

# FINAL PROJECT REPORT

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Project title: *Enhanced forest monitoring with tree rings to support Navajo management of forest resources*

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## SECTION 2. PUBLIC SUMMARY:

Drought stress threatens forest health across the southwestern US, including forests of the Navajo Nation. We augmented forest monitoring on the Navajo Nation by sampling tree-ring data in a subset of the Navajo Forestry Department's spatial network of forest inventory plots. Analysis of the tree-ring and forest inventory data showed declining forest health at the scale of trees, forest stands, and the forested landscape with warming and drought stress. Small growth rings (slower tree growth) are associated with drier- and warmer-than-average conditions. Unusually warm spring temperatures have an especially negative effect on tree growth and hence forest health. Productivity of the three dominant tree species has declined significantly from 1990 to the present with warming. In addition, warm spring temperatures have a synchronizing effect on forest productivity: productivity is reduced at all elevations and in all forest types when spring temperatures are unusually high. We conclude there is a heightened risk of forest transformation to woodland, shrubland, or grassland through the combination of drought-induced tree mortality and/or high-severity fire. Use of low- to mixed-severity fire or thinning treatments to reduce the density of overstocked stands can help reduce competition for soil moisture and the risk of catastrophic fire, increasing forest resilience and preventing forest loss. Forest management on Indigenous lands is under-funded and requires investment and cooperation to ensure that local communities continue to benefit from the resources provided by forests – water, wood, wildlife, forage for livestock, and traditional foods and medicines.

## SECTION 3. PROJECT SUMMARY:

The objectives of this project were twofold: answering questions posed by the Navajo Forestry Department (NFD) about the impact of climate variability and change on forest health on the Navajo Nation and creating a climate-sensitive version of a forest growth and yield model (the Forest Vegetation Simulator) for use as a forest management tool in the light of changing climate. Our approach was to collect tree-ring data from 1,100 trees in a stratified random subset (n=56) of the NFD's network of forest inventory plots, representatively sampled with respect to elevation, tree species composition, and the size and number of trees per plot. We then analyzed the tree-ring and forest inventory data to quantify the effects of climate variability and change across time and space, focusing on basal area increment as an indicator of forest health. We found that all three dominant tree species

on the forested landscape of the Navajo Nation are negatively affected by drought conditions, i.e., warm temperatures and low precipitation. Exceptionally warm spring temperatures are especially associated with slower tree growth, hence poor forest health. Forest productivity is on a declining trend from 1990 onwards, and years with very warm spring temperatures are synchronizing the growth of trees across this forested landscape, suggesting a loss of landscape-scale resilience to drought stress. We conclude that warming and drought associated with anthropogenic climate change are negatively impacting forest health on the Navajo Nation, leading to a heightened risk of forest transformation to woodland, shrubland, or grassland through the combination of drought-induced tree mortality and/or high-severity fire. Climate projections for the southwestern US predict further warming, drying and increased precipitation variability, underscoring the likelihood of ever-increasing drought stress. These factors point to the urgency of taking action to mitigate the risk of forest loss on the Navajo Nation to protect watershed health, reduce the risk of high-severity wildfire, floods, and debris flows, and ensure the continued provisioning of forest resources - wood, wildlife, forage for livestock, and traditional foods and medicines.

## **SECTION 4. REPORT BODY**

### **Purpose and Objectives:**

The objective of this project was to provide technical assistance to the Navajo Forestry Department (NFD) in answering their questions about the impact of climate variability and change on forest health on the Navajo Nation. In addition, a long-term objective was to provide a climate-sensitive version of a forest growth and yield model (the Forest Vegetation Simulator) to facilitate management in the light of changing climate, i.e., management aimed at increasing forest resilience. To meet both objectives, we collected tree-ring data from all trees in a subset of the NFD's Continuous Forest Inventory (CFI) plots and analyzed those data to quantify the effects of climate variability and change, focusing on basal area increment as an indicator of forest health. A third objective was to conduct the research in a collaborative manner, with frequent and bidirectional flow of information between the university and NFD partners, through in-person and virtual meetings, project reports, and email, as well as to communicate the broader issues of forest health to the community through outreach activities.

