Spatio-Temporal Relationships of Historic Wildfires: Using the NASA RECOVER Historic Fires Geodatabase to Perform Long-term Analysis of Wildfire Occurrences in the Western United States

Jonah Davis and Keith T. Weber
Idaho State University GIS Center

Abstract

An analysis of historic wildfires in the western United States provides discernment of long-term trends in historic wildfire activity. Understanding these trends and the spatial distribution patterns of wildfire aids in providing relevant decision support to both land management agencies and the public. The NASA RECOVER decision support system's historic fires geodatabase contains all fire areas documented between 1950 and 2017 for 11 western states. Statistical analysis of the spatio-temporal patterns of these wildfires was conducted using geographic information systems (GIS) software. Analysis of annual fire frequency and acres burned reveals a near exponential growth in fire frequency (R^2 = 0.74) and size (R^2 = 0.68) since 1950 across the western US. During this same time, the mean and median acres burned per year suggests the occurrence of mega-fires is also increasing. The mean size of fires occurring in the 1950's was 1,550 acres. In the current decade, mean fire size has more than doubled, reaching an average of 3,478 acres. Similar analysis by state provides finer resolution and provides the most relevant decision support for a given state. This analysis revealed similar exponential trends in fire frequency and burned area with the exceptions of Idaho and California, which follow a linear trend. While wildfire events are still increasing in these states, this result suggests Idaho and California have experienced more consistent fire events since 1950.

Introduction

The increase in wildfire frequency and size over the past decades, has been accompanied by increased concerns regarding the ecological, socio-economic, and land-resource impacts of these fires. Wildfires in the United States threaten life and property every fire season. To combat these threats, land managing agencies employ the most advanced technologies and allocate expansive resources to efficiently suppress wildfires. Regardless of suppression efforts, wildfires continue to increase in size and occurrence. Many studies have focused on solving causation of wildfire increase, and similar conclusions have been formed. The causes of wildfire are part of a dynamic and complex system that is influenced by environmental and human activities. Common causes for the current wildfire upsurge are human population increase, changes in fuel load, invasive species, weather, and climatic conditions. (Gill et al., 2013). Reallocation of resources by management agencies has become imperative to combat the increasing complexity of fires burning on public and private lands.

The US Forest Service (USFS) has been the most affected agency with regards to fire occurrence and size (Table 1). The USFS budget for fire management has increased from 20% before 2000 to 43% in 2009 (Calkin et al., 2011, US Forest Service, 2009). The overall USFS budget has remained relatively stagnant through the shift in monetary allotments, and has thus starved other non-fire sectors of the agency for funding (Calkin et al., 2011). Fire management practices are complex, and the increase in agency's responsibilities towards fire management has created an overall dysfunction throughout managing practices (Stephens and Ruth, 2005). The complexity of management for wildfires in the US is derived from the interdisciplinary responses of landscapes and people to wildfire occurrences in both pre- and post-fire environments.

The increase of wildfires in recent years, has promoted a rise in research on wildfire impacts. In general, wildfires can have both negative and positive effects on ecosystems. Because of the large amount of research available, the implications of wildfires on ecosystems will be discussed briefly to establish some background for subsequent discussions.

Robichaud et al. (2000) compiled a near comprehensive description of possible ecosystem related events that can occur following a burn. Generally, wildfires have the potential to cause losses in soil productivity, encroachment of invasive weeds, and downstream sedimentation due to surface erosion and loss of streambank stability. Changing fuels and climatic conditions have also been shown to have adverse effects on wildfire occurrence (Gill et al., 2013). Both short- and long-term effects are observed in post-fire environments. Short-term effects include loss of property and loss of natural resources. Mass movements, loss of infrastructure due to reordered landscapes, and encroaching invasive plants are some long-term effects that can follow a wildfire (Keegan et al., 2004). All orders of ecosystem services are influenced by wildfire occurrence, and in the last 50 years ecosystems and ecosystem services have been altered more than any other period in human history (Millennium Ecosystem Assessment, 2005). The complexity of ecosystem services and their valuation lend to the complexity of management and reestablishment of those services (Carpenter et al., 2009).

