2022-12

FORESTRY AND FIRE MANAGEMENT IN THE WEST: A DYNAMIC HOMELAND SECURITY ENEMY

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MONTEREY, CALIFORNIA

THESIS

FORESTRY AND FIRE MANAGEMENT IN THE WEST: A DYNAMIC HOMELAND SECURITY ENEMY

by

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December 2022

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** December 2022	**3. REPORT TYPE AND DATES COVERED** Master's thesis

4. TITLE AND SUBTITLE
FORESTRY AND FIRE MANAGEMENT IN THE WEST:
A DYNAMIC HOMELAND SECURITY ENEMY

5. FUNDING NUMBERS

6. AUTHOR(S) Sabrina L. Lehrke

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release. Distribution is unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT (maximum 200 words)

This thesis answers two questions: How has the difference between western states' forestry and fire management practices affected wildland fire response and how can forestry and fire management stakeholders address wildfire scale and frequency in the western United States? Through a comparative analysis approach, the research presented in this thesis showcases three western states (Arizona, California, and Alaska) to offer a glimpse at similar wildfire behavior and impacts across the West. Thus, the research provided in this thesis applies to most western states and underscores the point that resiliency against wildfires is imperative to ensuring the protection of the nation's natural resources, communities, and critical infrastructure. As a result, this thesis offers four recommendations that include community involvement, the allocation and utilization of resources (i.e., personnel, equipment, and technology), immediate action from policymakers, and examination of alternative solutions (i.e., technology and "Smokey the Beaver"). In all, the wildfire threat will continue to evolve in the United States, especially in the West, so action must be taken, and solutions must be identified for years to come to mitigate wildfire impacts on forests, communities, and critical infrastructure.

14. SUBJECT TERMS wildfires, forestry and fire management, western U.S., climate change, human activity, United States Forest Service, Arizona, California, Alaska, community involvement, technology	**15. NUMBER OF PAGES** 215
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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**FORESTRY AND FIRE MANAGEMENT IN THE WEST:
A DYNAMIC HOMELAND SECURITY ENEMY**

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Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF ARTS IN SECURITY STUDIES
(HOMELAND SECURITY AND DEFENSE)**

from the

**NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

This thesis answers two questions: How has the difference between western states' forestry and fire management practices affected wildland fire response and how can forestry and fire management stakeholders address wildfire scale and frequency in the western United States? Through a comparative analysis approach, the research presented in this thesis showcases three western states (Arizona, California, and Alaska) to offer a glimpse at similar wildfire behavior and impacts across the West. Thus, the research provided in this thesis applies to most western states and underscores the point that resiliency against wildfires is imperative to ensuring the protection of the nation's natural resources, communities, and critical infrastructure. As a result, this thesis offers four recommendations that include community involvement, the allocation and utilization of resources (i.e., personnel, equipment, and technology), immediate action from policymakers, and examination of alternative solutions (i.e., technology and "Smokey the Beaver"). In all, the wildfire threat will continue to evolve in the United States, especially in the West, so action must be taken, and solutions must be identified for years to come to mitigate wildfire impacts on forests, communities, and critical infrastructure.

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LIST OF ACRONYMS AND ABBREVIATIONS

4FRI	Four Forest Restoration Initiative
AI	artificial intelligence
ARF	Anaktuvuk River Fire
BAER	Burned Area Emergency Response
BIA	Bureau of Indian Affairs
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
CAA	Clean Air Act
CAL FIRE	California Department of Forestry and Fire Protection
CE	categorical exclusions
CEQ	Council on Environmental Quality
DFES	Australia Department of Fire and Emergency Services
DFFM	Arizona Department of Forestry and Fire Management
DHS	Department of Homeland Security
DOD	Department of Defense
DOF	Division of Forestry
DOI	Department of the Interior
EA	environmental assessments
EIS	environmental impact statement
EO	executive order
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GLO	General Land Office
HFI	Healthy Forest Initiative Grant
IA	Individual Assistance
IMTs	incident management teams
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act

NFPA	National Fire Protection Association
NIFC	National Interagency Fire Center
NPS	National Park Service
PA	Public Assistance
PSD	plastic sphere dispenser
SCAT	San Carlos Apache Tribe
SDLE	Stay and Defend or Leave Early
SRA	State Responsibility Area
USDA	U.S. Department of Agriculture
USFS	U.S. Forestry Service
USGS	U.S. Geological Survey
WIMS	Weather Information Management System
WMAT	White Mountain Apache Tribe
WUI	wildland-urban interface

EXECUTIVE SUMMARY

In the 2020 *Homeland Threat Assessment*, the Department of Homeland Security listed wildfires as a top threat to the homeland.[1] More specifically, in the western United States, more than 26,000 wildfires burned approximately 9.5 million acres, resulting in 43 direct deaths and 3,000 indirect deaths and totaling $16.5 billion in damages in 2020.[2] Most wildfires (80%) have been on federal lands; nonetheless, a unified front is necessary for addressing Western wildfires, as 85% of wildfires are caused by humans.[3] Within the last decade, wildfires in the western United States have increased in scale and frequency due to climate change factors and human activity.[4] In the same vein, across the West, there has been a significant rise in the number of people living in the wildland-urban interface (WUI) and personnel shortages for wildfire suppression and mitigation, which is problematic for obvious reasons.[5] Since the wildfire threat is expected to return yearly, the United States needs to ensure communities and critical infrastructure are protected and prepared against the threat and that forest health is strong to preserve the homeland's resiliency.

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[1] Department of Homeland Security, *Homeland Threat Assessment* (Washington, DC: Department of Homeland Security, 2020), https://www.dhs.gov/sites/default/files/publications/2020_10_06_homeland-threat-assessment.pdf.

[2] Katie Hoover and Laura A Hanson, *Wildfire Statistics*, CRS Report No. IF10244 (Washington, DC: Congressional Research Service, 2022), https://crsreports.congress.gov/product/pdf/IF/IF10244; Jeff Masters, "Reviewing the Horrid Global 2020 Wildfire Season," Eye on the Storm, January 4, 2021, http://yaleclimateconnections.org/2021/01/reviewing-the-horrid-global-2020-wildfire-season/; Marshall Burke and Sam Heft-Neal, "Indirect Mortality from Recent Wildfires in California," Global Food, Environment and Economic Dynamics (blog), September 11, 2020, http://www.g-feed.com/2020/09/indirect-mortality-from-recent.html.

[3] Wildfire Causes and Evaluations," National Park Service, March 8, 2022, https://www.nps.gov/articles/wildfire-causes-and-evaluation.htm; Hoover and Hanson, *Wildfire Statistics*, 2022.

[4] Deb Schweizer, "Wildfires in All Seasons?," *U.S. Department of Agriculture* (blog), July 29, 2021, https://www.usda.gov/media/blog/2019/06/27/wildfires-all-seasons.

[5] Federal Emergency Management Agency and U.S. Fire Administration, *Wildland Urban Interface: A Look at Issues and Resolutions* (Washington, DC: Federal Emergency Management Agency, 2022), https://www.usfa.fema.gov/downloads/pdf/publications/wui-issues-resolutions-report.pdf; Zach Urness, "Labor Shortage Leaves U.S. Struggling to Hire Firefighters Despite Record Wildfire Funding," *Statesman Journal*, May 11, 2022, sec. Nation, https://www.statesmanjournal.com/story/news/nation/2022/05/11/worker-shortage-western-drought-wildfire-season-2022-wildland-firefighter-hirings/65354018007/.

This thesis compares and evaluates forestry and fire management practices in the western United States to identify a more unified approach among stakeholders to address wildfire scale and frequency. In doing so, this thesis seeks to answer the questions: How has the difference between western states' forestry and fire management practices affected wildland fire response and how can forestry and fire management stakeholders address wildfire scale and frequency in the western United States? For this thesis, forestry and fire management stakeholders include firefighters, forestry managers, policymakers, and citizens. In all, the intention behind this thesis and the research showcased is to bring the conversation of the West's wildfires to the forefront of the nation's agenda to advocate for a unified approach, as catastrophic wildfires impact the country every year.

In addition to the introduction and conclusion, this thesis has four main chapters that detail key factors and conversations surrounding the wildfire threat in the western United States. Through a comparative analysis approach, the research presented in this thesis showcases three western states (Arizona, California, and Alaska) to capture the historical and current forestry and fire trends to convey wildfire impacts on forest health, communities, and critical infrastructure. This thesis also offers two fictional scenarios based on real events that are intertwined with simulation models via FARSITE, a tool offered by the U.S. Forest Service (USFS) to produce fire growth simulations, to visualize the effectiveness of mitigation efforts on wildfire growth and illustrate wildfire impacts on communities and forest health. Furthermore, this research compares the factors, resources, and costs associated with prescribed burns and wildfires and wildfire suppression and mitigation to provide decision-makers and citizens with the effects behind each action and advocate for the prioritization and investment for prescribed burns and mitigation projects. Last, this thesis covers landmark legislation and recent federal initiatives that relate to and influence forestry and fire management to showcase the opportunities and potential challenges posed to forestry managers. This research also details the discussion surrounding post-wildfire hazards and recovery efforts, including insurance dilemmas and the need for community involvement to demonstrate the critical components of maintaining resilient communities, and further emphasizes wildfire impacts. Overall, showcasing the three western states offers a glimpse at similar wildfire

behavior and impacts across the West. Thus, the research provided in this thesis applies to most western states and underscores the point that resiliency against wildfires is imperative to ensuring the protection of the nation's natural resources, communities, and critical infrastructure.

