1. TITLE: Mapping global tree vulnerability under climate change

2. NAME AND CONTACT INFORMATION:

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4. PROPOSED PROJECT:

Objectives. Recent studies indicate that current predictions of forest vulnerability to climate change may grossly underestimate the effects of warming (*1*). This project aims to create a Shiny app that highlights where previous predictions underestimated warming impacts and more accurately map where forest vulnerability is highest under climate change. Leveraging existing data from over 6.3 million observations of annual tree growth (Figure 1) this project will achieve the following objectives:

1. Map tree species that are at increased risk of climate-induced mortality by (a) creating risk maps for over 126 global tree species and (b) analyzing drought-sensitivity across species' ranges;
2. Predict future tree growth using the Representative Concentration Pathway (RCP) global climate scenarios;
3. Help private and public organizations that would benefit from spatially-explicit conservation and management prioritization strategies by aggregating climate data and risk maps into a publicly accessible, interactive Shiny app.
4. Optional: Analyze normalized difference vegetation index (NDVI) data from Google Earth Engine to improve predictions of changing forest health under climate change.

<u>Significance.</u> Forests cover approximately 30% of Earth's land surface, absorb more carbon than all other terrestrial ecosystems, and provide trillions of dollars' worth of ecosystem services. Climate change, however, is causing dramatic changes in forests, including drought-induced diebacks and declines in productivity. Scientists warn that forests will continue to shift from carbon sinks to sources as climate change-related disturbances increase. To effectively manage and respond to these changes, there is a critical need for accurate predictions and maps detailing which forests will be most vulnerable to drier and hotter conditions.

<u>Background</u>. Currently, most regional and global maps of forest vulnerability to climate change assume that forests will contract in hot dry regions and expand into cooler, wet regions (*2*). However, recent evidence suggests that trees growing in moderate growing conditions relative to their niche are the most vulnerable to climate change because they are less drought-adapted (*3*). This oversight suggests that current climate change predictions grossly underestimate the effect of climate change on global forests. Using a cutting-edge analysis of global tree-ring data, this project will provide more accurate predictions of climate change impacts and greatly improve our ability to prioritize management interventions in a rapidly warming world.

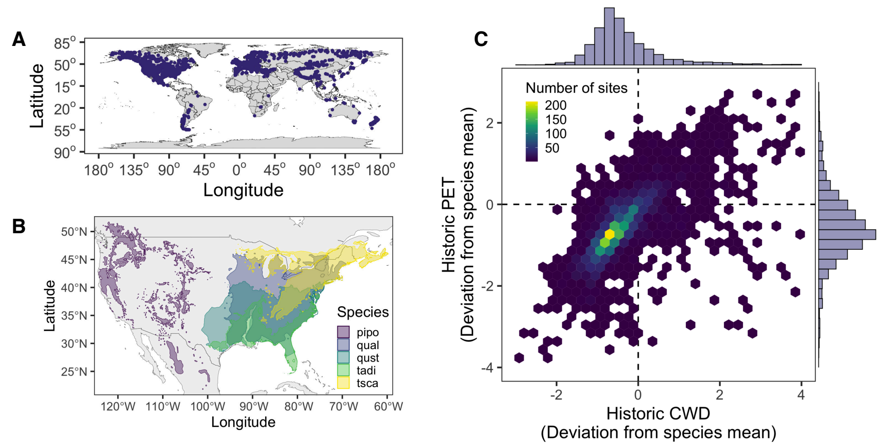

Figure 1. (**A**) Locations of ITRDB sites across the globe. (**B**) An example of five tree species' range maps in the US; range maps were extracted for all species in the ITRDB. (**C**) Distribution of ITRDB sites across each species' standardized, historic climatic niche.

<u>Equity.</u> The impacts of climate change will likely have disproportionately large and negative impacts on low-income and other underserved communities. Strategies to project local and global forests will broadly help reduce these negative impacts. Further, these maps can help identify highly vulnerable areas—i.e., underserved communities abutting forests that are at risk of major mortality events. Providing a platform that is easily accessible and user-friendly will help policymakers and management agencies develop interventions that can support forest health and improve underserved community outcomes under climate change.

<u>Data.</u> All data are publicly available from the US government, Google Earth Engine, and other repositories, see list below. The datasets required for this project include global tree-ring data, global climate data, global tree species distribution data, and possibly NDVI data (Normalized Difference Vegetation Index).

