Using GIS and Remote Sensing to Identify Vulnerabilities in the Power Grid Due to Wildfire: A Literature Review

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While numerous studies have been published regarding wildfire and the power grid, the following 14 papers were selected for review because they are current and highly applicable to this Idaho State University/Center for Advanced Energy Studies research project.

Abatzoglou, J. T., Battisti, D. S., Williams, A. P., Hansen, W. D., Harvey, B. J., & Kolden, C. A. (2021). Projected increases in western US forest fire despite growing fuel constraints. *Communications Earth and Environment*, *2*(1). https://doi.org/10.1038/s43247-021-00299-0

Summary

In the western United States, as the years have passed, the number of acres burned by wildfires has drastically increased. The most impactful contributing factors to this upward trend are the high levels of excess, dry fuel loads and increasing duration of fire-weather seasons and weather extremes caused by global warming. However, it is predicted that this increase in burned area may result in less excess arid fuel available. thereby creating fire-fuel feedback loops that reduce the capacity of a forest to sustain a fire. The relationship between climate change, fire-fuel feedback loops, and the potential for future fire activity was modeled. Through multiple iterations of this modeling, it was found that fire-fuel feedback loops only moderately limit the extent of wildfires and that the area for potential burn of forests in the western United States will continue to increase despite this. Large-scale fuel constraints are not yet impactful enough to offset the effects of climate change or to affect the acreage burned in wildfires. This may change as time passes, however the model used in this study provides short term utility in predicting the impacts of fire-fuel and fire-climate relationships. The technology and data used to learn this will allow for sound policy making decisions to be made regarding climate and wildfire related issues in the future.

Connection to our study

This study can be cited when discussing the increases in acreage burned from wildfires in the West. Understanding this concept is vital when communicating with utility companies that fire ignitions from their infrastructure can lead to high-impact consequences, inciting a sense of urgency or importance for prevention.

Dillon, G. K., Menakis, J., & Fay, F. (2015). ***Wildland Fire Potential: A Tool for Assessing Wildfire Risk and Fuels Management Needs*****.**

Summary

This paper describes the purpose, methods, and potential uses of a Wildland Fire Potential (WFP) map. The purpose of the map is to inform wildfire managers about where wildfires are likely to be and show areas that would be difficult for suppression resources to contain. This was done by combining data from the Large Fire Simulation system, fuel and vegetation data from LANDFIRE 2008, and historic fire locations from the Fire Program Analysis system. The final product was a 270-meter resolution map of the conterminous United States. This map should be used jointly with other data (e.g. valuable infrastructure) to determine long-term strategic fuels management.

Connection to our study

This paper can be cited when discussing the land management aspect of assessing wildfire risk. Though the raster layer product will not be directly incorporated into our study, it can be referenced when making conclusions about how our analysis is relevant to land managers.

Finney, M. A., McHugh, C. W., Grenfell, I. C., Riley, K. L., & Short, K. C. (2011). A simulation of probabilistic wildfire risk components for the continental United States. ***Stochastic Environmental Research and Risk Assessment*****,** ***25*****(7), 973–1000. https://doi.org/10.1007/s00477-011-0462-z**

Summary

A simulation for large-scale fires in the contiguous United States was conducted to provide policy makers with the tools and knowledge necessary to make sound decisions regarding wildfire risk and management. The simulation performed burn probability assessments to determine average probability of a wildfire occurrence and average fire sizes. The simulation was run in artificial time allotments of years that were composed of 365 values of variables that were relevant to the simulation. Some such variables include wind speed and direction and fuel composition and moisture levels. The simulation was run for tens of thousands of years to ensure adequate collection of simulated data. This simulation showed that fire probabilities are significantly higher in the western portion of the United States. This simulation was the first of its kind and provided the public with tools with the potential to be used for fire management and mitigation options as well as fire risk assessment.

Connection to our study

This paper is useful to my research because the fire simulation was used to produce many of my relevant datasets, specifically Burn Probability. By understanding the methods, we can better understand how models and conclusions in later papers were drawn.