The impact of wildfires on social systems does not carry uniformly across areas where fires occur. Rather, the social aspects of wildfires are a composite set of changes that are difficult to quantify (Paveglio et al., 2015, Calkin et al., 2008). Federal wildfire policy accommodates these non-market social perceptions in an effort to preserve social benefits from burned areas (Venn and Calkin, 2011). Labor markets, in areas with wildfires, increase during fires, but wildfires create instability in the local economy after containment due to the uncertainty in labor necessities (Moseley et al., 2012). The value of information in pre- and post-wildfire decision making can be seen in its ability to reduce uncertainty in wildfire environments (Williamson et al., 2002). Uncertainty in decision making drives the value of information higher, and the best decisions are made with the most relevant and current information (Kangas et al., 2010). As such, NASA's Rehabilitation Capability Convergence for Ecosystem Recovery (RECOVER) project strives to provide fire managers with the most current and relevant information (Schnase et al, 2014).

The management of pre-, active-, and post-wildfire events is now being influenced by the technological advancements of GIS and remote sensing. Further, the RECOVER project, a post-fire decision support system for recovery of burned landscapes, seeks to address some of the concerns land managers face when developing their rehabilitation plans. RECOVER is a service that uses highly advanced computer technologies to form a web-based map server. The map service provides geospatial data layers selected by land managers based on their needs. The GIS TReC at Idaho State University is the provider of corrected and active data layers. The project is funded by NASA, through the Applied Sciences Program. Using an internet browser, land managers can access 26 geospatial data layers and request additional data based on their interests and concerns. The RECOVER DSS excels in aiding rehabilitation efforts through the visualization of the entirety of affected areas. Through this process rehabilitation efforts can be distributed based on their importance relative to the entire fire area. The RECOVER DSS provides layers such as habitat and debris flow probability which are areas of concern when rehabilitating, stabilizing, and restoring the area back to its pre-fire conditions.

Managing and preserving the earth's ecosystem services has gained importance and recognition within the last century following a transition from industrialized systems. Ecosystem services encompass a vast array of natural resources from the mining industry to recreation. Management practices of these services have experienced an alteration in their process due to the continuous progression of technology. Providing rapid results describing the progression and impacts of a wildfire is vital in restoration efforts. Furthermore, understanding pre-fire conditions is important in restoring the natural landscape to its original condition. Rehabilitation efforts can be streamlined through the use of RECOVER by providing a centralized location for data relevant to the reestablishment of pre-fire conditions. Using NASA RECOVER's historic fires geodatabase, this study was conducted to better understand past trends and how future fire seasons may unfold.

Materials and Methods

Long-term trends in wildfire occurrence can be important to aid our understanding of future wildfires. The spatial extent of the NASA RECOVER DSS includes the entire western contiguous United States ranging north to south along the eastern border of Montana, Wyoming, Colorado, and New Mexico and then moving westward to the coast (Figure 1). These 11 states experience the majority of fires occurring in the United States. All data layers provided by RECOVER are confined to the western 11 states, and the analysis discussed here is limited to that same extent. RECOVER uses a standardized geospatial reference system throughout its database; Albers Equal-Area Conic uses unequally spaced parallels and equally spaced meridians to prevent distortion in scale and shape along two parallels (Snyder, 1982). The Albers projection is used commonly throughout government agencies in the United States, and is an ideal projection for the spatial extent of RECOVER. The historic fires geodatabase is maintained by the NASA RECOVER team, and is updated annually to accommodate the most recent fire year. Most recently, the 2017 fire perimeters were acquired from the Geospatial Multi-Agency Coordination (GeoMAC). GeoMAC is a web-based map application that has archived shapefiles from 2000 to 2017. The web-map application was originally designed to accommodate fire managers regulating current fire locations. Web development is provided by the US Geological Survey (USGS), and the location data is provided to the web service via the National Interagency Fire Center (NIFC). Fire perimeters are updated daily through incident intelligence sources, GNSS data, and infrared imagery from aircraft and satellites. The shapefiles downloaded from GeoMAC contain information such as: perimeter mapping method, fire name, date started, fire year, multiple identifiers, as well as others. For RECOVER's purposes, the fields are edited to conform to the set standards of the Historic Fires Geodatabase. In addition to GeoMAC, Inciweb has previously been used to acquire some fire perimeters for RECOVER as well.

The primary focus of this research is to define wildfire trends over long time scales to better understand the historic and future implications of wildfire occurrence. The historic fires geodatabase contains information that was used to determine the patterns of wildfire occurrences from 1950 to 2017 in the western 11 states. The frequency and size of fires were the main variables that were investigated. The spatial scales of the inquiry varied from the 11 western states to by state breakdowns of the data. Using the year that individual fires occurred and the size of those fires, in acres, fire frequency and total acres burned were graphed to represent the change in fire frequency and size over time. Large scale analysis of all western 11 states and small scale analysis of individual states was performed to investigate these wildfire trends. The temporal range of each analysis varied, but the complete time range was used based on data availability. All graphs were created in Microsoft Excel, and a trend line was fitted to the data points. The trend line type was selected based on the highest R^2 value. An R^2 value quantitatively defines how well the trend line represents the displayed data. The distribution of wildfires across spatial and temporal scales provides fire management agencies with current and relevant information to make the best informed decisions.