In answering the two research questions posed, the bottom line is forestry and fire management operations at the federal and state levels are not negatively impacting wildland fire response, as they all share a similar mission, conduct mitigation projects, and receive and distribute funds to reduce the wildfire threat. However, the primary drivers affecting wildland fire response in each state are the climate conditions, human activity, invasive species, the availability of personnel and resources during and off-season, and the expansion of the WUI. Regarding the second question, four recommendations are offered to forestry and fire management stakeholders to address wildfire scale and frequency in the western United States.

There is no single answer to reducing wildfire impacts and improving the West's resiliency against wildfires. Nonetheless, steps can be made among all stakeholders to address the wildfire threat. For one, community involvement is integral to addressing wildfire scale and frequency. Community engagement among residents, tribes, forestry professionals, and scholars is crucial in identifying community solutions to mitigate wildfire impacts. Second, additional resources and utilization of technology would prove beneficial in mitigating wildfire threats. For instance, simulation tools, like FARSITE, can inform strategic mitigation projects and citizens about the success mitigation projects can offer. Ultimately, resource allocation and sustainment are vital to wildfire prevention and suppression. Third, action is needed among policymakers to incentivize mitigation operations, push funding to forestry agencies, address insurance concerns, and create a cohesive approach among western states. Last, examining alternative solutions and being open to implementing them is critical for forestry managers, as these solutions can effectively mitigate wildfires. All in all, the wildfire threat will continue to evolve in the United States, especially in the West, so action must be taken, and solutions must be identified for years to come, to mitigate wildfire impacts on forests, communities, and critical infrastructure.

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ACKNOWLEDGMENTS

I am forever grateful to be a part of the Naval Postgraduate School's Center for Homeland Defense and Security (CHDS) program. The CHDS staff and the 2103/2104 cohort gave me invaluable memories, thoughts, support, and (ultimately) an incredible education. Second, I would like to give the ultimate thanks to my thesis committee, Dr. Tom Mackin and Kristen Fletcher, for their indispensable guidance and devotion to the topic of this thesis, and to Collette O'Connor, who had the painstaking task of reading my drafts.

Second, a very, very special thank you to my colleagues at the Arizona Department of Emergency and Military Affairs and a special shoutout to the Operations Section. Thank you for the time, conversations, support, and encouragement during work and my academics. If it weren't for you, I would have never known about CHDS, been able to apply, or have had the time to continue pursuing.

Of course, I would like to thank my family and friends for their encouragement and support for all my endeavors, as they have taught me to pursue my passions fiercely and to always do good in the world. In the same vein, thank you to my mother and father for taking me on adventures to explore our incredible backyard, Lake Tahoe, for playing in the Sierra Nevada developed my love of nature.

Last, the beauty of the nation's forests and landscapes would not be possible without Theodore Roosevelt and others, who led the charge on conserving the nation's national forests. With that said, thank you to all the conservationists and forestry managers working toward preserving and protecting the irreplaceable beauty of the nation's landscape. Ultimately, thank you to the firefighters who risk their lives and spend time away from family to protect our homes, forests, and lives.

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I. INTRODUCTION

A. PROBLEM STATEMENT

During the last decade, forests throughout the western United States have experienced a shift in wildfire scale and frequency due to climate change and human activity.[1] According to the National Aeronautics and Space Administration (NASA), lightning initiated many of the region's fires in 2020. Still, severe meteorological conditions—including extreme wind and dry air and a buildup of fuels on top of severe drought—contributed to the scale and intensity.[2] Indeed, the western fire season used to be four months—between June and September—but now lasts six to eight months. Likewise, in recent years, western wildfires have spread across thousands of acres, preventing forests from regenerating as quickly as in previous decades.[3] In 2020 alone, the western United States experienced more than 26,000 wildfires that burned approximately 9.5 million acres, resulting in 43 direct deaths, 3,000 indirect deaths, and totaling $16.5 billion in damages, the third-highest-cost on record.[4] The extended period of the season strains response resources and shortens the period during the off-season to conduct mitigation efforts. For these reasons, the 2020 *Homeland Threat Assessment*, published by the Department of Homeland Security (DHS), lists wildfires as a top threat to the homeland and emphasizes the need to "undertake better and more active land

[1] Deb Schweizer, "Wildfires in All Seasons?," *U.S. Department of Agriculture* (blog), July 29, 2021, https://www.usda.gov/media/blog/2019/06/27/wildfires-all-seasons.

[2] National Aeronautics and Space Administration, "Historic Fires Devastate the U.S. Pacific Coast," Earth Observatory (NASA Earth Observatory, September 9, 2020), https://earthobservatory.nasa.gov/images/147277/historic-fires-devastate-the-us-pacific-coast. ("Record-breaking air temperatures, periods of unusually dry air, and blasts of fierce winds—on top of serious drought in some areas—led fires to ravage forests and loft vast plumes of smoke to rarely seen heights.")

[3] Alejandra Borunda, "The Science Connecting Wildfires to Climate Change," Planet Possible, September 17, 2020, https://www.nationalgeographic.com/science/article/climate-change-increases-risk-fires-western-us.

[4] Katie Hoover and Laura A. Hanson, *Wildfire Statistics*, CRS Report No. IF10244 (Washington, DC: Congressional Research Service, 2021), https://sgp.fas.org/crs/misc/IF10244.pdf; Masters, "2020 Wildfire Season"; Burke and Heft-Neal, "Indirect Mortality from Recent Wildfires in California."

management" at all levels of government.[5] The DHS *Threat Assessment* underscores the need for state and private entities to collaborate with federal partners on improved forestry and fire management practices to prevent wildfires.

The western landscape consists of multiple owners with varying and, at times, conflicting land management objectives, which can pose socioecological concerns to forestry management.[6] In the West, 80% (4.9 million acres) of burned land in 2021 was on federal lands.[7] The remaining percentage consisted of the wildland-urban interface (WUI) with family and individual ownership, corporate ownership, and ownership by other private entities.[8] The U.S. Fire Administration defines the WUI as "the zone of transition between unoccupied land and human development. It is the line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels."[9] Thus, land management practices at all levels of government, including private entities, determine the growth of forests that fuel the scale and intensity of wildfires. This thesis compares and evaluates these forestry and fire management practices in the western United States to identify a more unified approach among stakeholders to address wildfire scale and frequency.

B. RESEARCH QUESTIONS

How has the difference between western states' forestry and fire management practices affected wildland fire response? How can forestry and fire management stakeholders address wildfire scale and frequency in the western United States?

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[5] Department of Homeland Security, *Homeland Threat Assessment* (Washington, DC: Department of Homeland Security, 2020), https://www.dhs.gov/sites/default/files/publications/2020_10_06_homeland-threat-assessment.pdf.

[6] Harold S. J. Zald and Christopher J. Dunn, "Severe Fire Weather and Intensive Forest Management Increase Fire Severity in a Multi-Ownership Landscape," *Ecological Applications* 28, no. 4 (June 2018): 1068–80, http://www.jstor.org/stable/26623209.

[7] Hoover and Hanson, *Wildfire Statistics*, 2021.

[8] U.S. Forest Service, *Who Owns America's Trees, Woods, and Forests?*, NRS-INF-31-15 (Washington, DC: U.S. Department of Agriculture, 2015), https://www.fs.fed.us/nrs/pubs/inf/nrs_inf_31_15-NWOS-whoowns.pdf.

[9] "What Is the WUI?," U.S. Fire Administration, https://www.usfa.fema.gov/wui/what-is-the-wui.html.

C. LITERATURE REVIEW

This literature review examines the scientific debate on how much climate change has affected forest health in the western United States and the need for adaptive forest management practices. The stakeholders interested in this debate range from federal and state policymakers, the U.S. Forest Service (USFS), private landowners, and the logging industry. Federal agencies, policymakers, scientists, experienced professionals, and academic institutions dominate forestry and fire management discussions with important reports, articles, and legislation. The media commonly reiterates findings from academic institutions and government agencies. In addressing the leading schools of thought, this literature review addresses the scientific debate regarding the role of climate change in wildfire scale and intensity. The section concludes with an analysis of scientific discussions on the need for adaptive management to mitigate the impact of climate change.

