**Rocky Mountain Disasters**

*Using NASA Earth Observations to Monitor Post-Fire Vegetation Recovery on the Colorado Front Range*

**Project Team**

***Project Team:***

Eric Jensen (Project Lead)

Audrey Colley

Zackary Werner

Lauren Kremer

***Advisors & Mentors:***

Dr. Paul Evangelista (Colorado State University, Natural Resource Ecology Laboratory)

Dr. Catherine Jarnevich, (United States Geological Survey, Fort Collins Science Center)

Dr. Tony Vorster (Colorado State University, Natural Resource Ecology Laboratory)

Peder Engelstad (Colorado State University, Natural Resource Ecology Laboratory)

Nick Young (Colorado State University, Natural Resource Ecology Laboratory)

***Team POC:*** Eric Jensen, erjensen@colostate.edu

***Partner POC:*** Dr. Charles C. Rhoades, crhoades@fs.fed.us

**Project Overview**

***Project Synopsis:*** This project partnered with the US Forest Service Rocky Mountain Research Station to evaluate post-fire vegetation recovery in the Colorado Front Range using Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM+), and Landsat 8 Operational Land Imager (OLI). The team quantified post-fire spectral recovery trajectories, analyzed relationships between spectral recovery and measures of forest condition, modeled contemporary forest cover percentages, and modeled post-fire seedling regeneration. In addition, the team analyzed drivers of post-fire seedling regeneration including topography, climate, fire, and soils. These products will help guide and define expectations for post-fire watershed recovery and forest restoration.

***Abstract:*** Forest composition and structure in the Colorado Front Range has been altered by changing wildfire regimes. In particular, increased moderate- and high-severity fire significantly reduces forest cover following fire and often results in reduced seedling regeneration. Reduced tree canopy regrowth has chronic effects on upland ecological function and downstream water quality. This project partnered with the US Forest Service to estimate long-term vegetation recovery following four Colorado Front Range fires between 1996 and 2002—the Bobcat, Buffalo Creek, Hayman, and High Meadows fires—using Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM+), and Landsat 8 Operational Land Imager (OLI). The random forest algorithm was applied to produce maps of percent forest canopy cover for coniferous trees, deciduous trees, and all trees using time-series variables for pre- and post-fire as inputs. Similarly, maps of post-fire seedling regeneration were produced using random forest for coniferous trees, deciduous trees, and all trees using ecological drivers (soil, climate, fire, topography) and pre-fire remote sensing predictors. Relationships between ecological drivers of post-fire vegetation trajectories were also evaluated. Additional analyses were conducted to (1) assess whether seedlings could be detected by Landsat or synthetic aperture radar (SAR) time-series analysis (2) assess pre-fire and post-fire Landsat variables against pre-fire and post-fire tree cover estimates to evaluate whether magnitude of forest change can be detected. Understanding variables that influence vegetative recovery, vegetation type conversion, and watershed characteristics will aid forest restoration efforts and water quality management.

***Key Terms:***

remote sensing, Landsat 8 OLI, Landsat 5 TM, Landsat 7 ETM+, wildfire, vegetation recovery, Random Forest, LandTrendr

***National Application Area Addressed:*** Disasters

***Study Location:*** Colorado Front Range

***Study Period:*** 1996-2019 (May – October)

***Community Concerns:*** Communities within the boundaries of the catastrophic Bobcat Gulch (2000), Buffalo Creek (1996), Hayman (2002), and High Meadows (2000) fires along the Colorado Front Range have experienced multiple impacts and are facing a future with increased fire frequency and severity. These fires have direct impacts on infrastructure and local economies. For instance, the Hayman fire destroyed 600 structures, including 132 residences. Additionally, these fires have long-lasting impacts on forest function and water quality. Impacts include:

* Reduced forest cover and heterogeneity
* Reduced forest regeneration
* Poor post-fire water quality from increased nutrient and sediment loads

Methods of tracking post-fire ecosystem recovery at landscape scales will guide the use of limited restoration resources, benefiting scientists, managers, and fire-impacted communities. Understanding the impacts of severe fire on forest regeneration and water quality is critically important for communities across the western US whose water originates in fire-prone, forested watersheds.

