**Arizona Water Resources II**

*Utilizing Aerial Imagery and NASA Earth Observations to Assess Pinyon-Juniper Tree Mortality in Flagstaff, AZ*

**Project Team**

***Project Team:***

Arina Morozova (Project Lead)

Jessica Birk

Jamal Jaffer

Greg Peargin

***Advisors & Mentors:***

Sean McCartney (Science Systems and Applications, Inc., NASA Goddard Space Flight Center)

Joseph Spruce (Science Systems and Applications, Inc., Consultant)

***Past or Other Contributors:***

Nicole Ramberg-Pihl (Project Fellow)

Margaret Jaenicke

Anne Britton

Abbi Brown

Liam Megraw

***Fellow:***

Carli Merrick

***Team Contact:*** Arina Morozova, arina.o.morozova@gmail.com

***Partner Contact:*** Mark Szydlo, mark\_d\_szydlo@nps.gov

**Project Overview**

***Project Synopsis:***

Persistent drought conditions in the American Southwest have contributed to major pinyon-juniper woodland (PJW) mortality events in recent years throughout Wupatki National Monument and the surrounding region. PJWs are a vital habitat for local flora and fauna and are culturally important to the region’s Hopi, Navajo, and Zuni peoples. In this project, methodologies from the Spring 2022 term were refined to map PJW tree mortality and assess its potential underlying environmental causes. A standard operating procedure (SOP) was presented to project partners alongside the team’s methodologies and findings in a virtual hand-off.

***Abstract:***

Pinyon-juniper woodlands (PJW) provide critical and resilient habitat for the local mammal and small bird species of Arizona's northern xeric environment. Drought in Arizona has been persistent for many decades, yet in 2021 PJW experienced a mass tree mortality event at the Wupatki National Monument (WNM) and in other areas across the American Southwest. Previously, researchers at the National Park Service (NPS) and the team from the NASA DEVELOP National Program attempted to quantify the extent of mortality in Northern Arizona between 2015 and 2021 using high resolution National Agricultural Imagery Program (NAIP) aerial photographs. This project aimed to improve the previous term’s methodology and expanded the comparison of the post-mortality event in 2021 to include tree cover assessments for 2017 and 2019. In this iteration, the team utilized NAIP imagery in conjunction with Landscape Fire and Resource Management Planning Tools (LANDFIRE) to calculate the total difference in PJW mortality using an unsupervised classification model trained from multi-date Modified Soil-Adjusted Vegetation Index (MSAVI) and the Visible Atmospherically Resistant Index (VARI) data for the study area. The research also assessed correlations between tree mortality and environmental factors using Western Land Data Assimilation System (WLDAS) modelled climate data. Average PJW mortality from 2015 to 2021 was 21.63% including 19.8% in WNM with the vast majority of dieback occurring between 2019 and 2021. The correlations were weak with the most correlated variables being bare soil evaporation (0.15), rainfall (0.14), groundwater storage (0.13), and wind speed (0.12), perhaps indicating drought as a likely driver of PJW mortality.

***Key Terms:***

pinyon-juniper woodlands, tree mortality, drought, plant water stress, National Park Service, remote sensing, climate change, Indigenous peoples

***National Application Area Addressed:*** Water Resources

***Study Location:*** Flagstaff, AZ

***Study Period:*** January 2015 – December 2021

***Community Concerns:***

* Pinyon-juniper tree mortality has led to a loss of habitat and food sources for many local species, as well as unpredictable changes to the ecosystem, leading to ecological and hydrological shifts in the region such as altering the local fire regime.
* Drought-induced tree dieback has increased the tree vulnerability to insect attacks such as bark beetle infestation, as well as the risk of wildfires and plant pathogens.
* Consequences of tree mortality have threatened Southwestern culture as these woodlands have been crucial to the Hopi, Navajo, and Zuni indigenous peoples as a source of food, shelter, material, and clothing.