1. Impact of Climate Change on Western U.S. Forest Health

Scientific and academic institutions, media, and government policies indicate that since the 1980s, climate change has affected forest health and is one of the primary causes of the increased scale and intensity of wildland fires.[10] Nonetheless, a debate within the scientific community concerns how climate change has affected forest health and fire intensity. For instance, government institutions such as the National Interagency Fire Center (NIFC) and the USFS contend that climate change has influenced forest

[10] Tara M. Barrett and Guy C. Robertson, eds., *Disturbance and Sustainability in Forests of the Western United States*, PNW-GTR-992 (Washington, DC: Department of Agriculture, 2021), https://www.fs.fed.us/pnw/pubs/pnw_gtr992.pdf; Glenn Ahrens, "Managing for Healthy Forests in the Future," Oregon State University, April 2020, https://extension.oregonstate.edu/node/143196/printable/print; House Committee on Science, Space and Technology, "National Wildland Fire Risk Reduction Program Act" (Washington, DC: Congress House of Representatives, November 2021), https://science.house.gov/news/press-releases/hr-5781-national-wildland-fire-risk-reduction-program-act; Paul F. Hessburg et al., "Wildfire and Climate Change Adaptation of Western North American Forests: A Case for Intentional Management," *Ecological Applications* 31, no. 8 (2021): 1–17, https://doi.org/10.1002/eap.2432.

health and fire severity.[11] As defined by Oregon State University, "fire severity is a quantitative measure of the effects of a fire on the environment, typically considering both the damage to vegetation and the impacts on the soil" and characterized high severity fires as "greater than 75% tree mortality, extensive mineral exposure."[12] The USFS monitoring of historical data, Geographic Information System (GIS) analysis, and current trends demonstrated, "over the last four decades [increased burned area in the boreal forest region] has been linked to higher temperatures as a result of human-induced climate change."[13] Likewise, Safford, Meyer, and North, ecologists with the U.S. Department of Agriculture (USDA), revealed that 30% of wildfires have burned at high severity in the Sierra Nevada mountains in the past decade due to climate change and increasing forest fuels.[14] Thus, most government institutions that are critical stakeholders in forestry and management, such as the NIFC and USFS, insist that climate change has impacted forest health and fire intensity since the 1980s based on scientific findings.

In comparison, Safford, Meyer, and North revealed, "Fires at the beginning of the record [1980–2007] burned at an average of about seventeen percent high severity."[15] Additionally, the authors attributed increased fire size and area to "spring climate variables (spring precipitation and minimum temperature)."[16] Similarly, seven professors and researchers (Williams et al.) from different universities evaluated varying wildfire

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[11] William J. De Groot, Michael D. Flannigan, and Brian J. Stocks, "Climate Change and Wildfires," in Proceedings of the *Fourth International Symposium on Fire Economics, Planning, and Policy: Climate Change and Wildfires*, PSW-GTR-245 (Washington, DC: U.S. Department of Agriculture, Forest Service, 2013), 1–10, http://www.fs.usda.gov/treesearch/pubs/44494; Environmental Protection Agency, "Climate Change Indicators: Wildfires," Climate Change Indicators, April 2021, https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires.

[12] Carrie Berger et al., "Fire FAQs—What Is Fire Severity?," Oregon State University, October 2018, https://catalog.extension.oregonstate.edu/em9222/html.

[13] De Groot, Flannigan, and Stocks, "Climate Change and Wildfires," 1.

[14] H.D. Safford, M.D. Meyer, and Malcom North, "Climate Change and the Relevance of Historical Forest Conditions," in *Managing Sierra Nevada Forests*, ed. Malcom North (Davis, CA: Department of Agriculture, 2012), 28, https://doi.org/10.2737/PSW-GTR-237; J. D. Miller et al., "Quantitative Evidence for Increasing Forest Fire Severity in the Sierra Nevada and Southern Cascade Mountains, California and Nevada, USA," Ecosystems 12, no. 1 (February 2009): 16–32, https://doi.org/10.1007/s10021-008-9201-9.

[15] Safford, Meyer, and North, "Climate Change and the Relevance of Historical Forest Conditions," 28.

[16] Safford, Meyer, and North, 28.

records in California from 1972 to 2018.[17] The researchers credited the increased wildfire scale to "warming-driven increases in atmospheric aridity, which works to dry fuels and promote summer forest fire" in California's North Coast and the Sierra Nevada regions.[18] Based on recent trends and historical data, government institutions and some academic institutions concur that climate change has changed forest health and increased fire severity and scale.

Conversely, despite the agreement among government agencies and academics on the impact of climate change on forest health and wildfire severity and scale, some scholars and researchers reject the hypothesis that climate change drives forest fires and wildfires. Some scholars—most notably DellaSala, with the Geos Institute, and Hanson with the Earth Island Institute—maintain the need to consider additional biodiversity factors in the ecosystem benefits from fires.[19] These scholars argued that recent studies neglect fire benefits, including high-severity fires, on forest ecology. For instance, DellaSala and Hanson suggested, "Such fires facilitate high levels of beta diversity at landscape scales, providing a broad suite of habitat for both fire-seeking and fire-avoiding species."[20] Furthermore, DellaSala and Hanson critiqued Safford, Meyer, and North's findings and question the increase in high-severity fires. They stated: "these studies often did not reflect the vegetation that existed at the time of the fires analyzed."[21] Thus, according to DellaSala and Hanson, the findings of the USDA ecologists and USFS are misleading, and the upward trend of high-severity fires does not exist.

Similarly, William Baker, an ecology professor at the University of Wyoming, critiqued findings on increasingly high-severity fires. Baker determined that high-severity

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[17] A. Park Williams et al., "Observed Impacts of Anthropogenic Climate Change on Wildfire in California," *Earth's Future* 7, no. 8 (2019): 892–910, https://doi.org/10.1029/2019EF001210.

[18] Williams et al., 905.

[19] Dominick A. DellaSala and Chad T. Hanson, "Are Wildland Fires Increasing Large Patches of Complex Early Seral Forest Habitat?," *Diversity* 11, no. 9 (September 2019): 2, https://doi.org/10.3390/d11090157.

[20] DellaSala and Hanson, 9.

[21] DellaSala and Hanson, 8.

fires and dense forests were historically present before the 1980s based on historical records of tree-ring reconstructions, historical research, and General Land Office (GLO) survey data in Oregon's Cascade Mountains. Using GLO data to test several hypotheses, Baker concluded that "76.5% of forest area had structural evidence of mixed- or high-severity fire, and only 23.5% of forest area had evidence solely of low-severity fire."[22] Examining other biodiversity factors will ensure consideration of all components of forest health when drawing conclusions about climate change's impacts.

Additionally, Baker found "25% of forest area had very dense forests."[23] In other words, the ecology professor challenged the historical baseline for dry forests and suggests that the high-severity fire of today appeared throughout history. Likewise, Baker questioned the need to implement adaptive management and ecological restoration projects.[24] Baker has published a few reports on his findings, which maintained that high-severity fires and dense forests have historically been present. Notably, Williams and Baker concluded that from the 1800s, "fires varied in severity, including 15–65% high severity fire," based on their forest reconstructions.[25] Thus, Baker challenged the historical context of forest health and wildfire severity before the 1980s, which conflicted with the findings of many government institutions and some scholars, such as Safford, Meyer, and North.

Despite ecological findings based on historical data, some researchers using similar historical data find an increase in fire severity. Eighteen academics and experienced professionals (Fulé et al.) countered Williams and Baker by questioning the basis of the findings, maintaining they lack several critical aspects of evaluating historical and modern-day data on forest health and high-severity fires. For instance, Fulé et al.

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[22] William L. Baker, "Implications of Spatially Extensive Historical Data from Surveys for Restoring Dry Forests of Oregon's Eastern Cascades," *Ecosphere* 3, no. 3 (2012): 14, https://doi.org/10.1890/ES11-00320.1.

[23] Baker, 14.

[24] Baker, 19.

[25] Mark A. Williams and William L. Baker, "Spatially Extensive Reconstructions Show Variable-Severity Fire and Heterogeneous Structure in Historical Western United States Dry Forests," *Global Ecology and Biogeography* 21, no. 10 (October 2012): 1042,1050, https://doi.org/10.1111/j.1466-8238.2011.00750.x.

concluded: "The weight of scientific evidence indicates that conservation of native dry western forest ecosystems … is not consistent with the modern pattern of large, high-severity fires."[26] Hence, Fulé et al. asserted that the scientific evidence supports the hypothesis of an increase in forest density and a shift in forest ecosystems, resulting in dry forests and high-severity fires because of climate conditions. Furthermore, the USFS indirectly reinforced Fulé et al.'s hypothesis based on their findings that "warmer temperatures and drier conditions are driving an eight-fold increase in annual area burned by high severity fire across western forests from 1985–2017."[27] Additionally, research led by the University of Washington and the University of California, Santa Barbara, concurred that low-severity fire was historically common in the West, based on climate, vegetation growth, wildfire risk simulations, and historical scientific research.[28] Studies conducted by government and academic institutions maintain that forest ecology has shifted to dense forests and more high-severity fires over time.