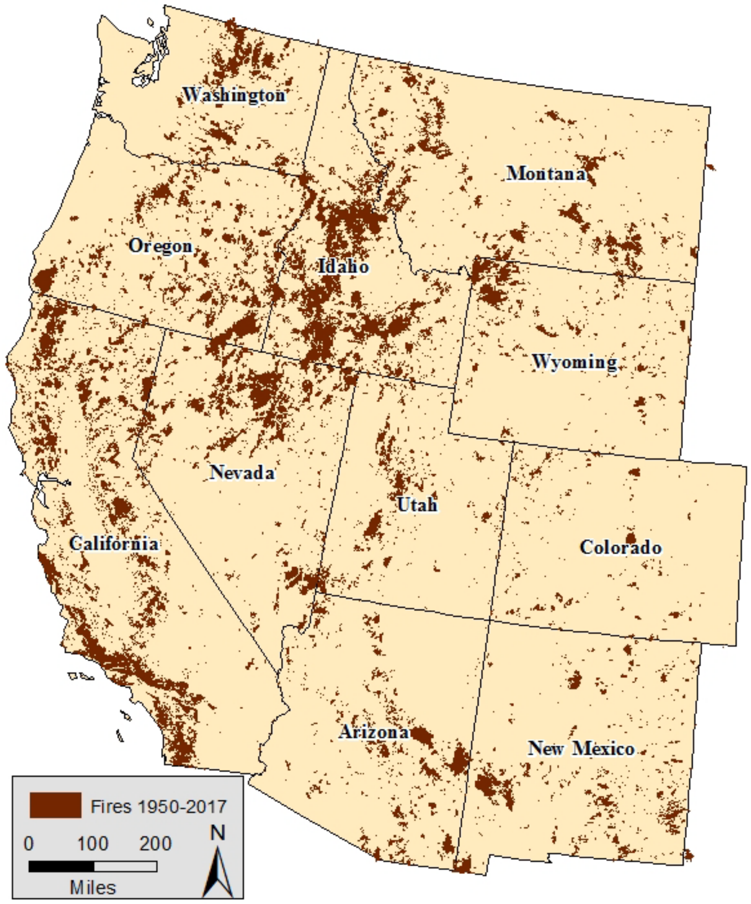

Figure 1. Spatial extent of NASA RECOVER in the Western United States overlaid by historic fire perimeters from 1950 to 2017.

Land management agencies are responsible for management of pre- and post- wildfire environments. The Surface Management Agency (SMA) polygon dataset depicts the boundaries where a particular management agency operates. The SMA data were acquired from government data sources developed and compiled by the US Department of Interior. Affected management agencies was determined by intersecting the polygons of the SMA features with the polygons from the historic fires geodatabase. The production of this information allows managing agencies, as well as researchers, to determine the best management practices in the specific areas each agencies is responsible for.

Results and Discussion

Figure 1 depicts the spatial distribution of wildfires from 1950 to 2017 across the study area. Fires over the past 67 years follow a semi-clumped distribution suggesting the occurrence of wildfires are not random. The tendency of a fire to occur is dependent on a host of complex and interacting factors like weather, previous-fires, climate, vegetation, topography, and human