Holden, Z. A., Morgan, P., Crimmins, M. A., Steinhorst, R. K., & Smith, A. M. S. (2007). Fire season precipitation variability influences fire extent and severity in a large southwestern wilderness area, United States. *Geophysical Research Letters*, *34*(16). https://doi.org/10.1029/2007GL030804

Summary

Satellite data were collected for the years 1984 - 2004 to quantify trends in wildfire occurrence and severity and to analyze the relationship between these fires and the intensity of precipitation events throughout their respective annual fire seasons. Relative Difference Normalized Burn Ratios (RdNRB) were created for each of the 114 fires in the study area, so as to determine the severity of the burn. These data were cross-referenced with historical precipitation data such as the total annual number of days without rain. The results showed a strong correlation between the severity of wildfires and the number of days without rain, suggesting that fewer rain-free periods equates to fewer and less-severe fires. Upward trends in fire severity and occurrence in the study area can be attributed, at least in part, to a decrease in the consecutive and total number of days with rain. Snowpack was also considered in this study, but it was determined that the amount of annual snow has little effect on wildfire severity. By observing the relationships between environmental factors and wildfires, sound decisions can be made regarding environmental policy.

Connection to our study

We are using precipitation as a wildfire driver in statistical analysis. This paper can be cited when arguing the effect of precipitation on burn probability between both study areas.

Jahn, W., Urban, J. L., & Rein, G. (2022). Powerlines and Wildfires: Overview, Perspectives, and Climate Change. *IEEE Power and Energy Magazine*, *20*(1), 16–27. https://doi.org/10.1109/mpe.2021.3135140

Summary

There are a multitude of factors that contribute to wildfire ignition and spread, the majority of which are human-influenced. Overhead power-lines are a major source of ignition, as electrical faults caused by foreign objects coming into contact with the line or by lightning can trigger thermal expansion and melting of metals that then fall onto vegetation below and ignite. Wind and weather, exacerbated by climate change, are also major contributors to wildfire ignition and spread. These wildfires contribute to carbon emissions which results in a decrease in moisture levels in vegetation, which leads to an increase in fire spread and intensity. These factors result in an increased danger to power-lines of further fire ignition and propagation. Although not all parts of the world follow these trends and they are more applicable on a local scale, they are consistent enough to be acknowledged. With this knowledge, wildfire prevention and mitigation strategies can be improved and implemented.

Connection to our study

This article acts as a broad summary of the power grid-wildfire nexus. It contributes to our understanding of wind dynamics and its effect on power lines and resulting ignitions. It contains graphics and further reading that can be helpful in developing the final paper.

Keeley, J. E., & Syphard, A. D. (2018). Historical patterns of wildfire ignition sources in California ecosystems. *International Journal of Wildland Fire*, *27*(12), 781–799. https://doi.org/10.1071/WF18026

Summary

The frequency and acreage of wildfires in California has been recorded since the 1910's by both federal and state agencies such as United States Forest Service (USFS) and Cal Fires. Upon statistical analysis of these datasets, several variables proved to be factors as to the frequency and acreage of the wildfires. The variables looked at in the study include the following: lightning, arson, debris, smoking, playing with fire, equipment, vehicles, and power lines. These variables, when looked at over time, show spatial patterns in California. Trends vary over space and time, creating associations in the data. The most notable associations are that lightning strikes were more common in northern latitudes and in higher elevations, and that humans are generally the cause of the most fires. Additionally, the variables vary in intensity over time, showing a decrease in the overall number of wildfires from 1980 to 2016. Fire ignitions total, excluding fires caused by power lines which have been increasing, have all been decreasing in frequency. Despite the number of fires decreasing, the total acreage burned by fires stayed relatively consistent throughout the years. Therefore, there is no strong correlation between number of fires and acreage burned. These insights can be used in fire prevention and mitigation practices.

Connection to our study

This study can cite the finding that fires caused by power lines have been increasing in California compared to other human causes. It can be referenced when discussing the selection of lightning as a potential wildfire driver and may explain the difference in strike frequency between the Low BP area (higher elevation) and High BP area (lower elevation).

Keeley, J. E., & Syphard, A. D. (2019). Twenty-first century California, USA, wildfires: fuel-dominated vs. wind-dominated fires. *Fire Ecology*, *15*(1). https://doi.org/10.1186/s42408-019-0041-0

Summary

Although not all contributing factors can be taken into consideration at once, many fires in California in the twenty-first century can be modeled into a simple classification system; those that are fuel-dominated and those that are wind-dominated. The classification of fires into these two categories allows researchers to better understand past behaviors and predict future behaviors, thereby hopefully reducing the impact of California wildfires in the future. Fuel-dominated fires, which frequently occur in the central and northern parts of California, generally come about as a result of poor land management and fire suppression tactics combined with natural ignitions, such as lightning strikes. However, most of these fires do not result in significant loss of life, as these fires occur in low population density areas. The impact of these fires can be minimized using mitigating forest practices such as tree removal and prescription burning. Wind-dominated fires occur mainly in southern California, an area of high population density. Because of this, the majority of these fires are caused by human activity and can therefore be prevented with human activity. The impact of these fires can be minimized using proper fire prevention and planning strategies. These ideas can be used in fire classification and prevention practices.

