OPINION

Managing for disturbance stabilizes forest carbon

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Forest ecosystems sequester approximately 12% of anthropogenic carbon emissions, and efforts to increase forest carbon uptake are central to climate change mitigation policy (1). Managing forests to store carbon has focused on increasing forested area, decreasing area lost to logging and clearing, and increasing forest carbon density. Warming, drought, and wildfires challenge the stability of carbon stored in forests (2, 3). By contrast, natural cycles of low-intensity fires in dry forests can, over the long term, promote forest carbon storage by protecting carbon in soil and in large, old trees. The conundrum is how to balance immediate, disturbance-driven carbon loss with long-term, stable carbon storage and account for these risks in policies for forest carbon management (Fig. 1).

What has been missing is the explicit use of disturbance ecology to factor in tree mortality risk. For wildfire and other impactful disturbances, our understanding is now sufficient to incorporate these risks into policy mechanisms that enhance forest carbon storage. Doing so would substantially improve global forest carbon policies aimed at climate-change mitigation.

Fig. 1. Carbon-management policies would do well to use disturbance ecology to factor in tree mortality risk. For wildfire and other impactful disturbances, researchers now have the capability to incorporate these risks into policy mechanisms that enhance forest carbon storage. Doing so would substantially improve global forest carbon policies aimed at climate change mitigation. Image credit: Shutterstock/Christian Roberts-Olsen.

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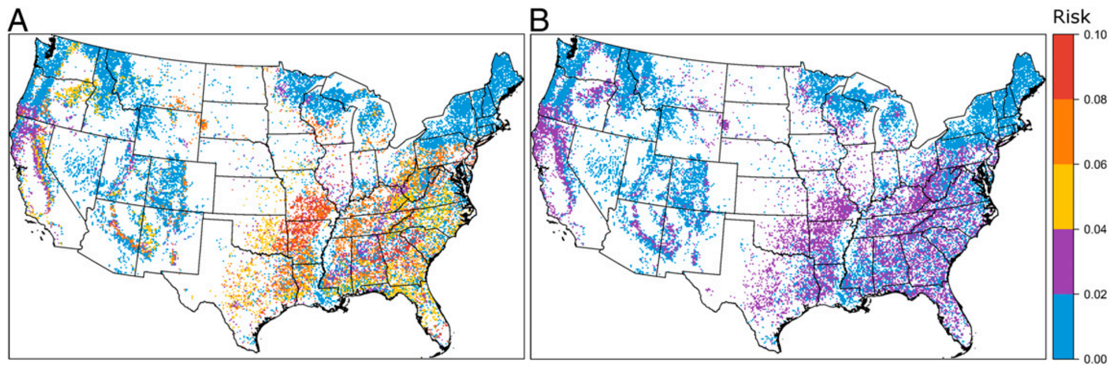

Fig. 2. The risk rating of different forested areas within the United States. (*A*) Risk is calculated as $VD \times \frac{1}{mFRI}$, where mFRI is the pre–fire suppression fire return interval and VD is an index of how departed the current forest is from that maintained by regular fire. (*B*) The risk rating declines in frequent-fire forests when management intervention decreases VD to 0.2.

Governments currently use our understanding of natural hazards and societal risk to inform building codes for earthquakes (4) and wildfires (5) and for national flood insurance (6). Underlying these policies are the quantification of the probability of a natural hazard occurring and an assessment of the societal impact. Current carbon policy and management need to use stability and risk accounting based on our understanding of disturbance probability and severity.

For example, one of the largest carbon markets is California's cap and trade program, which is being closely watched by several US states and other countries as a potential model for developing their own markets. California companies can buy forest carbon offsets that may be anywhere in the United States (7). Out-of-state offsets are valued by bid price and standing carbon stores. Yet, this pricing does not account for reversal risks because of disturbance and size variation in tree susceptibility to mortality. Including these factors in pricing will create incentives to manage forests for greater resilience.

To illustrate this point, we highlight fire because it is the most common disturbance in dry forests worldwide. A combination of changing climate and fire suppression is significantly increasing carbon loss as trees in high-density, fuel-loaded forests die from drought and larger, hotter fires. Failure to account for these factors can destabilize carbon markets and undercut climate-change mitigation efforts.

