Wildfire Analysis in U.S.

Data Science as a Field - CU Boulder

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1.1 Motivation

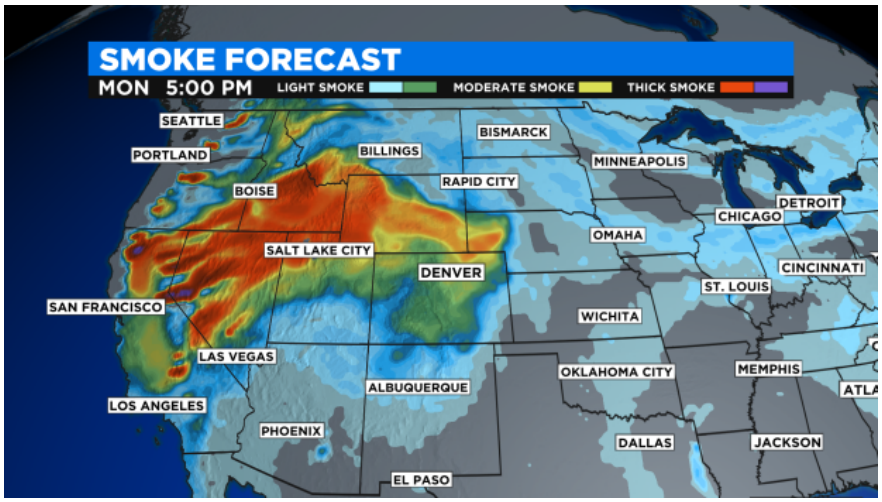


Figure 1: Colorado's Air Quality is Pretty Bad Today and Will Get Worse

Wildfires, like many other natural disasters, demand everyones' attention. From being a direct threat to the constant reminder of a smoke caused haze. The smoke from the California wildfires in 2021 has massively impacted the air quality of Colorado State.

The noticeable air pollution reached such levels that the state government recommended active children and adults reduce prolonged or heavy outdoor activities. This impact helped inspire this report.

The general motivation behind this project is to understand the history of wildfires in the U.S., see how they've changed over time and understand when and where they are most severe. The following questions are what this report will specifically try to answer.

1. Have the number of wildfires increased over time? Have the fires that occur become more severe?
2. During which time of the year is there the most wildfire activity?
3. Which states have the most wildfire activity? Of the top state, which counties had the most wildfires activity?

Here is the work space link: https://github.com/Firewatch-DTSC5301/wildfire

2 Design of Data and Methodology

2.1 Data Resource and Explanation of Variables

The dataset used for this report was found via the US Department of Agriculture. It provides information on 2,166,753 wildfires in the U.S. from 1992-2018, with a variety of information including spacial, cause, size, discovery/containment dates and different classifications.

Thanks to **U.S. DEPARTMENT OF AGRICULTURE** for providing the dataset.

```
##Read the dataset
# create db connection
conn <- dbConnect(SQLite(), 'FPA_FOD_20210617.sqlite')
# pull the fires table into RAM
fires <- tbl(conn, "Fires") %>% collect()
# disconnect from db
dbDisconnect(conn)
# select the column we need for this project
fires <- fires[,c('FIRE_NAME', 'FIRE_YEAR', 'DISCOVERY_DATE',
                  'NWCG_CAUSE_CLASSIFICATION',
                  'NWCG_GENERAL_CAUSE', 'FIRE_SIZE',
                  'FIRE_SIZE_CLASS', 'STATE', 'FIPS_CODE')]
```

```
## Description for attributes
# get column names and rename
fire_df_colname <- matrix(colnames(fires), ncol = 1)
colnames(fire_df_colname)[1] <- "Related-Variable"
# cbind the description for variable
fire_df_colname <-
  cbind(fire_df_colname,
  Description=
  c('Name of the incident from the fire report',
  'Date of Year on that fire',
  'Date on which the fire was discovered or confirmed to exist',
  'Code for the (statistical) cause of the fire',
  'Description of the (statistical) cause of the fire.',
  'Estimate of acres within the final perimeter of the fire.',
  'Code for fire size based on the number of acres within the final fire perimeter expen
  'Two-letter alphabetic code for the state in which the fire burned (or originated), ba
  'Numbers which uniquely identify geographic areas.'))
# kable related variable
kbl(as.data.frame(fire_df_colname), booktabs = T, longtable = T,
    caption = "The Variables of Interest in the Dataset") %>%
  kable_styling(full_width = T) %>%
```

```
  column_spec(1, color = "red") %>%
  column_spec(2, width = "25em")
```

Table 1: The Variables of Interest in the Dataset

Related-Variable	Description
FIRE_NAME	Name of the incident from the fire report
FIRE_YEAR	Date of Year on that fire
DISCOVERY_DATE	Date on which the fire was discovered or confirmed to exist
NWCG_CAUSE_CLASSIFICATION	Code for the (statistical) cause of the fire
NWCG_GENERAL_CAUSE	Description of the (statistical) cause of the fire.
FIRE_SIZE	Estimate of acres within the final perimeter of the fire.
FIRE_SIZE_CLASS	Code for fire size based on the number of acres within the final fire perimeter expenditures (A=greater than 0 but less than or equal to 0.25 acres, B=0.26-9.9 acres, C=10.0-99.9 acres, D=100-299 acres, E=300 to 999 acres, F=1000 to 4999 acres, and G=5000+ acres).
STATE	Two-letter alphabetic code for the state in which the fire burned (or originated), based on the nominal designation in the fire report.
FIPS_CODE	Numbers which uniquely identify geographic areas.

