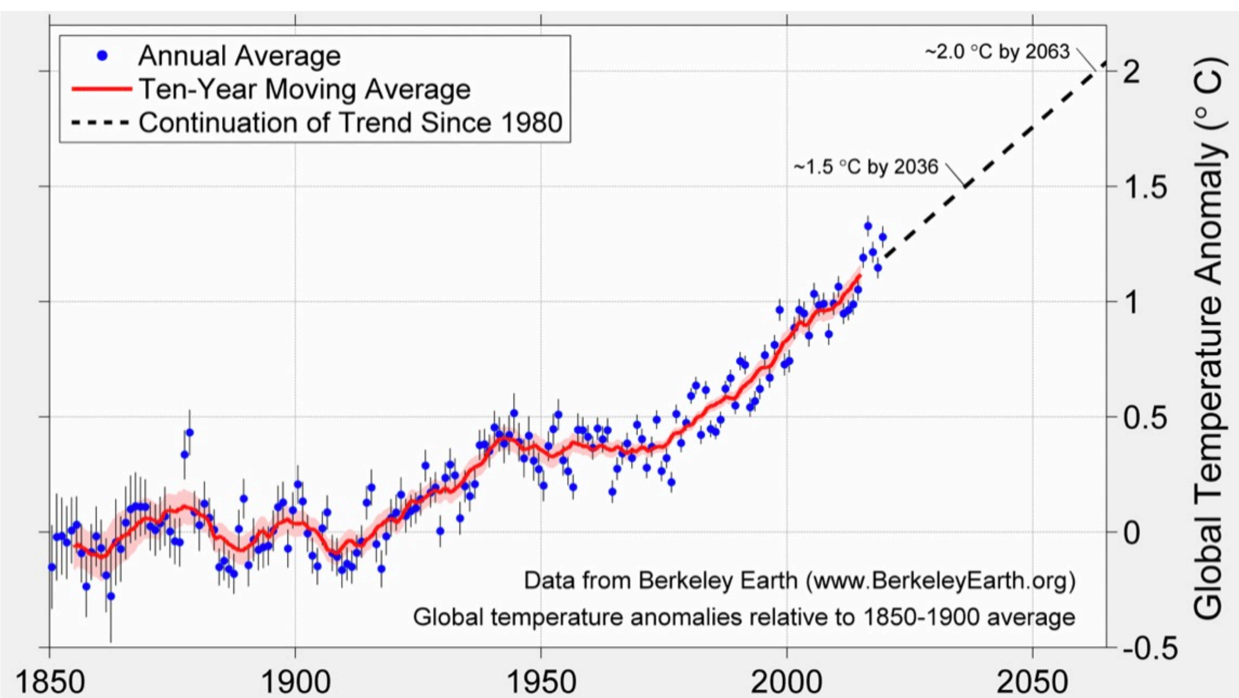
G Afforestation and Reforestation

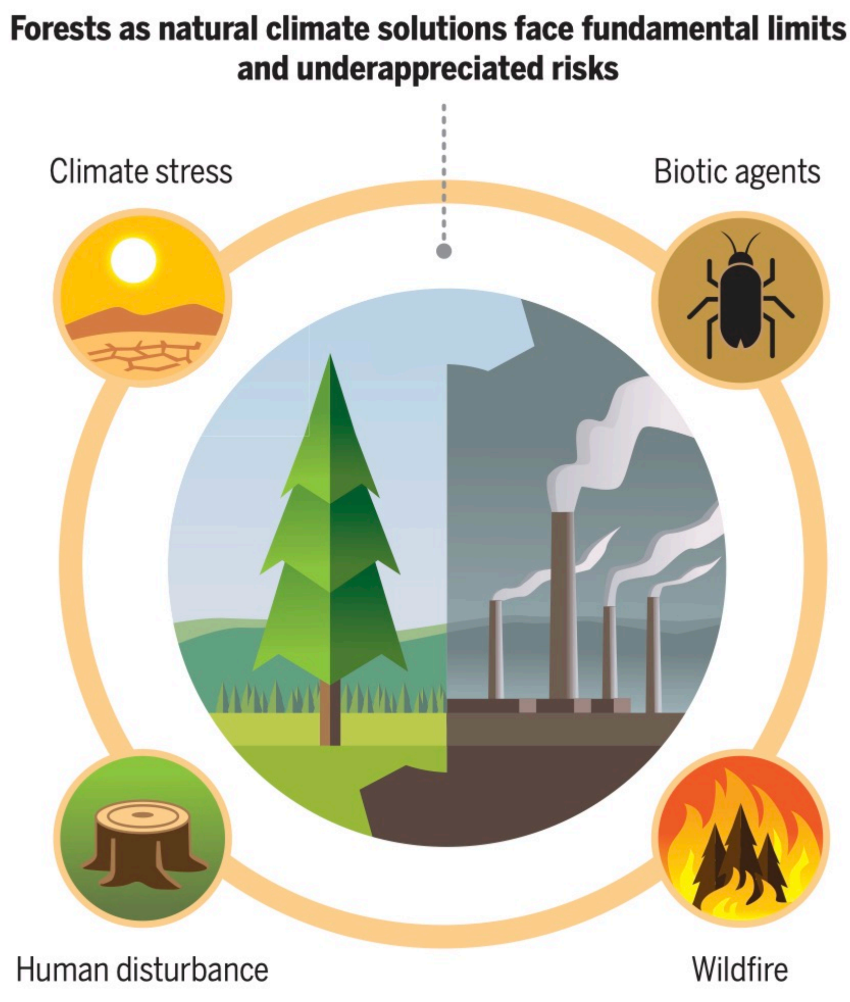
Afforestation refers to planting trees on land that has not previously had trees. "Plant a trillion trees and the climate crisis will be fixed." This is a popular sentiment for many. So why haven't we placed it front and center for projects we would like to support? While we have no wish to disparage this approach, many have expressed a number of cautions about afforestation/reforestation. The following are some of them.

