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Sierra Nevada Water Resources

A Quantitative Assessment of Wildfire Severity and its Effects on Snow Water Equivalent Throughout the Sierra Nevada

**Technical Report**

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**I. Abstract**

[Placeholder - do not put anything here until the final draft submission. The abstract in the project summary is where the working draft of the abstract should “live”]

**Keywords**

Climate change, fire ecology, forestry, remote sensing, snowpack, Landsat, seasonal trend analysis, Fire Severity Index (FSI)

**II. Introduction**

The Sierra Nevada (SN) is a mountain range extending approximately 400 miles through California, including a small portion of western Nevada. Home to a rich diversity of characteristic flora and fauna, this iconic landscape was formed as a function of interactions between regional climate, local biota, geomorphology, and geology (cite). It provides a plethora of ecosystem services that affect environmental, economic, and socio-cultural elements (cite). California communities rely heavily on these services, which include carbon sequestration, water purification and storage, timber production, habitat for wildlife, and human recreation (Bales et al. 2011). However, due to climate change, as well as anthropogenic factors, these services are being degraded, adversely impacting the surrounding communities (cite).

Given California’s Mediterranean climate, characterized by wet winters and dry summers, the Sierra Nevada’s winter snowpack is of particular importance to the state, providing more than 60% of its water (Bales et al. 2011). Major metropolitan centers, such as  San Francisco, Oakland, and the Los Angeles Basin, all rely on water originating in Sierra Nevada watersheds (cite). The SN is a natural reservoir for California, accumulating and storing winter precipitation and releasing it gradually via snowmelt during the spring and summer months (Bales et al. 2011). However, SN snowpack has been diminishing—snowpack in the 2015 water year was only 6% of its normal amount—due to severe drought and climate change-induced increases in temperature (cite). Climate change projections for California, including those made by the Intergovernmental Panel on Climate Change (IPCC), predict a temperature increase between 1.5° C and 4.5° C by the end of the century (Cayan et al. 2007). This is expected to cause a 25% decrease in snowpack by 2050 (Department of Water Resources 2008), by which time California’s population is predicted to increase 30% to 50 million (cite). These increasing temperatures will reduce the Sierra Nevada’s function as a natural reservoir through less snowpack accumulation, earlier snowmelt, and a greater proportion of precipitation falling as rain rather than snow (Cayan et al. 2007, Kapnick and Hall 2010).

SN ecosystems are also heavily affected by management practices. Federal policies enacted in the 1930s mandated and enforced a strict policy of wildfire suppression, although many of these forest ecosystems adapted to, and required, frequent low severity wildfires to remain healthy (cite). This policy altered the natural fire regime—the historic pattern, frequency, and intensity of fires—of the SN and allowed the proliferation of shade-tolerant species, the buildup of ladder fuels, and an overall increase in vegetation density (cite). These changes, augmented by drought and climate change, have increased the frequency of high severity fires uncharacteristic of SN ecosystems, degrading soil quality, changing stand structure, and decreasing the available water resources (cite). In general, a more dense forest reduces the amount of water flowing downstream from increased root mass and evapotranspiration. It also reduces snowpack retention by catching a higher proportion of snowfall in the canopy, thus exposing it to more incoming solar radiation (Bates et al. 2011). The effects of wildfire severity, and resulting changes in stand structure, on snowpack retention is a current knowledge gap and may have serious implications for California water resources.

In order to quantify these impacts of wildfire severity on snowpack and snow water equivalent (SWE)—the theoretical amount of liquid water held in snowpack—remote sensing and geographic information systems (GIS) were utilized to analyze contiguous data on a landscape scale. NASA Earth Observation Systems (EOS) Landsat provided high spatial and temporal resolution, 30 m x 30 m pixels and 16-day cycles (cite). This allowed for analysis to occur over a 30-year timespan from 1984-2014 over the entire SN. Other ancillary datasets were used as inputs in GIS software, mainly ArcMap and TerrSet, to relate wildfire severity to 270 m downscaled 2014 California Basin Characterization Model data on precipitation, land surface temperature (LST), snow water equivalent (SWE), and soil water storage.

The results of this study will directly benefit the USDA U.S. Forest Service (USFS) and National Park Service (NPS) by providing baseline data on how fire severity affects SWE. These results could inform management of water resources and ecosystem health under the novel ecological conditions of the 21st century.

**III. Methodology**

This study attempts to provide baseline information quantifying the effects of wildfire severity on snowpack and snow water equivalent. The steps necessary to do this included (1) data collection and preprocessing, (2) a time series trend analysis, (3) comparison to BCM data, and (4) conducting a seasonal trend analysis.

