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Creating a Comprehensive Western American/Canadian Fire Dataset, 1880-2018

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ADVISORY COMMITTEE

Dr. Michael Medler

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GRADUATE SCHOOL

Dr. David Patrick, Dean

Master’s Field Project

Abstract

The currently available fire-history data of Western North America (US/Canada) available for geographic and other analyses is largely piecemeal and difficult to find. Data from before the 1980s is scattered among many sources and held by a plethora of different agencies. The aim of this project was to change that daunting reality and provide a single dataset that would fill that data gap and make doing research on and mapping of fires in the late 19th and early 20th centuries more accessible.

This data encompasses 138 years (1880 - 2018), 12 US states, three Canadian provinces and two Canadian territories. Currently existing digital datasets were combined and streamlined into a single dataset with unified attributes and units. During this process, I found a total of 143,702 fires that totaled 1,793,542.62 sq. kilometers of burned area. The final data is available to the public via the web as a set of ESRI shapefiles.

Acknowledgements

I have a lot of people to thank for their part in helping me finish this project and program. I couldn’t have finished this master’s degree without the encouragement and support of the people around me, and I want to express how grateful I am to have a wonderful support network.

I want to extend my deepest gratitude to my family for their love and support through this process, and for cheering me on continually until the very end. I want to thank my parents for the tough love I needed when I hit low points and wanted to give up. I also want to thank my brothers, Jared and Quinn, and my sister-in-law, Landon, for their humor and encouragement along the way. I’d also love to thank my grandparents for their support and continued encouragement of my academic endeavors.

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Cheryl O'Brien, Rio Grande National Forest

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Mark Vaughn, National Parks Service

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Maps and Figures

Introduction

Fire is an integral part of the history of the North American West, but it is a part we don't understand comprehensively. Our understanding of the history of wildland fires is in bits and pieces, scattered among different datasets with varying spatial and temporal resolutions and coverage. Some studies based on paleoproxies like burn scar or soil charcoal studies offer a very long record but cover very small study areas. Others, like modern satellite-derived government datasets, cover large areas but are only available for a few decades (Burke, 1980; Barnett et al, 1997; Bigio, 2013; among others). Historical records based on field observations cover longer periods than satellite-based records but are often only available for a specific region managed by an individual agency.

Compiling historical records from multiple sources and harmonizing them to allow direct comparisons among different data sources is a time-consuming task that hampers research into historical fire dynamics. We need more comprehensive data to understand the past and the present, as climate change and human intervention change how our world burns (Westerling et al. 2006; Covington and Moore, 1994).

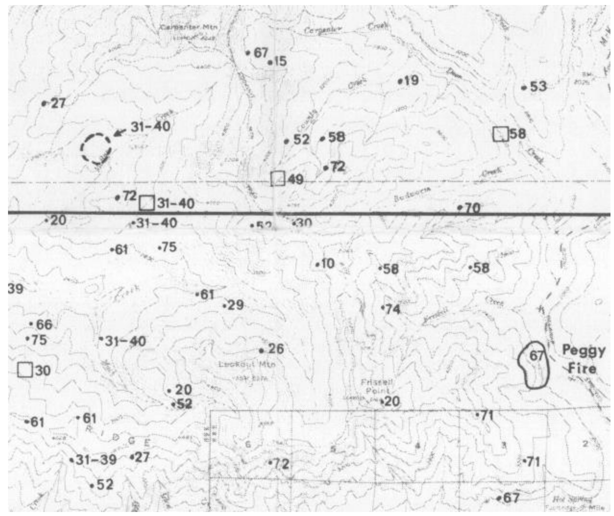
The aim of this project was to create an atlas of observed historical fires over the past 140 years in western North America. This dataset bridges the gap between historical, manually mapped fires and more modern and comprehensive datasets created using satellite data, such as Monitoring Trends in Burn Severity ("MTBS", 2017). This atlas provides unified fire perimeters and occurrence data from 1880-2018 as completely as possible. The data for this atlas originates from a variety of government sources in the US and Canada.

Understanding more about both the history and future of wildfires in the West will allow us to better protect our communities and wildlands. Almost five million homes and one-third of the US population live in the Urban-Wildland interface, areas that are vulnerable to wildfires due to their proximity to fire-prone wilderness areas ("Statement", 2015; Martinuzzi et al. 2010). Knowing which areas are already fire-prone might allow us and our communities to plan for better fire resilience and reduce fire-related costs and mortality. A longer fire history of the West will also aid in changing the public perceptions that wildfires are an "act of God" type tragedy and a new part of American life. After decades of fire suppression led the public to the conclusion that fires are a new anomaly, and could be helpful for public outreach and education (Moser, 2005; Parks et. al 2015; Schoennagel et al. 2017). Other researchers may also find this data useful for a variety of analyses and background research for local ecological studies.

Spatially comprehensive records of fires in North America stretch back less than 50 years, a decade after the advent of the Landsat satellites in the 1970s when the newly available wealth of satellite data started to be used to track and monitor fires ("MTBS", n.d.). Before that pivotal decade in fire science, the data we have is incomplete. Some of it is very thorough, but only in a narrow geographic or temporal scope and contain records for a small geographic area or a short period of time (Burke, 1980; Barnett et al, 1997; Bigio, 2013; among others). Much of it is painted in overly broad strokes, with records available only in terms of total acres burned in a large area or narrative formats rather than as spatially explicit datasets (Littell et al. 2013; Pyne, 2010). Other data are simply geographic locations of fire centroids without context, area, year burned, source, or any other information ("BLM", n.d.). None of these datasets are particularly helpful for a variety of analyses despite adding to the collective scientific knowledge base about wildland fires.

Figures 1-5: Examples of unhelpful but interesting fire history data from various sources.