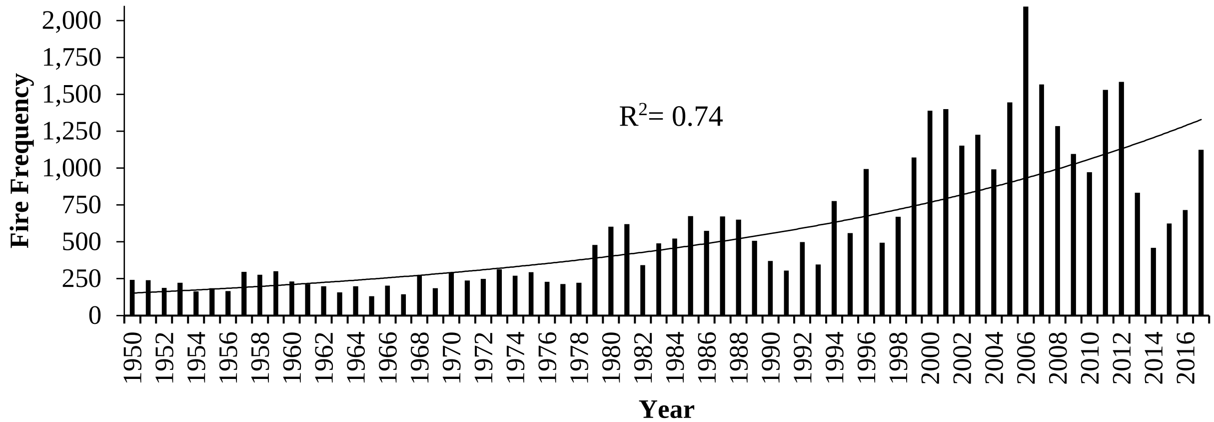

Figure 2. Fire frequency per year generated by counts of fire occurrence representing all documented fires occurring from 1950 to 2017 across 11 western states. Fire frequency best follows an exponential trend line with an R^2 value of 0.74.

activities (Marlon et al., 2012). These elements combine to form complex ecosystems that influence the dynamic tendencies of wildfires. The distribution of fire occurrence shows a general spatial tendencies of wildfire occurrence which is valuable to determine areas of interest for fire risk reduction and prevention.

To track the pattern of wildfires over the course of many years, geographic analysis was conducted based on attributes within the historic fires geodatabase. These data help visualize the occurrence of wildfires throughout time. Fire frequency is best fit through an exponential trend line with an R-squared of 0.74 (Figure 2). This suggests fire frequency is increasing throughout the Western United States at a rapid rate. The summed total of acres burned within the Western US also follows an exponential trend line with an R-squared of 0.68(Figure 3). This indicates that not only are the number of fires rapidly increasing, but also the total area that those fires burn increases relatively proportional to the frequency. It is intuitive to assume that as the number of fires increases, that so to, does the area burned. Figure 2 and Figure 3 express similar patterns, suggesting this assumption is true. For 2017, the total acres burned (Figure 3) is one of the higher values relative to the other values on the graph. In Figure 2, the fire year of 2017 was

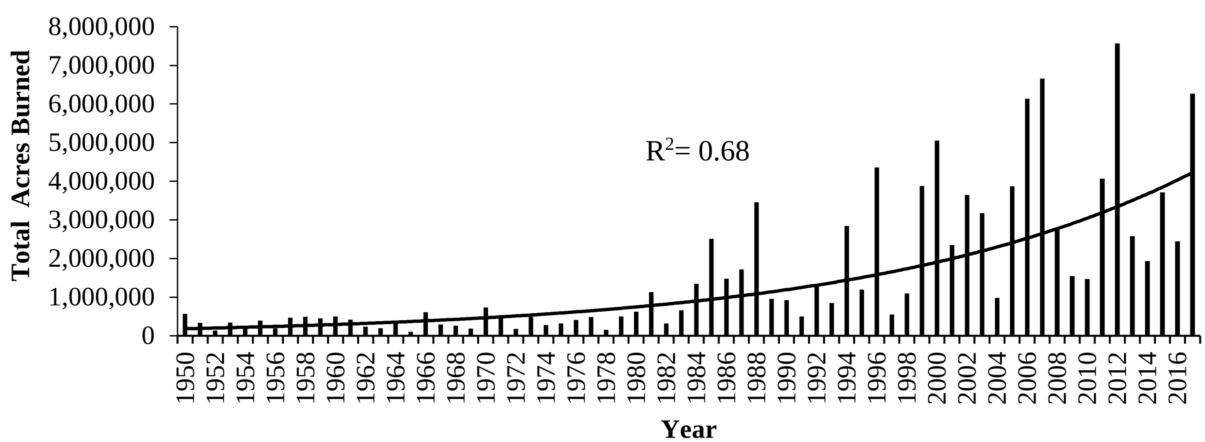

Figure 3. Total acres burned for a fire year summed for all 11 western states from 1950 to 2017. This follows an exponential trend with an R-squared value of 0.68.