Despite the debate among researchers, both schools of thought agree on some gaps in historical data. Thus, forestry managers and policymakers must consider the findings that resulted in policy change and adjusted forest management practices. Overall, most of the literature agrees that climate change affects forest health and, to a significant extent, contributes to the increase in wildfire scale and intensity. In turn, the debate over the direct effect of climate change influences the discussion of the need to implement adaptive forestry management practices.

2. Adaptive Management in Response to Climate Change

Most scientific and academic findings support the idea that climate change is shifting the forest environment and the scale and intensity of wildfires. These findings

[26] Peter Z. Fulé et al., "Unsupported Inferences of High-Severity Fire in Historical Dry Forests of the Western United States: Response to Williams and Baker," *Global Ecology and Biogeography* 23, no. 7 (December 2013): 828, https://doi.org/10.1111/geb.12136.

[27] U.S. Forest Service, "Area Burned by Severe Fire Has Increased 8-Fold in Western U.s. Forests Over Past Four Decades," USDA Forest Service, November 30, 2020, https://www.fs.usda.gov/rmrs/news-releases/area-burned-severe-fire-has-increased-8-fold-western-us-forests-over-past-four-decades.

[28] Maureen C. Kennedy et al., "Does Hot and Dry Equal More Wildfire? Contrasting Short- and Long-Term Climate Effects on Fire in the Sierra Nevada, Ca," *Ecosphere* 12, no. 7 (July 2021): 3, https://doi.org/10.1002/ecs2.3657.

pose the additional need to determine whether adaptive management must combat climate change and improve forest health.[29] The Department of the Interior (DOI) defined adaptive management as a flexible decision process to adjust to uncertain outcomes from management actions and other events.[30] As the DOI noted, scientific findings could improve and policies or operations could change through monitoring adapted practices.[31] Across the board, the shared understanding—according to researchers, professionals, and professors in forest ecology, who agree with the DOI—is that adaptive management of forestry and fire management practices poses uncertainty and will influence the overall long-term environment of the forests.[32] Nevertheless, in recent scientific discussions of adaptive management, the USFS noted that a controversial issue has been whether to continue adjusting forestry and fire management practices.[33] Ultimately, the DOI guide on adaptative management is a tool for forest managers to use when implementing and analyzing forestry management practices by involving all key stakeholders, but it does not suggest the need for adaptive management across the board.

One school of thought advocates the role of adaptive forest management in fighting climate change. For instance, some scholars and experienced professionals—including the U.S. National Commission on Science for Sustainable Forestry—contend

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[29] Keala Hagmann et al., "Evidence for Widespread Changes in the Structure, Composition, and Fire Regimes of Western North American Forests," *Ecological Applications* 31, no. 8 (August 2021): 1–34, https://doi.org/10.1002/eap.2431.

[30] Byron K. Williams, Robert C. Szaro, and Carl D. Shapiro, *Adaptive Management: The U.S. Department of the Interior Technical Guide* (Washington, DC: U.S. Department of the Interior, 2009), https://www.doi.gov/sites/doi.gov/files/migrated/ppa/upload/TechGuide.pdf.

[31] Williams, Szaro, and Shapiro.

[32] Annecoos Wiersema, "Uncertainty, Precaution, and Adaptive Management in Wildlife Trade," *Michigan Journal of International Law* 36, no. 3 (2015),: https://repository.law.umich.edu/mjil/vol36/iss3/1; Rasoul Yousefpour et al., "A Framework for Modeling Adaptive Forest Management and Decision Making Under Climate Change," *Ecology and Society* 22, no. 4 (December 2017), https://www.jstor.org/stable/26799027.

[33] George H. Stankey, Roger N. Clark, and Bernard T. Bormann, *Learning to Manage a Complex Ecosystem: Adaptive Management and the Northwest Forest Plan,* PNW-RP-567 (Portland, OR: Department of Agriculture, 2006), 161, https://www.fs.usda.gov/treesearch/pubs/24764.

that combating increased global temperatures requires adaptive management.[34] Additionally, supporting the management of biological diversity provides forest managers and policymakers with the means to reduce uncertainty in forest management practices.[35] For example, two environmental lawyers and academics, Craig and Ruhl, posited that adaptive management can be complex in practice.[36] However, the adaptive management process provides stakeholders with a productive forum for assessing short and long-term tradeoffs and "provide [s] the desirable service of reducing the risk of catastrophic wildfire."[37]

Another school of thought contests the effect of adaptive forest management practices but recommends further adaptation. A group of scholars, Susskind, Camacho, and Schenk, maintained that collaborative adaptive management practices have failed due to the ability to "carefully formulate management processes and adjust them over time."[38] Nonetheless, the scholars held that "collaborative adaptive management is a promising approach to managing scarce natural resources in the face of significant uncertainty and changing conditions."[39] In this context, recent government hearings and policies reflect this recognition and call for adjusted forest management practices, such as

[34] Lorne A. Greig et al., "Insight into Enabling Adaptive Management," *Ecology and Society* 18, no. 3 (2013): 1–11, https://www.jstor.org/stable/26269366; National Commission on Science for Sustainable Forestry, *Conserving Biodiversity Through Sustainable Forestry: A Guide To Applying NCSSF Research* (Washington, DC: National Council for Science and the Environment, 2007), https://www.ddcf.org/globalassets/news-and-publications/imported-news-and-publications/conserving-biodiversity-through-sustainable-forestry.pdf.

[35] National Commission on Science for Sustainable Forestry, *Conserving Biodiversity Through Sustainable Forestry*, 148.

[36] Robin Kundis Craig and J. B. Ruhl, "Adaptive Management for Ecosystem Services Across the Wildland-Urban Interface," *International Journal of the Commons* 14, no. 1 (2020): 611–26, https://doi.org/10.5334/ijc.986.

[37] Craig and Ruhl, 623.

[38] Lawrence Susskind, Alejandro E. Camacho, and Todd Schenk, "A Critical Assessment of Collaborative Adaptive Management in Practice," *Journal of Applied Ecology, A Critical Assessment of Collaborative Adaptive Management*, 49, no. 1 (2012): 47, https://doi.org/10.1111/j.1365-2664.2011.02070.x.

[39] Susskind, Camacho, and Schenk, 50.

the National Wildland Fire Risk Reduction Program.[40] Likewise, ecology researchers and USDA professionals highlight that the USFS has accepted some recommendations and proposed adaptive forestry management practices. Furthermore, the acceptance has initiated several scientific debates on the need for adaptive management and defining effective management practices.[41] Most government institutions and some scholars embrace and advocate for adaptive management to combat climate change impacts on forest health and wildfires.

A different group of scholars—most notably Jandl et al.—argued that adaptive management is unnecessary for some areas considering its challenges for the environment and stakeholders involved. Concerns from the academic and scientific community include the difficulty in providing funding for mitigation projects and changes to timber supply.[42] Indeed, as the authors contended, most old-growth forests do not need management because of "the carbon storage and the contribution to biodiversity" it provides.[43] However, Jandl et al. suggested some adaptation can be beneficial in lodgepole pine forests, such as those in Yellowstone National Park, Wyoming, because it can ensure the forest can endure ranges in climate.[44] On another note, a group of USDA researchers identified best practices for adaptive management.[45] Still, they concluded that determining whether adaptive management is "a success or not

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[40] *Forest Management, Forest Products, and Carbon: Hearing before the Committee on Energy and Natural Resources,* Senate, 117 Cong., 1st sess., May 20, 2021, https://www.energy.senate.gov/hearings/2021/5/full-committee-hearing-on-forest-management-forest-products-and-carbon; *Forest Management to Mitigate Wildfires: Hearing before the Committee on Environment and Public Works*, Senate, 115th Cong., 1st sess., September 27, 2017, https://www.epw.senate.gov/public/index.cfm/2017/9/hearing-on-forest-management-to-mitigate-wildfires-legislative-solutions; *House Committee on Science, Space and Technology, National Wildland Fire Risk Reduction Program Act*.

[41] Lief A Wiechman et al., *Adaptive Management and Monitoring*, RMRS-GTR-389 (Washington, DC: Department of Agriculture, Forest Service, 2019), https://www.fs.fed.us/rm/pubs_series/rmrs/gtr/rmrs_gtr389/rmrs_gtr389_02.pdf.

[42] Bernard T. Bormann, Richard W. Haynes, and Jon R. Martin, "Adaptive Management of Forest Ecosystems: Did Some Rubber Hit the Road?," *BioScience* 57, no. 2 (February 2007): 186–91, https://doi.org/10.1641/B570213; Robert Jandl et al., "Forest Adaptation to Climate Change—Is Non-Management an Option?," *Annals of Forest Science* 76, no. 48 (April 2019): 1–13, https://doi.org/10.1007/s13595-019-0827-x.

[43] Jandl et al., "Forest Adaptation to Climate Change," 4.

[44] Jandl et al., 9.