### **Organization and Approach:**

#### **Task 1: Enhanced forest monitoring by adding tree-ring sampling.**

The first field season was conducted in the fall of 2019, yielding 562 increment cores from 425 trees in 30 CFI (forest inventory) plots. In the fall of 2021, we conducted a second field season, collecting 733 increment cores from 675 trees in another 26 CFI plots. These field campaigns were led by a Diné forester (MSc Forestry, Northern Arizona University) assisted by Diné forest technicians. The successful execution of these field campaigns was made possible with the assistance of NFD leadership and field crews. NFD committed significant time (hence, resources) to facilitating this research, by coordinating their visits to CFI plots with the SWCASC-funded crew. The resulting tree-ring collection from CFI plots includes a total of 1,100 trees sampled in a stratified random subset ( $n=56$ ) of the larger network of CFI plots, representatively sampled with respect to the size and number of trees and elevation. It is an exceptional dataset to evaluate the health of Navajo forests across time and space.

#### **Task 2: Analyze drivers and trends of forest health.**

In 2020 and 2021, the project's post-doctoral fellow developed analyses of basal area increment as a metric of forest health. This consisted of scripts in R to handle the tree-ring data and other forest

inventory measurements, prepare data objects for multiple regression analysis, analyze basal area increment as a function of climate, forest stand conditions, and biophysical variables, along with analyses of forest productivity trends and landscape-scale synchronicity. In 2022 and 2023, a Scientific Analyst (Diné, MSc Forestry, Northern Arizona University) took over the role of analyzing project data, adding the second field season's data into the existing analytical workflow and developing a manuscript publishing the results of the project. These analyses are documented as a reproducible workflow in a GitHub repository that ensures continuity of the project. Note however that this GitHub repository is private, respecting the Navajo Nation's data sovereignty and ownership. The Scientific Analyst's work on this project continued in 2023 and 2024 supported by the Department of Interior's Bureau of Indian Affairs through its Tribal Resilience Program.

### Task 3: Regular, bidirectional communication and co-production of knowledge.

We maintained regular communication between university and Tribal partners throughout the project through a combination of in-person and virtual project meetings, a 22-page project report (in 2021), a fact sheet (in 2023), and numerous updates via email.

### Project Results, Analysis and Findings:

All three dominant tree species on the forested landscape of the Navajo Nation (ponderosa pine, Douglas-fir, and common pinon) are negatively affected by drought conditions, including warm temperatures and low precipitation (Figure 1). In particular, exceptionally warm spring temperatures are associated with slower tree growth, indicating poor forest health, and years with elevated spring temperatures are becoming more frequent and less exceptional over the past ~30 years. Forest productivity (basal area increment at the forest plot scale) is on a declining trend from 1990 onwards. In addition, years with very warm spring temperatures synchronize the growth of trees across this forested landscape (Figure 2), suggesting a loss of landscape-scale resilience to drought stress.

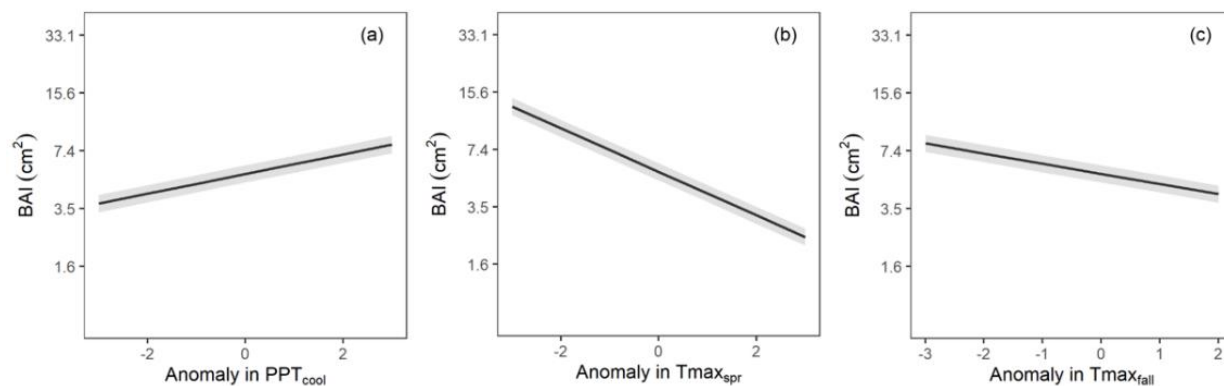


Figure 1. Effect of (a) cool season precipitation anomaly, (b) spring maximum temperature anomaly, and (c) previous fall maximum temperature anomaly on ponderosa pine growth, measured in basal area increment (cm<sup>2</sup>). More precipitation leads to more growth, and higher temperatures lead to lower growth, indicating that drought stress reduces tree health.

