Written Testimony of

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On average, the global climate has already warmed by ~ 1°C above pre-industrial levels. Formerly unprecedented climate extremes – from droughts to deluges to heat waves – are becoming commonplace. One need only look to recent wildfires in Australia, the Amazon, and closer to home in Texas and California to see that climate extremes can be catastrophic. The scientific consensus is that our changing climate is the direct result of anthropogenic carbon emissions. These carbon emissions derive primarily from burning fossil fuels, including oil, coal, and natural gas, and, to a lesser extent, from deforestation and other land use change [2].

Current business-as-usual emissions are projected to result in average warming of 2°C by the year 2050 and 3-4.5°C by the year 2100 [1, 2]. Staying below 1.5°C of warming looks increasingly ambitious, relying on reductions in total global greenhouse gas emissions of 45% by 2030 and net zero emissions by 2055 [3]. Meanwhile, the difference between 1.5°C and 2°C total warming is associated with increased risks of extreme events and adverse social and economic consequences [3], and even achieving 2°C will require deeper cuts to emissions than are currently pledged under the Paris Agreement [1].

As an Earth scientist with a longstanding interest in these issues, it is immensely cheering to see the climate crisis receiving the bipartisan attention that it has long deserved. This is a necessary first step towards the type of action on climate that can and will reverse the climate crisis. Action on climate should include diverse approaches, including forest restoration and prevention of deforestation, but must rely fundamentally on reducing emissions at the source via decreasing our dependence on fossil fuels.

It is easy to understand the appeal of forests as a solution to the climate crisis. According to proponents of tree planting, forests putatively offer a win-win-win, combining carbon drawdown, conservation, and forestry-sector productivity, while also sparing us the necessity of difficult changes in our lifestyles and economy. Although the idea is an old one, tree planting has gained prominence recently following a 2019 study [4] and subsequent press campaign claiming that trees may sequester up to 205 gigatons of carbon, offsetting as much as $^{2}/_{3}$ of total historical anthropogenic carbon emissions or, alternately, sequestering carbon from 20 years of carbon emissions at current rates. Like most things that seem too good to be true, it was. These estimates are wrong and have been widely disputed [5-8], but have nonetheless gained traction in a political climate desperate for solutions to the increasingly urgent challenge of anthropogenic climate change.

Here, I elaborate on the main problems with focusing on trees as the only solution to climate change. First, forestation is risky, especially outside the historic range of forests. Second, carbon sequestration by forests is slow. And third, even in the best-case scenario, the reality is that mitigating fossil-fuel emissions by planting trees (or even via nature-based solutions more generally) is not enough. Any plausible solution to the climate crisis must fundamentally rely on burning less fossil fuels. In more detail:

1. *Forestation is risky.* The growth and persistence of trees, once they are planted or regenerate, is a key consideration in estimating the potential of forests and plantations for emissions mitigation. Tree mortality can be substantial (> 90%, depending on age and species), even in environments that favor forest establishment, and geographic targets for tree planting often include areas that historically are not forested (including tree planting

proposals from the UNEP as referenced in H.R. 5859) and may not be appropriate for sustainably supporting forests.

Forest restoration is usually considered to be more successful when forests are allowed to regenerate naturally [9]. Trees survive at higher rates, resulting in more diverse forests and increasing carbon storage, although note that ecological processes depend heavily on forest type and that post-planting investment in tree survival tends to improve outcomes (especially appropriate in*, e.g.*, agricultural or urban contexts) [10]. Facilitating natural forest regeneration and avoiding deforestation are therefore broadly considered more effective for storing carbon than artificially re-planting trees.

Afforestation exacerbates these issues. Afforestation is defined as the establishment of forests in places where they did not occur in the recent past, whereas reforestation is defined as the re-establishment of forests in places where they once occurred but were deforested. Afforestation increases the risk of tree mortality and exacerbates adverse effects including, *e.g*., downstream water shortages and extreme fire risks, resulting in economic and infrastructure costs, as well as costs to human life. Crucially, species and ecosystem ranges are defined not only by average environmental conditions, but also by, *e.g.*, droughts, which are increasing in their frequency and are strongly associated with tree mortality [11] and fires [12]. Outside their range, therefore, the risks increase dramatically that major investments in afforestation will fail to store carbon in the medium and long term.

Future climate change will exacerbate these risks; for example, fire extent in western US forests has already increased in area by a factor of 5 since the 1980s [12]. To mitigate these risks, we must manage forests explicitly for carbon storage and explicitly account for a changing climate, taking into account effects of, *e.g.*, aridification/drought and fire.

Polar regions come with special risks from afforestation. Far from cooling the climate, polar forests have a net warming effect on local climate because they increasing absorbance of solar radiation [13, 14] (*i.e.*, snow is lighter in color than evergreen trees and therefore absorbs less heat). Although forests at low latitudes cool the climate via carbon storage, forests in polar regions instead increase local temperatures by almost 1^{o}C in a region already subject to faster warming than anywhere else on Earth. From a national perspective, this is most relevant in Alaska and in mountains with substantial winter snowpack [14]. More broadly, focusing on carbon dioxide alone is insufficient. Rather, an explicit focus on climate change is necessary to tackle the climate crisis. In the context of the legislation under discussion, H.R. 5859 proposes to remove language from the Forest and Rangeland Renewable Resources Planning Act that aims to ‘mitigate the buildup of atmospheric carbon dioxide and reduce the risk of global climate change’; this language should be retained, since it keeps the focus explicitly on reducing the risk of climate change, instead of on wood production.

