Gambling With the Climate: How Risky of a Bet Are Natural Climate Solutions?

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There is widespread and growing interest in using forests and, more broadly “natural and working lands,” as nature-based climate solutions (NCS) to mitigate human-caused climate change. NCS frequently bring an array of potential co-benefits, including to biodiversity and conservation, and thus make an attractive potential tool to tackle climate change (Griscom et al., 2017). Crucially, to function as climate mitigation, NCS efforts must meet several fundamental criteria including: (a) providing additional carbon storage beyond what would have occurred otherwise, (b) accounting for emissions that shift elsewhere due to NCS activities (termed “leakage”), (c) having a net cooling effect on the climate by integrating the central biophysical and biogeochemical impacts of ecosystem changes, and finally (d) achieving a level of carbon storage “permanence” over long periods of time (typically considered to be 100 years or longer) (Figure 1) (Anderegg et al., 2020; Anderson et al., 2011; Hurteau et al., 2013; Ruseva et al., 2017). If climate change drives losses of carbon storage in forests, that would dramatically undermine the role and potential of NCS in climate goals and policy (Baldocchi & Penuelas, 2019; Anderegg et al., 2020). Thus, cutting-edge science to evaluate the permanence of forest carbon storage in the 21st century is critically important to a wide array of stakeholders from governments to corporations to non-governmental organizations.

The State of California has set an ambitious suite of climate goals that aim to leverage forest-based NCS strategies through several key avenues. Forest carbon offsets are currently widely used as part of the cap-and-trade carbon market and the State’s Natural and Working Lands Climate Change Implementation Plan aims to broadly leverage California landscapes to contribute to carbon sequestration goals. In light of these ambitious and rapidly developing efforts, Coffield and colleagues draw upon four complimentary and widely used empirical approaches to quantify and project future carbon storage of California forests across a wide range of climate models and future scenarios (Coffield et al., 2021). This study is incredibly timely, exemplifies science that is important and directly applicable to policy and planning, and provides one of the most thorough and rigorous studies to date examining California’s carbon sequestration projections in natural lands.

The two most important findings of the study are that rising temperatures are projected on average to drive declines in forest biomass and carbon storage in California’s forests across the 21st century in all emissions scenarios and that the declines are most dramatic in high emissions scenarios. Precipitation strongly regulates projected biomass, but consistent with much other work (e.g., Cayan et al., 2008; Polade et al., 2017), there is large uncertainty of future precipitation changes across climate models at regional scales, including in California. Differences among climate scenarios highlight that NCS efforts are most likely to be potentially useful for climate mitigation if they are paired with aggressive reductions of greenhouse gas emissions from human sources. However, net losses of carbon over the 21st century even in the lower emissions scenario reveal that NCS efforts are a risky gamble that might not actually contribute to climate change mitigation in highly climate-sensitive regions like California.

Two other central findings of Coffield et al. are important to note. First, the climate risks to forest offset projects located in California are remarkably high and substantially underestimated in current versions of voluntary and compliance markets’ forest offset protocols (Anderegg et al., 2020). Second, the authors find consistent spatial patterns of vulnerability with higher climate losses of carbon projected at low elevations and in the coastal and northern areas of California’s conifer forests. The spatial patterns in climate-driven biomass loss are also consistent with where widespread drought- and insect-driven tree mortality was observed in the 2011–2017 severe drought in California (Goulden & Bales, 2019; Young et al., 2017).
Several key uncertainties and limitations in this work provide crucial avenues for future research to inform NCS policies and efforts. First, this study uses an array of empirical or statistical models, which have strengths in the data required, computational demands, and feasibility, but more mechanistic vegetation model simulations are urgently needed as well. Mechanistic vegetation models have the potential to more directly capture important climate-sensitive disturbances, such as fire and drought, and also incorporate other key ecological dynamics such as effects of forest age and demography, land use legacies and management, and the effects of rising atmospheric CO$_2$ concentrations, which were not directly considered in this study. Mechanistic vegetation models have limitations and large uncertainties as well, such as structural uncertainty in process representation such as wildfires or drought-induced tree mortality (Hantson et al., 2020; Trugman et al., 2021; Venturas et al., 2021), but combinations of both approaches would more fully capture future risk profiles and the uncertainty around them. There are also common, long-standing uncertainties to both empirical and mechanistic approaches, including tree species' migration rates, future precipitation projections from climate models, role of land management in historical biomass patterns and in mediating future changes. Coffield et al. did include a method to examine migration rates and found large uncertainties across different migration scenarios. The study focuses only on forests and shrublands, as well, and thus does not look at potential changes in carbon storage in grasslands (Dass et al., 2018) or human-dominated landscapes.

Finally, NCS efforts broadly represent a clarion call to Earth Scientists and Ecologists where more research is urgently needed. The fundamental and longstanding questions about carbon balance of ecosystems and future climate impacts have an increasingly urgent policy need and audience. The scientific community and funding agencies can and must provide as much guidance as possible about when and where the climate risks are highest, how land management might influence carbon storage potential and risk patterns, co-benefits and trade-offs to different NCS approaches, environmental justice implications of NCS deployment, and whether and where forest-based NCS efforts are a win for both ecosystems and the climate or a risky gamble that could go up in flames.

**Conflict of Interest**

The authors declare no conflicts of interest relevant to this study.
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