***Project Objectives:***

* Applied remotely sensed data to quantify spectral recovery and detected post-fire tree canopy cover.
* Modeled suitability for post-fire tree seedling regeneration and evaluated spatial ecological drivers.

**Partner Overview**

***Partner Organization:***

|  |  |  |  |
| --- | --- | --- | --- |
| **Organization** | **POC (Name, Position/Title)** | **Partner Type** | **Boundary Org?** |
| **USDA Forest Service Rocky Mountain Research Station** | Dr. Charles Rhoades, Research Biogeochemist | End User | Yes |

***Decision-Making Practices & Policies:*** The end user has extensive experience conducting field studies to measure burn severity, forest recovery, and watershed response. Field-based studies have been limited to transect and watershed scales after individual fires. Burn severity is typically mapped by the end user immediately post-fire using a combination of remote sensing and field observations. While these maps are useful in guiding more immediate soil erosion mitigation, they are not intended to capture long-term ecosystem response. Commonly used sensors like Landsat and LiDAR are effective in determining wildfire predictor and response variables over a large spatial-temporal scale. Additionally, remote sensing techniques can reduce field costs and improve site accessibility

**Earth Observations & End Products Overview**

***Earth Observations:***

|  |  |  |
| --- | --- | --- |
| **Platform & Sensor** | **Parameters** | **Use** |
| Landsat 5 TM  | Landsat surface reflectanceSpectral vegetation indicesDerived time-series rasters such as post-fire slopes and differenced post-fire – pre-fire-images. | Landsat imagery was used to track long-term post-fire vegetation recovery using a time series of spectral vegetation indices. |
| Landsat 7 ETM+ |
| Landsat 8 OLI  |
| ALOS PALSAR | HV polarization bandDerived differenced images from first and last years of collection. | Synthetic aperture radar (SAR) L-band data are useful for characterizing post-fire vegetation structure |
| Sentinel-1 | VH polarization bandDerived differenced images from first and last years of collection. | Synthetic aperture radar (SAR) C-band data are useful for characterizing post-fire vegetation structure |

***Ancillary Datasets:***

***Predictors:***

* USDA and United States Geological Survey (USGS) Monitoring Trends in Burn Severity, Burn Severity Maps—This dataset was used to assess initial burn severity as measured immediately post-fire.
* Oak Ridge National Laboratory DayMet V3: Daily Surface Weather and Climatological Summaries—This dataset was used to calculate 30-year climate means and annual values for ecologically-relevant variables.
* Duke University and USGS POLARIS Soil Properties rasters—This dataset interpolates the Soil Survey Geographic Database (SSURGO) and State Soil Geographic Database (STATSGO) data to estimate soils variables like fractional sand, silt, and clay, soil moisture capacity, and others.
* USGS National Elevation Dataset—This dataset was used to derive topographic variables such as slope and aspect which were used for modeling
* Conservation Science Partners (CSP) Ecologically Relevant Geomorphology (ERGo) datasets—This dataset includes topographic variables such as heat load index and landform which were used for modeling.

***Training data:***

* US Forest Service Rocky Mountain Research Station, vegetation inventory field data—Vegetation inventory data was used to evaluate accuracy of vegetation recovery maps.
* Google Earth imagery—Contemporary and historical imagery were used to estimate tree canopy cover and regeneration prior to and following fires.

***Masking:***

* Pike San Isabel National Forest, Forest Restoration Areas—GIS data of tree planting after the Hayman fire was used for the analysis of vegetation recovery patterns.

***Modeling:***

* Random Forest (POC: Dr. Tony Vorster, Colorado State University) – This algorithm was used to model relationships between post-fire recovery and topography, land cover, forest restoration areas, initial burn severity, and burn severity patch size.
* LandTrendr (POC: Dr. Tony Vorster, Colorado State University) – This algorithm was used to obtain post-disturbance recovery information.