***Project Objectives:***

* Map changes in PJW mortality over the study period and measure the extent using the methods from the previous term of this project while incorporating new methodology based on refined modelling procedures.
* Examine if pinyon-juniper mortality correlates to environmental factors, such as air temperature, precipitation, total and bare soil evapotranspiration, soil moisture, soil temperature, wind speed, ground water storage, and specific humidity over the study period.
* Provide partners with a standard operating procedure (SOP) outlining the PJW assessment methods from this work to support their decision-making practices.

***Previous Term:***

2022 Spring (GSFC) – Arizona Water Resources

**Partner Overview**

***Partner Organization:***

|  |  |  |
| --- | --- | --- |
| **Organization** | **Contact (Name, Position/Title)** | **Partner Type** |
| **National Park Service, Flagstaff Area National Monuments** | Mark Szydlo, Biologist | End User |

***Decision-Making Practices & Policies:***

The NPS focuses on landscape, natural resource, cultural resource, and wildlife management and monitoring at the Wupatki National Monument near Flagstaff, Arizona. To preserve the local environment, the NPS at Wupatki National Monument works closely and makes decisions in conjunction with the United States Forest Service at Coconino National Forest, the Arizona Game and Fish Department, the Grand Canyon National Park, the Bureau of Land Management, Forest Service, the United States Geological Survey, and Nature Conservancy. In particular, the NPS uses controlled burns to help manage vegetation health and improve the local habitat. They also use thinning methods to counteract pinyon and juniper encroachment where necessary. The NPS primarily uses ground observations and field data to monitor trees and assess the tree health conditions. In addition, the NPS informs local agencies, landowners, and governments on regional environmental conditions and ongoing issues through their NPS website and at the park’s visitor centers. This project aimed to improve knowledge of the current tree mortality extent and build the partner’s capacity to integrate NASA Earth observations into their current park management decisions.

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| **Terra MODIS** | All platforms & sensors were assimilated into the WLDAS model to derive air temperature, precipitation, soil moisture, soil temperature, ground water storage, snowfall, total and bare soil evapotranspiration, wind speed, and specific humidity | WLDAS uses NASA’s Land Information System (LIS) to simulate land surface states and fluxes. WLDAS data was used to assess climate characteristics and trends in the region over time and evaluate potential effects on pinyon-juniper tree mortality. |
| **Suomi National Polar-orbiting Partnership VIIRS** |
| **GRACE** |

***Ancillary Datasets:***

* United States Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP) – High resolution aerial imagery from 2015 (1-meter spatial resolution), 2017, 2019, and 2021 (0.6-meter spatial resolution) used for land cover classification, and map validation
* LANDFIRE Existing Vegetation Type v1.4.0 – Detailed 2016 and 2020 land cover classifications merged for the study region and used for masking out ponderosa pine areas (30-meter spatial resolution)
* Public Land Boundaries from Protected Areas Database of the United States (PAD-US) [v2.1] – Shapefiles for the boundaries of Coconino National Forest, Wupatki National Monument, and Grand Canyon National Park as of 2020
* US Census Bureau, Department of Commerce – Shapefile for the boundary of Current National American Indian Tribal Subdivisions as of 2017

***Modeling:***

* Land Data Assimilation System Optimized for the Western United States (WLDAS) – air temperature, rainfall, snowfall, total evapotranspiration, bare soil evaporation, soil moisture, soil temperature, wind speed, ground water storage, and specific humidity at 1-kilometer spatial resolution

***Software & Scripting:***

* Esri ArcGIS Pro 2.9.3 – Perform land cover classification, evaluate PJW mortality and its relation to environmental variables, generate maps
* Python 3.9.13 – Process WLDAS dataset, extract environmental variables and analyze them in relation to PJW mortality
* Microsoft Excel – Create climate trend graphs for 30-year periods.