[45] Bormann, Haynes, and Martin, "Adaptive Management of Forest Ecosystems."

is difficult to assess because results are slow to emerge and alternative outcomes can only be imagined."[46] Williams and Baker further highlighted some misdirected adaptive management practices in Oregon, California, and Arizona based on the misuse of historical baselines and false narratives.[47] Ultimately, they questioned the legitimacy of forestry management practices' impact on decreasing fire intensity.[48] The discussion among scholars and experienced professionals hesitant to adopt adaptive management mainly emphasizes the need to implement adapted practices in specific forests and recognizes many challenges involving stakeholders. However, a few ecologists, including Williams and Baker, determine that implementing adaptive management may be ineffective until ecologists can agree on the historical baseline of fire severity and forest health. Despite the changes implemented thus far, some scholars and experienced professionals denounce the need to implement adaptive management and warn of the potential consequences of changing the trajectory of the forest environment.

On the contrary, as supported by most of the literature, combatting climate change, improving forest health, and mitigating wildfire scale and intensity requires adaptive forest management. For example, Schaffer, in her Naval Postgraduate School thesis, held the view that "decisive national leadership toward climate adaptation is urgently needed in the United States" based on the concerns of natural hazards amplified by climate change listed in the 2015 *National Security Strategy*.[49] Therefore, identifying specifically adapted forestry management practices and evaluating adjustments made thus far are essential to determine the effect on forest health and wildfire scale and intensity.

Most of the literature contends that climate change has reshaped the forest environment. Thus, maintaining adaptive management in some areas is necessary to mitigate the impact on forest health and wildfire severity and intensity. Nonetheless,

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[46] Bormann, Haynes, and Martin, 190.

[47] Mark A. Williams and William L. Baker, "High-Severity Fire Corroborated in Historical Dry Forests of the Western United States: Response to Fulé Et Al.," *Global Ecology and Biogeography* 23, no. 7 (February 2014): 831–35, https://doi.org/10.1111/geb.12152.

[48] Williams and Baker, 832.

[49] Patricia A. Schaffer, "Climate Security Threat—America's Achilles' Heel?" (master's thesis, Naval Postgraduate School, 2018), v, https://www.hsdl.org/?view&did=821415.

the scientific community has not reached a unified conclusion on how climate change affects forest health compared to historical data. Additionally, discrepancies remain in determining which forestry management practices are practical and necessary. Subsequently, all perspectives must be considered to gauge effective management practices.

D. RESEARCH DESIGN

This thesis has two aims. First, it seeks to determine how forestry and fire management practices affect wildland fire response in the West. Second, it aspires to determine whether a unified front among stakeholders would decrease wildfire scale and intensity and protect critical infrastructure. To this end, this thesis uses a comparative analysis approach, which includes case studies of real and fictional scenarios to derive best practices for forestry managers and policymakers. Most of the literature used in this thesis comes from secondary sources (including peer-reviewed books and articles, theses and dissertations, and media coverage). Still, primary sources will also be used (to include government reports, including reports prepared by forestry managers and forest ecologists).

The thesis first reviews the debate within the scientific community on the extent to which climate change has affected forest health in the West and the need for adaptive management. It compares U.S. government reports and academic research on current forest health conditions to historical data. The literature review portrays the similarities and discrepancies among the scientific community's review of historical data and recent findings.

Second, this thesis analyzes five case studies: three actual and two fictional. The real-life case studies include wildfires and responses in three different western United States forest areas. The case studies were selected based on the wildfires' challenges to communities and the environment, including drought, an increasing number of fires, fire severity, and proximity to critical infrastructure. Additionally, each case study represents common forest types throughout the western United States. For instance, ponderosa pine in Arizona is also common in Oregon, Idaho, and Wyoming. Each case study provides

the historical context of the land and wildfires based on scientific findings and current forestry management practices, and each concludes with a summary detailing the factors that contribute to wildfire scale and frequency. The two fictional scenarios follow a standard outline: current forest and wildfire conditions, several modeling scenarios, and a summary discussing the difficulties posed to wildland firefighters and forestry managers in combating and mitigating severe wildfires in the West. The case studies and fictional scenarios identifies commonalities and differences among the different Western states' forestry and fire management practices.

Next, this thesis presents two sets of models in Arizona and California within the fictional scenario chapter and utilizes the same information provided in the case studies to 1) visualize the factors that contribute to wildfire scale and intensity, 2) demonstrate the status quo of forestry and fire management practices, and 3) illustrate how computer simulations of fire behavior can be used to inform adaptive management projects. The research uses FARSITE, software utilized by the U.S. Forest Service, to produce the fire growth simulations.[50] The modeling aggregates quantitative data provided by historical and recent reports from government and academic institutions. As a result, the modeling further supports the comparative analysis approach to determine the difference between maintaining the status quo of forestry and fire management and the recommendations to implement adaptive management. The comparative analysis approach evaluates policy to determine the need to adjust or implement policies at the federal, state, or local level. Finally, based on the findings of the comparative analysis, this thesis provides recommendations to federal and state policymakers, forest managers, and local communities on how to establish a unified front to combat the impacts of severe wildfires and improve forest health in the western United States.

[50] Mark A. Finney and Charles W. McHugh, "FARSITE," FARSITE, accessed March 23, 2022, https://www.fs.usda.gov/rmrs/tools/farsite.

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II. CASE STUDIES

It is important to look at the historical baselines of dominant forests in the West to understand where, why, and how wildfire scale and intensity shifted since the mid-1980s.[51] This chapter examines three different forest types in the western United States, which are relevant to other western forests that are not covered in this thesis. Forest types covered in this chapter include ponderosa pine in Arizona, chaparral in Southern California, and the tundra in Alaska. Each case study in this chapter provides the historical context of the land and significant wildfires that swept through the land. The case studies also include key forestry management stakeholders. This chapter concludes with a summary of findings. The background information of these forests provides the foundation for the fictional case studies in the next chapter, as it details the historical baselines and identifies the shift in wildfire scale and frequency.

A. ARIZONA: PONDEROSA PINE

Arizona consists of three landforms in the southwest part of the United States—the Colorado Plateau, the transition zone, and the Basin and Ridge Region—and is home to six national forests, as shown in Figure 1.[52] About 18.6 million acres (27%) of the state is forested and is managed by federal, state, and tribal agencies.[53] The USFS is responsible for 7.7 million acres (41%) of forest land in Arizona and private landowners are responsible for 7.3 million acres (39%).[54] Arizona's forests consist of ponderosa

[51] A. L. Westerling et al., "Warming and Earlier Spring Increase Western U.S. Forest Wildfire Activity," *Science* 313, no. 5789 (August 18, 2006): 940–43, https://doi.org/10.1126/science.1128834.

[52] Mehdi Tork Qashqai, Juan Carlos Afonso, and Yingjie Yang, "The Crustal Structure of the Arizona Transition Zone and Southern Colorado Plateau from Multiobservable Probabilistic Inversion," *Geochemistry, Geophysics, Geosystems* 17, no. 11 (November 3, 2016): 4308–32, https://doi.org/10.1002/2016GC006463; "Region 3 - Regional Overview," USDA Forest Service, accessed May 30, 2022, https://www.fs.usda.gov/main/r3/about-region/overview.

[53] John D Shaw et al., *Arizona's Forest Resources,* 2001–2014, RMRS-RB-25 (Fort Collins, CO: Department of Agriculture, 2018), https://www.fs.fed.us/rm/pubs_series/rmrs/rb/rmrs_rb025.pdf; National Association of State Foresters, "Arizona's Forest Action Plan," National Association of State Foresters, accessed May 10, 2022, https://www.stateforesters.org/districts/arizona/.

[54] Shaw et al., 20, 21.

pine, mixed-conifer, pinyon-juniper, mesquite, and evergreen oak.[55] This section primarily focuses on ponderosa pine, as it is one of the dominant forest types in Arizona.

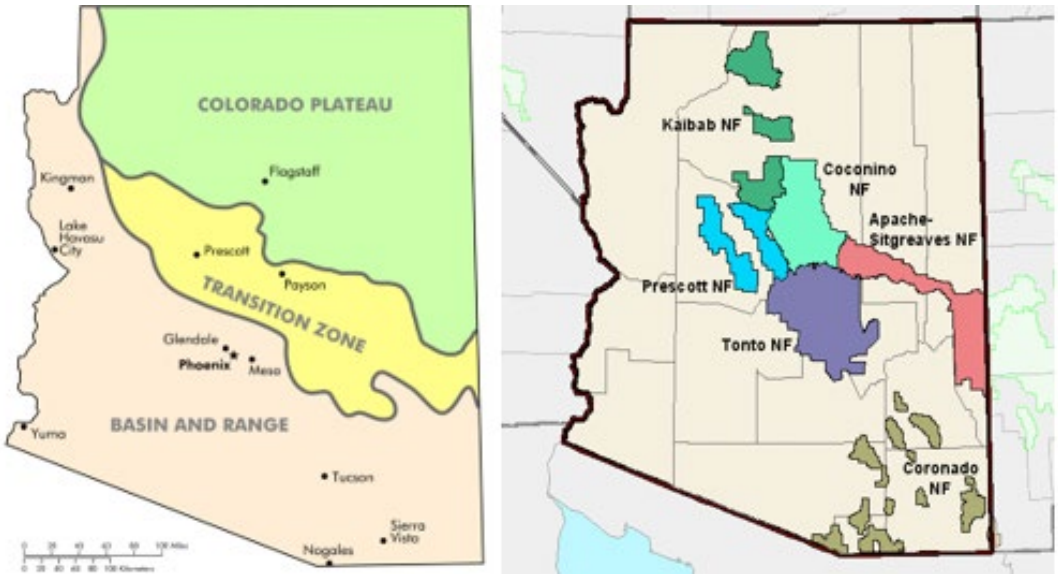

Figure 1. Arizona Regions and National Forests[56]

Arizona's forests are a vital source of the state's water supply.[57] Throughout the forests, watersheds collect most of the state's surface water, which feeds into Arizona's rivers that supply the metropolitan areas.[58] Maintaining watershed health and meeting the water demand has become challenging in the state due to declining precipitation, drought, and wildfires, which alters the watersheds.[59] Aside from water, Arizona's forests also

[55] U.S. Forest Service, "Forests at a Glance," Arizona Forest Overview, accessed May 29, 2022, https://www.fs.fed.us/rm/ogden/overviews/Arizona/OV_Arizona.htm.

