What is a megafire? Defining the social and physical dimensions of extreme U.S. wildfires (1988-2014)

by

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What is a megafire? Defining the social and physical dimensions of extreme U.S. wildfires (1988-2014)

Thesis directed by Associate Professor Jennifer K. Balch

Wildfires have burned about 2 million hectares annually in the United States since 1988 with the influences of anthropogenic climate change, long-term suppression policies, and annual burned area predicted to increase. Since the early 2000s, changes in wildfire characteristics, including large, destructive fires occurring in places that had not experienced such fires in the past, has led to the use of the term "megafire" among researchers, fire managers, and the public. While the term is familiar to nearly everyone, there is no single, consistent, quantitative definition of a megafire. To investigate the megafire phenomenon, we analyzed researchers described megafires by keeping track of specific terms used throughout academic literature. We also noted all wildfires cited as megafires at least twice by different sources in both academia and the media; creating a dataset of commonly cited megafires. Using these commonly cited megafires, we propose that megafire classification does not fit under a single overarching definition, but instead three definitions need to be investigated.

ACKNOWLEDGEMENTS

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CHAPTER I

1. INTRODUCTION

Extreme disturbances—from severe storms to droughts—have increased in the past several decades (Emanuel 2005; Nghiem et al. 2012; Meehl et al. 2000; Easterling et al. 2000). Megafires are yet another disaster to add to that list. In the mid-2000s the term surfaced in the scientific community and public discourse, leading researchers and others to conclude that we had moved into an "Age of Megafires" (Attiwill and Binkley 2013; Pyne 2015; Tedim et al. 2018).

Since the mid-1980s, incidence of large wildfires, especially in forests of the Western United States, have increased (Schoennagel et al. 2017; Balch et al. 2017; Littell et al. 2009). At the same time, the total area burned has increased more than six and a half times than the previously observed values in the western U.S. (A L Westerling et al. 2006). Many researchers believe that human factors such as fire suppression policies (Glassman et al. 2015; Pyne 2015; Kodas 2017; Walsh 2013; Williams 2013), and the expansion of the Wildland-Urban Interface (WUI) (Lannom et al. 2014; Kodas 2017; Gill and Stephens 2009) combined with anthropogenic climate change (Abella and Fornwalt 2015; Adams 2013; Kodas 2017) have driven these changes over the last 30-years.

Several exemplary events reflect these changes. During the summer of 1988, multiple fires burning in Yellowstone National Park, captured public attention and concern, burning nearly 289,000 hectares over 158 days and killing 4 people (Binkley 2012; Lannom et al. 2014; Pyne 2007; Williams and Hamilton 2005).

Although similar wildfires burned in the 18th century, these contemporary fires precipitated conversations in both scientific and public spheres about the trends and unique roles or large fires in the U.S. (Williams and Hamilton 2005).

With the backdrop of ongoing conversations on wildfires, these events expanded into states not previously known for exceptionally large wildfires (Abella and Fornwalt 2015; Larkin et al. 2015; Malmsheimer et al. 2008). One such fire was the 2002 Hayman fire, which ignited on June 8th west of Colorado Springs, Colorado. Though this fire was not exceptionally large, it was a historically significant wildfire for Colorado; burning for 25 days and consuming 55,749 ha before firefighters had it contained (Abella and Fornwalt 2015; Pyne 2015). This fire quickly became the largest, fastest-moving fire and most destructive in the state's history (NIFC).

As the impact of fires grew beyond wildlands and areas sensitized to wildfire, the scientific community began holding workshops and conferences to study and characterize this new phenomenon (Pyne 2015; Williams and Hamilton 2005; Williams and Albright 2011; Williams 2013). One such working group led by Jerry Williams, coined the term *megafire* and conceptually described the key identifiable social and physical characteristics of megafire events (Williams and Hamilton 2005; Williams and Albright 2011; Williams 2013).

Williams' group observed that megafires are most notable for their physical characteristics, including size, duration, complex fire behavior, severity and resistance to control, as well as their social characteristics, including suppression cost, damages and fatalities (Williams and Hamilton 2005).

While most researchers have relied on the foundation Williams' group built, most acknowledge that the term megafire lacks a robust, quantitative definition (Ascherfeld 2011; Lannom et al. 2014; Tedim et al. 2018; Rein 2013; Rui Zhang 2015).

Though many researchers agree that social influence and impact are a critical consideration when analyzing the megafire phenomenon (Ager et al. 2014; Craig et al. 2015; Gill and Stephens 2009; Maditinos and Vassiliadis 2011; San-Miguel-Ayanz, Moreno, and Camia 2013), most researchers tend to focus on physical characteristics of megafires that do not have standard thresholds (Neary 2009; Bainbridge and Galloway 2010; Dimitrakopoulos et al. 2011; Rui Zhang 2015; Abella and Fornwalt 2015; Tedim et al. 2018). This has led researchers to create their own thresholds for physical characteristics. For example, some researchers rely heavily on the size of a fire and use varying thresholds from 4,047 ha in size (Craig et al. 2015) to 10,000 ha in size (Stephens et al. 2014) to designate a wildfire as a megafire.

Despite substantial use of the term megafire and the increasing trend of large fires, there has been no quantitative assessment of the physical and social characteristics of these extreme wildfire events. Here we look at a set of wildfires that the research and fire management communities have characterized as "megafires" and explore the nature of these events and the relationship between their physical (i.e., size, speed, duration, and burn severity) and social (i.e., suppression costs, damages, structures threatened, and fatalities) characteristics. We expect that increasing duration, speed, and size would be related to increasing suppression costs, damages, and level of social disruption. We also expect that fire severity is closely related to either physical or social characteristics of megafires, or a combination of both. Finally, we suspect that megafire identification depends on the physical or social extremeness of the event, with some megafires showing extremes in both categories.

2. METHODS

2.1. Defining Megafire

From June 2016 to October 2016 we conducted a systematic literature search for academic and grey literature referencing the term megafire. We queried Google Scholar, EBSCO Host, and RefSeek search engines using the following variations: "megafire", "megafires", "mega-fire", "mega-fires", "mega fire", and "mega fires". This yielded 44 articles, 40 of which attempted to explain and/or define a megafire, however there was significant variability across these definitions. Given this variability, we made a second pass through the literature to identify the key characteristics/variables identified as part of the megafire phenomenon. We then organized these variables into a hierarchical classification system. The variables fit broadly into two categories: social characteristics (Table 2) and physical characteristics (Table 3). The physical characteristics included three sub-categories: fire behavior, scale, and environment which could each also be broken down into finer detail (Table 3). The social characteristics included the socio-economic impacts of megafires and the societal factors that put more people at risk. Contributing socioeconomic factors included politics and the WUI (Table 2). The societal impacts included social disruption, casualties, politics, public health impacts, media, response complexity, damages and suppression costs (Table 2). Finally, we quantified how often researchers used these variables to characterize megafires (Table 4). Based on our definition analysis we chose four physical and four social variables that were both used often and easy to quantify; size, duration, speed, severity, social disruption, fatalities, damages and suppression costs.