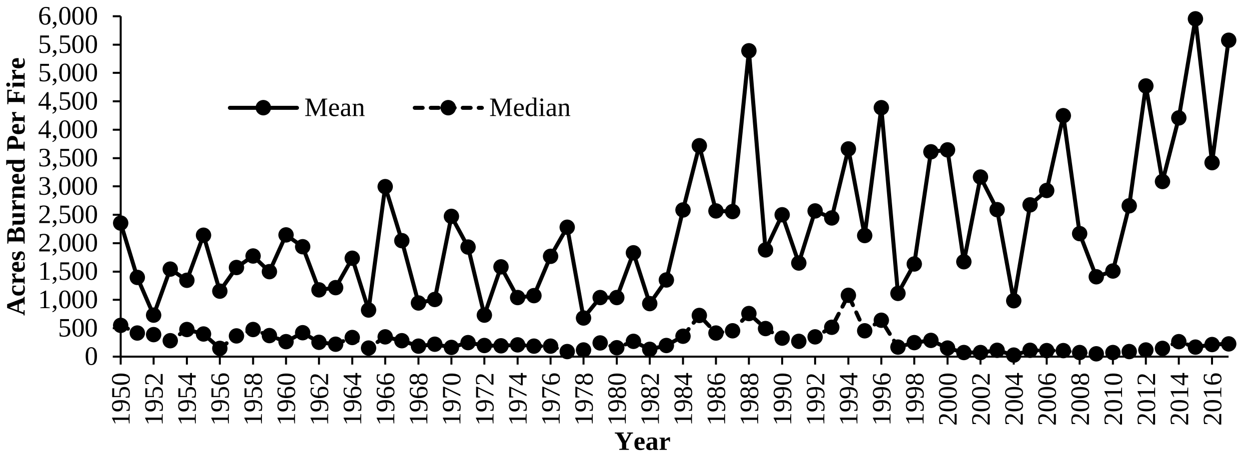

Figure 4. Average and median acres burned in the western United States from 1950 to 2017. Demonstrates the resilience of the median as a statistic, and the susceptibility of the mean.

relatively average for the fire frequency over the past 2 decades. This suggests that 2017 wildfires tended to be large relative to other years.

Figure 4 suggests the average number of acres burned per year is highly influenced by a few large-area fires. This is evidenced by comparing mean (average) with median. Furthermore, this is likely because of the statistical susceptibility of the mean as a non-resilient value. The mean statistic can be influenced largely by outliers residing above or below the majority population. Figure 4 represents the mean and median number of acres burned historically. As shown, the median proves to be a more resilient statistic to the low frequency, high magnitude events or mega-fires (greater than 100,000 acres). Overall the median size of fires in the Western US, has remained relatively constant through the historical record. Still the occurrence of mega-fires increasing in the more recent years does provide some cause for concern.

By conducting state by state analyses, the trends in fire occurrence and size were assessed. Most of the 11 states exhibited similar increasing exponential trends, but California's

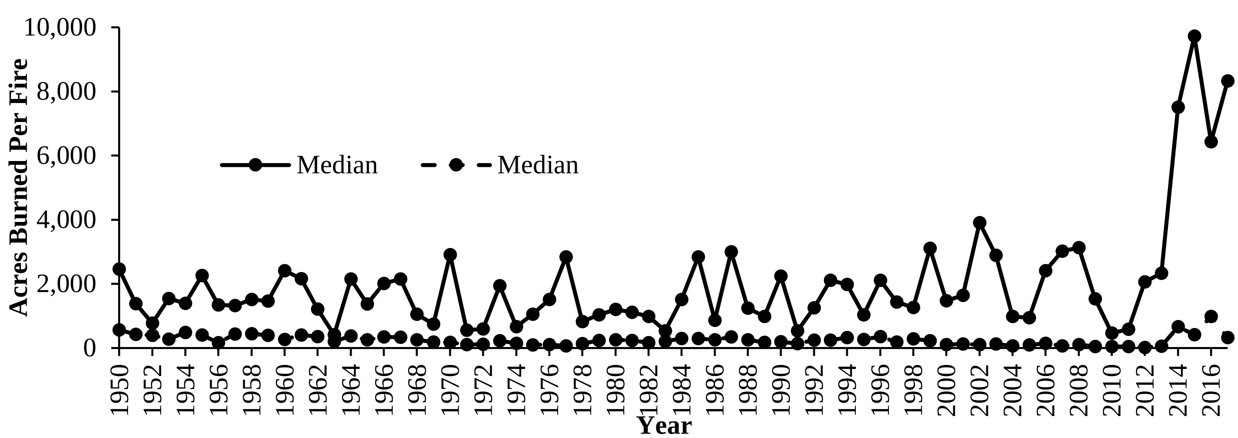

Figure 5. Average and median acres burned from 1950 to 2017 in California. The increase in the average fire size in the past 4 years reveals the increase in "mega-fire" occurrences. Proves the vulnerability of the mean and the resilience of the median as a statistic.