[56] Adapted from Mortadelo2005, "Physiographic Regions of Arizona," Wikimedia Commons, July 22, 2007, https://commons.wikimedia.org/wiki/File:Physiographic_regions_of_Arizona.svg; U.S. Forest Service, "Forest Service Schedule of Proposed Actions- Arizona," U.S. Forest Service, accessed August 12, 2022, https://www.fs.usda.gov/sopa/state-level.php?az.

[57] Marie-Blanche Roudaut and Susanna Eden, "Water Resources Protection Spurs Forest Restoration Actions," University of Arizona Water Resources Research Center, 2016, https://wrrc.arizona.edu/water-resources-rrotection-spurs-sestoration-actions.

[58] Roudaut and Eden.

[59] Arizona Department of Forestry and Fire Management, *Arizona Forest Resource Strategy* (Phoenix, AZ: Arizona State Forestry Division, 2010), 12, https://dffm.az.gov/sites/default/files/Arizona-Forest-Resource-Strategy-2010.pdf.

surround other critical infrastructure, including the WUI, military bases, and power lines. For instance, Camp Navajo is a National Guard base that stores Navy and Air Force nuclear missile and rocket motors worth $5 billion.[60] There are obvious security implications as well: Camp Navajo is surrounded by the Coconino National Forest and Kaibab National Forest, which is at risk for catastrophic wildfires.[61] Additionally, as of 2017, 45% of Arizona residents live in the WUI.[62] As a result, Arizona's forest health is essential in maintaining and protecting critical infrastructure and communities for residents and for the resilience of the homeland.

Within the Colorado Plateau, the Coconino National Forest holds the largest ponderosa pine forest in the world.[63] In addition to the Colorado Plateau, ponderosa pine is prominent throughout Arizona, as depicted in Figure 2.[64] Ponderosa pine is a wide-ranging conifer that lives in different landscapes throughout the United States and provides most of the Southwest with its lumber.[65] Uniquely, one can identify a ponderosa pine by smelling the bark, as it smells like vanilla or butterscotch.[66] Visually, it can be recognized by its height and rusty-orange bark that splits into big plates.[67] Types of ponderosa pine can be found throughout the West in states such as California,

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60 Readiness and Environmental Protection Integration Program, *Camp Navajo* (Washington, DC: U.S. Department of Defense), accessed May 30, 2022, https://www.repi.mil/Portals/44/Documents/Buffer_Fact_Sheets/Army/CampNavajo.pdf.

61 Arizona Army National Guard, *Camp Navajo Integrated Natural Resources Management Plan* (Bellemont, AZ: Arizona Army National Guard, 2020), 1, https://dema.az.gov/sites/default/files/Camp-Navajo-Integrated-Natural-Resource-Management-Plan.pdf.

62 Anne Mottek, "Fire Adapted Communities– A Common Theme at the Arizona Wildland-Urban Interface Summit," Fire Adapted Communities Learning Network, June 15, 2017, https://fireadaptednetwork.org/fac-common-theme-arizona-wildland-urban-interface-summit/.

63 *Arizona Tourism*, "The Largest Stand of Ponderosa Pines," (blog), January 12, 2014, https://arizonatourism.com/2014/01/12/largest-stand-ponderosa-pines/.

64 Renee A O'Brien, *Arizona's Forest Resources, 1999*, RMRS-RB-2 (Ogden, Utah: U.S. Department of Agriculture, Forest Service, 2002), https://www.fs.usda.gov/rm/pubs_series/rmrs/rb/rmrs_rb002.pdf.

65 Russell T Graham and Theresa B Jain, "Ponderosa Pine Ecosystems" (Washington, DC: USDA Forest Service, 2005), https://www.fs.fed.us/psw/publications/documents/psw_gtr198/psw_gtr198_a.pdf.

66 Daniel Kraker, "Ponderosa Pines: Rugged Trees With A Sweet Smell," Morning Edition, accessed May 30, 2022, https://www.npr.org/2009/08/17/111803772/ponderosa-pines-rugged-trees-with-a-sweet-smell.

67 "Ponderosa Pine," National Park Service, February 24, 2015, https://www.nps.gov/brca/learn/nature/ponderosapine.htm.

Wyoming, and Montana, as there are 35 different species in the United States.[68] In turn, conserving ponderosa pine is essential to maintaining the beauty of the Coconino National Forest, providing lumber for the Southwest, and preserving the forest's' health.

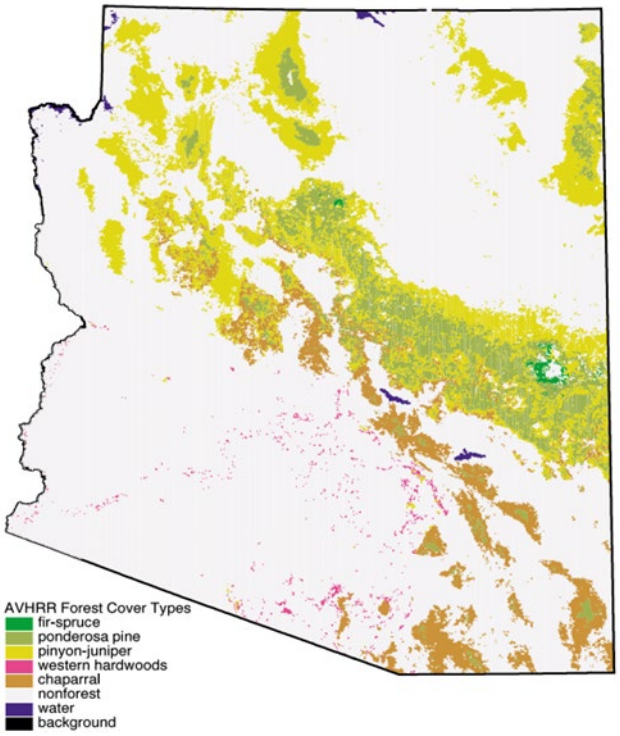

Figure 2. Arizona Ponderosa Pine[69]

1. Historical Context

In compiling pre- and-post-1900s historical data, Swetnam, with the U.S. Forest Service, revealed that wildfire scale increased post-1900s in Arizona.[70] He hypothesized that the increase was partly due to changes in climate conditions and/or fuel loads, public

[68] William W. Oliver and Russell A. Ryker, "Ponderosa Pine," USDA, accessed May 10, 2022, https://www.srs.fs.usda.gov/pubs/misc/ag_654/volume_1/pinus/ponderosa.htm.

[69] Source: O'Brien, *Arizona's Forest Resources*, 1999.

[70] Thomas W. Swetnam, *Fire History and Climate in the Southwestern United States*, RM-191 (Tucson, AZ: U.S. Department of Agriculture, 1990), 8, https://www.fs.fed.us/rm/pubs_rm/rm_gtr191/rm_gtr191_006_017.pdf.

and commercial access to national forests, and the cycling of different fire regimes.[71] Swetnam also suggested that El *Niño* -Southern Oscillation , which recurs every two to 10 years, may factor in the year-to-year fire load throughout the Southwest.[72] Iniguez, Swetnam, and Yool highlighted that historical trends suggest ponderosa pine wildfires naturally burn quicker than other mixed-conifer forests due to grasses and long needle fuel beds.[73] Additionally, Schussman, Enquist, and List noted that wildfires in Arizona were historically frequent, but the intensity was lower than it is today.[74] Before the 1850s, ponderosa pine forests held different characteristics than they do today. For example, prior to the 1850s and up to the 1990s, pine stands used to have an open structure, a low abundance of underbrush and small trees, and had rare occasions of new trees sprouting, as portrayed in the top photo in Figure 3.[75] In Figure 3 the top photo shows ponderosa pine in Coconino County in the 1990s whereas the bottom photo shows the same area in 2012. In all, the historical context of Arizona improves understanding of the leading causes of large fires, including human and natural elements and the impacts of climate change on the land.