2.2. Cited Megafires

During our second pass through the literature, we noted any fires explicitly cited as megafires. To call a cited fire a megafire in our study, we decided that at least two different sources needed to identify it as a megafire at least twice in different articles. We expanded our search to include grey literature, including the National Interagency Fire Center's (NIFC) lists of historic and large fires (Fire Center 1999) and media articles to ensure we captured as many commonly cited megafires as possible. Out of the original 44 scientific journal articles, 26 articles identified specific fires as megafires. We found 68 media articles that focused on megafires; 48 of which cited specific megafires. Finally, the NIFC historic fires list contained 41 fires after 1987, and the NIFC large fires list contained 120 fires after 1987. We listed all the individual fires from our four lists (scientific journal articles, media articles, NIFC large fires list, and NIFC historic fires list) and totaled the number of megafire citations for each wildfire event, using the NIFC historical and large fires lists as single citations (Table 5), and created a supplemental reference list (Appendix B).

After compiling our list of megafires, we gathered data on the physical characteristics and social factors of each megafire from multiple sources. First, we used Karen Short's Fire Occurrence Database (FOD) and searched for the "Fire Name", "ICS_Name", "MTBS_Fire_Name", and "Complex_Name" fields to find all possible names used for each fire and to find the Monitoring Trends in Burn Severity (MTBS) ID and the Incident Command System (ICS) Incident Number(s) so we could link each megafire to other databases that used these identification numbers. We excluded all international wildfires because the MTBS and ICS datasets only contained information on U.S. wildfires. We also excluded the 1991 Oakland Hills Fire because we were unable to find the corresponding information in our datasets.

After we had the MTBS names and IDs, we used the MTBS fire perimeters to find the megafires that occurred before 1992 and map all our 55 potential megafires (Figure 1) and plot them by year to understand their temporal distribution (Figure 2). These 55 commonly-cited megafires between 1988-2014 based on our analysis will now be what we refer to hereafter as megafires.

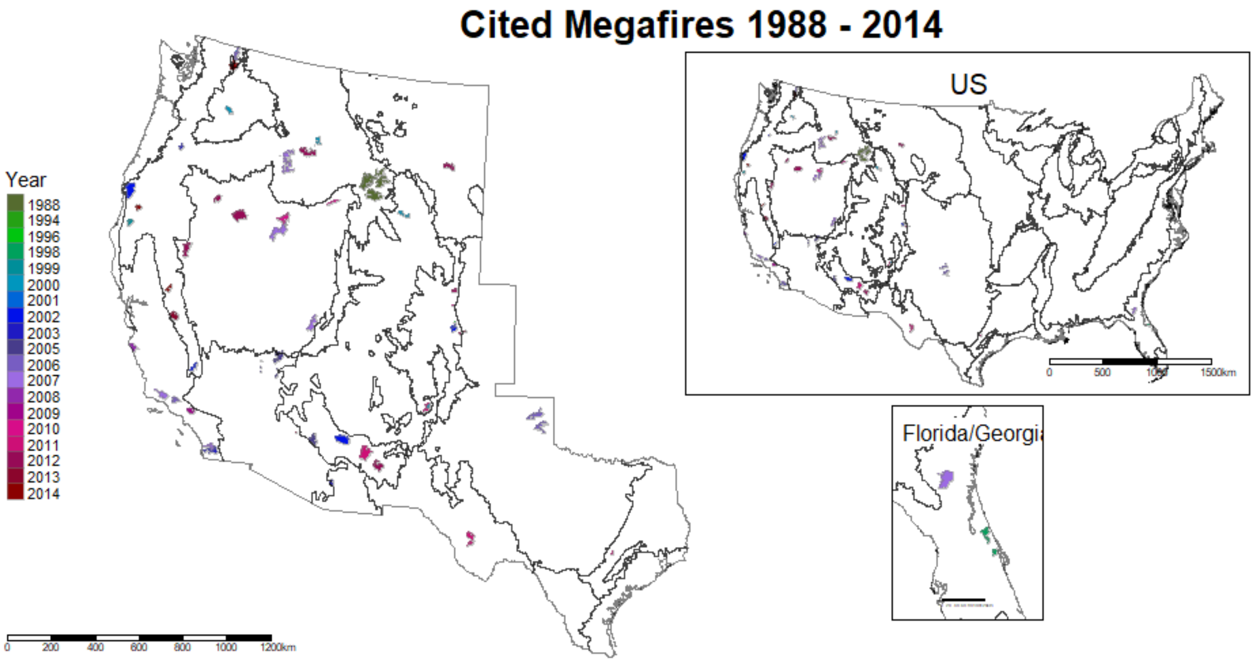

Figure 1: Spatial distribution of 55 commonly cited megafires in the United States. Boundaries with in the United States are the level II ecoregions. Fire perimeters colored by megafire year.

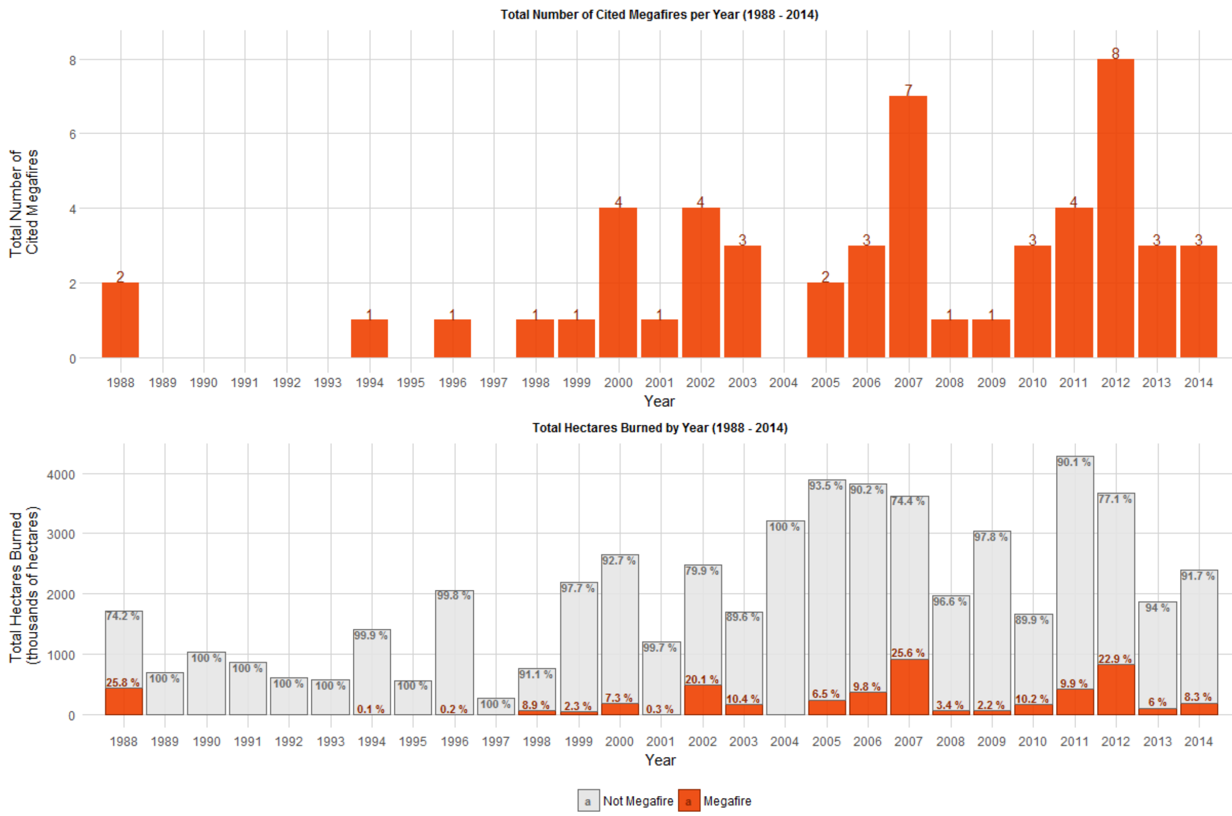

Figure 2: Temporal distributions of commonly cited megafires in the United States from 1988-2014. (a) Number of cited commonly-cited megafires for each year. (b) Total hectares burned by all wildfires and percent of total hectares burned by commonly-cited megafires and non-megafires by year.