Connection to our study

It is important to look at the variables of fuel and wind when differentiating the burn probability between the two study areas. Understanding which study area is dominantly fuel- or wind-dominated may provide more insight and information in regards to fire prevention around energy infrastructure.

National Academies of Sciences, Engineering, and Medicine (2017). Enhancing the Resilience of the Nation's Electricity System. Washington, DC: The National Academies Press. 64-66. https://doi.org/10.17226/24836

Summary

As time passes and as the climate continues to change and become warmer, there is increased risk for more frequent wildfires in the United States. Additionally, wildfire intensity is also increasing because of this. These fires have the potential to cause localized negative impacts on the power grids in their area. This is not always avoidable, so other measures need to be taken by the United States government to prevent the disruption of power systems. Complete and comprehensive data sets are necessary to ensure the continued operation of power systems. Additionally, hazard and risk assessments must be performed for further assurance.

Connection to our study

This paper can be cited when discussing the direct effects of wildland fire to power system hardware, the time it takes to restore power, and the monetary impacts to companies and communities.

Radeloff, V. C., Hammer, R. B., Stewart, S. I., Fried, J. S., Holcomb, S. S., & Mckeefry, J. F. (2005). The Wildland-Urban Interface in the United States. In *Communications Ecological Applications* (Vol. 15, Issue 3). http://www.silvis.forest.wisc.edu/projects/WUI

Summary

The Wildland-Urban Interface (WUI) in the contiguous United States is the area in which human settlements meet undeveloped wilderness areas, and it covers approximately 9.4% of land area and houses 38.5% of all housing units at the time this analysis was conducted. Data was collected from the United States Geological Survey National Land Cover Data set and analyzed. Sensitivity analyses were applied to assess the accuracy of WUI area estimates, determining that the WUI assessment was indeed robust. Although WUI does not directly assess the risk of a wildfire occurring, it provides insights to many larger issues such as appropriate housing development locations and wildland conservation efforts.

Connection to our study

This paper details the premise of the Wildland-Urban Interface, how it can be mapped, and its ecological implications. We will use this paper specifically for its information regarding fire management.

Schoennagel, T., Veblen, T. T., & Romme, W. H. (2004). The Interaction of Fire, Fuels, and Climate across Rocky Mountain Forests. *BioScience*, *54*(7), 661–676.

Summary

Fire mitigation practices such as thinning are being applied unilaterally across forests in the Rocky Mountain region of the United States without precautions being taken as to what kinds of ecosystems and forests exist in the regions. There are three types of historical fire regimes identified in the study: high severity, low severity, and mixed severity, each with their own fire mitigation strategies. High severity fire regimes typically occur in subalpine forests where climatic variation is the driving factor behind fire severity. It was found that fire suppression tactics such as fuel load reduction are generally ineffective for preventing fires in these types of forests, and that they may have negative effects on the ecosystem instead. This is not the case in ponderosa pine dominated forests, as it was shown that areas with low-severity fire regimes do in fact respond well to fuel load reduction tactics. Mixed-severity fires were shown to have moderate responses to fuel load reduction tactics. In order to both improve fire suppression and mitigation techniques as well as properly preserve the ecosystems of the United States' diverse forests, policy makers cannot treat all forests as the same and must take into consideration the type of forests present.

Connection to our study

Citing this paper, we can make the argument that when land and utility managers are planning fuel reduction strategies around power infrastructure, they need to consider the type of forest surrounding the infrastructure.

Scott, J. H., Thompson, M. P., & Calkin, D. E. (2013). *A Wildfire Risk Assessment Framework for Land and Resource Management*. http://www.fs.fed.us/rmrs

Summary

A scalable and flexible framework to assess the risk posed by wildfires was developed by the United States Department of Agriculture to assist policy makers in the decision-making processes. In this framework, wildfire risk is defined as the likelihood of a fire, the intensity of a fire, and the susceptibility of an environment to a fire's effects. These factors are independent of each other. Other major factors included in the assessment are exposure and effect analysis. Risk is characterized through wildfire simulation and a comprehensive analysis process, with any uncertainties having been considered. Burn Probability is modeled and other, comparable analyses are performed using software. The results are used to determine wildfire risk, which is in turn used in tandem with management objectives and opportunities to create a proper wildfire risk mitigation strategy which can then be implemented in a community or even on a larger scale.