[71] Swetnam, 8.

[72] Swetnam, 6 and 10.

[73] Jose M. Iniguez, Thomas W. Swetnam, and Stephen R. Yool, "Topography Affected Landscape Fire History Patterns in Southern Arizona, USA," *Forest Ecology and Management* 256, no. 3 (April 2008): 300, https://doi.org/10.1016/j.foreco.2008.04.023.

[74] Heather Schussman, Carolyn Enquist, and Michael List, *Historic Fire Return Intervals for Arizona and New Mexico: A Regional Perspective for Southwestern Land Managers* (Washington, DC: Department of Agriculture, 2006), 16, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprd3851949.pdf.

[75] Alix Rogstad, Michael Crimmins, and Gregg Garfin, "Climate Change and Wildfire Impacts in Southwest Forests and Woodlands" (Tucson, AZ: University of Arizona College of Agriculture and Life Sciences, 2006), 1, https://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1425.pdf.

Figure 3. Ponderosa Pine in Coconino County, circa 1990 (top); and in 2012 (bottom).[76]

To demonstrate wildfire scale, intensity, and destruction over Arizona's landscape throughout the years, the following sections list the top three largest wildfires in Arizona history. Additionally, each fire listed provides details pertaining to location, type of forest, and total cost to highlight researchers' findings that wildfires in the West have grown more severe in recent decades.

a. Wallow Fire

From May 29, 2011, to July 8, 2011, Arizona's largest wildfire in history, the Wallow Fire in the Apache-Sitgreaves National Forest, burned more than 534,639 acres on tribal, state, and federal lands.[77] Additionally, the fire burned thousands of acres in the Fort Apache Indian Reservation, San Carlos Indian Reservation, New Mexico, and Arizona state and private land.[78]

[76] Source: Rogstad, Crimmins, and Garfin, "Climate Change and Wildfire Impacts."

[77] *Arizona Wallow Fire Recovery and Monitoring* Act, S. 1344, 112th Congress, 2nd sess. § (2012), https://www.congress.gov/congressional-report/112th-congress/senate-report/126.

[78] S., *Arizona Wallow Fire Recovery and Monitoring Act*.

Type of forest: The Apache-Sitgreaves National Forest comprises 42% ponderosa pine and pinyon-juniper woodlands and 17% of a variety of timber and woodland types (i.e., evergreen).[79]

Cause: The Wallow Fire was ignited by an unattended campfire.[80]

Severity: About 16% (86,115 acres) of the fire burned at high intensity and about 13.7% (73,634 acres) burned at moderate intensity.[81] According to the USFS, the high level of burn severity from this fire changed the vegetation type in the area, which poses challenges for regeneration.[82]

Critical Infrastructure/WUI: 32 residences, four commercial buildings, and 36 outbuildings were damaged or destroyed.[83]

Lives lost: No deaths were reported.[84]

Cost: The fire cost $95 million to suppress and resulted in $109 million in damages.[85]

[79] Paul Rogers, *Forest Resources of the Apache- Sitgreaves National Forest* (Ogden, UT: Department of Agriculture, 2003), https://www.fs.fed.us/rm/pubs_series/forest_resources/apache_sitgreaves.pdf.

[80] Wink Crigler, "The Rancher and the Wallow Fire," Arizona State University Voices from the Future (blog), July 21, 2020, https://globalfutures.asu.edu/futurevoices/2020/07/21/the-rancher-and-the-wallow-fire/.

[81] S. 1344, Arizona Wallow Fire Recovery and Monitoring Act.

[82] Lance Cheung, "Apache-Sitgreaves National Forests," Flickr, December 7, 2018, https://www.flickr.com/photos/usdagov/47242115951/.

[83] National Aeronautics and Space Administration, "Wallow Fire, Arizona," NASA Earth Observatory, June 2011, https://earthobservatory.nasa.gov/images/50999/wallow-fire-arizona.

[84] Michele Nelson, "Wallow Fire: No One Can Stop This Monster," Payson Roundup, November 7, 2017, https://www.paysonroundup.com/catastrophe_a_forest_in_flames/chapter-31---wallow-fire-no-one-can-stop-this-monster/article_acec269b-d6b5-5a4b-a7e1-5e019312f15b.html.

[85] S. 1344, Arizona Wallow Fire Recovery and Monitoring Act; Bureau of Indian Affairs, *Wallow Fire Fuel Treatment Effectiveness on the Fort Apache Indian Reservation* (Washington, DC: Bureau of Indian Affairs, 2011), https://www.bia.gov/sites/default/files/dup/assets/public/pdf/idc015931.pdf.

b. Rodeo-Chediski Fire

Arizona's second largest wildfire, the Rodeo-Chediski Fire, burned about 462,600 acres in less than three weeks, from June 18, 2002, to July 7, 2002.[86] The two fires started two days apart in different locations on the Fort Apache Indian Reservation, then merged on June 22, 2002, burning land on the Tonto National Forest and the Apache-Sitgreaves National Forests.[87]

Type of forest: The two national forests are dominantly ponderosa pine forests.[88]

Cause: The fire was a result of two separate human-induced ignitions. The Rodeo Fire was caused by an arsonist and the Chediski Fire was caused by a lost hiker trying to signal for help.[89]

Severity: The fire burned in a mosaic pattern with mixed severity, which is common for western forests.[90] Nonetheless, the fire was so large and burned so fast, it created its own weather system.[91]

Critical Infrastructure/WUI: 500 homes were damaged or destroyed.[92]

Lives lost: No deaths were reported.[93]

Cost: In total, the fire took $45 million to suppress and the total cost of damages

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[86] Peter F Ffolliott et al., *Rodeo-Chediski Wildfire: A Summary of Impacts* (Flagstaff, AZ: Department of Agriculture, 2010), https://www.fs.fed.us/rm/pubs_journals/2010/rmrs_2010_ffolliott_p003.pdf.

[87] Rodeo-Chediski Fire Salvage Project, "Rodeo-Chediski Fire," Arizona State Library, Archives, and Public Records, 2000, https://azlibrary.gov/dazl/learners/research-topics/rodeo-chediski-fire.

[88] Ffolliott et al., Rodeo-Chediski Wildfire: A Summary of Impacts, 27.

[89] Peter F Ffolliott et al., *The 2002 Rodeo-Chediski Wildfire's Impacts on Southwestern Ponderosa Pine Ecosystems, Hydrology, and Fuels*, RMRS-RP-85 (Fort Collins, CO: U.S. Department of Agriculture, 2011), https://www.fs.fed.us/rm/pubs/rmrs_rp085.pdf.

[90] Dennis C. Odion et al., "Examining Historical and Current Mixed-Severity Fire Regimes in Ponderosa Pine and Mixed-Conifer Forests of Western North America," *PLoS ONE* 9, no. 2 (February 3, 2014), https://doi.org/10.1371/journal.pone.0087852.

[91] Ffolliott et al., *The 2002 Rodeo-Chediski Wildfire's Impact*.

[92] Ffolliott et al.

[93] Gayle Tyler Special, "Remembering the Rodeo-Chediski Fire 20 Years Later," *White Mountain Independent*, June 17, 2022, https://www.wmicentral.com/news/remembering-the-rodeo-chediski-fire-20-years-later/article_ef97c699-bfb2-56db-bfc5-f4bf3431b413.html.

was $175 million.[94]

c. Cave Creek Complex Fire

The Cave Creek Complex Fire is Arizona's third largest fire in history, burning 248, 310 acres from June 22, 2005, to July 11, 2005, in the Tonto National Forest.[95] Additionally, this fire is considered one of the largest fires in the Sonoran Desert ever recorded.[96] This fire is considered a 'complex fire' because it combined several fires that were near each other.[97]

Type of forest: The area of the fire primarily burned Sonoran Desert Scrub (i.e., saguaros, barrel cactus, Palo Verde trees, and mesquite trees).[98]

Cause: Lightning was the ignition source for several of the fires that occurred in the complex.[99]

Severity: No field reports were found detailing the severity of the fire, but there is evidence that shows the fire was able to grow quickly due to invasive grasses and drought.[100]

Critical Infrastructure/WUI: 11 homes were destroyed in the fire and power turbines at Glen Canyon Dam were temporarily shut down.[101]

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[94] Ffolliott et al., *The 2002 Rodeo-Chediski Wildfire's Impact*.

[95] Josh Chesler, "Cave Creek Complex Fire-After," Sonoran News, November 13, 2013, http://www.sonorannews.com/archives/2013/131113/news-cc-complex-fire.html.

[96] Casey D. Allen, Jeremy D. Dorn, and Ronald I. Dorn, "Fire in the Desert: Initial Gullying Associated with the Cave Creek Complex Fire, Sonoran Desert, Arizona," *Yearbook of the Association of Pacific Coast Geographers 71* (2009): 182–95, https://www.jstor.org/stable/24043773.

