon storage and the timescale of carbon recovery in degraded forests is uncertain.

Quantitative understanding of carbon loss and recovery from broad-scale tropical forest degradation could be furthered by the development of forest dynamics models that are simple, generalizable and constrained by data. Unlike existing forest models that have largely been developed on a site-specific basis, new models should aim for widespread applicability if they are to be useful tools for REDD+ at national and regional scales. Rather than seeking to provide an optimal fit to stand-level carbon dynamics at one particular site, new generalizable models would predict how carbon trajectories in logged stands vary across a much broader area. This shift in focus requires changes in the amount of detail and complexity that models incorporate, as well as changes in how such models are calibrated against observational data that are geographically extensive, but potentially include less site-level information. By capturing robust patterns of carbon uptake and release that occur across different forest types over broad areas, generalizable forest dynamics models could serve as effective tools for predicting carbon fluxes under a range of forest management scenarios. Such models would prove valuable in quantifying expected carbon offsets from new REDD+ initiatives and in aggregating these to national scales.

Forest dynamics models project how demographic processes, such as tree growth, mortality, recruitment and harvesting, lead to changes in population structure and community composition, along with resultant carbon stocks and fluxes. These models can be used

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to project how different selective logging practices and intensities affect stand-level carbon dynamics through time. For example, reduced-impact logging techniques have been shown to effectively reduce short-term carbon losses relative to conventional logging by up to 50% [3], but their long-term effects are less well understood, due to the time and cost of extended monitoring efforts. Model-based projections have been used to quantify long-term carbon recovery under both reduced-impact and conventional logging, and to compare carbon recovery trajectories to the projected carbon storage capacity of intact forests [4,5]. Forest dynamics models can also project the outcome of alternative practices that might vary the type and extent of logging impacts, without the need to first implement such changes on the ground.

Existing forest dynamics models for tropical forests fall into a range of computational frameworks (e.g., individual-based, matrix and integral projection models [6]) and incorporate varying degrees of process detail. Models have proven successful in addressing questions related to tropical forest succession [7], fragmentation [8] and optimal cutting cycles [9], in addition to carbon storage [4,5]. To date, tropical forest dynamics models have been developed and calibrated through detailed field measurement campaigns at individual study sites. The resulting model forms and parameters are highly suited for capturing local forest dynamics, but their intensive data requirements mean it is unclear whether such models can be applied more broadly to other forest conditions.

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To be most useful for REDD+ programs, forest dynamics models need to be developed that are applicable at national or regional scales. Models with broad applicability at these larger scales should focus on encapsulating generic sources of variation in tree vital rates through a limited number of model parameters and state variables, all of which must be widely obtainable from data. Models of this kind would need to avoid complex formulations of growth, mortality or recruitment that may fit well at local study sites, but that do not have broad applicability across different forest types and conditions. Also, the data needed to parameterize detailed processes, such as spatially explicit forms of competition or seed dispersal, may not be widely available. Instead, simple models might express variation in demographic rates through a combination of basic size and shading effects [10], or applying differential equations to represent the aggregate biomass dynamics of distinct functional types [11]. The chosen model forms should be evaluated based on the resulting model's ability to reproduce temporal patterns of stand-level carbon loss and gain that are observed in logged forests across a given country or region. By capturing forest carbon dynamics at these broader scales, generalizable forest dynamics models would be much better suited to regional REDD+ assessments than models developed primarily on a site-specific basis.

Development of broad-scale forest dynamics models requires geographically extensive data for estimating model parameters. The required ecological parameters describe the demographic processes of tree growth, mortality and recruitment, as well as key allometric scaling relationships. Model parameters for selective logging may specify the species, size and number of trees felled, the extent of collateral stand damage and the time intervals between harvests. Unlike site-specific models, generalizable forest dynamics models need to describe how these parameters vary across space. The parameters of a generalizable model might change with climatic or edaphic conditions, species or functional-type composition, market demands, governance failures or the prevailing disturbance regime. Across Bolivia, for example, tree growth rates have been shown to increase both across a spatial gradient in water availability and with the intensity of logging over the past 6 years, but are not strongly related to soil fertility or texture [12]. Broad-scale analyses such as this can be incorporated into modelling efforts to describe spatial variation in stand dynamics across wide areas.

The data required to estimate model parameters at regional scales are now increasingly available. Several data networks (The Center for Tropical Forest Science Forest Dynamics Plot network, RAINFOR, AfriTRON) have been assembled to collect and maintain long-term re-measurements of unlogged permanent forest plots in tropical regions [13–15]. A recent effort has also established a network of logged permanent sample plots (Tropical managed Forests Observatory [101]) that will serve to synthesize impacts of selective logging based on long-term monitoring across the tropics. By using formal parameter estimation methods to incorporate broad patterns in tree demography found within these databases, tropical forest dynamics models can be developed and applied at scales that have not previously been possible.

There are a number of challenges to understanding carbon loss and recovery that broad-scale modelling efforts should recognize. Tropical forests contain extraordinary species diversity, and so models typically need to aggregate species to obtain adequate sample sizes for analysis. There has been recent progress in functional-type classification of tropical tree species to draw upon [16], but the effects of such classification schemes on model behavior remain largely unresolved. There has also been considerable discussion of the responses of tropical forests to climate change and CO_2 fertilization [17]. The future effects of these environmental changes on tree demography are not clearly understood. Models that account for environmental changes should work from credible (and explicit) assumptions as the mechanistic basis of climate-related demographic responses remains an active research topic. In a management context, logged stands often exhibit elevated mortality from site disturbance [18], but the magnitude and duration of these increases can be difficult to accurately assess, particularly for large trees. Understanding the full importance of logging impacts will require a combination of long-term monitoring and sensitivity analyses of model projections. In dealing with each of these uncertainties, comparisons between different types of models (local vs general, ground- vs remote-sensing-based, mechanistic vs empirical) will offer insights into the reliability, and weaknesses, of predictions from new broad-scale modelling efforts. Rigorous assessment of uncertainty is essential to establishing defensible models that can help inform REDD+ decision-making.

Progress in developing simple, generalizable and easy-to-use tropical forest dynamics models would provide an important tool for quantifying carbon fluxes from forest degradation at national and regional scales. As we gain a greater predictive understanding of carbon stocks and fluxes in degraded and intact forests, and under a range of logging practices and intensities, it will become easier to manage tropical forests for their carbon storage potential under REDD+. Advances in data-constrained forest dynamics modelling, combined with increasing availability of geographically extensive tropical forest plot data, will help to bring this undertaking within reach.

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▪ **Website**

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