**NASA DEVELOP National Program**

**2022 Fall Project Proposal**

**Maryland – Goddard**

**Arizona Water Resources II**

*Utilizing Earth Observations to Refine Juniper Tree Mortality Assessments in Flagstaff, Arizona*

**Project Overview**

***Project Synopsis*:** Arizona has experienced drought conditions for over 25 years. In 2021, the National Park Service (NPS) observed a dramatic tree mortality event in Pinyon-Juniper Woodlands (PJWs) throughout Wupatki National Monument and the surrounding region. PJWs support a wide variety of wildlife by functioning as breeding habitats and foraging grounds for local mammal and bird species. This project aims to refine existing methods for estimating pinyon-juniper mortality using NASA Earth observations, Landsat 8 OLI/TIRS, Landsat 9 OLI-2/TIRS-2, Terra MODIS, SMAP, GPM IMERG, and SRTM, in conjunction with Sentinel-2 MSI and NAIP imagery. Refined mortality maps will identify the extent of pinyon-juniper mortality across the landscape. The team will also examine how pinyon-juniper mortality changes in relation to environmental factors, such as temperature, precipitation, soil moisture, and soil type over time. A Standard Operating Procedure (SOP) will be provided to the partners outlining the PJW assessment methods from this work to aid their decision-making practices.

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

***Study Period:*** January 2000 – August 2022

***Advisors:*** Sean McCartney, (NASA Goddard Space Flight Center, SSAI), Joe Spruce (Consultant, SSAI)

**Partner Overview**

***Partner Organization:***

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

***End User Overview***

***End User’s Current Decision-Making Process & Capacity to Use Earth Observations:***The NPS engages in wildlife monitoring and landscape management at the Wupatki National Monument in Flagstaff, Arizona. In particular, the NPS uses prescribed burns as a method to help manage forest vegetation. Additionally, the NPS is responsible for disseminating information on local environmental conditions at their visitor centers and through their NPS website, sharing information with nearby schools, land owners, and other local agencies. The NPS at Wupatki National Monument works closely with the United States Forest Service at Coconino National Forest, the Arizona Game and Fish Department, and the Grand Canyon National Park. In their effort to monitor the local environment, the NPS utilizes some remote sensing techniques and employs ArcGIS technicians. This project builds the partner’s capacity to further integrate NASA Earth observations into their current management decisions.

**Earth Observations Overview**

***Earth Observations:***

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| --- | --- | --- |
| **Platform & Sensor** | **Parameter(s)** | **Use** |
| **Landsat 8 OLI** | Surface reflectance, Normalized Moisture Index (NDMI), Normalized Vegetation Index (NDVI) | Surface reflectance will be used to create land cover maps of the region that identify healthy and declining forest and woodland areas. NDMI and NDVI products will be computed to provide an understanding of how temperature, vegetation moisture, and plant health are impacted over time. |
| **Landsat 8 TIRS** | Land surface temperature (LST) | LST products will provide an understanding of how temperature has changed across the landscape over time. |
| **Landsat 9 OLI-2** | Surface reflectance, NDMI, NDVI | Surface reflectance will be used to create land cover maps of the region that identify healthy and declining forest and woodland areas in 2022. NDMI, and NDVI products will be computed to provide an understanding of how temperature, vegetation moisture, and plant health are impacted over time. |
| **Landsat 9 TIRS-2** | LST | LST products will be provide an understanding of how temperature varied across the landscape in 2022. |
| **SMAP** | Soil Moisture | SMAP data will be used to assess soil moisture over time in the region and in relation to pinyon-juniper mortality. |
| **GPM IMERG** | Precipitation | Precipitation accumulation data, derived from algorithms to predict interpolated values, will be used to assess precipitation trends over time and in relation to pinyon-juniper mortality events. |
| **SRTM** | Elevation, slope, and aspect | Elevation, slope, and aspect will be used to map topographic characteristics of the landscape, create elevation-based masks to distinguish pinyon-juniper trees, and assess relationships between pinyon-juniper tree presence and topographic variables. |
| **Terra MODIS** | Evapotranspiration, Burn boundary | Evapotranspiration will be assessed over time in the region and in relation to pinyon-juniper mortality. Burn boundary data will be used to create masks of burned areas in the region. |
| **Sentinel-2 MSI** | Surface reflectance | Surface reflectance will be used to identify pinyon-juniper woodlands and for comparison to lower spatial resolution Landsat data. |

***Ancillary Datasets:***

* United States Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP) – High resolution aerial imagery from 2015 to 2021 which can be used for land cover classification and validation
* WorldClim Historical Weather Data – Modeled temperature and precipitation data used to assess climate data over time at 1 km resolution
* LANDFIRE Existing Vegetation Type [v1.4.0] – Detailed 2016 land cover classification for the study region which can be used for masking out highly-probable ponderosa pine areas
* LANDFIRE Existing Vegetation Height [v2.0.0] – Detailed 2016 classification of vegetation height which can be used for masking out highly-probable non-PJW trees
* 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
* National Park Service (NPS) Vegetation Inventory Maps – Geospatial vegetation map products for Wupatki National Monument from 2004
* Monitoring Trends in Burn Severity (MTBS) Burned Area Maps – Shapefile with burn boundaries between 2015 and 2020 for the study region
* National Park Service (NPS) Juniper Survey Points – Ground truth PJW sites within Wupatki National Monument from 2021 used for classification validation
* United States Forest Service (USFS) – Ground truth PJW sites within the Coconino National Forest and Southern Kaibab National Forest from 2021 used for classification validation
* USGS Soil Survey Geographic (SSURGO) – Data on soil characteristics used for analyzing mortality in relation to environmental factors including soil type