<table>
<tr>
<td>Point Data only, no extent data

(Kaib, 1998)</td>
<td>


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<tr>
<td>Spatial extent with no context such as fire year

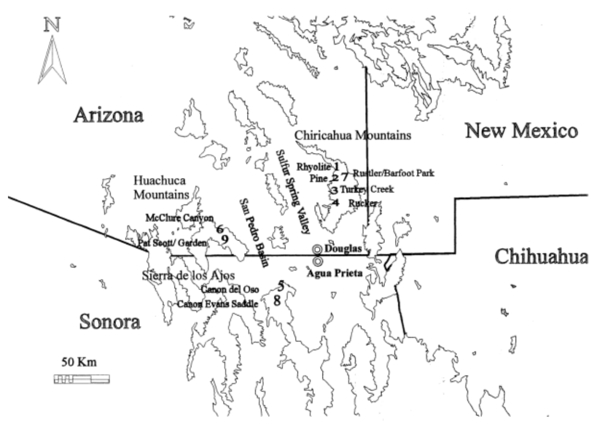
(Burke, 1980)</td>
<td>


FIGURE 2.1 The Southwest Borderlands fire history reconstruction sites encompassing the lower Sulfur Spring and upper San Pedro Valleys. Canyon pine-oak sites are clockwise from the northwest; Rhyolite (1), Pine (2), Turkey Creek (3), and Rucker (4) Canyons in the western Chiricahua Mountains; Cañon del Oso (5) in the Sierra Ajos, and McClure (6) Canyon in the Huachuca Mountains. Upper-elevation mixed-con forest sites include Barfoot/Rustler Park (7), Cañon Evans Saddle (8), and Sawmill/Pat Scott Peak (9) sites in contiguous mountain ranges.
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<tr>
<td>Timelines or summaries such as acreage totals or estimates

(Danzer, 1998)</td>
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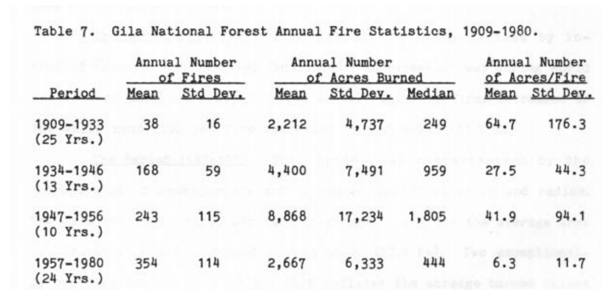

Table 7. Gila National Forest Annual Fire Statistics, 1909-1980.

Period	Annual Number of Fires Mean	Annual Number of Fires Std Dev.	Annual Number of Acres Burned Mean	Annual Number of Acres Burned Std Dev.	Annual Number of Acres Burned Median	Annual Number of Acres/Fire Mean	Annual Number of Acres/Fire Std Dev.
1909-1933 (25 Yrs.)	38	16	2,212	4,737	249	64.7	176.3
1934-1946 (13 Yrs.)	168	59	4,400	7,491	959	27.5	44.3
1947-1956 (10 Yrs.)	243	115	8,868	17,234	1,805	41.9	94.1
1957-1980 (24 Yrs.)	354	114	2,667	6,333	444	6.3	11.7

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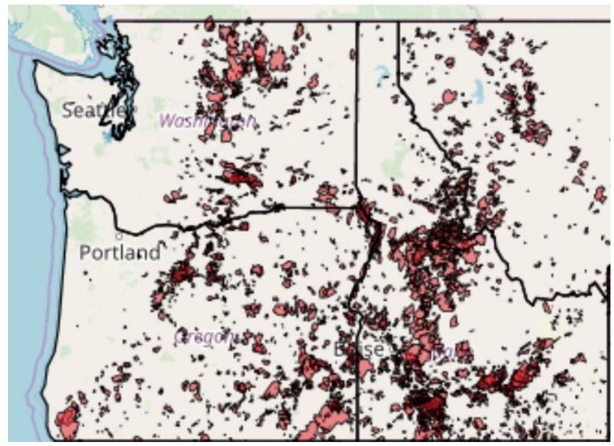
<td>Short Temporal Scope or data that is only very recent or restricted to satellite data only

(MTBS, 2019)</td>
<td>



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<tr>
<td>Limited geographic scope such as small Scale Studies, such as single-site or area charcoal studies.

(Swetnam, 1983)</td>
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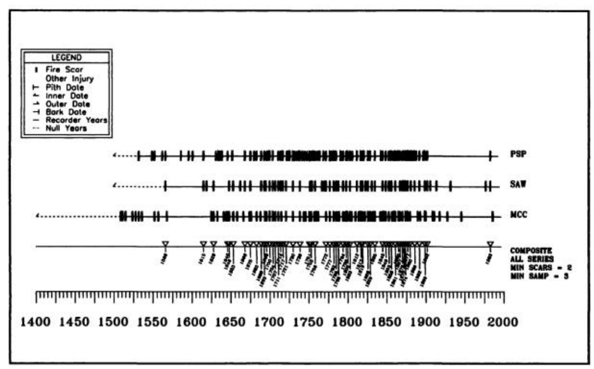

Figure 9. Comparison of the Garden Canyon (PSP and SAW) fire history with the McClure Canyon (MCC) fire history, showing fire dates common to all three sites.

