Geography of forest disturbance

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For some, the phrase “forest disturbance” conjures a vision of bulldozed trees to make room for agricultural fields. For others, the term evokes a mental picture of a tree falling in the forest, creating a gap. In reality, these are two end-members on a continuum of physical disturbances that commonly take place in forests. Critically, the frequency, size, and type of disturbances—the disturbance regime—is a fundamental characteristic of forests associated with processes ranging from carbon and water cycling to the interactions among the flora and fauna (1, 2). As a result, interest in the geography of disturbance has not only increased in forest ecology, it is also recognized in the climate-change science and policy-development arenas (3). In this context, a report by Chambers et al. (4) in PNAS takes us another step forward to determining the geography of natural disturbance in the central Amazon basin. More broadly, their work provides a fresh perspective on ways to address the challenge of quantifying and understanding forest disturbance regimes.

Tropical forests undergo a panoply of natural disturbances occurring on multiple—and often interacting—spatial and temporal scales. First, the disturbance regimes of tropical forests are largely defined by a process known as gap-phase dynamics (5) (Fig. 1). When a cluster of trees falls, the newly formed gap is infiltrated by light-harvesting species that fill the newly available space. Eventually the gap pioneers are replaced by slower-growing species, which can live for centuries before falling and creating another gap, thereby initiating the cycle again.

Beyond the endogenous and ubiquitous process of gap-phase dynamics, some regions are also prone to much more rare, large-scale natural exogenous events, such as “blowdowns,” associated with powerful weather fronts (Fig. 1). Blowdowns are stand-resetting events varying in size from tens to many thousands of hectares, and they have been documented in central Amazonia (6, 7). However, other disturbances are associated with a hybrid of natural endogenous and exogenous processes. For example, droughts can have a differential impact on contrasting growth-forms in tropical forests, and these growth-forms often vary markedly in their likelihood of canopy failure. Vast swaths of southwestern Amazonian forest contain bamboo that undergoes widespread dieback during drought (8, 9), resulting in structural failures that pull neighboring trees to the ground (10). Moreover, disturbance often begets disturbance in tropical forests: a gap created by a felled tree can change the microclimate for neighboring survivors, subsequently leading to additional mortality, a pattern referred to as “contagion” (11).

The question challenging modern forest ecology in the tropics, and elsewhere, revolves around the precise spatial and temporal frequency of these disturbance events. The importance of quantifying this is hard to overstate: understanding the disturbance regime is requisite to understanding nearly every other ecological process in a forest. For decades, the end-members on the disturbance continuum have been carefully estimated from opposing vantage points. Field plots have been used to estimate rates and

patterns of gap-phase dynamics (12, 13). In contrast, large disturbances—those driven by humans, such as logging and fire, as well as natural events like blowdowns—have been mapped at the stand-offish distances afforded by satellite sensors (6, 14). Integrating these approaches, and filling in the continuum of disturbance sizes and frequencies between these extremes, ends up being the biggest challenge of all.

Chambers et al. (4) present a unique approach to achieving this goal by combining field work, satellite observations, and a probabilistic simulation model. In doing so, they gain a spatially and temporally explicit understanding of a fuller disturbance spectrum for an old-growth forest near Manaus, Brazil. Their simulation results suggest that long-term increases in carbon sequestration driven by growth are punctuated by stand-resetting disturbance events of varying size and frequency, many of which are larger in scale than the gap-phase dynamics apparent in field plots. A useful byproduct of their analysis is a minimum bound on the size of a field plot that would be necessary to pick up these large, infrequent events. The authors estimate that plots larger than 10 ha would provide the greatest sensitivity (Fig. 1), which stands in stark contrast to nearly every permanent sampling plot found in the Amazon today, each of which is usually less than 1 ha in size (15).

Chambers et al. (4) also tell us that very large natural disturbance events of 4–10 ha in size (equivalent to about 600–2,700 trees per event) are rare in the central Amazon. Their simulations suggest that these events occur at a given 1-ha patch of forest once in 20,000–330,000 y. Given the mismatch between these very rare events and the median estimated tree age of 175 y, these largest of disturbances may not play a big role in biasing the estimated Amazon carbon sink reported from smaller field-plot and micro-meteorological tower measurements (16–18). However, it is the middle portion of the gap-size frequency continuum—the events larger than single-tree falls but smaller than the very largest and rarest disturbances—that may create the most uncertainty in

Fig. 1. Forest disturbance is expressed as continuum of canopy gap sizes and temporal frequencies, ranging from small single-branch and tree-scale gaps like the one shown on the far left, to massive blowdowns caused by powerful storm events, like the one to the far right. These images were taken using Light Detection and Ranging from the Carnegie Airborne Observatory, which show the height and spatial arrangement of tree crowns in four forests of the western Amazon. Tall canopies are white and forest gaps are black.

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long-term carbon sequestration studies. In central Amazonia, Chambers et al. (4) estimate that disturbances of about 15–40 trees per event occur every 50–200 y in a given hectare of forest. Most tropical forest plots have been monitored for less than 25 y (19), and so these events will be hard to incorporate into calculations based on field work alone. The impact of these events on net carbon uptake is profound: these disturbances wind back the clock at a spatial scale and temporal frequency that challenges current measurement and modeling efforts. Indeed, given the limited size of most field plots, such disturbance events will require large-area mapping at high spatial resolution (20) to improve upon these early estimates by Chambers et al.

Although the Chambers et al. (4) study helps us to fill out the forest disturbance continuum in one portion of Amazonia, caution must be exercised when considering the extent to which their results can be extrapolated to other regions. Both the drivers of disturbance and the subsequent biotic responses vary geographically. For example, the Brazilian region of focus for Chambers et al. (4) is a known alley of squall line activity (7, 21), and the large-scale blowdowns they observe may be less prevalent in other regions of the Amazon. Similarly, gap-size frequency distributions vary by forest physiology (22), and Amazonian canopies span

an impressive range of architectures, floristic composition, and biomass levels (23, 24). Finally, disturbance research will need to address subcanopy losses—branches of trees—in a spatially explicit way to account for this

potentially major contributor to the carbon dynamics of forests (25). These and still other factors require additional study in the effort to develop a global geography of forest disturbance.

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