The data for this project was obtained via the websites mentioned above and compiled into one sqlite file to be read into R. There are some missing some values and certain information. The na.omit function was used to remove empty rows from the dataset and the usmap library was used to filter the state name column of the dataset.

The description for each variable inside the dataset can be found in the **Kaggle** dataset website. This website provides the yearly wildfire data for the United States. Although it is an out-of-date dataset the description for the variable still useful for our dataset. This website provides reshaped data to some extent which is originally from the national Fire Program Analysis (**FPA**).

2.2 Preparing the Data

The following was done to prepare the dataset for analysis:

1. Drill in on States/Counties impacted most by wildfires using the "include" parameter in the plot_usmap() function.
2. Remove rows missing information on fire size and fire cause.
3. Due to different categories for the dataset, only a subset of the columns were used in order to not duplicate the information.
4. Format date information to a more usable form.
5. Create a table that provides more information about each variable in the dataset.

2.3 R Library Foundations of the Project

This project may be imported into the RStudio environment and compiled by researchers wishing to reproduce this work for newest plot with future data sets, and having new findings or discussions from that.

> The Core of Statistics were done using R 4.1.0 (R Core Team, 2021-05-18), the ggplot2 (v3.3.5; RStudio Team, 2021-06-25), and the knitr (v1.34; Yihui, 2021-09-08) packages.

ggplot2 Package: this package has been used for creating graphics such as box plot, line plot, bar plot, and density plot from the reshaped datasets.

knitr Package: this report is constructed to have reproducibility that it can regenerate the plot based on the latest dataset contains yearly report in the future, using literate programming techniques for dynamic report generation in R.

> The Initial Scenarios package is usmap 0.5.2 (Paolo Di Lorenzo, 2021-01-21).

*usmap** Package: we use plot_usmap(based on ggplot object) to plot the US map. The map data frames include Alaska and Hawaii placed to the bottom left.

> The Most Frequently Used package is dplyr (v1.0.7; RStudio Team, 2021-06-18).

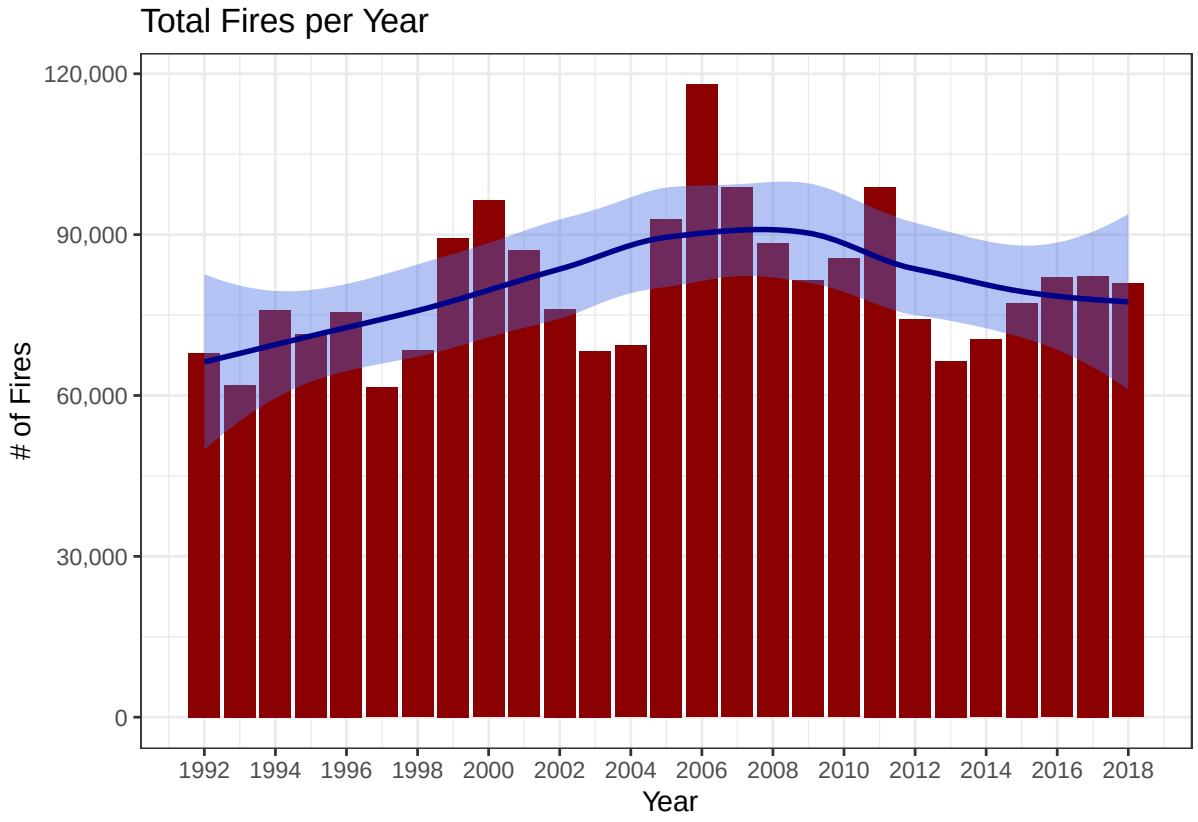
dplyr Package: many functions were used to reshape the dataset and working with data frames.