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Product** | **Data used** | **Partner Benefit & Use** | **Software Release Category** |
| **Pinyon-Juniper Mortality Maps** | NAIP | Maps will demonstrate the extent of pinyon-juniper mortality across the landscape between the years 2015, 2017, 2019, and 2021, providing the partners with spatial and temporal information about drastic mortality events. | N/A |
| **Bivariate Choropleth Maps representing areas with high tree mortality and most impactful environmental variables** | NAIP and WLDAS, acquired using Moderate Resolution Imaging Spectroradiometer (MODIS) from Terra satellite, Visible Infrared Imaging Radiometer Suite (VIIRS) from Suomi National Polar-orbiting Partnership weather satellite, and instruments from Gravity Recovery and Climate Experiment (GRACE) mission | These maps will provide partners with spatial information regarding the specific areas in the study region with highest percentage of tree mortality and corresponding environmental variable. | N/A |
| **Expanded Time Series of Environmental Variables impacting tree mortality** | WLDAS, acquired using Moderate Resolution Imaging Spectroradiometer (MODIS) from Terra satellite, Visible Infrared Imaging Radiometer Suite (VIIRS) from Suomi National Polar-orbiting Partnership weather satellite, and instruments from Gravity Recovery and Climate Experiment (GRACE) mission | Plots of environmental variables will provide the partners with a record of how these variables have changed between 1991 and 2021, across the study period given prolonged drought conditions. Data will provide a longer record for climate variables to assess climate trends and anomalies in the region. | N/A |
| **Standard Operating Procedure (SOP) for Monitoring Pinyon-Juniper Mortality** | N/A | Refined methodology will be detailed in a framework allowing the partners to continue detecting and monitoring pinyon-juniper mortality after the DEVELOP term. | N/A |

***Product Benefit to End User:***

This project yielded a preliminary view into the environmental factors for the PJW mortality event. Pinyon pine and juniper trees are among the least studied trees, despite covering millions of acres. Therefore, additional research from this project provided great value in terms of how best to proceed in preserving and understanding these species. Additionally, this project benefited the end user by offering tree canopy change maps in which overstory tree mortality can be spatially identified across the study area. Such maps have helped the NPS resource managers and scientists to assess the pinyon juniper die-off, better understand the environmental reasons behind it, and use that information to adapt their decision-making practices.

**References**

Clifford, M.J., Royer P.D., Cobb N.S., Breshears D.D., & Ford, P.L. (2013). Precipitation thresholds and drought-induced tree die-off: insights from patterns of *Pinus edulis* mortality along an environmental stress gradient. *New Phytologist* *200,* 413-421. doi: 10.1111/nph.12362.

Erlingis, J.M., Rodell, M., Peters-Lidard, C.D., Li, B., Kumar, S.V., Famiglietti, J.S., Granger, S.L., Hurley, J.V., Liu, P.-W., & Mocko, D.M.. (2021). A High-Resolution Land Data Assimilation System Optimized for the Western United States. *Journal of the American Water Resources Association, 57*( 5): 692– 710. https://doi.org/10.1111/1752-1688.12910.

Floyd, M.L., Clifford, M., Cobb N.S., Hanna, D., Delph, R., Ford, P., & Turner, D. (2009). Relationship of stand characteristics to drought-induced mortality in three Southwestern piñon-juniper woodlands. *Ecological Applications, 19*(5), 1223-1230. doi: 10.1890/08-1265.1.

Jaenicke, M., Britton, A., Brown, A., & Megraw, L. (2022). Arizona Water Resources: Utilizing Aerial Imagery and NASA Earth Observations to Assess Pinyon-Juniper Tree Mortality in Flagstaff, AZ​. In *2022 Spring DEVELOP.*

National Park Service. (2015). *Pinyon-Juniper Woodlands - Introduction & Distribution.* Retrieved September 20, 2022, from https://www.nps.gov/articles/pinyon-juniper-woodlands-distribution.htm.

National Park Service. (2015). *Pinyon-Juniper Woodlands – Species Composition and Classification*. Retrieved September 15, 2022, from https://www.nps.gov/articles/pinyon-juniper-woodlands-species-composition-classification.htm.