We then used the new ICS 209 Research Dataset (St. Denis et al. 2019) to obtain data for our four physical and four social characteristics of our megafires from 1999 to 2015 and manually compiled the ICS data from the National Interagency Coordination Center (NICC) Incident Management Situation Reports (IMSR) online historical record (Center 2019). These ICS 209 daily situation reports date back to 1990 and allow us to supplement information that predates the ICS 209 research dataset (Table 1).

For our physical variables, we collected fire size (in hectares burned, taken from the ICS 209 final report or IMSR where needed), fire duration (days from fire start day to containment day from ICS 209 or IMSR where needed), fire speed (hectares burned per day calculated using final fire size divided by fire duration) and severity (percent dominant burn severity extracted from the MTBS burn severity mosaics).

Our social variables include number of fatalities (final number of fatalities on the final 209 or IMSR where needed), estimated suppression cost (estimated final suppression cost from the final 209 or IMSR where needed), structural damages (total number of residential, commercial and outbuildings reported damaged or destroyed on the final 209 or IMSR where needed), and social disruption (maximum number of residential, commercial, and outbuildings reported threatened on the ICS 209 reports or ISMR where needed).

2.3. Statistical Analysis of Cited Megafires

After assessing the spatial and temporal distribution of our megafires, we removed 12 cited megafires due to incomplete data. We removed all fires (N=11) from 1988-2001 due to missing social disruption data and the 2006 East Amarillo Complex because there was no reported final suppression cost.

We plotted histograms for all physical and social variables for the commonly cited megafires to visualize the distribution of our data on physical and social characteristics across the N=43 remaining megafires (Figure 3). To determine if our physical and social variables were correlated, we used Pearson's correlation (Figure 4). We then did a principal component analysis (PCA) and created a scree plot to determine the minimum number of principal components (PC) that explained the most variability within our data (Figure 5). Finally, we decided to complete a redundancy analysis (RDA). We chose RDA, as opposed to (PCA) because we wanted to determine the best explanatory variables for our megafires.

Based on the analysis of the eigen values, we determined that using our first three PCs would be best as the three PCs explained 70.4% of the variation in our data, where only 54.5% of the variation was explained by the first two PCs. In this paper we present the RDA biplot using the first two PCs for ease of interpretation (Figure 6).

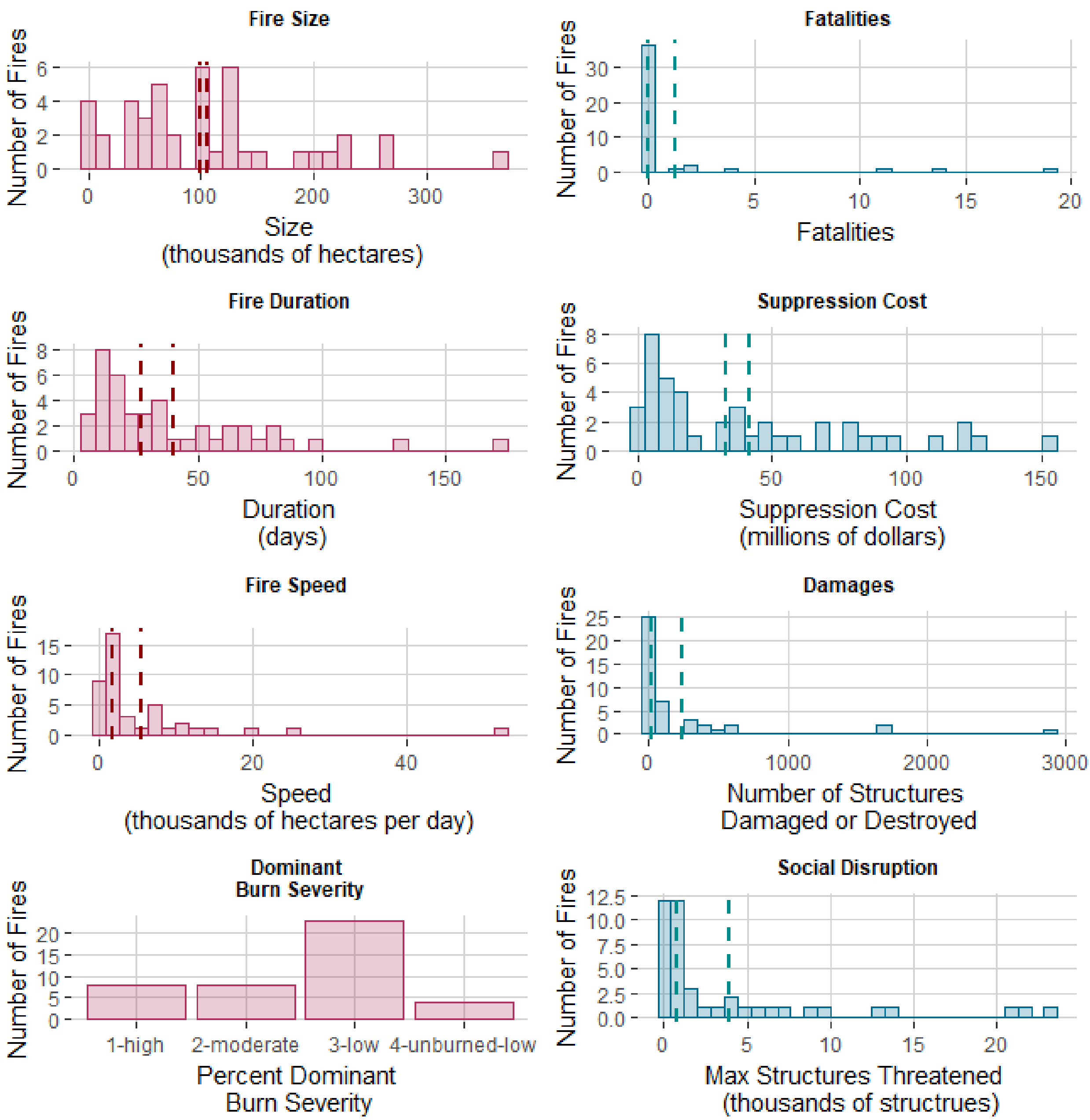

Figure 3: Histograms of physical and social characteristics for 4 megafires with all data. Histograms on the left side of the figure are physical characteristics and histograms on the right side of the figure are social characteristics. Dotted lines on each graph denote the mean and median values respectively.