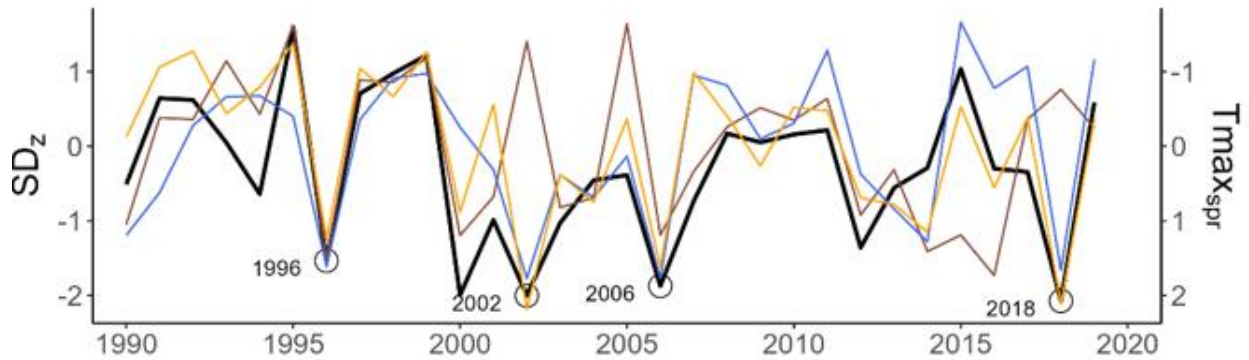


Figure 2. Time series of maximum spring temperature (black line) and spatial variation in productivity ( $SD_z$ ) of the three dominant tree species in Navajo forests, common pinon (brown line), ponderosa pine (yellow line), and Douglas-fir (blue line) over the period 1990-2019. Spatial variation in productivity is measured by the standard deviation of plot-level productivity, across the 56 sampled plots. Temperature data are inverted to emphasize the match between exceptionally warm spring temperatures and the loss of spatial heterogeneity in productivity.

### Conclusions and Recommendations:

Warming and drought associated with anthropogenic climate change are negatively impacting forest health on the Navajo Nation. Tree rings showed that trees grow more slowly when temperature is warmer than average or precipitation is less than average. In addition, a trend of reduced stand-level growth and increased spatial synchrony in growth variability since 1990 are indicators of forest ecosystem stress, suggesting that the Diné forest may be at, or near, a crucial tipping point and potentially collapse. Reduced growth, hence reduced tree vigor, is likely to make trees more susceptible to insect and disease infestations, raising concerns about future widespread tree mortality in the Diné Forest. Climate projections for the southwestern US predict further warming, drying and increased precipitation variability, underscoring the likelihood of ever-increasing drought stress.

For all these reasons, we conclude there is a heightened risk of forest loss via transformation from forest to another vegetation type such as woodland, shrubland, or grassland through the combination of drought-induced tree mortality and/or high-severity fire. Such vegetation type transitions have been documented across the US southwest, highlighting regional-scale vulnerabilities to abrupt and potentially irreversible vegetation change. These factors point to the urgency of taking action to mitigate the risk of forest loss on the Navajo Nation to protect watershed health and reduce the risk of wildfire, floods, and debris flows.

Navajo Nation [President Nygren signed a letter](#) to the California Air Resources Board (CARB) on April 21, 2023 to move forward a carbon credit project based on forest carbon sequestration. This new agreement had significant consequences for the Navajo Forestry Department in terms of implementation of CARB-required protocols for measurement, monitoring, reporting, and verification (MMRV) of forest carbon. NFD is understaffed to meet this directive, which has overshadowed NFD's other efforts at monitoring (measurement in the CFI plot network) and developing new management tools (i.e., the climate-sensitive growth and yield model [FVS] we originally sought to create). The value of such a climate-sensitive forestry model remains strong and NFD now has an exceptional dataset to do so, but the fitting of such a model and creation of a user-friendly interface would require an additional

investment of resources. FVS is the foundation for a number of CARB-approved tools for forest carbon accounting, so a climate-sensitive version of FVS would be able to address this new objective of carbon crediting, but it would require collaboration with individuals with a specific set of skills to rework FVS and especially to make it user-friendly.