Note: There were other packages used for limited purposes, they are not listed here.

3 Exploration

3.1 Number of Fires Over Time

```
fires_date <- fires %>%
  select(FIRE_YEAR, FIRE_SIZE) %>%
  group_by(FIRE_YEAR) %>%
  summarise(Total_Fires = n(), Burn_Size = sum(FIRE_SIZE))
fires_date %>% ggplot(aes(x= FIRE_YEAR)) +
  geom_col(aes(y = Total_Fires), fill = "darkred") +
  stat_smooth(aes(method = "lm", y = Total_Fires),
              color = "darkblue", fill = "royalblue") +
  scale_x_continuous(name = " Year",
                     breaks = round(seq(min(fires_date$FIRE_YEAR),
                                        max(fires_date$FIRE_YEAR), by = 2),1)) +
  scale_y_continuous(name = "# of Fires", labels = scales::comma) +
  ggtitle("Total Fires per Year") + theme_bw()
```



Observing the first plot, *Total Fires Per Year*, it shows the number of fires has not increased. In fact the data shows there was a peak around 2006 after which the number of fires decreased.

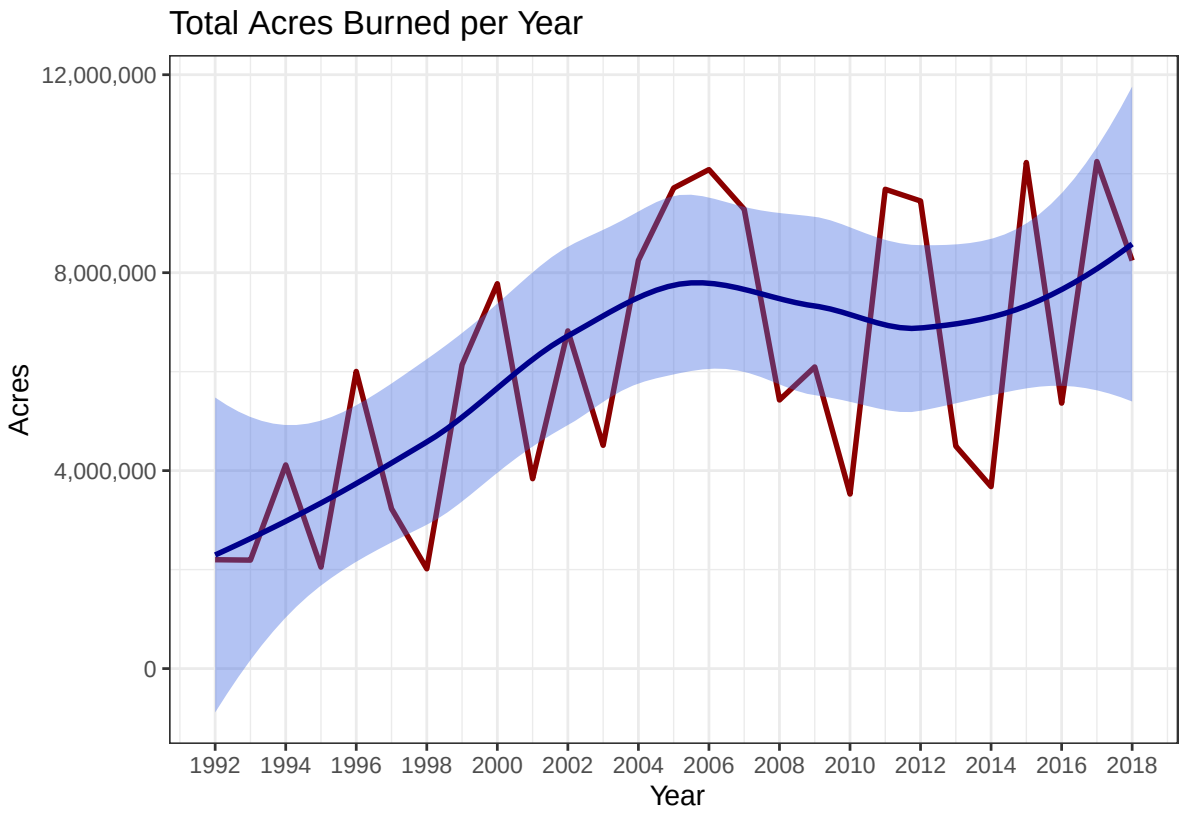
A linear regression model was applied further confirming that there is not a relationship between year and fire count.