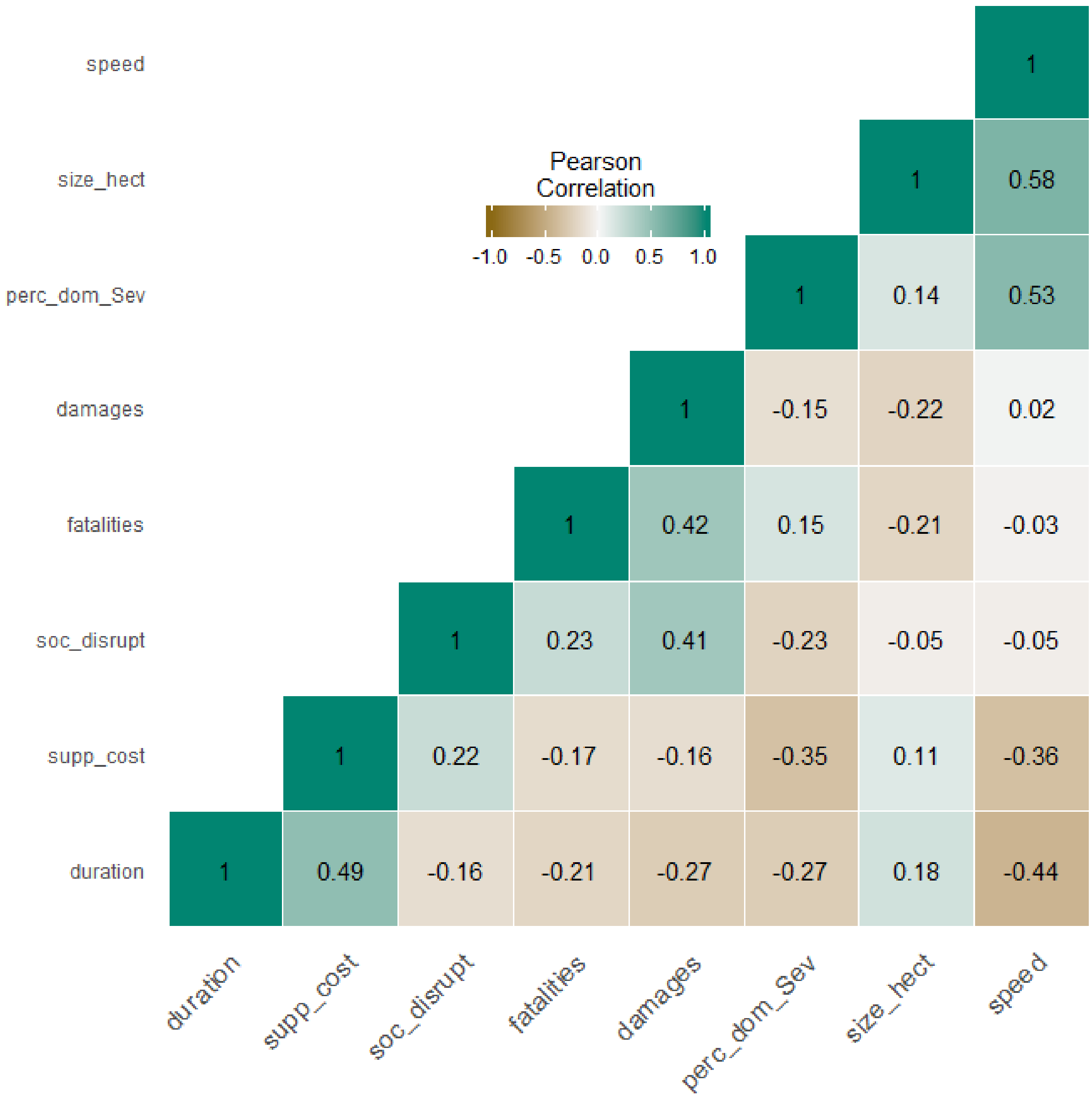

Figure 4: Correlation plot showing Pearson Correlation values for the physical and social characteristics of 43 megafires. Brown colored boxes have a negative correlation and green colored boxes have a positive correlation. Darker colored boxes have stronger correlation values (i.e., closer to 1 or -1) and lighter colored boxes have weaker correlation values (i.e., closer to 0.)

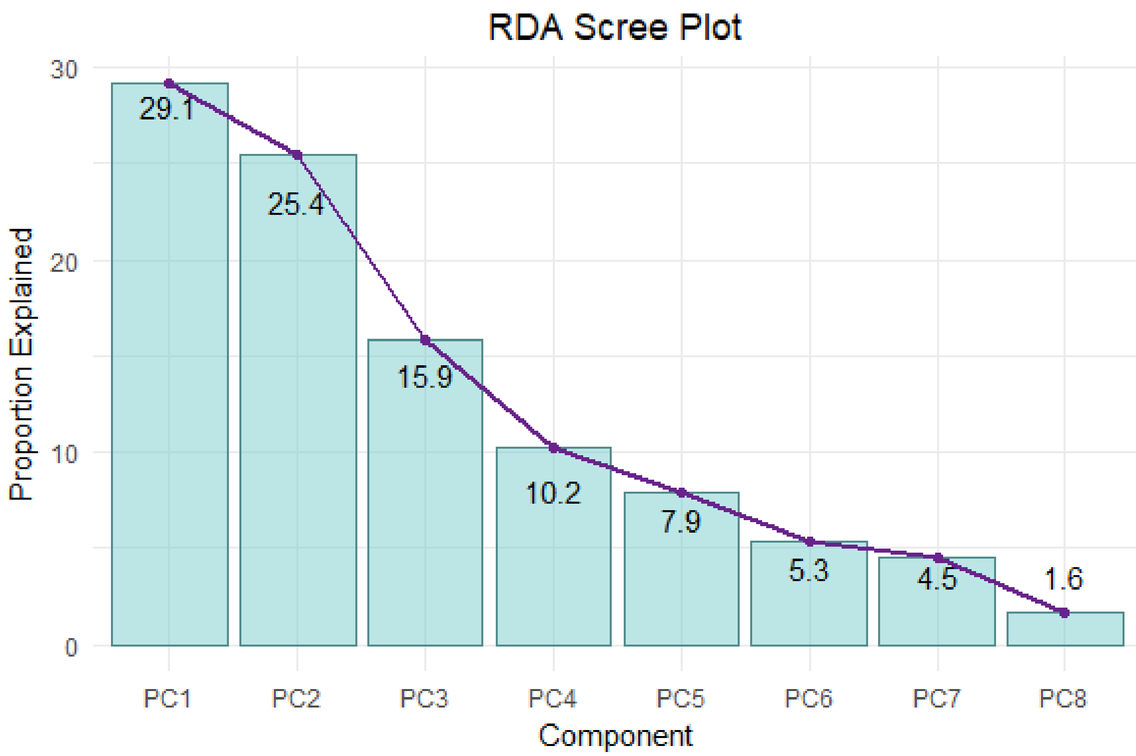

Figure 5: Scree plot of all 8 principal components. The purple line shows the trend in proportion explained by each principal component, and the numbers show the proportion explained by each principal component.