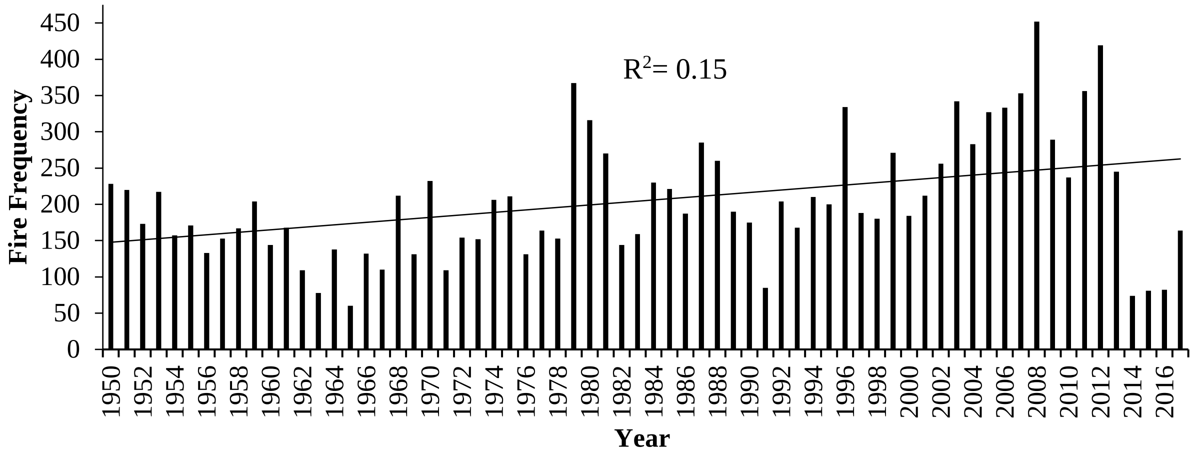

Figure 6. Number of fires occurring in California from 1950-2017 for each year. The best fit trend line is linear with an R^2 value of 0.15.

line of best fit for fire frequency and total acres burned were linear. Fire frequency, in Idaho, also exhibited a linear trend, while total acres burned followed an exponential trend. The linear fit suggests fires have been occurring relatively consistently since 1950.

The average fire size in the state of California between 2014 and 2017 substantially exceeded the average for the remaining Western states during the same years (Figure 5). The average fire size, in California for the past four years, has been greater than 6,400 acres. In all other states across the Western US, the average fire size never exceeded 6,000 acres in 2014-2017. The wildfire frequency for California (Figure 6) between 2014 and 2017 was substantially lower than the trend line would suggest. The average fire frequency for 2014- 2017 was 100.25. This shows California has been plagued by "mega-fires" over the last four wildfire seasons. Figure 7 shows these "mega-fire" years are not an infrequent occurrence in California as one can see multiple years where the total area burned lies well above the trend line.

The line of best fit for annual acres burned in Idaho, another state affected by numerous wildfires, was exponential with a R^2 correlation coefficient of 0.39 (Figure 8). In 2007, wildfires occurring in Idaho accounted for 37.5 percent of the total area burned in the Western United