3.2 Fire Severity Over Time and Model

```
simple.fit = lm(FIRE_YEAR~Burn_Size, data=fires_date)
summary(simple.fit)
```

```
##
## Call:
## lm(formula = FIRE_YEAR ~ Burn_Size, data = fires_date)
##
## Residuals:
##    Min     1Q Median     3Q    Max
## -8.854 -5.455 -0.600  4.028 12.796
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept) 1.995e+03  3.106e+00 642.383  < 2e-16 ***
## Burn_Size   1.568e-06  4.634e-07   3.383  0.00236 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 6.704 on 25 degrees of freedom
## Multiple R-squared:  0.3141, Adjusted R-squared:  0.2866
## F-statistic: 11.45 on 1 and 25 DF,  p-value: 0.002363
```

```
fires_date %>% ggplot(aes(x= FIRE_YEAR)) +
  geom_line(aes(y = Burn_Size),size = 1, color = "darkred") +
  stat_smooth(aes(method = "lm", y = Burn_Size),
              fill = "royalblue", color = "darkblue") +
  scale_x_continuous(name = " Year",
                     breaks = round(seq(min(fires_date$FIRE_YEAR),
                                        max(fires_date$FIRE_YEAR), by = 2),1)) +
  scale_y_continuous(name = "Acres", labels = scales::comma) +
  ggtitle("Total Acres Burned per Year") + theme_bw()
```



In the second plot, *Total Acres Burned per Year*, the number of acres burned per year or in other terms, the severity of the fires. The linear regression model for the relationship shows a positive correlation between year and total acres burned.

3.3 Time Period with the Most Wildfire Activity

```
fires_1 <- as.data.frame(fires)
fires_1$DISCOVERY_DATE<-as.Date(fires_1$DISCOVERY_DATE, format = "%m/%d/%Y")
fires_1 <- fires_1 %>%
  mutate(day = format(DISCOVERY_DATE, "%d"),
         month = format(DISCOVERY_DATE, "%m"),
         year = format(DISCOVERY_DATE, "%Y")) %>%
  group_by(month, day) %>%
  summarise(total = sum(FIRE_SIZE)/27) %>%
  mutate(date = make_date(month = month, day = day))
ggplot() + geom_line(aes(x = date, y = total), fires_1, color = 'darkred') +
  scale_x_date(date_breaks= "1 month", date_labels = "%b") +
  xlab("Day of Year") + ylab("Average Number of Acres Burned") +
  theme(plot.background = element_rect(fill = "#BFD5E3"))
```