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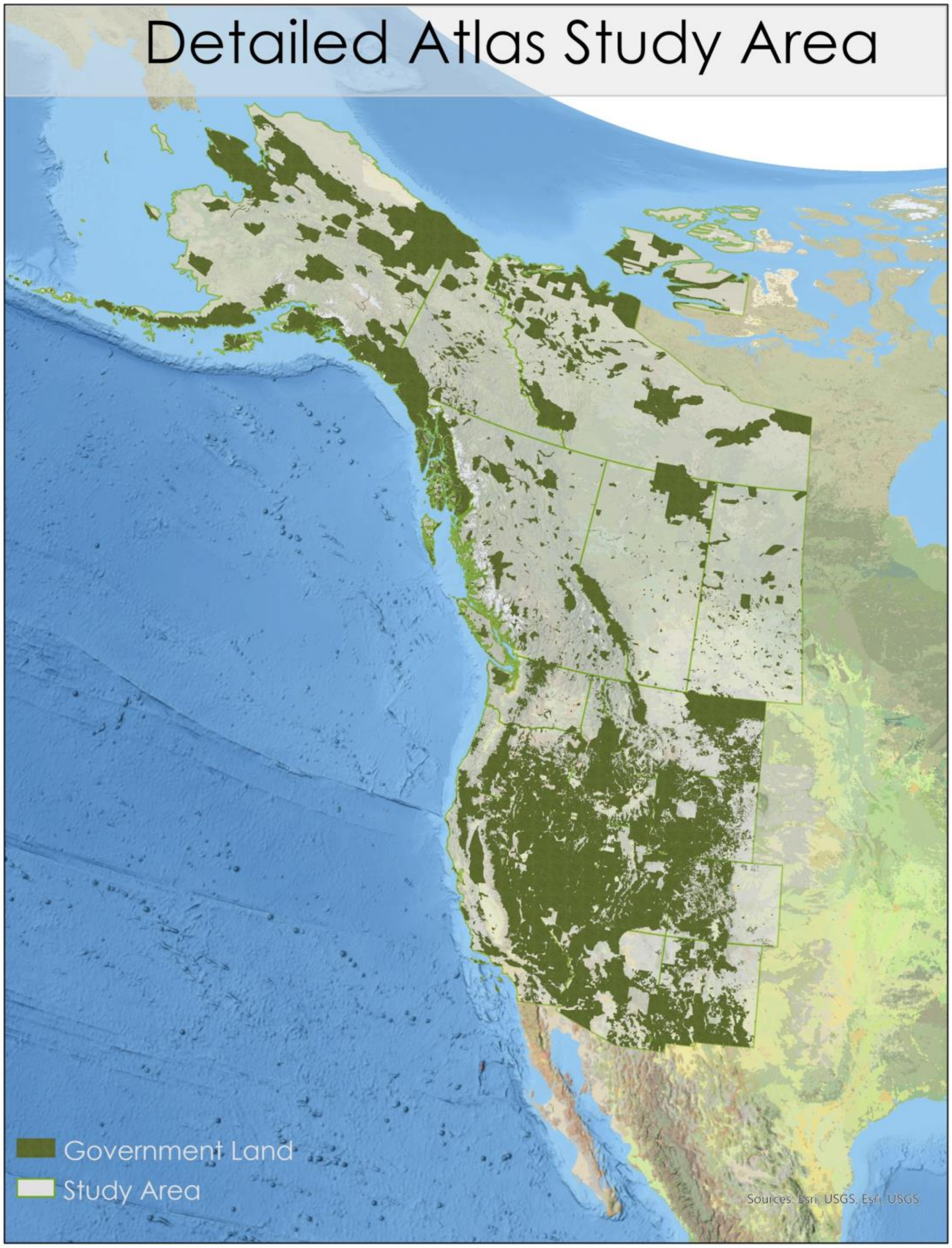
</table>

This project aims to create the most complete fire occurrence database and fill a data gap not currently fulfilled by the available data. With that being said, available potential sources did limit the scope of the atlas. Data that was not digitized or not in the form of a perimeter polygon was not included in the atlas. The inclusion of point data and data that remains on paper maps was not in the scope of this project. Collated data is only as good as the sum of the data it comes from. This dataset thus represents all recorded fire perimeters within the jurisdictions that released usable data but is not a comprehensive record of all fires in all places in all years.

There are three deliverables for this project, including the final dataset as a set of geodatabases, a digital presentation of findings, and this technical report detailing the process used to create the data. A web map with relevant figures, web maps, and static maps present the outcomes in a digestible and accessible way through an online interface. The study area for this project includes the Western US and Canada (Map 1.1 and 1.2).

Map 1.1. The final study area includes 17 states, territories, and provinces in the US and Canada.



Map 1.2: This map shows a more detailed view of the information in *Map 1.1*. The actual federal lands under the jurisdiction of the Agencies that created or reported the data for the Atlas are shown in dark green. Please note that many Canadian Crown lands are not included in this map, so these areas are not inclusive of the entirety of reported Canadian fires.

A Brief History of Fire Data and Remote Sensing

The quality and availability of data used in this project are intrinsically tied to the history and development of available technology used for mapmaking and geographic data gathering. Different data gathering and storage methods have yielded varied results that have undoubtedly affected the continuity of available data. Before satellite-data based standardization in the US and Canada in the 1980s, the data would have been gathered using a variety of methods, such as manual surveying or using aerial orthophotos (MTBS, 2019; Canadian Wildland Fire Information System, 2019).

Prior to World War I, aerial imagery was rare and sometimes only a novelty -- gathered via hot air balloons and early airplanes. Orthoimagery and photogrammetry were developed for domestic use beginning in the 20s following the use of aerial imagery for reconnaissance during the war (Fischer, 1975; Campbell and Wynne, 2011). Before this time, fire perimeters would have been mapped using traditional surveying methods or through word of mouth, as no other means of mapping were available. Surveying large areas was slow and expensive, and only as reliable as the surveyors.

Infrared and other non-visible imaging was first used during World War II. After the war, the technology was applied elsewhere for domestic and civilian purposes, primarily agricultural information gathering (Campbell and Wynne, 2011; Collier, 2002). It is unclear whether this technology was used for documenting wildfire occurrences. None of the non-satellite gathered data explicitly stated the method of initial data gathering, just that some of it was digitized from paper maps.

The space race and creation of satellite technology in the 1950s, 60s, and 70s led to the current primary methods of documenting wildfire areas. The Cold War and ensuing government desire to spy on the Soviet Union led to further advances in non-visible imaging and satellite imagery. However, much of these advances were out of reach or unknown to civilian and non-military agencies until earth-monitoring satellites were developed for their own sake. The first satellites used for environmental monitoring were initially intended to be used for meteorology starting in the early 1960s (Campbell and Wynne, 2011; Babington-Smith, 1957).