***Software & Scripting:***

* Google Earth Engine – Viewed, filtered, derived and exported satellite imagery for analysis.
* R statistical software – Organized and filtered data and run random forest model.
* Esri ArcGIS – Visualized model results. Created map products.
* Google Earth Pro – Collected pre-fire and post-fire training data.

***End Products:***

|  |  |  |  |
| --- | --- | --- | --- |
| **End Products** | **Earth Observations Used**  | **Partner Benefit & Use** | **Software Release Category** |
| Long-TermVegetation Raster Layers | Landsat 5, Landsat 7, and Landsat 8 | These raster layers characterized spectral recovery in burned areas. This approach complemented already-produced burn severity maps that evaluated impacts immediately after fires. | N/A |
| Analysis ofVegetation RecoveryPatterns | Landsat 5, Landsat 7, and Landsat 8 | Partners and other decision makers utilized field observations and initial burn severity maps to study post-fire vegetation recovery and associated water quality impacts. We evaluated the relationships between fire and vegetation at larger scales and across multiple fires. | N/A |
| Maps of Post-Fire Tree Cover Percentage | Landsat 5, Landsat 7, and Landsat 8, Sentinel-1, ALOS PALSAR | These maps of percentage cover of coniferous, deciduous, and all trees provided valuable spatially continuous data to partners for further watershed and forest condition analysis. | N/A |
| Maps of Post-Fire Seedling Regeneration Probability | Landsat 5, Landsat 7, and Landsat 8 | Partners and forest managers were interested in drivers of post-fire conifer, deciduous tree, and all tree regeneration. In the process of mapping regeneration probability, the team provided valuable information about environmental drivers of regeneration. | N/A |

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

Post-fire vegetation recovery maps and model-derived indications of which drivers influence wildfire patterns can provide large-scale insight into the smaller-scale work our partners have executed. Additionally, the proposed products can help adapt and target late-stage restoration treatments by evaluating the effectiveness of past restoration treatments and identifying critical areas with poor vegetation recovery.

**References**

Chambers, M. E., Fornwalt, P. J., Malone, S. L., & Battaglia, M. A. (2016). Patterns of conifer regeneration following high severity wildfire in ponderosa pine – dominated forests of the Colorado Front Range. *Forest Ecology and Management* *378,* 57-67. <https://doi.org/10.1016/j.foreco.2016.07.001>

Chaney, Nathaniel W., et al. (2019). POLARIS Soil Properties: 30‐m Probabilistic Maps of Soil Properties Over the Contiguous United States. *Water Resources Research 55:4*, 2916–2938. doi:10.1029/2018wr022797.

Kent, B., et al. Social and Economic Issues of the Hayman Fire. *United States Forest Service (USFS)*, 315-316.

Leon, J.R.R., Van Leeuwen, W.J., & Casady, G.M. (2012). Using MODIS-NDVI for the Modeling of Post-Wildfire Vegetation Response as a Function of Environmental Conditions and Pre-Fire Restoration Treatments. *Remote Sensing* *4*, 598-621. https://doi:10.3390/rs4030598

Liaw, A. & Wiener, M. (2002). Classification and Regression by RandomForest. *R News 2,* 18-22.

Pal, M. (2005) Random forest classifier for remote sensing classification, I*nternational Journal of Remote Sensing 26:1*, 217-222. https://doi: 10.1080/01431160412331269698

Rhoades, C. C., Chow, A. T., Covino, T., Fegel, T. S., Pierson, D., & Rhea, A. E. (2018). The legacy of a severe wildfire on stream nitrogen and carbon in headwater catchments. *Ecosystems 22*, 643-657**.** https://doi.org/10.1007/s10021-018-0293-6

Vogeler, J. C., Braaten, J. D., Slesak, R. A., & Falkowski M. J. (2018). Extracting the full value of the Landsat archive: Inter-sensor harmonization for the mapping of Minnesota forest canopy cover (1973–2015), *Remote Sensing of Environment 20,* 363-374.

Walker, J. J. & Soulard, C. E. (2019). Phenology Patterns Indicate Recovery Trajectories of Ponderosa Pine Forests After High-Severity Fires. *Remote Sensing 11:23*, 2782. <https://doi.org/10.3390/rs11232782>