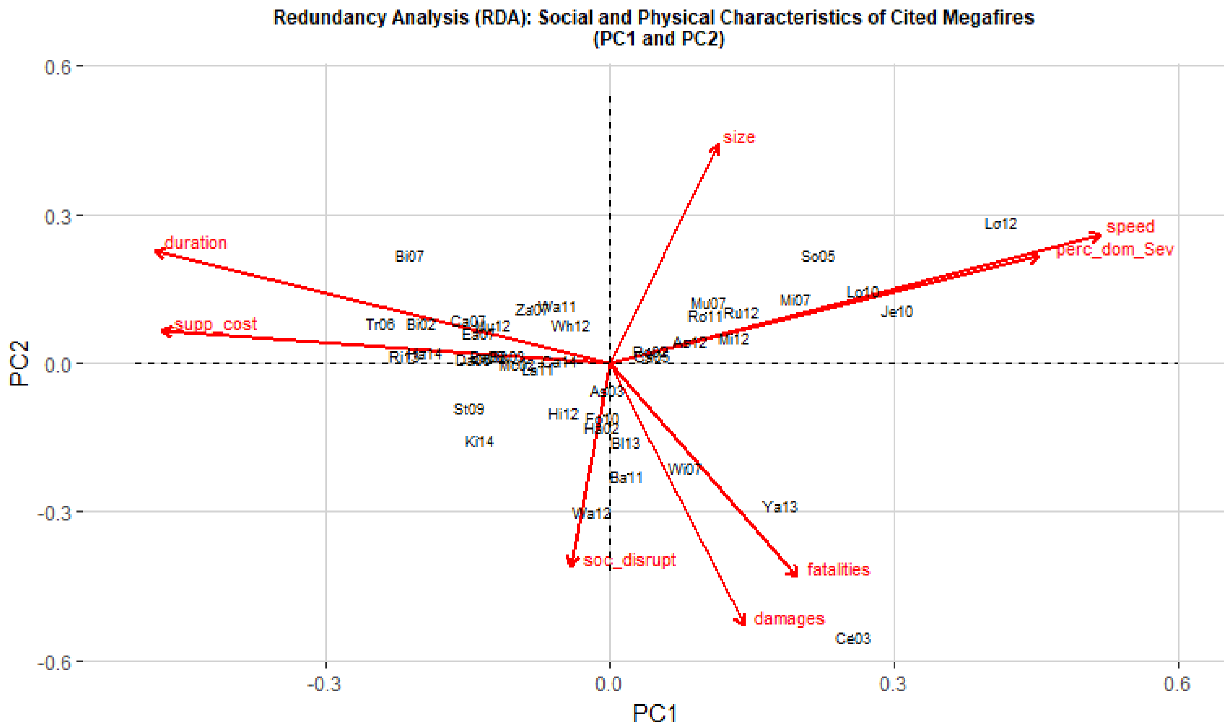

Figure 6: Biplot of the first two PCs from the redundancy analysis of the physical and social characteristics of the 43 megafires. Identifiers for each megafire consist of the first two letters of the megafire name and the last two digits of the year the megafire burned. The axes on the plot show the values for PC1 and PC2 for individual megafire. The red vectors are the physical and social characteristics (explanatory variables).

3. RESULTS

3.1. Megafire Definitions

When researchers define megafires, we found they broadly describe megafires in either physical and/or social terms. After drilling down to the lowest level of our hierarchical classification of these terms, we found that size was the most common descriptor with 80% of the articles acknowledging some measure of size in their definition (Table 4). The least used descriptor was fauna, with only 5% of the articles discussing how megafires affected the local fauna.

3.2. Spatial and Temporal Distributions

Megafires (1988-2014) appear evenly distributed across the western and southeastern US (Figure 1), with 1-12 events per state. Moreover, these fires occurred in 10 of the 21 level 2 ecoregions with Western Cordillera, Cold Deserts and Warm Deserts being the dominant ecoregions that sustained these megafires. Eight of these fires burned across multiple ecoregions. In total, these 55 events burned 4,874,088 ha, representing 9% of the total burned area across this same period in the coterminous U.S.

Starting in 2005, there seems to be some periodicity to megafire occurrence with peaks in 2007 and 2012 (Figure 2a). These peaks don’t match the large fire years (2005 and 2011), in terms of total burned area, but occur one to two years after large fire years. We found that only 6 of our 55 fires occurred before the year 2000. While we have seen an increase of fires cited as megafires, they remain a small percent of fires each year (Figure 2b). Since 2000, megafires have accounted for larger portions of hectares burned each year (Figure 2b).

3.3. Physical and Social Megafire Characteristics

All non-categorical physical (size, duration, and speed) and four social variables (suppression cost, damages, social disruption, and fatalities) of the 43 megafires with complete data had heavy right-tailed distributions, indicating that some of the megafires have truly exceptional characteristics.

Of the physical variables, mean megafire size was 118,711 ha (range 2,501-367,100 ha). The mean duration of burning was 40 days (range 3-169 days). The mean speed was 5,493 ha per day (range 276-52,400 ha per day). Further, megafires tend to burn at a low severity.

Of the social variables for the 43 megafires, mean suppression cost was 41.9 million dollars (range <1-153 million dollars). The mean damages were 245 structures (range 0-2883 structures). The mean social disruption was 3,896 structures threatened (range 25-23,260 structures threatened). Finally, while 34 of these fires did not have associated fatalities, seven did; with a range of 1 to 19 fatalities.

3.4. Correlation Between Physical and Social Characteristics

We investigated the relationships between the physical and social characteristics of the cited megafires. Overall, we noted that our social characteristics were more highly correlated with other social characteristics, and physical characteristics were more highly correlated with other physical characteristics (Figure 4). There was one exception however; we found that fire duration was highly correlated with suppression cost (correlation coefficient: 0.49).

3.5. Megafire Characteristics and Dominant Burn Severity

Since the physical and social characteristics were not highly correlated, we looked at how two social characteristics, total suppression cost and total damages, and two physical characteristics, total hectares burned and average fire duration, of the cited megafires were related to their dominant burn severity (Figure 7).