Finally, reducing deforestation and forest restoration are laudable activities. However, avoiding afforestation will also help to avoid risks that compromise long-term carbon storage goals; differentiating between reforestation and afforestation is crucial. Note that, throughout, H.R. 5859 treats afforestation and reforestation as equivalent, which is likely to exacerbate risks and compromises carbon storage goals. I would also urge the inclusion of scientists in any National Reforestation Task Force to ensure that locations for reforestation are appropriate.

2. *Forest regeneration is slow.* Trees grow slowly. Exactly how slowly depends on their environment, but carbon from forestation will everywhere accumulate later than currently projected – too late to appreciably change climate in the short term.

   Even successful forest regeneration takes decades to centuries to recover the carbon storage potential of mature primary forests, depending on environmental context. In tropical forests, degraded agricultural landscapes regain the carbon storage potential in biomass of mature forests after a few decades of regrowth [15], although soil carbon takes longer to recover; however, carbon accumulation is slower in temperate forests and even slower in evergreen boreal forests, where forests achieve their full carbon storage potential after only a century or more [16]. Nowhere is planting trees or regenerating forests an immediate solution to the problem of carbon emissions, and the major benefits of any current accelerated investment in forest restoration will only ramp up after 2030 and beyond. This is too slow and too late to help achieve 1.5ºC warming targets, but may help to achieve medium- and long-term cuts to net emissions.

   By contrast, slowing rates of deforestation now will have immediate effects, since avoiding deforestation reduces carbon emissions now. Avoiding deforestation will help hit short- and medium-term climate change targets, and should be a priority.

3. *Trees are not enough.* An exclusive focus on trees and forests ignores the potential of a broader range of 'nature-based solutions' to the climate crisis. Specifically, it's not just trees that store carbon. Carbon is stored in other types of plants and in soils, as well. In some systems, most notably peatlands, decomposition is extremely slow and carbon builds up in soils. Eventually, total ecosystem carbon can vastly exceed that stored in nearby forests. In the US, peatlands are concentrated in boreal and tundra regions of Alaska. Globally, peatlands are at risk of extreme fires, especially when forestry and development activities drain and disturb soils, resulting in substantial carbon emissions [17]. For instance, in 1997, Indonesian peat fires emitted between 0.81 and 2.57 gigatons of carbon, equivalent to 15-40% of annual global fossil fuels emissions [18]. As such, peatlands deserve explicit attention for their carbon storage potential, especially focused on keeping carbon in the ground.

   Grasslands can also store substantial carbon in soils. In grasslands like the Argentinian pampa or North American prairie, encroachment by trees has been estimated to reduce total ecosystem carbon by as much as 45% [19]. This happens because the losses of carbon in soils are greater than the gains of carbon stored in trees. Curiously, carbon losses from tree encroachment are highest in wetter grasslands [19], where trees are usually considered most viable. Clearly, some open ecosystems should be considered alongside forests for restoration to promote carbon sequestration.

   The issue of non-tree carbon also highlights one of the main limitations of recent estimates of the potential of trees to sequester carbon [6]. Many ecosystems identified as targets for tree planting already store substantial carbon, but existing carbon is sometimes neglected in calculations of the carbon gains associated with tree planting. (For a simple example, consider the following: If you want to fill a bucket, but it is already ¾ full, you can only add an additional ¼ to the bucket. Some estimates mistakenly count the full bucket as new storage potential, when in fact you can only really count ¼ of a bucket as new storage.) This substantially biases estimates and tends to suggest that trees store more carbon than they actually do. Elements of H.R. 5859 share this limitation; for instance, the 'Lifecycle Analysis' in Section 103b focuses too narrowly on carbon stored in wood, ignoring other components of ecosystem carbon and on carbon costs to transportation, production, etc., which are substantial.

Correcting estimates of the global potential for tree planting to sequester carbon yields an estimate of potential carbon sequestration that is 80% less [6] than recent estimates [4], for a total carbon sequestration potential of ~ 42 gigatons of carbon. This is in fact equivalent to only $^{1}/_{15}$ of total historical emissions, or 4 years of carbon emissions from fossil fuels at current rates. These revised estimates make it abundantly clear that forest restoration alone is not the silver bullet to solve the climate crisis, and that long term emissions reductions (and, ultimately, net zero emissions) must rely on reductions in fossil fuel use itself.

These corrected estimates are based on up-to-date estimates of tree viability, net cooling potential of forestation, soil carbon stocks, and qualitative evaluations of fire and water risk. But there's a simple way to build this intuition. Returning carbon to the biosphere can sequester only as much carbon as was in the biosphere to begin with. This means that restoring forests can sequester all the carbon emitted by deforestation but not also that emitted by fossil fuels (a much more substantial flux) [5]. To return to the bucket analogy: if the pre-industrial biosphere is a bucket, it was once full of carbon that was released via changing land use and deforestation. We can put carbon back in the bucket to reverse those effects, but we can't hope that the biosphere bucket will hold not only its own contents, but also those of *another separate* fossil-fuel bucket. The analogy isn't perfect (*e.g.*, we could debate whether the bucket was full to begin with and whether the size of the bucket is changing), but it's a useful first approximation.

In summary, tree planting alone does not offer a viable solution to the ongoing climate crisis. Forests do have a role to play: Any plausible attempt to limit climate change within our lifespans depends on avoiding further deforestation and on appropriate and responsible forest restoration. However, it is also crystal clear that tree planting alone will not fix our ongoing climate emergency. Our primary focus must be reducing our dependence on fossil fuels. The illusion that tree planting is a silver-bullet solution to the climate crisis is a distraction from real action.

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