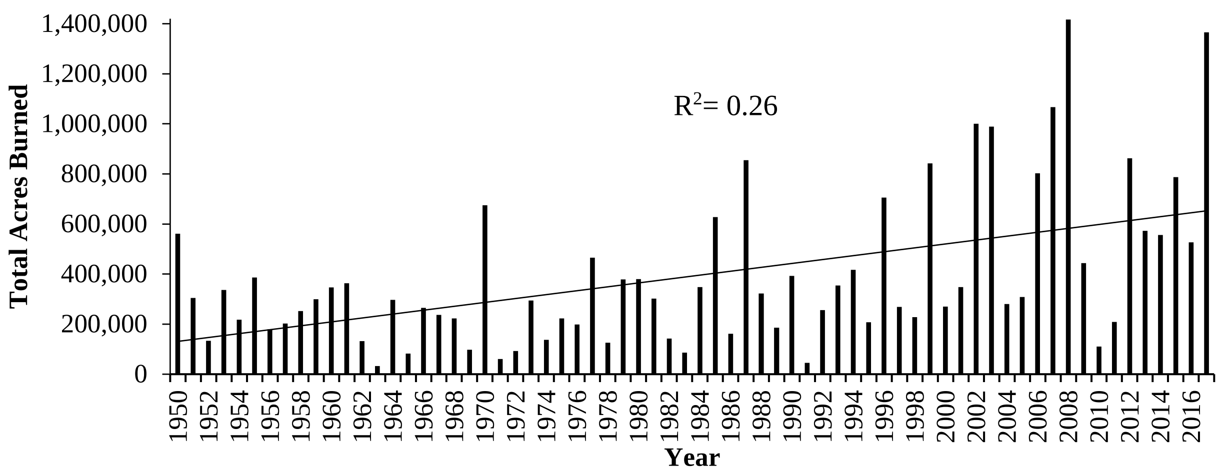

Figure 7. Total acres burned summed for each year from 1950-2017 in California. The line of best fit is linear with an R^2 value of 0.25.

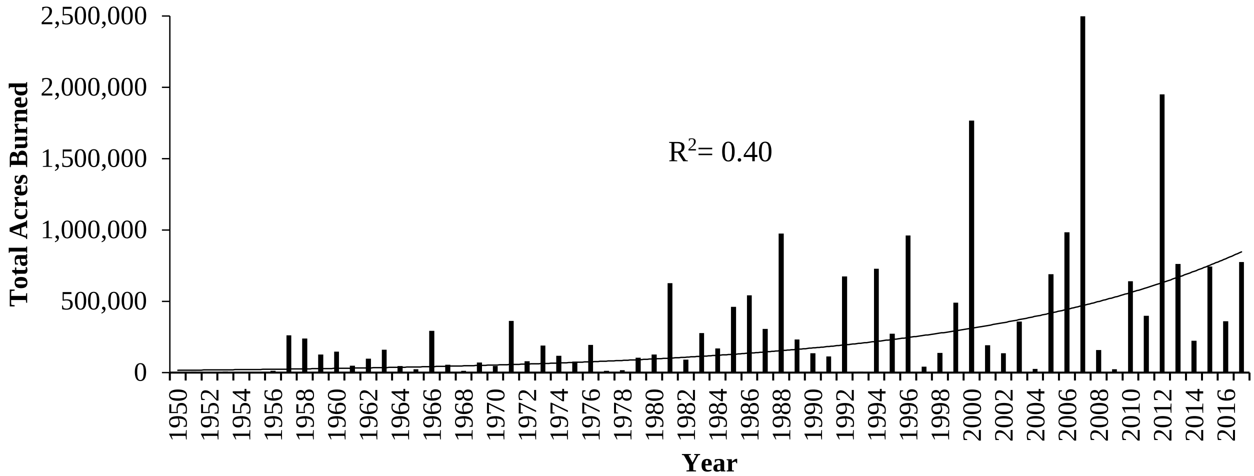

Figure 8. Total acres burned per year for wildfire occurring in Idaho from 1950-2017. The best fit trend line is exponential with an R^2 value of 0.3966.

States. The frequency of wildfires taking place in Idaho follows a linear trend line (R^2 = 0.48), which like that seen in California, suggests fires have been consistently increasing since 1950 (Figure 9). California, in general, encounters more wildfire incidences than Idaho. Intuitively, California should have more fires and more area burned because of the state's larger size.

Land management agencies are the primary responders to wildfires occurring on federal, state, and private land. The management agencies are tasked with handling and restoring landscapes in pre- and post-fire environments. To determine the primary "victim" of wildfires, the SMA and historic fires datasets were intersected to calculate fire frequency (and proportion) and acres burned by agency. Table 1 depicts the percentage of area burned for an agency out of the total amount of acres burned for that given year. Also, the total acres that are managed by an agency are included to establish the extent of each management division. The BLM manages the largest area of land in the Western United States, but the USFS has consistently encountered the largest percentage of areas burned. The analysis of the SMA with regards to historic fire perimeters allows insight to the agency most affected by wildfires. Agencies that are included in