In 1972, Landsat 1 was launched and was the first satellite launched specifically to gather information about the earth's land and features, rather than its weather. Uniform fire data from the Landsat satellites, either gathered at the time of the fire or after the fact, started in the 1980s ("The Landsat Program - History", 2009).

Each of these technology changes would have changed the nature of the fire data available. Advancements sometimes come with tradeoffs. Surveying and orthoimagery can yield high levels of detail, but were expensive to undertake, and it was possible for fires to be missed or excluded. Satellite imagery trades quality for quantity (Parson et al., 2010). The resolution of Landsat and especially later MODIS data has a much lower maximum achievable resolution than earlier methods, but have the advantage of capturing every fire without needing intentional data gathering. Some data can now be gathered mostly without the use of human technicians, as NASA generates some remotely sensed data and indices automatically (Loboda, T., O'Neal, K. J., & Csiszar, I. 2007).

Fire data is now largely standardized and unified in both the US and Canada. Monitoring Trends in Burn Severity or MTBS is the US interagency project that collects, creates, and hosts uniform datasets for US fire perimeters over 1,000 acres in the Western US ("MTBS Project Overview", n.d.). The National Interagency Fire Center also maintains and creates data for "large" fires, which they characterize as fires over 100-300 acres, depending on the location and ecosystem of the fire ("NIFC Maps & Data", n.d.).

The Canadian National Fire Database maintains a national dataset using contributed data by the provincial and territorial governments, and as such, the data varies by area. National data used for carbon emissions calculations exist from 1986 onwards. The Canadian Forest Service also maintains a national dataset from 1990 onwards (Natural Resources Canada, n.d.).

Data Sources

The final data used was spread among many sources and was not easily usable or accessible to researchers or students wishing to do analyses using historical fire data over a large geographic area or a long time. The final study area included the 17 states, provinces, and territories that roughly make up the western US and Canada. The beginning of the data was limited to 1880, despite there still being data and sources purporting to have data before 1880, the number of reported fires dwindles significantly in a way that does not represent the reality of the time, according to fire area summaries from the time. The data before the early-mid 20th century should be treated as a very conservative estimate of the total number and area of fires, as the lack of technology needed to comprehensively survey remote areas from the air means that some fires were likely not recorded.

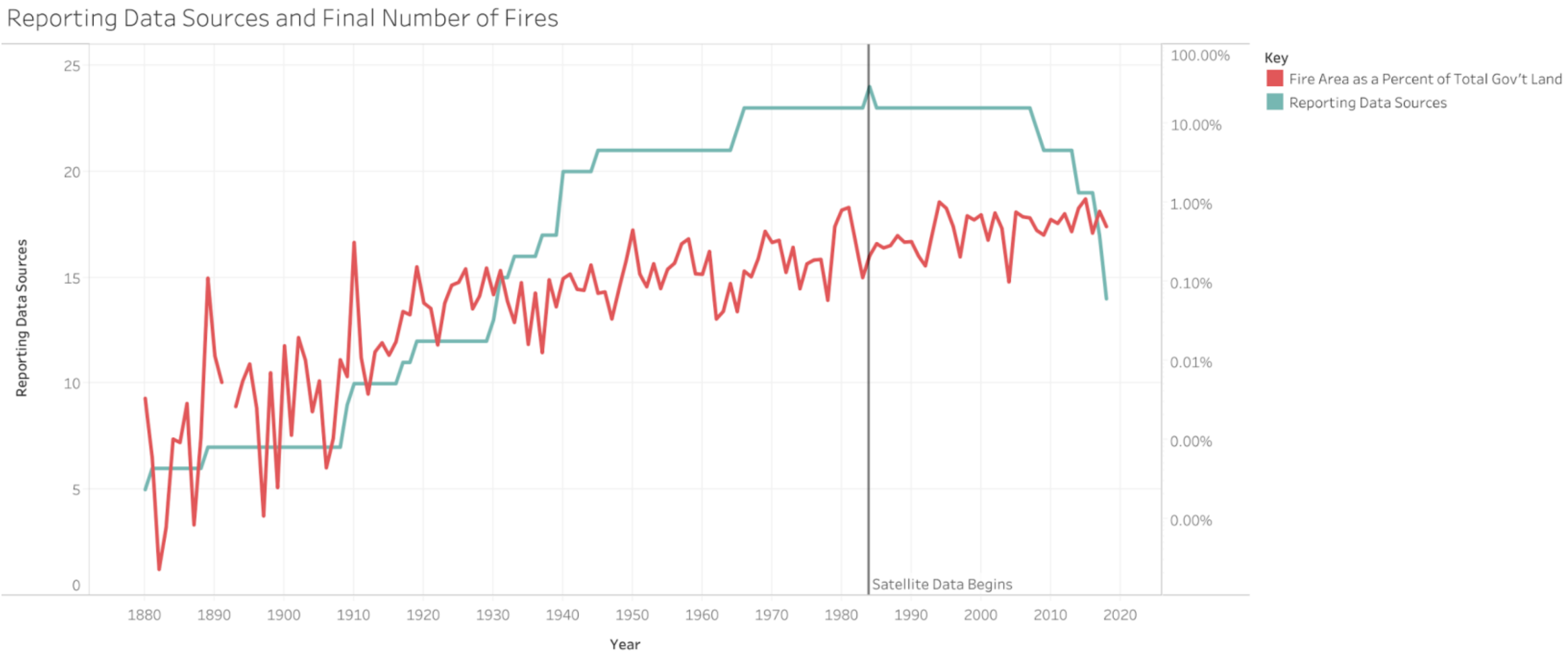


Figure 6: The number of sources reporting data dwindles significantly before the 1930s and 40s. The number of reporting sources can be seen to visibly dwindle in the mid to early 20th century.