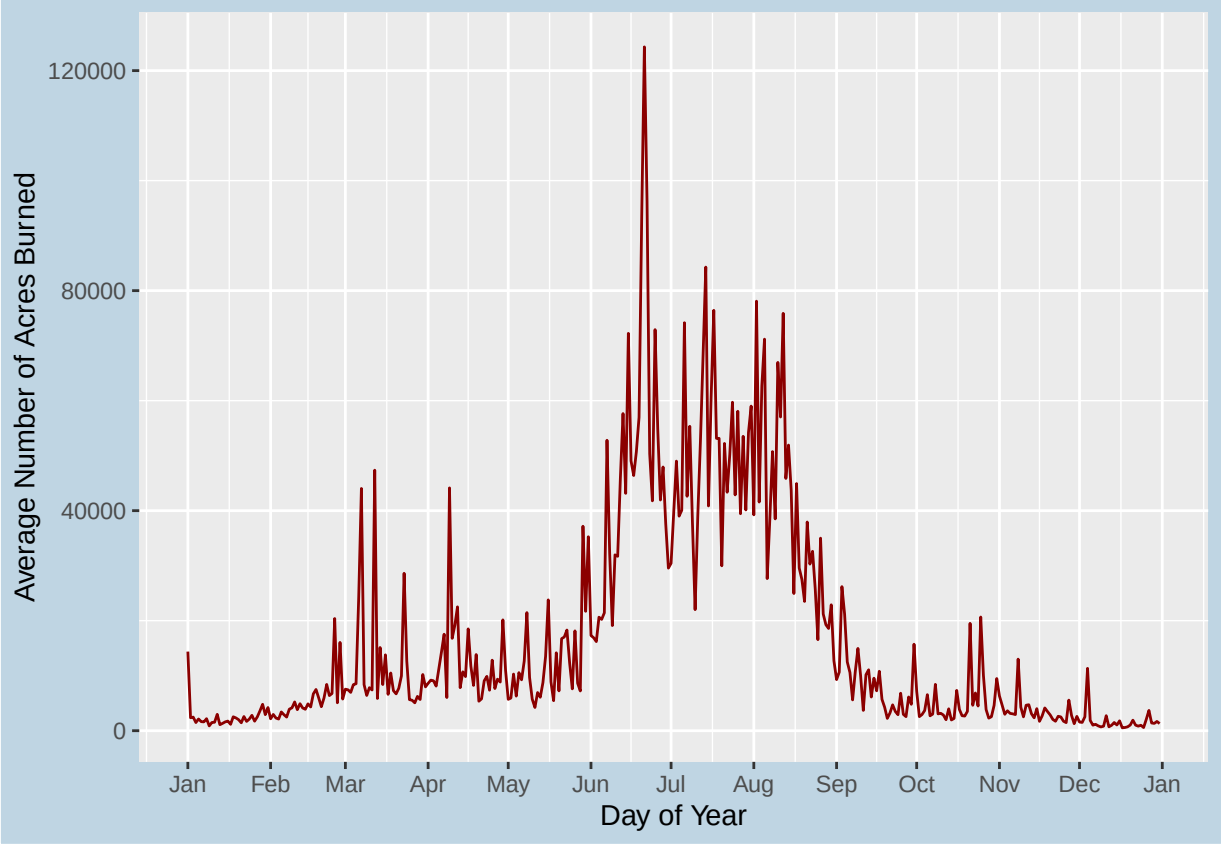


Figure 2: Average Number of Acres Burned by Day of Year

The graph was plotted between the average number of acres burned and day of year from 1992 to 2018. The graph shows there is a peak during June to September every year. Possible

reasons for this are hot temperature and low rainfall during that part of the year. The graph is similar when limiting the data to 2013 to 2018, indicating that this correlation has not changed over time.

3.4 States with the Most Wildfire Activity

```
fires_6 <- as.data.frame(fires)
fires_6 <- fires_6 %>%
  group_by(STATE) %>%
  summarize(total = sum(FIRE_SIZE)/27) %>%
  na.omit()
fires_6 <- as.data.frame(fires_6)
colnames(fires_6)[1] = "state"
plot_usmap(data = fires_6, values = "total",
           color = "darkred", exclude = c("AK"), labels = TRUE) +
  scale_fill_continuous(low = "white", high = "darkred",
                        name = "Acres Burned per Year", label = scales::comma) +
  theme(legend.position = "right",
        legend.title = element_text(size=14),
        legend.text = element_text(size=16),
        plot.caption = element_text(size=20))
```

The heat map of total acres burned of the U.S. show the western states like California, Idaho, and Texas have more severe wildfires than the eastern states. When Alaska is included in the calculations it has the most acres burned than any other state. However, due to the low population of this state, wildfires are allowed to burn with minimal intervention, so for this analysis, Alaska is excluded. This is to highlight states where wildfires are a true threat to the population.

3.5 CA Counties with the Most Wildfire Activity

```
fires_7 <- as.data.frame(fires)
fires_7 <- fires_7 %>%
  filter(STATE == 'CA') %>%
  group_by(FIPS_CODE) %>%
  summarize(total = sum(FIRE_SIZE)/27) %>% na.omit()
fires_7 <- as.data.frame(fires_7)
colnames(fires_7)[1] = "fips"
plot_usmap(data = fires_7, values = "total", "counties",
           include = c("CA"), labels = FALSE, size = 0.4) +
  scale_fill_continuous(low = "white", high = "darkred",
                        name = "Acres Burned per Year", label = scales::comma) +
  theme(legend.position = "right",
        legend.title = element_text(size=16),
        legend.text = element_text(size=18),
        plot.caption = element_text(size=22))
```