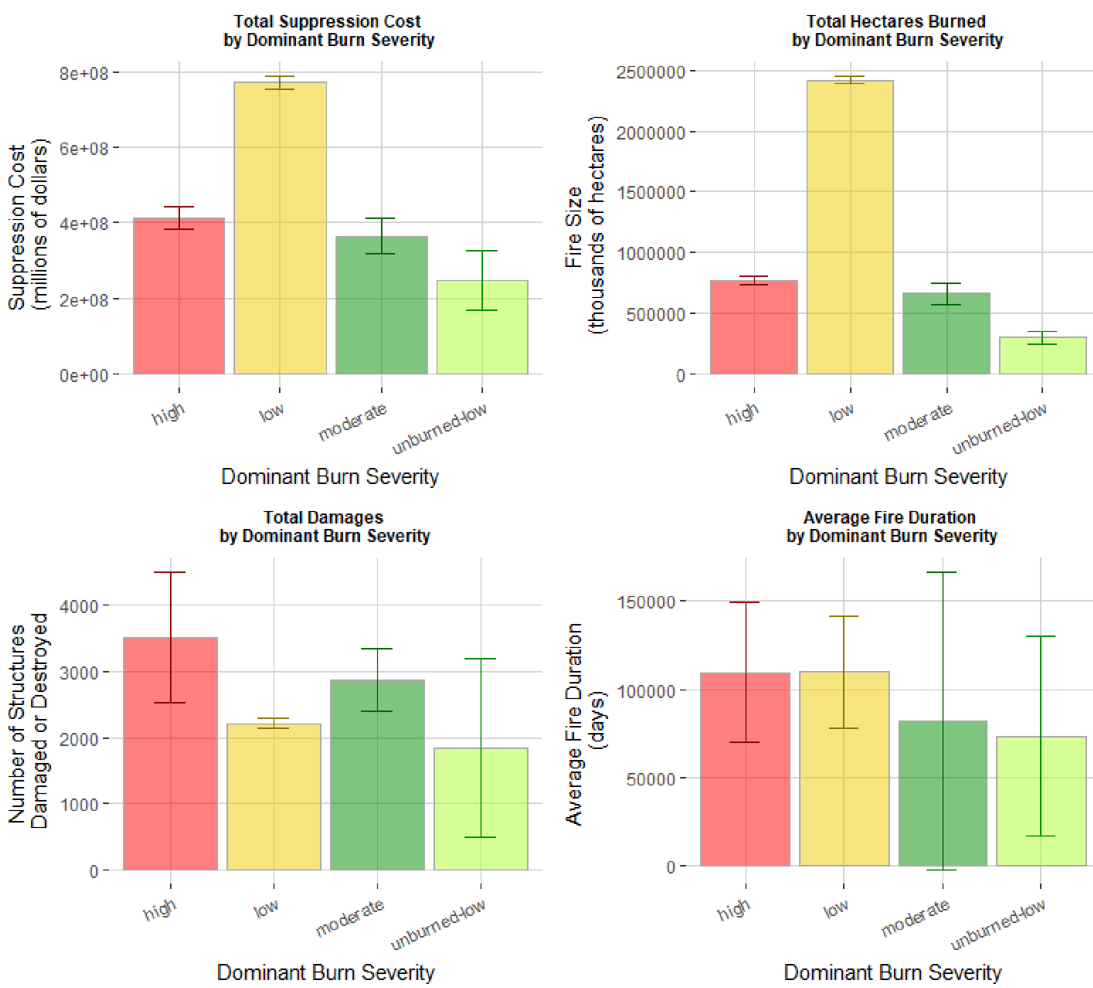

Figure 7: Suppression Costs, Damages, Fire Size and Fire Duration as functions of dominant burn severity.

We found that our cited megafires that burned at a low severity were costing more to suppress, were burning larger areas and lasting longer, whereas the cited megafires dominated by high severity burning were damaging or destroying more structures.

3.6. RDA Analysis

To being determining which physical and social characteristics were the best explanatory variables for our megafires, completed a PCA and plotted a scree plot (Figure 5), and completed an RDA. Based on this RDA we identified three major megafire clusters; those dominated by their social characteristics (disruption, damages and fatalities), those dominated by their physical characteristics (size, speed and percent dominant severity), and those dominated by their duration and suppression cost (Figure 6).

Megafires dominated by their social characteristics, located in quadrants III and IV of the biplot, are defined by having negative values for PC2 and values between -0.3 and 0.3 for PC1. Megafires dominated by their physical characteristics, located in quadrant I of the biplot, have positive values for PC1 and PC2. Megafires dominated by their duration and suppression cost, located in quadrant II of the biplot, have negative PC1 values and PC2 values that range from-0.04 to 0.93.

4. DISCUSSION

Megafires are events that are extreme both physically and socially. However, our research shows there are distinct clusters based on different social consequences and physical characteristics of commonly cited megafires between 1988 and 2014 across the conterminous U.S. We found that, unlike previous assertions (Williams and Hamilton 2005; Williams and Albright 2011; Williams 2013), there is not just a single definition of megafire; there are three. Of the 43 commonly cited megafires, we found 12 socially defined, 12 physically defined, and 19 defined by their duration or suppression cost. The biplot of the initial RDA shows that megafires are quite exceptional. Nearly all megafires have unique combinations of physical and social variables, apart from megafires dominated by suppression cost (Figure 6).

We found that social megafires burn at a higher severity and damage or destroy more structures (Figure 7); meaning these megafires are more likely to burn in or near the WUI and threaten people and infrastructure (Figure 7). These fires also burn for shorter periods of time, fire managers work quickly to extinguish these fires to protect life and property (Schoennagel et al. 2017). We also found that physical megafires cost more to suppress and burn at a lower severity. Based on those factors, these megafires are more likely to be fires located in the wildlands and do not pose a substantial risk to humans. Because of their size and complexity, these wildfires catch the public's attention and garner extensive media coverage. Finally, combined physical and social type megafires were generally long and expensive to suppress, but often had other extraordinary physical and/or social properties.

Fire management strategies can be at least part of why these three types of megafires exist. When fire managers are dealing with a wildfire they may conduct burnout operations; a method of intentionally igniting areas in the path of a fire to decrease flammable fuels or to unburned islands within the fire perimeter (Kolden et al. 2015). This method increases the size of a fire and, since these burnouts tend to burn at a lower severity, increase the proportion of the fire burned at low severity.

People are also contributing to our megafires, starting 38% of the events in this study. On a national scale people start 84% of our nation's wildfires (Balch et al. 2017). There is an expectation that more and more people will move into the WUI (Theobald and Romme 2007; Gude, Rasker, and Van Den Noort 2008; Schoennagel et al. 2017). Given that researchers expect larger fires in the future (Dennison et al. 2014; Anthony Leroy Westerling 2016; Schoennagel et al. 2017), the increased development in the WUI will put more homes in the line of fire—creating a scenario where we may designate more socially defined megafires in the future.

The recent fires in California (the 2017 Thomas fire in Southern CA and the 2017 wildfires in Santa Rosa, CA, the 2018 Woolsey fire in Southern CA and 2018 Camp fire in Northern CA) represent the nexus of people living in flammable landscapes, coupled with a changing climate (Abatzoglou and Williams 2016;

Schoennagel et al. 2017; Balch et al. 2017) as the historic wildfires in 2017 were eclipsed by the wildfires in 2018.

Our research shows that there is not a single definition for megafires. While our approach does not define megafires by quantitatively thresholding their characteristics as previous studies have done (Lannom et al. 2014), it provides a more detailed framework to investigate the multiple dimensions of the phenomenon. Instead of focusing on the previously relied upon qualitative definition (Williams and Hamilton 2005; Williams and Albright 2011; Williams 2013), further research should consider the three types of megafires described here.

4.1. Limitations

While the ICS-209 Research Dataset has a wealth of information, politics plays a role in the data collected by the ICS-209 system. Often, fire managers use these reports to get more support at the federal level, so fire managers may overestimate suppression costs to get the actual support an incident commander needs. This becomes especially true of fires that occur during the height of the fire season when fire management resources are likely spread thin.

Our data show an increase in the number of wildfires cited as megafires after 2000. This may mean that megafires were rarer before the turn of the century, which is consistent with the findings that after the mid-1980s both the size of wildfires and the occurrence of large wildfires increased (Moritz et al. 2012; Anthony Leroy Westerling 2016). However, another explanation is that, prior to the early 2000s when the term megafire first emerged, megafires did not exist in the social psyche. The lack of this term may have led to a disproportionate number of wildfires identified as megafires in the early 21st century. One valuable avenue of future research would focus on determining which is truly the case.

Our study does not include many other social and physical characteristics that could be important. Future research should work to quantify other physical and social variables identified in our analysis of megafire definitions (i.e. smoke impacts (public health), fire management policy changes after a megafire event, etc.). With the increased popularity and use of social media, future research that includes some measure of impact on the collective memory of a community affected by a megafire could produce interesting results. One way to accomplish this would be to collect Twitter records for different megafires and see if there is continued conversation surrounding an event long after it has ended.

Finally, this study also did not set out to understand the difference between megafires and non-megafires by their characteristics, it only serves as a first step to understanding the use of this term.

5. CONCLUSION

This method of describing megafires sets the foundation for future quantitative analysis of their characteristics and drivers. Creating this new definition can bring mutual understanding of megafires to the scientific community, fire managers and the public. Agreement on the term's definition would let (1) researchers to investigate the same set of current and historic megafires, (2) fire managers to react to real time events in a manner appropriate to the situation, and (3) de-sensationalize the term in the public sphere; allowing the public to react to an event in a more rational manner.