I collected numerous spatial datasets, harmonized the attributes and spatial reference systems, and then created an atlas of fire perimeters. This included reprojecting the data, reformatting it into a single geodatabase, and a set of files with unified attributes and information about the source of the data. This dataset was checked for redundant fire perimeters in the same fire year by joining overlapping polygons and merging the attributes of spatially overlapping fires within the same year. This process merged the same fires reported by different data sources into a single polygon for that fire. It also had the effect of separating spatially distinct fires in the same year that were grouped as complex fires or for administrative purposes if they happened concurrently or had the same origin.

Additionally, information and documentation about the source, reliability, and spatial and temporal extent of each dataset were created to limit false precision in the data.

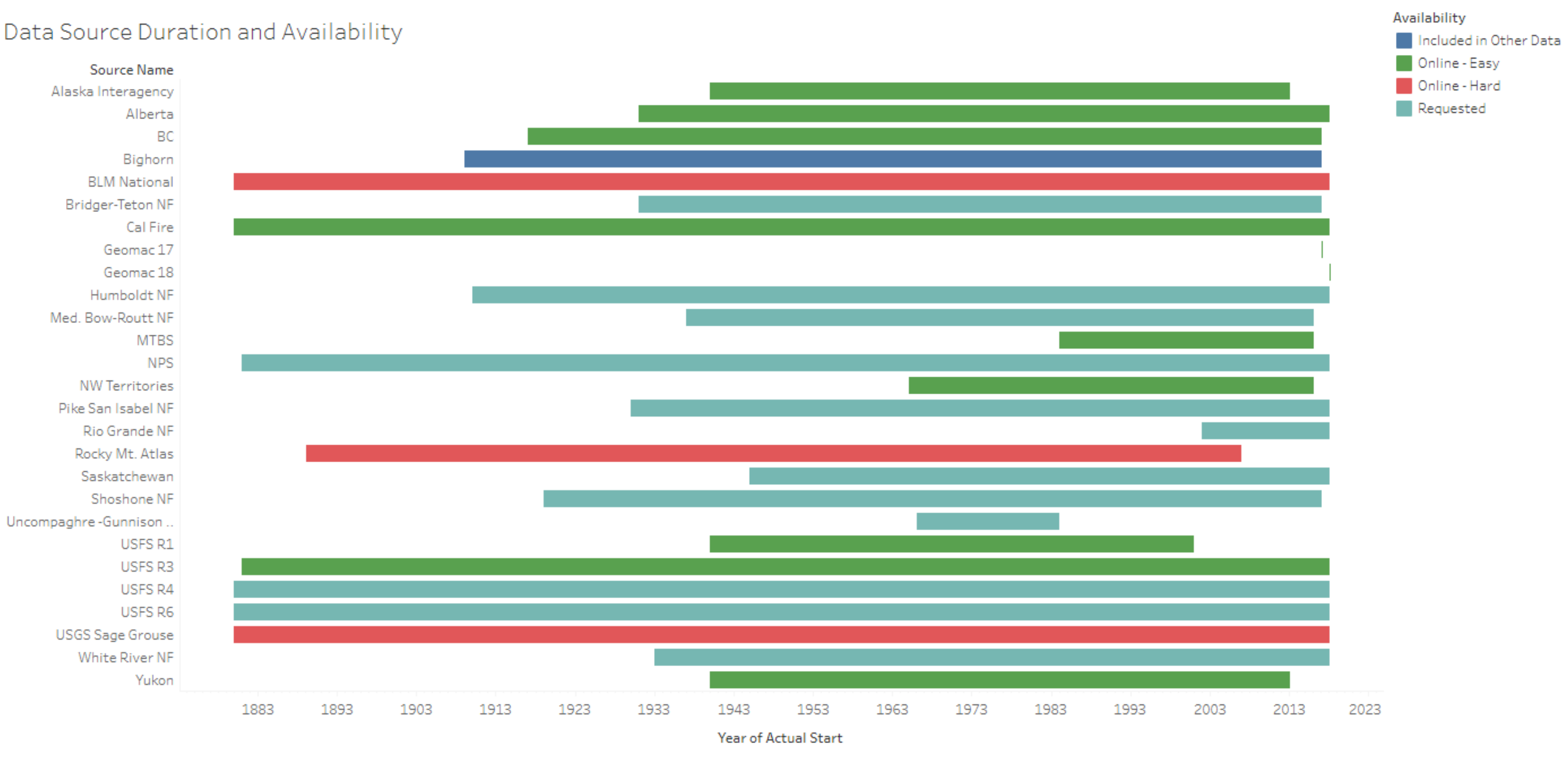


Figure 7: The duration of data covered by each dataset varied widely.

Much of these datasets were available through searching online or in governmental databases hosted by the USDA, BLM, USFS, and other agencies. Some data were obtained by contacting individual offices or employees of national forests and wilderness areas. A significant portion of the data used was not easy to find or published online or in any online databases and had to be specifically requested by contacting agencies or undergoing Freedom of Information requests or equivalent information request processes (*Table 1).*

Forest Service and BLM data were used to supplement the short timeline of MTBS interagency data. State data was requested but unavailable or did not exist for most states (Colorado, Wyoming, Utah, Arizona, New Mexico), or existed as points rather than fire perimeters (Oregon, Washington.) Forest service data were occasionally updated through the end of the 2018 fire season, but MTBS and several datasets were years out of date. To supplement the MTBS data, which ends in 2016, USGS Geomac Data from 2017 and 2018 was included as well.