*3.1. Data collection and preprocessing*

3.1.1. U.S. Forest Service (USFS) Region 5

The USDA Forest Service provides geospatial datasets for numerous purposes. For this study, Region 5 datasets were utilized in order to focus on the SN. A state-level dataset provided vector data for the northern and southern Sierran vegetation types originally assessed in 1934, but updated July 1998. This included information on dominant land cover type such as agricultural land or shrub and brush rangeland, as well as information on individual tree species composition such as White-fir (*Abies concolor*) mixed-conifer, Douglas-fir (*Pseudotsuga menziesii*) mixed-conifer, Ponderosa pine (*Pinus ponderosa*), and California black oak (*Quercus kelloggii*).

A regional level dataset provided vegetation burn severity information for CA fires within 1984-2014. This dataset was based on Landsat imagery, a relative difference normalized burn ratio (RdNBR), and a Composite Burn Index (CBI). Only fires that were labeled “Best Assessed” and that had a post 1-year assessment type were kept for the study.

3.1.1.A. Fire Severity Index

The spatial resolution of the burn severity rating data was too fine for the purpose of this study. Each fire consisted of several small polygons, representing a distribution of heterogeneous burn severity patches, varying from unchanged-unburned to low, moderate, and high severity. These categories had established values of 1, 2, 3, and 4, respectively, and were derived from the Composite Burn Index (CBI).

In order to give each fire one overall burn severity rating, a Fire Severity Index (FSI) was calculated for each fire as a whole. To calculate this, the proportional area of each burn severity class for each fire was divided by the total area of the fire to give the relative proportion of each burn severity for each fire. Next, a weighted average for each severity class in each fire was calculated by multiplying the relative proportion of each severity class by a severity factor—1 for unburned-unchanged areas, 2 for low severity, 3 for medium severity, and 4 for high severity. Values for each fire were added to obtain an FSI value for each fire. This resulted in an FSI in which unchanged-unburned fires had values from 1-1.9, low severity fires 1.9-2.3, moderate severity fires 2.3-2.8, and high severity fires 2.8-3.8.

At this point, a threshold of 404 hectares was established to only consider wildfires greater than this determined area. The median fires in each severity class were selected, along with a buffer of three fires on either side of each median, resulting in seven fires for each of the three severity classes. Fires were then further narrowed down based on whether there had been a previous fire in the same area. Nine fires were selected in total: three low-severity, three medium-severity, and three high-severity fires.

3.1.2. NASA Earth Observing System (EOS)

For the purpose of this study, Landsat imagery was collected between 1984 and 2014 in order to quantify changes in snowpack and SWE from the selected wildfires. Landsat 4-5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper (ETM+), and Landsat 8 Operational Land Imager (OLI) were used to derive snow cover measurements. Any errors resulting from Landsat 7 scan line corrector (SLC) were absolved by either discarding those images or by data collected on the region from other Landsat satellites. An Fmask was run on all Landsat data and automatically classified cloud cover, cloud shadow, snow cover, land, and water bodies. All images were zero-padded so data outside the image were assigned a value of zero. A resampling of all images was then performed to ensure proper alignment.

In order to collect elevation data for the SN region, as well as aspect and slope, data from the Shuttle Radar Topography Mission (SRTM) satellite were used.  These data were hosted by the USGS, and 15 separate tiles were downloaded to completely map the region.

3.1.3. Wilderness area and elevation mask

The Bureau of Land Management (BLM) National Landscape Conservation System (NCLS) provided vector data on wilderness areas within California. These areas are subject to different management practices relative to surrounding wildlands and are therefore of interest to the Forest Service and NPS.

Two different masks were created, one for wilderness areas and the other for elevation above 1500 m. The elevation mask threshold of 1500 m and above refined the study area to mid-elevation forests and higher where there is noticeable impact from wildfires on snowpack. The vegetation burn severity data were then clipped to these masks so that any intersecting data would be kept. This ensured the entire fire was preserved in the event that part of the fire extended outside of the masked areas.

3.1.4. Hydrologic Unit Codes 10 (HUC-10)

To determine in which watershed the particular wildfires of interest were located, HUC-10 data were downloaded from the USDA Natural Resources Conservation Service for all of California.

3.1.5. 2014 California Basin Characterization Model (BCM)

270 meter resolution, historic and future, climate data were downloaded from the USGS in order to collect information on factors such as land surface temperature (LST), precipitation, snowmelt, and soil water storage.

*3.2. Time Series Trend Analysis*

3.2.1. NDVI

3.2.2. NDSI

3.2.3. Raster Time Series

*3.3. Comparison to BCM data*

*3.4. Seasonal trend analysis*

**IV. Results & Discussion**

**V. Conclusions**

**VI. Acknowledgments**

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**VIII. Content Innovation**

**IV. Appendices**