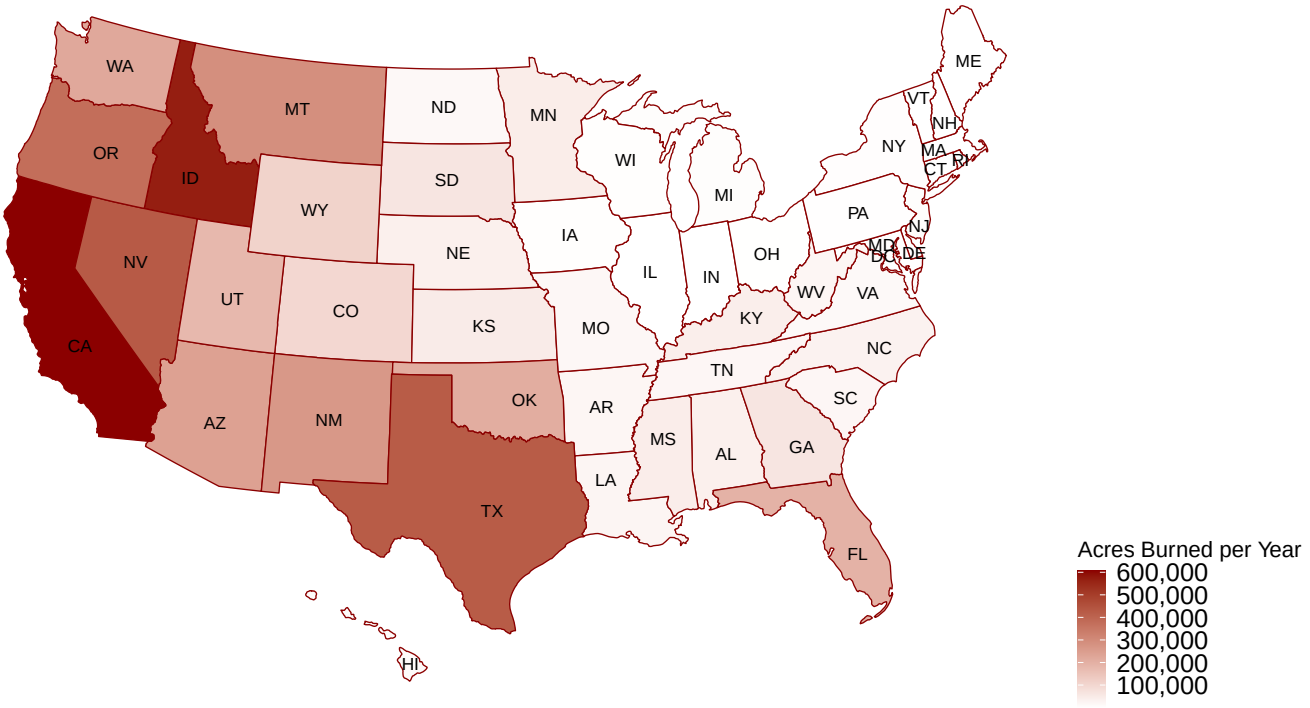


Figure 3: US Wildfres, 1992-2018. The spectrum from white to darkred indicates worse severity of wildfires in that State

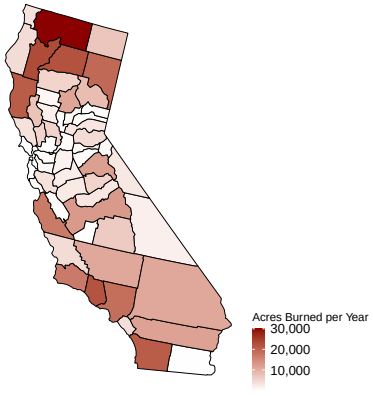


Figure 4: US Wildfires in CA, 1992-2018. The spectrum from white to darkred indicates worse severity of wildfires in that county

Highlighting California, the North and South counties are most at risk for wildfires. Longer periods of drought, high temperatures and high winds have caused these more severe wildfires.

4 Conclusion and Sources of Bias

Through this analysis, several conclusions can be made. First, that while the number of wildfires each year has not increased, the number of acres burned has steadily increased, indicating the severity of the wildfires has gotten worse over time. Second, the peak wildfire season is from June to September, and this season has not changed over the time frame of this dataset. Lastly, the region of the U.S. with the most severe wildfires is the West, specifically California, Idaho, and Texas when Alaska is excluded from the analysis.

However, there are possible sources of bias which could be influencing the findings of this report. It's unclear if the method of counting wildfires has changed over the years. It's possible what used to count as a wildfire does not, or in other terms, fires that occurred in the 90's might not count as a wildfire now, and would not be included in the data. Over the years how the estimate of acres burned by wildfires may have changed as technologies (such as satellite imaging) has improved. There is also the issue of recording smaller fires, or fires that do not persist for long periods of time, those may be missed and not recorded. Finally counties and states across the U.S. may be inconsistent in their reporting, causing bias by geographic location.

5 Further Exploration

There are other findings generated from the dataset that did not directly relate to the initial problem statement. However, they illustrate possible extensions of this analysis and other ways this dataset could be used.

5.1 Wildfires by Cause Classification

```
fires_3 <- as.data.frame(fires)
fires_3 <- fires_3 %>%
  group_by(NWCG_CAUSE_CLASSIFICATION) %>%
  summarize(total = n()) %>%
  na.omit() %>%
  arrange(desc(total))
ggplot(data = fires_3) +
  geom_bar(aes(x = "", y = total, fill = NWCG_CAUSE_CLASSIFICATION), stat = "identity")
  geom_text(aes(x = "", y = total, label = paste0(round(total / sum(total) * 100, 1), "%
  coord_polar(theta = "y") +
  theme_void() +
  theme(legend.position = "right",
        legend.title = element_text(size=10),
        legend.text = element_text(size=8))
```

This plot details the distribution of wildfires by their general cause.

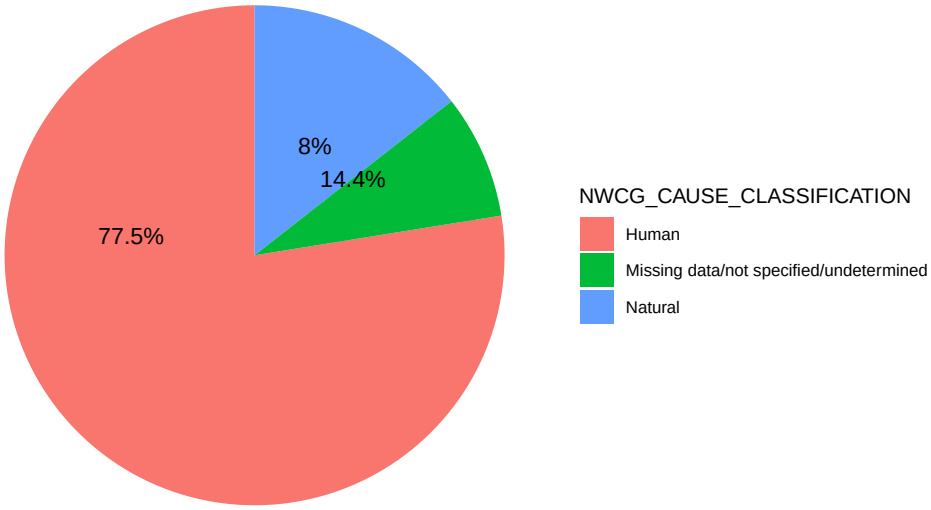


Figure 5: Number of US Wildfires by Cause Type.