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APPENDIX A

Fire Name	State	Year	Times Cited	Cause	Dominant Severity	Size (ha)	Duration	Percent Dominant Severity	Fatalities	Suppression Cost	Damages	Social Disruption
Biscuit	OR	2002	11	L	moderate	202,173	55	30	0	152,658,738	13	7,469
Hayman	CO	2002	14	H	high	55,751	25	43	0	39,200,000	600	10,000
McNally	CA	2002	2	L	low	60,986	39	31	0	55,587,000	22	210
Rodeo-Chediski	AZ	2002	11	H	high	189,655	20	37	0	48,737,663	6	13,500
Aspen	AZ	2003	2	H	low	34,298	29	43	0	16,000,000	333	530
B&B Complex	OR	2003	2	Unkn	low	32,268	78	46	0	41,198,000	13	1,239
Cedar	CA	2003	7	H	high	110,581	11	51	14	32,616,213	2,883	21,500
Cave Creek Complex	AZ	2005	3	L	low	100,490	22	45	0	18,300,000	11	4,350
Southern Nevada Complex	NV	2005	2	L	low	265,987	14	38	0	6,137,860	0	70
Day	CA	2006	2	H	low	65,845	69	42	0	78,000,000	15	4,518
Tripod	WA	2006	3	L	high	70,896	130	39	0	82,875,390	0	845
Big Turnaround Complex	GA	2007	3	L	low	228,706	169	51	0	67,029,235	26	2,700
Cascade Complex	ID	2007	3	L	high	122,370	95	37	0	53,240,816	6	503
East Zone Complex	ID	2007	2	L	high	121,417	86	28	0	33,000,000	14	551
Milford Flat	UT	2007	6	L	low	146,925	14	66	0	5,050,000	2	330
Murphy Complex	ID	2007	6	L	moderate	263,867	33	50	0	13,000,000	3	9,000
Witch	CA	2007	3	H	unburned-low	80,125	11	30	0	18,000,000	1,735	6,800
Zaca	CA	2007	2	H	high	97,210	61	73	0	122,533,385	1	595
Basin Complex	CA	2008	2	L	moderate	98,825	50	31	0	78,096,079	67	2,815
Station	CA	2009	2	H	moderate	64,985	52	38	0	95,510,000	266	12,500
Fourmile Canyon	CO	2010	3	H	moderate	2,501	8	34	0	9,947,993	330	500
Jefferson	ID	2010	2	H	low	44,288	3	86	0	50,000	1	25
Long Butte	ID	2010	3	L	low	123,882	10	82	0	4,225,000	12	150
Bastrop County Complex	TX	2011	2	H	moderate	13,787	27	38	0	8,037,385	1,709	1,159
Las Conchas	NM	2011	10	H	low	63,372	37	33	0	48,385,000	114	565
Rockhouse	TX	2011	3	H	low	127,254	34	67	0	8,399,072	27	55
Wallow	AZ	2011	16	H	low	217,745	32	38	0	109,000,000	74	3,900
Ash Creek	MT	2012	2	L	low	100,996	15	43	0	7,500,000	39	95
High Park	CO	2012	3	L	low	35,323	22	29	1	38,400,000	371	1,975
Long Draw	OR	2012	2	L	low	225,669	9	83	0	4,360,000	0	290
Miller Homestead	OR	2012	2	L	low	65,096	17	72	0	6,000,000	3	39
Mustang Complex	ID	2012	2	L	low	138,198	81	30	0	38,323,413	7	730
Rush	CA	2012	2	L	low	127,712	19	65	0	15,170,000	1	39
Waldo Canyon	CO	2012	7	Unkn	moderate	7,668	18	31	2	1,668,632	372	23,260
Whitewater-Baldy	NM	2012	4	L	unburned-low	120,536	65	45	0	23,000,000	20	65
Black Forest	CO	2013	2	Unkn	low	5,779	10	36	2	9,829,056	551	1,850
Rim	CA	2013	10	Unkn	low	104,134	69	32	0	127,350,000	119	5,506
Yarnell Hill	AZ	2013	7	L	moderate	3,592	13	64	19	5,447,983	114	525
Carlton Complex	WA	2014	3	L	low	103,645	43	44	0	68,800,000	471	1,103
Happy Camp	CA	2014	2	L	unburned-low	54,252	77	32	0	88,214,725	8	743
King	CA	2014	3	H	unburned-low	39,546	27	43	0	119,000,000	81	21,000
Canyon Creek Complex	OR	2015	2	L	low	44,622	86	33	0	31,453,602	103	700
Soda	ID	2015	4	L	low	115,484	14	76	0	6,250,000	2	145

Table 1: This table shows the physical and social for the 43 megafires used in the statistical analysis. The table contains identifying information: (1) the common name for each megafire, the year and state the megafire burned, the number of times each event was cited as a megafire in the literature, and the cause of the fire (H – Human, L – Lightning, Unkn – Unknown) (2) the physical characteristics of each megafire which include Dominant Severity (burn severity which the event burned at), Size (in hectares), Duration (number of days the megafire burned), and Percent Dominant Severity, and (3) the social characteristics of each megafire which include Fatalities, Suppression Cost, Damages (total number of residential, commercial and out buildings damaged or destroyed by the megafire), and Social Disruption (maximum number of residential, commercial, and outbuildings reported threatened during the event).

Article	Year	Socioeconomic									
		Contributors		Consequences							
		Politics	WUI	Social Disruption	Casualties	Politics	Public Health	Media	Response Complexity	Damages	Suppression Cost
Abella	2015										
Adams	2013		1				1	1			
Ager	2014			1		1				1	1
Ascherfeld	2011	1							1		
Attiwill	2013	1			1			1		1	1
Bainbridge	2010										
Binkley	2012				1		1			1	1
Bladon	2014		1	1	1		1		1	1	1
Bowman	2007				1		1			1	1
Craig	2015						1			1	
Dimitrakopoulos	2011										
Florec	2012		1	1	1					1	1
Gill	2009		1	1	1	1		1	1	1	
Glassman	2015	1									
Lannom	2014		1	1	1					1	
Larkin	2015	1	1		1	1	1		1		
Liu	2010	1	1						1		
Maditinos	2011		1	1	1		1	1		1	
Malmsheimer	2008		1			1					
Medina	2012			1		1			1	1	1
Neary	2009										
Pyne	2009	1									
Pyne	2014	1									
Pyne (mega burning)	2007	1	1	1		1			1		
Pyne	2007	1									
Pyne	2015	1	1	1	1	1		1	1	1	
Rein	2013			1							1
Rui Zhang	2015										
Ryan	2013	1	1	1			1		1	1	1
San-Miguel-Ayanz	2013	1		1	1				1	1	1
Forest Service	2013	1		1			1			1	1
Eftychidis	2007					1		1	1	1	1
Stephens	2014	1	1	1	1		1			1	1
Stephenson	2009			1	1					1	
Tedim	2013				1				1	1	
Williams, B	2013										
Williams, J	2013			1		1			1	1	1
Williams, J	2011			1				1	1	1	1
Williams, J	2005		1	1		1		1	1	1	1
Zaccone	2014						1				

Table 2: Social descriptions of megafires from academic literature.