Connection to our study

This paper can be cited when discussing the uses of wildfire simulations. It includes important wildland fire concepts that should be addressed, such as "the primary factors affecting wildfire intensity—fuel, weather, and topography—therefore also affect wildfire hazard (16)."

Scott, J. H., Gilbertson-Day, J. W., Moran, C., & Dillon, G. K.; (2020). ***Wildfire Risk to Communities: Methods for geospatial and tabular datasets*. https://doi.org/10.2737/RDS-2020-0016**

Summary

The Wildfire Risk to Communities project was developed to provide communities inside the United States (including Alaska and Hawaii) with a variety of spatial datasets with the intent to represent the potential threat that a wildfire could pose. This project focused on housing units inside of these localized communities as opposed to focusing on wildlands or rangelands in order to provide the most practical utility. A variety of datasets were used to gather the data necessary to make these resulting datasets, including LANDFIRE and census data. These data were then downscaled from having 270-meter spatial resolution to having 30-meter spatial resolution to improve utility within communities. The data were put into a simulation, accounting for errors and issues from previously run simulations, to estimate the hazard wildfires pose to developed communities. A resulting eight datasets were produced and released to the public for use. These datasets were the following: Burn Probability, Conditional Flame Length (CFL), Flame Length Exceedance Probability—4 feet (FLEP4), Flame-length exceedance probability—8 feet (FLEP8), Exposure Type, Conditional Risk to Potential Structures (cRPS), Risk to Potential Structures (RPS), and Wildfire Hazard Potential (WHP). Each of these datasets are frequently used when assessing the risk that wildfires pose to human settlements, and they provide necessary insights into actions that can be taken to mitigate risk.

Connection to our study

We are using the Burn Probability raster layer produced from this study. The raster was used to determine study areas (high and low burn probability). We will cite this paper as a data source.

Smith, J. T., Allred, B. W., Boyd, C. S., Davies, K. W., Jones, M. O., Kleinhesselink, A. R., Naugle, D. E., & Franke, W. A. (2022). Where there's smoke, there's fuel: predicting Great Basin rangeland wildfire. *Rangeland Ecology & Management.* https://doi.org/10.1101/2021.06.25.449963

Summary

In order to evaluate the utility of fire probability models, researchers are using machine learning. Randomized forest models are created using advanced classification algorithms to accurately predict the probability that some forest in the Great Basin Area burns based on given characteristics in a computer simulation. Some of the variables that were able to be manipulated in the simulation were herbaceous vegetation cover area, water availability, and climate variability. When the simulation was tested, it was observed that the burned area generally increased as predicted fire probability increased. The simulation also showed that herbaceous vegetation cover was the most influential variable in assessing wildfire probability. With this knowledge, informed decisions regarding the relative wildfire danger for the given area can be made. Additionally, small-scale best management practices can be implemented to mitigate the impacts that wildfires, when they do occur, have on communities.

Connection to our study

When describing why we used NDVI as a variable, we can explain how it is a proxy for vegetation productivity and can cite this paper when claiming that vegetation contributes to wildfire probability. We can also use this study when recommending vegetation reduction or other management around energy infrastructure.

Weber, K. T., & Yadav, R. (2020). Spatiotemporal Trends in Wildfires across the Western United States (1950-2019). In *Remote Sensing* (Vol. 12, Issue 18). MDPI AG. https://doi.org/10.3390/RS12182959

Summary

In the NASA RECOVER Historic Fires Database (HFD), which contains all fires documented in the western United States in the years 1950-2019, trends in fire severity and frequency can be observed and analyzed through the use of Geographic Information System (GIS) software. Although it is likely that some wildfires occurred in the early HFD years that were not documented, the difference in expected fire frequency and recorded fire frequency is small, resulting in the data still being accurate. Analyses were performed to determine statistics regarding fire frequency and acreage burned. In addition, several Difference Normalized Burn Ratio (dNBR) were applied to the data so that trends in severity could be analyzed as well. These analyses showed that wildfires are not random events and suggests that the frequency of wildfires is determined by environmental factors such as climate and fuel load and type. Additionally, shown was that fire severity is likely not driven by the same factors as fire frequency, rather being driven by location-specific factors. These results can be used by policy makers to make sound environmental decisions regarding wildfires and the effects they have on ecosystems and communities.

Connection to our study

When discussing the importance of preventing power-line ignited fires, this study can be referenced to emphasize the importance of preventing mega-fires, which are becoming more prominent as a result of increased fuel load due to decades of fire suppression.