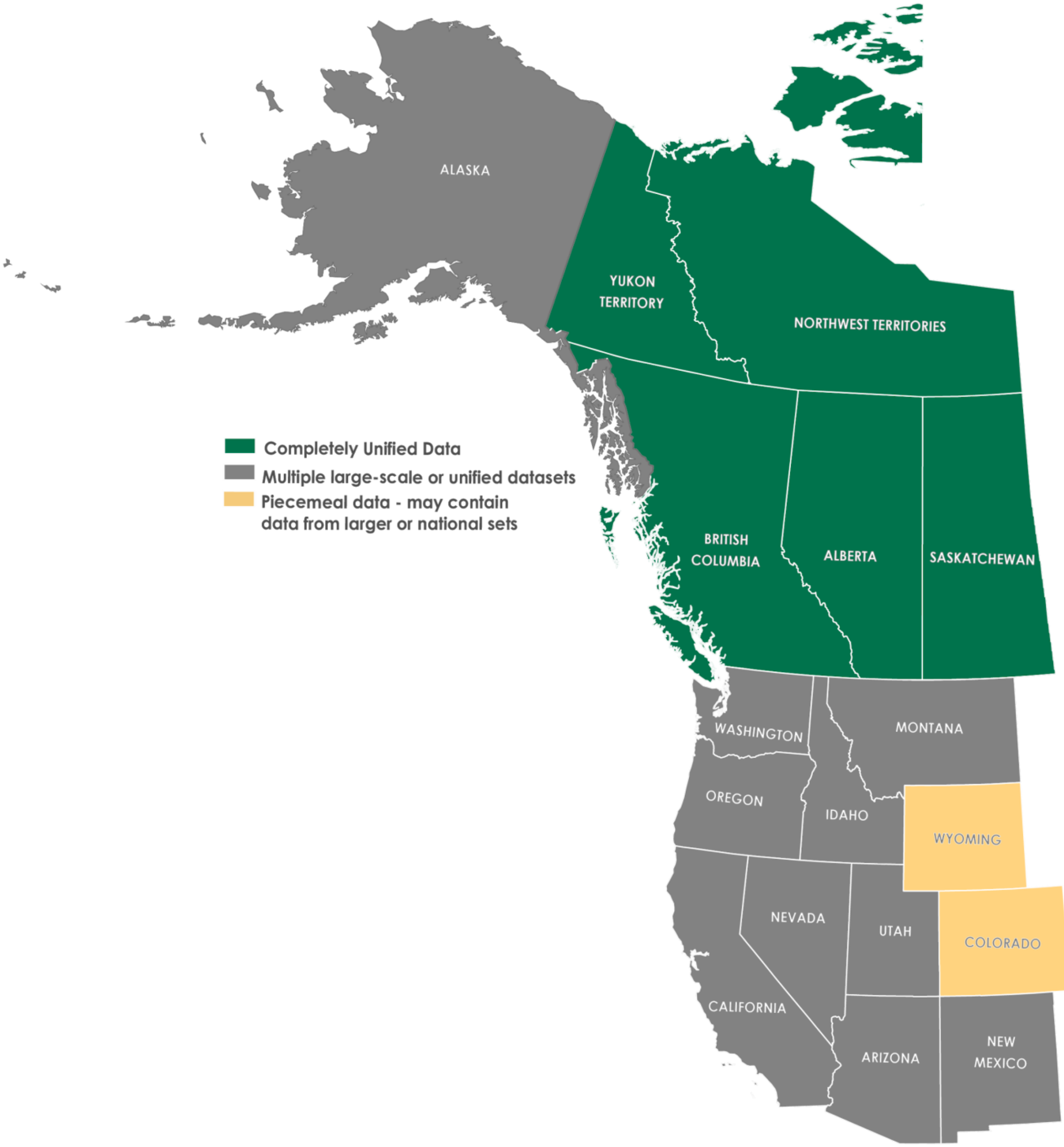
Several areas had interagency data for their jurisdiction, including Alaska, California, and every Canadian province and territory included in the study area. Multiple forest service regions had unified datasets, including regions 6, 3, 1, and 4, which were published during the study. The BLM National dataset was used, and it was confirmed by contacting the BIA, DOD, and USFWS that they do not keep independent fire records for their administered lands. BLM data includes fires in these agencies' jurisdictions but I was unable to confirm if the BLM records for these other jurisdictions were consistent and comprehensive.

Table 1: Data Sourcing Details. This table explains where each dataset came from and how it was acquired.

Data Name	Source	Acquisition Method
US Forest Service Region 6	Regional GIS Staff	Emailed/Called to ask for Data
Cal Fire	Cal Fire Site	Downloaded from Web
British Columbia	BC Data Catalogue Site	Downloaded from Web
Alberta	Alberta Wildfire	Downloaded from Web
Yukon	GeoYukon Geodata Portal	Downloaded from Web

Alaska	BLM Alaska Site	Downloaded from Web
Northwest Territories	Northwest Territories Centre for Geomatics	Downloaded from Web
Medicine Bow-Routt NF	Forest GIS Staff	Emailed/Called to ask for Data
Rio Grande NF	Forest GIS Staff	Emailed/Called to ask for Data
Uncompahgre-Gunnison NF	Forest GIS Staff	Emailed/Called to ask for Data
US National Parks	Forest GIS Staff	Downloaded from Web
Pike San Isabel NFs	Forest GIS Staff	Emailed/Called to ask for Data
White River NF	Forest GIS Staff	Emailed/Called to ask for Data
Rocky Mt. Fire Atlas	USDA Research Data Archive	Downloaded From Web
US Forest Service Region 1	USFS Region 1 Site	Downloaded from Web
Humboldt-Toiyabe National Forest	Forest GIS Staff	Emailed/Called to ask for Data
US Forest Service Region 4	USFS Region 4 Site	Downloaded from Web
Shoshone NF	Forest GIS Staff	Emailed/Called to ask for Data
Bridger-Teton NF	Forest GIS Staff	Emailed/Called to ask for Data
Bureau of Land Management Lands	BLM.gov	Downloaded from Web
USGS Sage Grouse Data	Data.gov	Downloaded from Web
Saskatchewan	Saskatchewan Ministry of Environment	Public Records Request Through Ministry of Environment

USFS Region 3	USFS Region 3 Site	Downloaded from Web
Geomac 2017	Geospatial Multi-Agency Coordination Site	Downloaded from Web
Geomac 2018	Geospatial Multi-Agency Coordination Site	Downloaded from Web
Bighorn NF	Shoshone NF GIS staff	Included in Another Dataset



Map 2: The existence of inter-agency or unified data varied both by area, but also by agency and area. Some agencies had unified data for some areas but not others, some areas were completely unified*, and others had no unified data at all other than applicable national datasets.