1. Climate data: https://www.worldclim.org/
2. Tree-ring data: https://www.ncei.noaa.gov/products/paleoclimatology/tree-ring
3. Species' distribution maps: available through a shared google drive
4. NDVI data: There are many different NDVI products available for this project, all available to the public through https://earthengine.google.com/

Computational Tools & Needs. Climate data, tree-ring data, and species distribution maps have been stored in a Google Drive that will be accessible for all team members. The primary programming language used will be R, as it provides access to a variety of packages for the analysis and visualization of tabular and geospatial data. Additionally, using R will facilitate the creation of an interactive Shiny app containing the species-specific risk maps and drought-sensitivity analysis. Python may be used as needed, but is not required. Depending on time, Google Earth Engine software may be used to incorporate data on the normalized difference vegetation index (NDVI).

Possible approaches. The statistical models have already been developed and the data are clean and ready to use, but the maps have not been created. To create the maps, students will first project current and future tree growth across global climate raster data. There are many different climate change scenarios; to simplify, we will select Representative Concentration Pathway (RCP) 4.5 and RCP 8.5 to capture the more extreme possibilities of ambient climate by 2100. The species-level predictions will be cropped to the known species' ranges and these will be added as additional layers that can be mapped on the Shiny app depending on the user's location and species of interest.

Deliverables. Using coding languages (R and possibly Python), students will develop various maps of global tree vulnerability to climate change. At least one of the maps will show current and predicted vulnerability to climate change (using various CMIP5 scenarios). A second map will include abundant species-level predictions and a possible third map will include genus-level predictions. These maps will be accessible on a Shiny app that is freely available to the public and hosted on my website and linked on the Bren website, as well as other non-profit organizations that are focused on climate change impacts and ecosystem management. If the students would like to continue working on this project over the summer, they would be welcome to publish a paper summarizing the results of their mapping project.

Audience. In addition to the client, Joan Dudney, this application is intended for researchers and private or public organizations to make more informed decisions regarding land management. The goal is that this tool will generate clear visualizations for areas or species of interest, allowing the public to identify and manage areas of highest risk.

5. SUPPORTING MATERIALS:

Citations.

1. C. D. Allen, D. D. Breshears, N. G. McDowel, On Underestimation of Global Vulnerability to Tree Mortality and Forest Die-off from Hotter Drought in the Anthropocene, Ecosphere 6, 1–55 (2015).

2. W. R. L. Anderegg, L. D. L. Anderegg, K. L. Kerr, A. T. Trugman, Widespread drought-induced tree mortality at dry range edges indicates that climate stress exceeds species' compensating mechanisms. Global Change Biology **25**, 3793–3802 (2019).

3. I. M. McCullough, F. W. Davis, A. P. Williams, A range of possibilities: Assessing geographic variation in climate sensitivity of ponderosa pine using tree rings. Forest Ecology and Management **402**, 223–233 (2017).

Budget and Justification. Successful completion of the proposed project will not require any funding beyond what is provided by the Bren School. All data and software required for project completion are free and publicly available.

Client Letter of Support.

Dear Capstone Committee,

I am delighted to extend my enthusiastic support of the MEDS capstone proposal entitled "Mapping global tree vulnerability to climate change." All of the data for this project are accessible to the public with appropriate attribution—i.e., the databases are citable, which is the only use requirement. I also have access to a shared google drive that contains most of the cleaned and "ready-to-go" datasets, except NDVI data from Google Earth Engine, which is available to the public but may or may not be used for this project (this will depend on the students' capacity and interest).

The tree-ring and climate data have been cleaned by my collaborators and are ready to be shared for anyone interested in using them. Though these data are currently not accessible to the public, the cleaned datasets will be freely available to the public soon (pending the publication of an upcoming paper). In the meantime, there will be absolutely no problems with publishing these data or any maps created by these data.

Broadly, this project is incredibly relevant and will ideally provide a platform that anyone can access to understand and identify tree species' vulnerability to climate change. Under a rapidly warming planet, a deeper understanding of how forests will change is critical to support managers on the ground and develop effective policies that reduce carbon emissions. This project will provide a major advance in our ability to map and predict tree vulnerability to climate change, which is critical to reduce the likelihood the forest mortality in the coming decades will accelerate carbon emissions and global warming.

Sincerely,

Joan Dudney
Assistant Professor
The Bren School & the Environmental Studies Program