In a recent study, with dozens of co-authors, Sullivan et al (2020) reported that measurements of carbon storage and growing conditions for some 500,000 trees around the world. This suggested some tropical forests, particularly in Africa and Asia, will—if left intact – continue to sequester large amounts of carbon even as global temperatures rise. **But only up to a point**. As the temperature rises the respiration rate of trees begins to exceed the photosynthesis rate and they produce more CO_2 than they sequester. If warming reaches 2°C above preindustrial levels, the study found that huge swaths of the world's tropical forests will begin to lose more carbon than they accumulate. The following figure shows that with business as usual the earth's temperature could reach 2°C over preindustrial era by 2063.



This would clearly qualify as one of the **tipping points** discussed in the section on **Global Warming is Real**. This suggests that many of the trees on earth may be useless as a CO_2 sink by 2063. Not good news. Already, the hottest forests in South America have reached that point (Pennisi, 2020).

Another recent paper by Andeegg et al, (2020) *Climate-driven risks to the climate mitigation potential of forests*, proposed that the effective use of forests as natural climate solutions needs to take into account climate change risks, such as fire, drought and insects. This is illustrated in the following figure.



Terrestrial ecosystems currently absorb ~30% of human carbon emissions each year (Friedlingstein, et al, 2019) and forests account for the vast majority of this uptake, an estimated 8.8 Pg CO_2e/year of a total land carbon over 2000–2007, where CO_2e denotes CO_2 equivalents. A fundamental assumption of the afforestation/reforestation efforts is that forests store carbon removed from the atmosphere in plants and soils over time horizons of 50 to 100 years or longer. However, forests are already facing substantial and increasing climate-driven risks that could fundamentally undermine their collective ability to take up and store carbon over the 21st century. These are listed below and in the above figure (Andeegg et al, 2020).

Forest Fires. Between 1997 and 2016, an average of ~500 million ha of land burned each year. Fire in forests emits ~1.8 Pg CO_2e/year. This problem is only expected to get worse.

Drought. As an example, the severe 2011–2015 drought in California killed more than an estimated 140 million trees and drove the full carbon balance of the state's ecosystems to be a net source of −600 Tg CO_2e from 2001 to 2015, which is equivalent to ~10% of the state's greenhouse gas emissions over that period (Sleeter, et al, 2019). A 2011 drought in Texas killed 9.5% of tree cover across the state, and much of the canopy loss occurred in areas that exceeded specific climatic thresholds (Schwantes, et al. 2017). Increasingly severe drought in Australia has also led to systematic increases in tree mortality and composition changes (Brouwers, N. et al, 2013). Droughts are only expected to get worse.

Biotic Agents. Biotic disturbance agents, including insects and pathogens, cause substantial tree mortality globally. For example, bark beetles, which feed on tree phloem and introduce fungi that interrupt tree water transport, have **killed billions of trees** across millions of hectares of land in temperate and boreal coniferous forests in the past two decades (Kautz, M. et al (2017) and have converted large regions of the Canadian boreal forest from a sink to a source over the course of a decade (Kurz, et al,2008). Biotic damage is only expected to get worse.

Production of greenhouse gases by trees themselves

Plants emit a substantial amount of biogenic volatile organic compounds (BVOCs)including isoprenoids, into the atmosphere. These BVOCs represent a large carbon loss and can be up to 10% of that fixed by photosynthesis under stressful conditions and up to 100gC/m^2 per year in some tropical ecosystems. BVOC emissions are probably increasing with warming and with other factors associated to global change, including changes in land cover, and could protect plants against higher temperatures. These increases in BVOC emissions could contribute in a significant way (via negative and positive feedback) to the complex processes associated with global warming (Penuelas and Llusia, (2003).

Methane The tropical wetlands have been found to emit large amounts of methane into the atmosphere (Tolleson, 2019). Further research on this is needed but this source of methane would be hard to combat other than by removing it from the atmosphere.

Other Disturbances. Other disturbances—particularly storms and wind-driven events, snow and ice events, and lightning—can also influence forest ecosystem carbon cycling. For example, Hurricane Katrina damaged 320 million large trees that contained 385 Tg CO_2e.

Human Interactions. Human actions can increase or decrease climate related permanence risks. Human appropriation of forest biomass is ~9.5 Pg CO_2e/year (97), which is more than annual fire emissions (Krausmann, et al, 2008).

Not enough land. Colorado State University atmospheric scientist Scott Denning, who studies how carbon moves through the global climate system, said the basic numbers of the trillion trees story don't add up.

"No doubt, if you replaced every area of non-forest with forest, you could sequester a lot of carbon," Denning said. "But very little of the world is available for planting a trillion trees. Most of the land that might be suitable is in use for farms and cities. Most of the places that can support forests, like the Amazon, Congo, Indonesia and Southeast Asia, already have forests."

In addition to these concerns, some worry that tree-planting proposals divert from the critical need to reduce CO_2 emissions. This was a such concern that coalition of 95 environmental groups sent a letter to Congress opposing the Trillion Trees Act as the "worst kind of greenwashing and a complete distraction from urgently needed reductions in fossil fuel pollution."

Of course, the same could be said of other NET proposals despite the fact that all the major organizations concerned with climate-change have stated that both the restriction of emissions and NET will be necessary.

In summary, planting trees, saving the Amazon and other forests, preventing forest fires and re-planting areas were trees have been destroyed, are critically important. However, we should not rely on the planting of trees as a major NET to combat climate change.

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