See *Map 1.2* for a more detailed view of which areas are under the actual jurisdiction of these agencies.

*By unified, that means the state, regional or Provincial government promotes the used dataset as being as complete as possible for their jurisdiction, however, this data may not include fires on private land.

Data Unification Process/Methods

The 40+ separate shapefiles were edited to have the following attributes first before merging to ease the process of mapping the attributes of the merged file:

Table 2: Included Attributes in the Final Data. The data type is as defined in the ESRI shapefiles.

Name	Type	Length	Description
FIRE_NAME	Text	255	The included fire or incident name, if applicable. Null values were accepted, it appears that naming fires is a more recent standard.
FIRE_YEAR	Text, later converted to Float	20	This is the 4-digit year that the fire took place during. Null values were accepted during the initial merge process.
AGENCY	Text	20	The abbreviated or shortened name

			of the agency in charge of the fire or land the fire took place on, such as “USFS” or “Private” or “State”. Agency names were standardized to uppercase, recognizable abbreviations.
DATA_SOURCE	Text	50	If a lower-level data source for a unified dataset was designated, that source was carried over. If not, the source was listed as the agency or entity from which the data came.
Shape_Length	Double	unspecified	These are automatically generated by ArcGIS Pro and cannot be changed. In this situation, they are in the standardized SI unit, meters, or kilometers.
Shape_Area	Double		

The data were then merged, with any additional files after the first merge added using append. The uniform attributes aided greatly in the field attribute mapping process, and most of the fields automatically self-sorted based on their names.

A definition query for each year allowed for each years' data to be dissolved with single-part features to eliminate overlapping perimeters. This method eliminated the need for judgment-based redundancy removal by taking the most generous estimation of the fire's area and eliminating the need to choose which agency might have the best or most accurate perimeter.

This single-year, the dissolved dataset was then spatially joined back to the original merged data for the year that was created prior to dissolving the areas to rejoin the non-spatial attributes. Summary statistics of removed area and perimeters were taken for each year for later analysis. Each final yearly shapefile was placed in the correct decade's geodatabase, merged into the rest of the decade to create a decadal file, and finally, the decades were merged to create a single final data file. Additional analytical layers and sub-files were also created based on location or to show other aspects of the dataset.

The data was divided into multiple time-based configurations in multiple geodatabases.

- A final, full dataset file, along with an analysis overlay of the number of times the study area had been burned was a single geodatabase.
- Decadal Fires in a geodatabase

Metadata Creation

Uniform metadata was used for all the created files in using the FGDC's (Federal Geographic Data Committee) current recommended metadata format and standards, ISO 19115/-1, or

International Standards Organization metadata (“Geospatial”, n.d.). ISO metadata is very similar to the standard CSDGM (Content Standard for Digital Geospatial Metadata) format but is internationally agreed upon and recognized. Given that this is a dataset that spans two countries, international accessibility and standardization are even more important.

This metadata was created after compiling important information and common themes from the source metadata. These themes included information about the spatial and temporal scale, appropriate use, non-assurance of quality and accuracy, data collection methods, and credits.

The metadata for the files are tailored for each file, but follow the same standard formula according to ISO standards.

Table 3: Metadata template that was tailored to and applied to the final dataset.

Field	Template
Tags	Wildland Fire, Fire History, Fire Perimeters, US, Canada, Historical Data, WWU
Summary (Purpose)	The purpose of this data is to study wildfire patterns and occurrences over the 138 year study period. This data cannot be used as a definitive source for data on all fires during this period due to data restrictions. General trends and observations can be made from this data. This data is in WGS 1984.
Description (Abstract)	This data is part of a set of files that contain wildfire perimeters for the Western US and Canada for the years 1880 - 2018. The area covered by this data contains the following provinces, territories, and states; Alaska, Alberta, Arizona, British Columbia, California, Colorado, Idaho, Montana, Nevada, New Mexico, Northwest Territories, Oregon, Saskatchewan, Utah, Washington, Wyoming, and Yukon Territory. This file is for data for the year(s) _____. This data comes from a multitude of government sources. The sources for this data may be found briefly in the

	attributes or the additional provided documentation for in-depth-citations. This data was created in partial fulfillment for the requirements of a Master's Degree at Western Washington University's Huxley College of the Environment in 2019. This data was created with the technical support of the Huxley Spatial Institute.
Credits	Kate Welch, kwelch95@gmail.com (Corresponding Author) Aquila Flower, Western Washington University Michael Medler, Western Washington University Citing this data: Welch, K. Flower, A., Medler, M. North American Fire Atlas 1880-2018. Bellingham, Washington. 2020.
Use Limitation(s)	This dataset cannot be described as comprehensive or complete due to the limitations of available data. It should not be used for definitive fire summaries but is appropriate for use in estimations or analyses with this limitation thoroughly acknowledged. Users should be aware that the perimeters in this set were originally gathered using multiple methods, including satellite and aerial imagery, surveying, and word of mouth mapping. These methods do not produce equivalent results, and more current data is more accurate than older data due to prior mapping limitations. American data after 1984 and Canadian data after 1986 can be considered standardized and were created or verified using Landsat satellite data. This dataset should not be used for legal purposes.
Appropriate Scale Range	1:50,000,000 (Continent) - 1:50,000 (City)
Bounding Box	Default Used

Findings and General Trends

During this process, I found a total of 143,702 fires that totaled 1,793,542.62 sq. kilometers of burned area. The average fire area for the study area of 12,903.18 sq. km per year, with an average of 1034 fires and 11.78 sq. km average area per fire. On average, 16,702.72 sq. km of redundant and overlapping area was removed from the dataset per year, along with an average reduction of 471 total fire perimeters. Some years removed a negative number of fire perimeters, and this is because of the data processing method ungrouped or separated previously grouped perimeters that may have been digitized as the same multi-part polygon or considered part of the same complex fire. For the purposes of this study, each individual perimeter was considered a distinct ecological event and complex fires were not maintained because it was impossible to know if they were caused by the same original ignition or simply digitized together due to administrative or other reasons.