Small Trees, Big Problem

Compared with large, overstory trees, small trees accumulate carbon at a much slower rate and have higher rates of mortality, yet they compete for resources with large trees. In seasonally dry forests, fire reduces small-tree density, spurring growth in large, long-lived trees that store more carbon. Fire suppression in these forests favors small-tree establishment and survival, boosting carbon stores to temporarily exceed that of frequently burned forests.

This additional small-tree carbon, however, is unstable and prone to shifting the natural disturbance regime from low- to high-intensity fire while increasing drought susceptibility that puts the stand's major carbon stocks, the large trees, at risk. By this approach, a short-term increase in a vulnerable pool of forest carbon increases the risk of carbon loss from an otherwise more resistant pool. Current forest carbon policy does not recognize the disproportionate contribution of large trees to carbon uptake and the risk of large-tree loss from fire and drought when forests are dense with small trees. Near-term carbon loss from management activities that restore natural disturbance regimes is required to achieve long-term carbon stability in the world's dry, fire-prone forests.

The combined economic, social, and climate costs of increasing area burned by high-severity wildfires are substantial. Over the past 2 decades, forest fires have emitted approximately 167 TgC in temperate North America (8). US federal fire-suppression expenditures for the 3 warmest years on record, at more than $7 billion, accounted for 20% of total federal suppression expenditures since 1985 (9). Economic losses from individual fire events can be in the billions.

The Right Price

Pricing risk into forest-based mitigation efforts is not new. Voluntary carbon offset programs (e.g., Verified Carbon Standard) and the California compliance program require an evaluation of non-permanence risk and the set-aside of forest offsets generated by the project to insure against reversal risk. Yet, natural disturbance risk ratings are determined based on past data, and the potential for extreme events that cause widespread tree mortality are absent.

The scientific community's understanding of natural disturbance has developed to the point that we can account for this risk in policy and quantify the value of mitigating these risks. For example, our research group employed publicly available data from LANDFIRE (10) to evaluate wildfire risk and thereby weigh carbon stores in different forests across the United States (Fig. 2*A*). Using the mean fire return interval to estimate a probability of wildfire and a measure of how departed current vegetation is from its pre–fire suppression state to estimate the potential for uncharacteristic wildfire, we show that across the United

States, the risk of carbon loss from wildfire ranges from a 1-in-1,000 chance to a 1-in-10 chance. The majority of forests south of 42°N latitude have a 1-in-25 chance or greater of being impacted by an uncharacteristic forest fire.

Decades of research in dry forests have demonstrated that management to remove small trees reduces the risk of large, hot wildfires (11), and the efficacy of these activities is central to US national strategy for managing wildfire (11). The approaches for doing so—mechanical thinning, prescribed burning, and managed fire—reduce forest carbon density and emit carbon to the atmosphere (12, 13)—and carry considerable economic costs. Yet, the value of these management activities can be quantified in terms of their contribution to reducing the risk of uncharacteristic wildfires that emit much more carbon than the management activities. Restoring surface fires to dry forests can yield a 60 to 80% decrease in the chance of uncharacteristic wildfires (Fig. 2*B*).

Better Management, Better Policy

Pricing the reduction in risk conferred by management provides a financial mechanism to stabilize forest carbon stores. The carbon costs of thinning are well established and vary as a function of thinning intensity (12). The choice between no action and management intervention is not binary. With the research community's understanding of fire, we can allocate more expensive mechanical thinning treatments to the highest-risk areas and use prescribed or managed fire elsewhere, decreasing both the carbon loss and economic costs of treatment (14).

Implementing our understanding of disturbance risk to forest carbon storage can be accomplished directly in forest carbon accounting mechanisms—such as the forest protocol for California's compliance market—and in voluntary programs by developing national-level–data products to quantify the probability of disturbance. Further, this approach could be included in the National Environmental Policy Act (Public Law 91-190) process, which requires that the Federal Government "attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences" (Sec. 101 [42 USC § 4331]). Accomplishing this would require the evaluation of management actions, or lack thereof, on the stability of forest carbon.

Much uncertainty surrounding both carbon stores and uptake in these systems lies in how ongoing climate change will influence the probability of wildfire and the ecosystem trajectory following wildfire. Although some forest loss in semi-arid systems is likely to occur as a result of hotter droughts (15), reducing the chance of large, hot wildfires has the potential to slow the rate of loss. The bottom line: There is considerable potential to sustain forests' role in climate mitigation by assigning economic value to management actions that employ forest disturbance ecology to mitigate the risk of large fires. By doing so, we stand to mitigate extreme fires and encourage better carbon sequestration worldwide.

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