		Fire Behavior					Scale		Environment							
									Contributing			Affected				
Article	Year	Fire Behavior	Control Efforts	Intensity	Severity	Speed	Size	Duration	Weather	Climate	Fuels	Fauna	Landscape	Ecosystem G&S	Environment	Climate
Abella	2015				1		1				1					
Adams	2013			1			1			1			1	1		1
Ager	2014		1				1				1			1		
Ascherfeld	2011	1	1	1		1	1		1		1					
Attiwill	2013			1	1		1			1	1			1	1	
Bainbridge	2010	1	1				1	1								
Binkley	2012	1	1	1		1	1		1		1					1
Bladon	2014	1	1		1		1			1	1			1		
Bowman	2007		1										1			1
Craig	2015			1			1								1	
Dimitrakopoulos	2011	1	1				1		1		1					
Florec	2012		1				1							1		
Gill	2009															
Glassman	2015			1	1		1			1			1			
Lannom	2014				1		1	1	1				1			
Larkin	2015	1	1	1			1	1		1	1				1	
Liu	2010		1						1	1	1				1	1
Maditinos	2011	1	1	1		1	1	1	1	1	1		1	1	1	1
Malmsheimer	2008						1	1		1	1					1
Medina	2012	1	1	1	1	1				1		1	1		1	
Neary	2009	1	1		1		1						1			
Pyne	2009									1	1					
Pyne	2014									1						
Pyne (mb)	2007		1	1	1		1	1	1	1	1					
Pyne	2007		1				1			1	1					
Pyne	2015	1	1	1			1		1	1	1			1		
Rein	2013			1		1	1	1		1	1				1	
Rui Zhang	2015	1	1	1			1									
Ryan	2013						1			1	1			1		
San-Miguel-Ayanz	2013		1	1		1	1	1	1	1	1				1	
Forest Service	2013	1	1		1	1	1		1	1	1		1	1		
Eftychidis	2007	1	1	1			1	1	1	1	1					
Stephens	2014		1	1	1		1		1	1	1	1	1	1	1	1
Stephenson	2009														1	
Tedim	2013	1	1	1	1	1	1		1		1					
Williams, B	2013			1			1									
Williams, J	2013	1	1				1		1		1		1	1	1	1
Williams, J	2011	1	1				1		1	1	1				1	
Williams, J	2005	1	1	1	1		1	1	1	1	1					
Zaccone	2014														1	

Table 3: Physical descriptions of megafires from academic literature

Measure	Times Measure Used	Percent Measure Used
Size	32	80
Control Efforts	25	62.5
Fuels	25	62.5
Damages	22	55
Climate (Contrib)	22	55
Intensity	19	47.5
Social Disruption	18	45
Fire Behavior	17	42.5
Suppression Cost	16	40
Weather	16	40
Response Complexity	15	37.5
Politics (contrib)	14	35
WUI	14	35
Casualties	14	35
Environment	13	32.5
Severity	12	30
Public Health	11	27.5
Ecosystem G&S	11	27.5
Politics (Conseq)	10	25
Duration	10	25
Landscape	10	25
Media	8	20
Speed	8	20
Climate (Affected)	8	20
Fauna	2	5

Table 4: Analysis of fine-scale characteristic descriptions used in definition analysis. Green rows are socioeconomic measures with the lightest green rows highlighting contributing factors and darker green rows highlighting consequential factors, yellow rows are fire behavior measures, blue rows are scale measures and orange rows are environmental measures. The lightest orange rows are contributing factors and the darker orange rows are factors directly affected.

Fire Name	State	Year	Times Cited															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Wallow	AZ	2011	1	3	4	14	17	18	19	25	26	27	34	37	58	61	75	74
Hayman	CO	2002	1	8	14	15	18	20	25	23	41	52	62	61	75	74		
Yellowstone	WY	1988	5	13	16	18	20	23	28	33	38	53	59	74				
Black Saturday	Aust	2009	4	5	8	10	14	21	24	2	49	57	67					
Biscuit	OR	2002	14	15	18	19	20	25	23	35	59	71	75					
Rodeo-Chediski	AZ	2002	14	15	18	20	25	23	26	27	68	75	74					
Las Conchas	AZ	2011	14	18	25	39	37	46	58	62	61	75	74					
Rim	CA	2013	12	14	18	11	47	63	69	72	75	74						
Waldo Canyon	CO	2012	2	4	8	18	37	40	74									
Yarnell Hill	AZ	2013	18	44	49	67	72	73	74									
Cedar	CA	2003	14	15	24	36	45	75	74									
Milford Flat	UT	2007	1	9	14	15	19	75										
Murphy Complex	ID	2007	9	13	15	19	75	74										
Fort McMurray	Can	2016	42	48	51	65	70											
Oakland Hills	CA	1991	29	30	36	39	74											
Cerro Grande	NM	2000	1	18	23	61	74											
Great Black Dragon	China	1987	5	25	24	23												
Soda	ID	2015	55	59	64	75												
South Canyon	CO	1994	18	20	23	74												
Whitewater-Baldy	NM	2012	1	34	75	74												
High Park	CO	2012	8	18	40													
King	CA	2014	32	47	69													
Mount Carmel	Isrl	2010	25	24	49													
Carlton Complex	WA	2014	31	60	75													
Cascade Complex	ID	2007	13	25	75													
Fourmile Canyon	CO	2010	18	54	74													
Rockhouse	TX	2011	18	19	75													
Tripod	WA	2006	14	59	75													
Valley Complex (Bitterroot)	MT	2000	15	25	75													
Big Turnaround Complex	GA	2007	19	75	74													
Cave Creek Complex	AZ	2005	18	75	74													
East Amarillo Complex	TX	2006	15	75	74													
Long Butte	ID	2010	14	75	74													
Volusia-Flagler Complex	FL	1998	25	23	74													
Witch (Creek)	CA	2007	14	18	75													
North Fork	MT	1988	13	64														
Aspen	AZ	2003	18	23														
B&B Complex	OR	2003	18	23														
Black Forest	CO	2013	18	67														
Buffalo Creek	CO	1996	41	61														
Canyon Creek Complex	OR	2015	64	75														
Central Russia Complex	Rus	2010	25	24														
Ghanzi	Bots	2008	5	24														
Kalimantan Complex	Indo	1997/8	24	54														
Roraima	Briz	1999	7	24														
Thirtymile	WA	2001	18	74														
24 Command	WA	2000	15	75														
Ash Creek	MT	2012	14	75														
Basin Complex	CA	2008	14	75														
Bastrop	TX	2011	18	74														
Day	CA	2006	14	75														
East Zone Complex	ID	2007	13	75														
Happy Camp	CA	2014	50	75														
Kate's Basin	WY	2000	15	75														
McNally	CA	2002	23	75														
Miller Homestead	OR	2012	14	75														
Mustang Complex	ID	2012	14	75														
Rush	CA	2012	14	75														
Southern Nevada Complex	NV	2005	15	75														
Station	CA	2009	14	75														
Zaca (Two)	CA	2007	14	75														
Long Draw	OR	2012	75	74														
Big Bar Complex	CA	1999	75	75														
Jefferson	ID	2010	75	74														

Key	
(green)	Academic Article
(blue)	Media Article
(orange)	NIFC Large Fires
(purple)	NIFC Historic Fires
#	Citation Number

Table 5: Citations for each megafire. Green squares are academic citations, blue squares are media citations, orange squares are NIFC large fires citations, purple squares are NIFC historic fires citations. The numbers in each square denote the article each citation came from (Appendix B). Wildfires cited as a megafire only once not included in this chart.

APPENDIX B

1. Academic Articles

(1) Abella, Scott R., and Paula J. Fornwalt. 2015. "Ten Years of Vegetation Assembly after a North American Mega Fire." Global Change Biology 21 (2):789–802. https://doi.org/10.1111/gcb.12722.

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