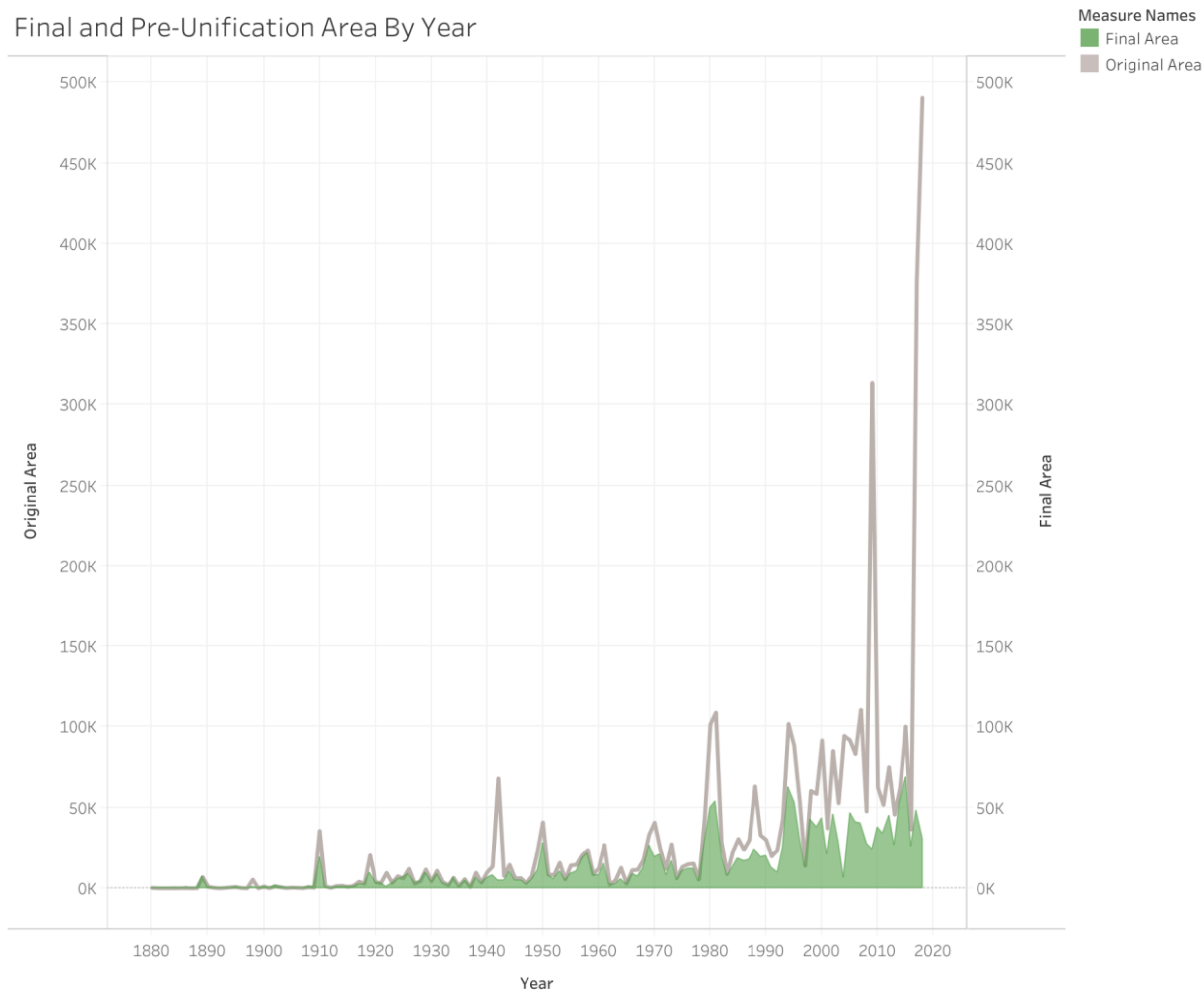


Figure 8: This graph shows how the number of fires changed by merging overlapping fire perimeters and by separating complex fires into individual data points.

Data Presentation and Hosting

Presenting such a large dataset in a way that gives enough details to provoke interest and give a brief overview was a project in itself. Using ArcGIS Online Story maps, I made a number of visual representations of the data, and some description about what the data shows and how it came together. The creation of some of this data required additional analysis and learning new skills, and refining old ones. Because of the sheer size of the final dataset, presenting it and hosting graphics about it is a challenge. Analyzing this data takes time and even with the use of python based parsing and iterative modeling, it was still a lengthy process. In order to present the data best, I used a combination of animated maps, slideshows, static maps, and interactive graphs made in Tableau. It was necessary to limit the number of interactive slideshows, maps, and other embedded features to allow the page to load and function properly. With such a large dataset, both my computer and ArcGIS online struggled to display and function under the processing strain, and editing these maps was a lengthy and patience-testing process.

This data is available for download on through Google Drive via a link in the story map and on ArcGIS online. This will allow the data to be freely accessible to all for years to come. The storymap can be viewed here.

Spatial Data Sources

Medicine Bow-Routt National Forests. (2016) Wildfire Perimeters. [Unpublished Geospatial Data]

Rio Grande National Forest. (2018) Wildfire Perimeters. [Unpublished Geospatial Data]

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