### **Outreach and Products:**

- Articles in preparation, under review, accepted, or published in peer reviewed journals and other non-peer reviewed journals
  - One article reporting the results of our work is nearly ready for submission (to *Forest Ecology and Management*). As of this writing, the manuscript is undergoing review by the Navajo Historic Preservation Office before it can be submitted. The citation for that manuscript is: Yazzie, J. O., M. E. K. Evans, E. C. Riordan, C. H. Guiterman, R. J. DeRose, A. Becenti, and F. Thompson. Drought stress detected in tree rings suggests an impending tipping point for forests on the Navajo Nation.
- Project-related conference presentations, seminars, webinars, workshops, or other presentations to the public made by research team members.
  - A research poster at the [Geoscience Alliance Conference](#) in June 2022 (by Yazzie, in person).
  - An invited research seminar in the Watershed Science Community Call (invited by Dr. Ken Williams, Chief Scientist, Watershed Function, Lawrence Berkeley National Laboratory) in September 2022 (by Yazzie and Evans, virtual).
  - Invited research seminars at Northern Arizona University (School of Forestry) and the University of Arizona (School of Renewable Natural Resources and the Environment) in October 2022 (by Evans, in person).
  - A research seminar at the US Forest Service's Forest Inventory and Analysis Stakeholder Science meeting in November 2022 (by Yazzie, virtual).
  - One-hour guest lecture on Indigenous forestry in an undergraduate/graduate-level Forest Ecology class at the University of Arizona in December, 2022 (by Yazzie, virtual).
  - A factsheet of the project's findings presented at the Intertribal Timber Council's Annual Meeting held in Walker, MN, June 13-15, 2023 (by Yazzie, in person).
  - A keynote address at the Festival of Science in Moab, UT on September 15, 2023 highlighting the Navajo forest health project and its findings (by Yazzie, in person).
  - A research talk at a dendroecology training workshop held at the Laboratory of Tree-Ring Research November 7-9, 2023. The audience in the workshop include ~40 participants from diverse university, government (e.g., US Forest Service and US Bureau of Indian Affairs), and non-profit entities (e.g., EcoTrust), primarily across the US, but also including participants from Mexico and Canada (by Yazzie, in person).
  - A presentation of project results to the Bureau of Indian Affairs' Branch of Forest Inventory and Planning (FIP), at the invitation of Dr. Ben Bagdon, including seven members of the BOFRP team, on February 5, 2024 (by Yazzie, virtual).

- A two-page factsheet and a one-slide synopsis on the project, as part of the Diné College Climate Adaptation Forum held in Tsaile, AZ on March 8, 2024 (by Yazzie, in person).
- An invited research seminar (and live webcast) in the University of Arizona's Laboratory of Tree-Ring Research's research seminar series on March 27, 2024, disseminating project findings (by Yazzie, virtual).
- Communications with decision-makers, including their name and agency and the date(s) and frequency of your communications. Information on whether the decision-makers were involved in the design of the project plan or if the research has been tailored to address a specifically-stated management need is also helpful.
  - The project was coordinated closely with the Navajo Forestry Department, including daily field work during the sampling campaigns of 2019 and 2021, in-person and virtual project meetings with Alexious Becenti and Frankie Thompson, a project report (2021) and fact sheet (2023), and frequent email. This discussion led, for example, to increased sampling at higher elevations in the Chuska and Lukachukai Mountains, and an analysis of trends in forest stand-level productivity.
- Websites created for the project and/or containing project information, data etc.
  - Nothing to report.
- Other products, such as data or databases, audio/video productions, fact sheets etc.
  - Products generated by this project include a collection of 1,100 increment cores permanently archived at the Laboratory of Tree-Ring Research at the University of Arizona and a database of growth ring width time series corresponding to each physical sample. In addition, the project generated a Github repository that records all data manipulations and analysis, including the scripts that generate figures prepared for publication of research results. Further, the project generated a 22-page report of results with strong visuals (July 2021) and a fact sheet (July 2023), each designed for delivery to the Navajo Forestry Department. Finally, a SWCASC podcast (Come Rain or Shine) focused on this project was produced and released July 6, 2022 (Season 3, Episode 7), titled "Assessing climate change vulnerability of Navajo Nation forests".