5.2 Wildfire by Size Class

```
fires_2 <- as.data.frame(fires)
size_classes <- c('A' = '0-0.25', 'B' = '0.26-9.9','C' = '10.0-99.9', 'D' = '100-299',
                  'E' = '300-999', 'F' = '1000-4999','G' = '5000+')
fires_2 <- fires_2 %>%
  group_by(FIRE_SIZE_CLASS) %>%
  summarize(total = n()/27) %>%
  mutate(FIRE_SIZE_CLASS = size_classes[FIRE_SIZE_CLASS])
ggplot(data = fires_2, aes(x=FIRE_SIZE_CLASS, y = total, fill =FIRE_SIZE_CLASS)) +
  geom_bar(stat = "identity") + scale_fill_brewer(palette = "Reds") +
  xlab("Number of Acres Burned") + ylab("Number of wildfires per Year") +
  geom_text(label = paste0(round(fires_2$total/sum(fires_2$total)*100, 1), "%")) +
  theme(plot.background = element_rect(fill = "#BFD5E3"))
```

This plot shows the distribution of wildfires by their class size, a predetermined classification based on total acres burned.

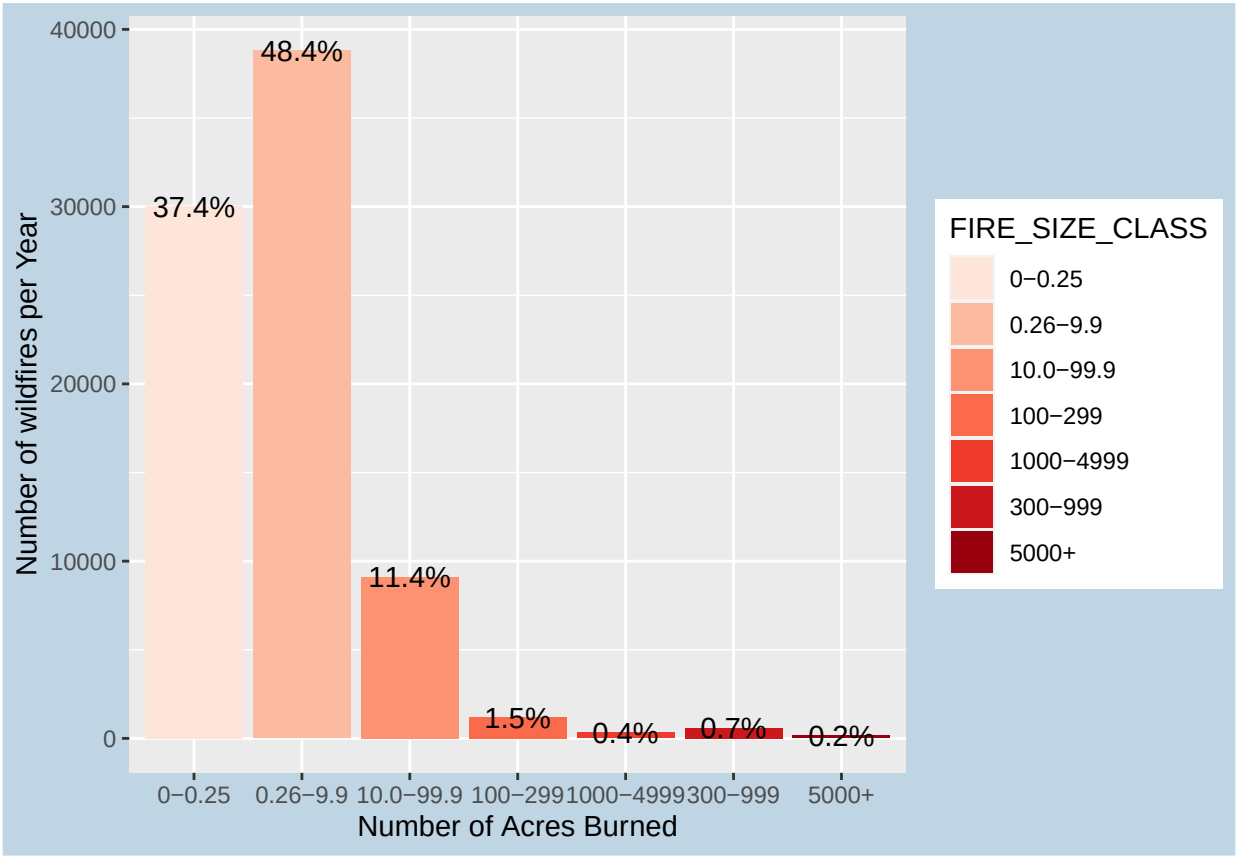


Figure 6: Number of Wildfires by Size Class

5.3 Wildfires by General Cause

```
fires_5 <- as.data.frame(fires)
fires_5 <- fires_5 %>%
  group_by(NWCG_GENERAL_CAUSE) %>%
  summarize(mean_size = mean(FIRE_SIZE, na.rm = TRUE)) %>%
  na.omit() %>%
  arrange(desc(mean_size))
ggplot(data = fires_5) +
  geom_bar(aes(x = reorder(NWCG_GENERAL_CAUSE, mean_size), y = mean_size), stat = "ident
  coord_flip() +
  xlab("WILDFIRE CAUSE") + ylab("Number of Acres Burned per Fire") +
  theme(plot.background = element_rect(fill = "#BFD5E3"))
```