**Decision Support Tool & End Product Overview**

***End Products:***

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| --- | --- | --- | --- |
| **End Product** | **Partner Use** | **Datasets & Analyses** | **Software Release Category** |
| **Refined Land Cover Maps** | Refined maps displaying land cover will identify forested areas throughout the study region for 2015, 2017, 2019, 2021, and 2022 These maps will provide an understanding of the composition of NPS lands. | NAIP, Landsat 8 OLI, Landsat 9 OLI-2, and Sentinel-2 MSI will be used to generate refined land cover classification. Esri ArcGIS Pro will be used to classify land cover and visualize land cover maps. | I |
| **Refined Pinyon-Juniper Mortality Maps** | Refined maps will demonstrate the extent of pinyon-juniper mortality across the landscape for 2015, 2017, 2019, 2021, and 2022. These maps will provide a deeper understanding of how PJW may have changed in relation to a stronger than normal drought year in 2018. | NAIP, Landsat 8 OLI/TIRS, Landsat 9 OLI-2/TIRS-2, and Sentinel-2 MSI data will be used to assess tree canopy characteristics and determine tree mortality. Esri ArcGIS Pro will be used for visualizing the extent of pinyon-juniper mortality through the study region over time. | I |
| **Expanded Time Series of Soil Moisture, Evapotranspiration, Precipitation, Temperature, NDMI, and NDVI** | Plots of environmental variables will provide the partners with a record of how these variables have changed between 2015 and 2021, across the study period given prolonged drought conditions. World Clim data will provide a longer record for temperature and precipitation to assess climate trends in the region. | Plots of environmental variables including SMAP soil moisture, Terra MODIS evapotranspiration, precipitation estimates from GPM IMERG/World Clim, LST from Landsat 8 TIRS/World Clim, and Landsat 8 OLI NDMI and NDVI, and Landsat 9 OLI-2/TIRS-2 will be generated in R for the last 20 years. | I |
| **SOP for Monitoring Pinyon-Juniper Mortality** | Refined methods will be detailed in a framework allowing the partners to continue detecting and monitoring pinyon-juniper mortality. This will allow the NPS to continue monitoring die-off events after the DEVELOP term. | Refined instructions on how NAIP, Landsat 8 OLI/TIRS, Landsat 9 OLI-2/TIRS-2, Sentinel-2, GMP IMERG, SMAP, SRTM, and Terra MODIS data can be used to monitor pinyon-juniper mortality will be compiled into a user-friendly document using Microsoft Word. | I |

**Project Timeline & Previous Related Work**

***Project Timeline:*** 2 Terms: 2022 Spring to 2022 Fall

***Multi-Term Objectives:***

* **Term 1:** 2022 Spring (GSFC) – Arizona Water Resources
  + The first term of this project explored approaches for mapping the extent of pinyon-juniper mortality within Wupatki National Monument and the surrounding area for the years 2015 and 2021. In addition to producing mortality maps, the team examined environmental factors, including soil moisture, evapotranspiration, temperature, NDMI, and NDVI between 2015 and 2021. Preliminary statistical analysis attempted to provide insight into whether pinyon-juniper mortality was associated with these factors. The methods were outlined in a framework that will provide a foundation for the second term to build off, while also allowing the partners to continue this work beyond the DEVELOP term.
* **Term 2 (Proposed Term):** 2022 Fall (GSFC) – Arizona Water Resources II
  + The team will refine the methods created for assessing and mapping pinyon-juniper mortality for years when NAIP imagery is available: 2015, 2017, 2019, and 2021. Climatological data from World Clim and soil survey data will be incorporated into the expanded time series examining juniper mortality in relation to environmental variables. Project end products will be transitioned to the partners in a virtual handoff event. Furthermore, an SOP detailing revised methods will build capacity in the NPS to continue mapping mortality in PJW beyond the DEVELOP project.

**Notes & References:**

***Notes*:** At the start of the first term, the NPS partners provided a list of priorities for project outcomes. The highest priority was assessing the extent of pinyon-juniper mortality throughout Wupatki and the surrounding area (spanning from the Coconino Forest managed by the USFS and the southern rim of the Grand Canyon managed by the NPS). The partners were also interested in understanding more about mortality in relation to tree stand density. Beyond those end products, the partners would like to know if there are correlations between environmental variables (especially drought related variables, including precipitation) and mortality. The first term tackled an ambitious project and worked to explore the data that could be effective for carrying out the needs provided by the partners. Overall, the first term provided a preliminary framework outlining methods that could be used to assess pinyon-juniper mortality across the landscape for the years 2015 and 2021. The second term will refine these methods for a broader range of years when NAIP imagery is available (2015, 2017, 2019, 2021) to better capture forest mortality across the landscape and over time. Incorporating World Clim data will provide long term data for assessing temperature and precipitation at a 1km resolution, which may be more appropriate when testing for correlations between mortality and environmental variables that could be driving mortality. Efforts will include the use of Landsat data products that occur over a broader time frame than NAIP and are more comparable in terms of the observation period to the climatological data.

***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.

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.

National Park Service. (2015, February 3). *Pinyon-Juniper Woodlands – Species Composition and Classification*. [Pinyon-Juniper Woodlands - Species Composition and Classification (U.S. National Park Service) (nps.gov)](about:blank)