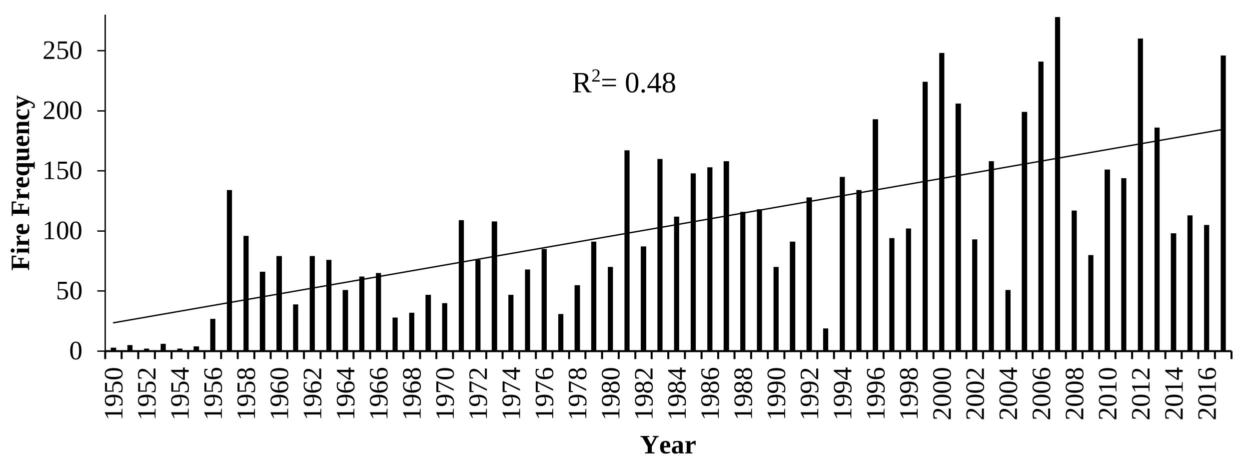

Figure 9. Number of fires occurring in Idaho from 1950-2017 for each individual year. The best fit trend line for fire frequency in Idaho is linear with an R^2 value of 0.4808.

“other” are: BIA, NPS, DOD, FWS, AF, BOR, Army, DOE, LG, MC, Navy, USDA, COE, GSA, BPA, FAA, CG, VA, DOI, FHA, other federal agencies, and undetermined ownership.

Table 1. Table 1. Surface Management agency affected by wildfires for a given fire year. Shown as a percentage of area burned on agencies land to the total area burned in that year. Also included is the total area that an agency manages in acres.

	Percent area burned by agency by year				**Total Acres managed**
	1997	**2007**	**2016**	**2017**	
BLM	21.3%	28.9%	17.9%	25.4%	172,492,350
USFS	25.2%	42.8%	39.8%	40.7%	140,964,839
State	4.2%	3.4%	3.6%	2.9%	46,718,772
Private	13.9%	13.2%	17.8%	15.1%	251,856,208
Other	35.5%	11.6%	20.9%	16.0%	146,778,936

Assessment of error and bias

All data used in the NASA RECOVER DSS were acquired from authoritative sources, and is considered the best available information. For the Historic fires geodatabase, the Geospatial Multi-Agency Coordination (GeoMAC) archives and maintains fire perimeters since 2000. These data provided by GeoMAC follow standard protocols to ensure consistency and accuracy (Walters et al., 2011). The Historic Fires geodatabase is believed to be the most exhaustive assemblage of fire perimeters for the Western United States. However, technological deficiencies, lack of fire reports, and inaccuracies of data acquisition can cause introductions of data discrepancies into the Historic Fires geodatabase. Confidence in data completeness increases as one approaches the present and while the data from 1980 to 2017 are considered comprehensive, it is difficult to absolutely confirm this. In the state specific analysis, fires sometimes burned across state boundaries and were included in both state-specific analysis. This means the area of some fires were duplicated across some of the state-by-state analyses. However, given the rarity of this circumstance, the duplication of a perimeter is not considered significant when included in the entirety of the state’s analysis. Finally, in the affected SMA calculations, the most current SMA data (2017) was used to analyze affected agencies for all other years (1997, 2007, 2016, and 2017). Land ownership and management has changed since 1997, and the 2017 SMA data does not accurately represent land holdings in other years. Once again these changes are relatively small and the overall trends observed likely have not changed.

Conclusions

Wildfires have been predicted by many sources, to increase each year. The analysis of the Historic Fires geodatabase demonstrates that wildfires are in fact increasing in both size and frequency across the Western United States. Furthermore, this study shows that wildfire occurrence and size have been increasing exponentially for the past 67 years. The mean and median fire size show that the occurrence of “mega fires” is also increasing. Examination of an individual state’s fire trends reveals a dynamic fire scene across the Western US. The complexity suggest there is no single best method for the management of wildfires. Rather, unique areas require diverse policies and management to effectively and efficiently manage wildfires. Due to the rapid increase in wildfires, land management agencies, such as the USFS and BLM, need reliable and consistent data. The NASA RECOVER DSS is focused on providing actionable information that supports well informed decisions. In addition, the RECOVER project focuses on delivering relevant information that improves efficiency and promotes best management practices.

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