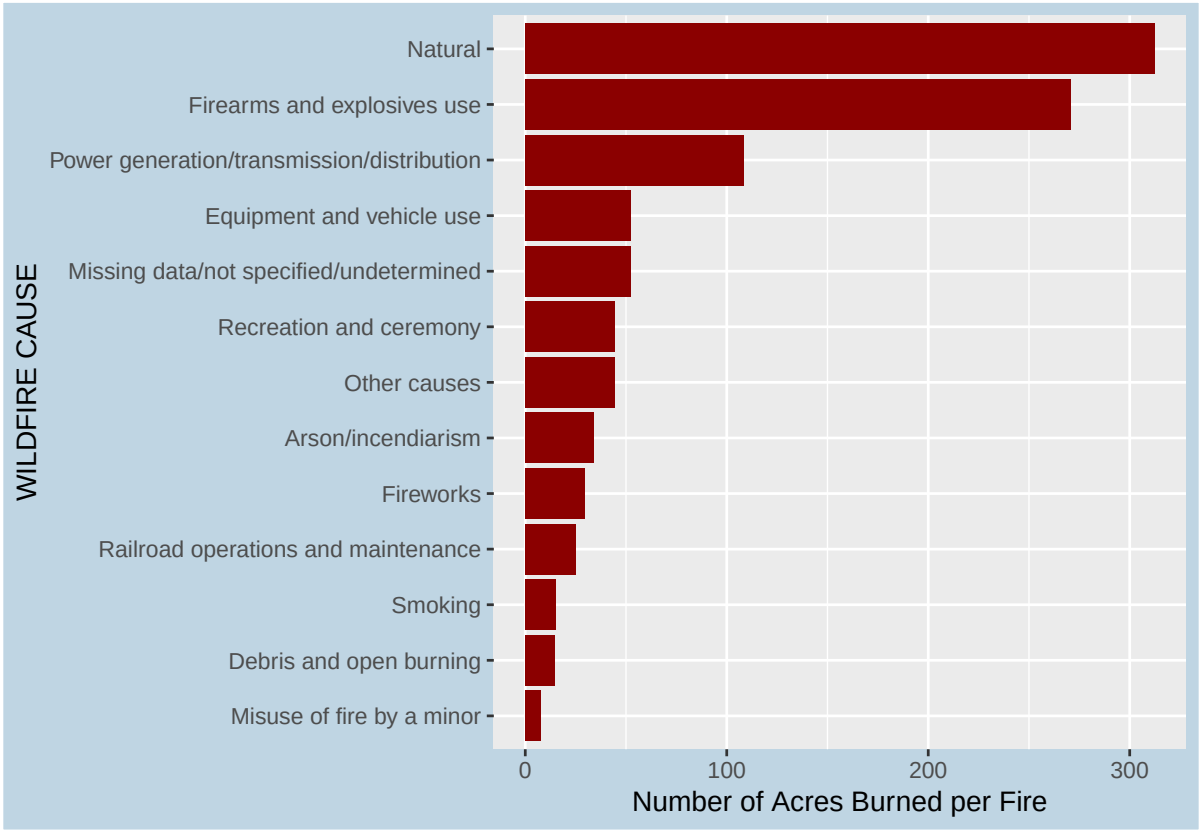


Figure 7: Average Wildfire Size by Cause

This plot shows the relationship between cause and average wildfire size.

6 Possible Extensions

From the information gleaned in the further exploration section, it's clear this dataset has much more to be explored. Extensions of this report include analyzing wildfire causes and how they relate to locations (are certain causes more common in certain parts of the U.S?) as well as building interactive maps using the Shiny application. Those maps could show how fire severity has changed over time across the U.S. or data for specific states like distribution of fire size or most common cause. Finally, it would be interesting to see if it's possible to build a predictive model, that could forecast the size of future wildfires, this might be accomplished by combining this dataset with others, like daily weather data.

7 Related Information and Inspiration

The following provided some inspiration for this project:

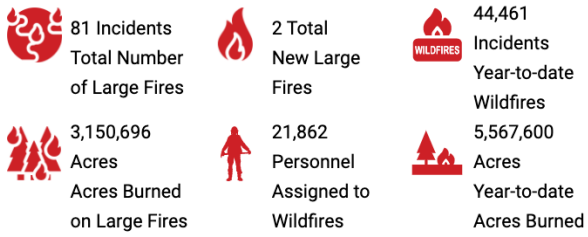


Figure 8: Wildland Fire Summaries for current national statistics

Figure 2 from National Interagency Fire Center on current wildfire statistics.

The **CAL FIRE** website is powered by California Department of Forestry and Fire Protection, under the direction of the state Board of Forestry and Fire Protection. This interactive web tool shows that details wildfire information. annually.

8 References

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