[97] "Wildfires Are Part of Life in Arizona and Here Are Some of the Worst," Arizona's Family, accessed August 12, 2022, https://www.azfamily.com/page/wildfires-are-part-of-life-in-arizona-and-here-are-some-of-the-worst.

[98] Amanda Keim, "Desert May Not Recover from Fires," *Arizona Daily Sun,* July 6, 2005, https://azdailysun.com/desert-may-not-recover-from-fires/article_567d9e91-e94b-5a0a-872d-33e56803f56e.html.

[99] Allen, Dorn, and Dorn, "Fire in the Desert," 2.

[100] Allen, Dorn, and Dorn, 2.

[101] "Cave Creek Complex Fire," AZ Central, accessed May 30, 2022, http://azfiretracker.azcentral.com/mostsignificant-cavecreekcomplex.html.

Lives lost: No reports were found regarding lives lost.

Cost: Arizona residents near the fire had to pay $312,190.89 to Rural Metro, a private fire protection and emergency medical services company. The total cost to contain the fire was $18,902,702.[102]

These top three wildfires demonstrate the negative interaction human activity can have on these landscapes, especially when combined with drought, low moisture, and high fuel loads. Four of the top 10 largest forest fires in Arizona history occurred between 2019 and 2021, and three out of the four recent fires were caused by humans.[103] Arizona has experienced climate change within the past four decades, with drought and extreme heat persisting for days, contributing to wildfire activities.[104] For instance, based on hydrologic data collected by the U.S. Geological Survey (USGS), drought persisted in Arizona during 1999–2004.[105] Four of Arizona's top ten wildfires ever recorded occurred between 2002–2005, which suggests drought was a factor in wildfire scale.[106] During the Wallow Fire, a successful case study was identified in a USDA report that explained the fire was significantly slowed from destroying the community of Alpine due to efforts made by residents to establish a half mile-wide, fuel-treated zone and ensured Firewise compliance prior to the fire.[107] As a result, fire crews had the opportunity to safely extinguish the fire and protect the community. Therefore, intense forestry

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102 "Tensions Rise as Cave Creek Fires Leave Valley Taxpayers with Hefty Costs," KTAR.Com (Arizona: KTAR News, August 3, 2020), https://ktar.com/story/3460132/tensions-rise-as-cave-creek-fires-leave-valley-taxpayers-with-hefty-costs/; AZ Central, "Cave Creek Complex Fire."

103 "Here Are the 5 Largest Wildfires in Arizona History," KTAR News, June 22, 2020, sec. Arizona News, https://ktar.com/story/2627306/here-are-the-5-largest-wildfires-in-arizona-history/.

104 *The Climate Reality Project,* "How the Climate Crisis Is Affecting Arizona," (blog), March 17, 2022, https://www.climaterealityproject.org/blog/how-climate-crisis-affecting-arizona.

105 U.S. Geological Survey, *Hydrologic Conditions in Arizona During 1999–2004: A Historical Perspective,* Fact Sheet (Washington, DC: U.S. Geological Survey, 2005), https://pubs.usgs.gov/fs/2005/3081/pdf/FS2005-3081WEB.pdf.

106 "Telegraph Fire Now Ranked in Top 10 Largest Arizona Wildfires," ABC 15 Arizona, June 8, 2021, https://www.abc15.com/news/wildfires/telegraph-fire-now-ranked-in-top-10-largest-arizona-wildfires.

107 Pam Bostwick, Jim Menakis, and Tim Sexton, How Fuel Treatments Saved Homes from the 2011 Wallow Fire (Washington, DC: Department of Agriculture), accessed May 30, 2022, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5318765.pdf.

management practices conducted by forestry managers and residents, such as fuel treatments, may be necessary to protect critical infrastructure and lives, especially in WUI areas.

An additional area of concern in Arizona is invasive species, ranging from the bark beetle to plants —including red brome, which contribute to the wildfire scale, as these species increase fuel loads in forests, especially when hot and dry conditions persist.[108] The bark beetle infests healthy and decaying trees, usually conifer trees, including ponderosa pine, thus killing the tree.[109] Tree mortality contributes to fuels within the forest.[110] According to the USFS, recent outbreaks of bark beetles are considered the most severe in history.[111] Per their findings, tree mortality caused by bark beetles in the West has become the leading cause of tree mortality in the last three decades, above both wildfire and drought.[112] Additionally, based on simulation models of historical data collected in several regions including Arizona, Sieg et al. discovered that "unexpected high fire severity can occur at low wind speeds and in forests with only a small amount of [beetle-induced] mortality."[113] In Arizona, Sieg et al. noted, "Since the mid-1980s, between 11 and 18 percent of ponderosa pine trees died in Arizona and New Mexico from drought-associated wildfire and bark beetle attacks."[114] A similar dilemma is occurring in the Sierra Nevada, where the bark beetle has contributed to

[108] José F. Negrón et al., "Bark Beetle-Caused Mortality in a Drought-Affected Ponderosa Pine Landscape in Arizona, USA," Forest Ecology and Management 257, no. 4 (September 3, 2008): 1353–62, https://doi.org/10.1016/j.foreco.2008.12.002; City of Scottsdale, "Remove Invasive Plants," City of Scottsdale, accessed May 30, 2022, https://www.scottsdaleaz.gov/fire/wild-fire-prevention/remove-invasive-plants; Arizona Department of Forestry and Fire Management, "Invasive Plant Grants," Arizona Department of Forestry and Fire Management, accessed May 30, 2022, https://dffm.az.gov/grants/forest-health/invasive-plant-grants.

[109] "Bark Beetles," Arizona Department of Agriculture, accessed May 30, 2022, https://agriculture.az.gov/pestspest-control/agriculture-pests/bark-beetles.

[110] Diane Godfrey et al., "Bark Beetles in Arizona: Clues to Climate Change?" (Pilot Classroom Unit, Arizona Science Center), accessed May 30, 2022, https://www.azscience.org/media/1631/bark_beetles.pdf.

[111] Christopher J. Fettig et al., *Bark Beetle and Fire Interactions in Western Coniferous Forests: Research Findings*, vol. 79, 1 (Washington, DC: U.S. Department of Agriculture, 2021), https://www.fs.fed.us/psw/publications/fettig/psw_2021_fettig006.pdf.

[112] Fettig et al.

[113] Carolyn Sieg, *Are Wildfires Following Bark Beetles More Severe?* (Flagstaff, AZ: Department of Agriculture, 2019), https://researchoutreach.org/articles/wildfires-following-bark-beetles-more-severe/.

[114] Sieg, 104.

wildfire scale and intensity.[115] The bark beetle has played a significant role and will continue to do so on a wildfire scale parallel with the timing of rising global temperatures and drought. The bark beetle and other invasive species are essential to consider in conversations about addressing wildfire mitigation and forestry management practices in protecting the land, critical infrastructure, and so forth.

In addition to invasive insects, invasive plants also contribute to wildfire scale and frequency, thus it is essential to analyze its impact on Arizona's wildfires and forests.[116] Arizona's invasive plants include buffel grass, camelthorn, red brome, and diffuse knapweed, increasing fire frequency.[117] After a fire, the spread of the invasive species is promoted further, creating a positive feedback loop.[118] For instance, buffel grass was planted in Southwest states in the 1930s for cattle grazing and soil erosion control, but then the grass began to develop ecological issues in the 1980s, including contributing to wildfire fuel, throughout the Sonoran Desert.[119] One of the leading causes of human-related fires in Arizona is partly due to roadside fires from lit cigarettes or vehicle chains dragging on the road.[120] In these incidents, sparks from vehicle trailer chains hitting the road are then caught by the nearby brush, including invasive plants like salt cedar and red brome, resulting in the ignition of a fire. For instance, the 377 Fire in June 2018 burned over 5,000 acres of land over 24 miles of SR 377 after a semitrailer began sparking as it

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115 Rebecca B. Wayman and Hugh D. Safford, "Recent Bark Beetle Outbreaks Influence Wildfire Severity in Mixed-Conifer Forests of the Sierra Nevada, California, USA," *Ecological Applications* 31, no. 3 (January 2021), https://doi.org/10.1002/eap.2287.

116 Emily J. Fusco et al., "Invasive Grasses Increase Fire Occurrence and Frequency Across U.S. Ecoregions," *Proceedings of the National Academy of Sciences* 116, no. 47 (November 4, 2019), https://doi.org/10.1073/pnas.1908253116.

117 "Invasive Plants," Arizona Department of Forestry and Fire Management, accessed May 30, 2022, https://dffm.az.gov/forestry-community-forestry/forest-health/invasive-plants.

118 Katherine M. Laushman, Seth M Munson, and Miguel L Villarreal, "Wildfire Risk and Hazardous Fuel Reduction Treatments Along the US-Mexico Border: A Review of the Science (1986-2019)," *Air, Soil and Water Research* 13 (September 2020), https://doi.org/10.1177/1178622120950272.

119 National Geographic, "Invasive Grass Is Overwhelming U.S. Deserts—Providing Fuel for Wildfires," National Geographic, March 2021, https://www.nationalgeographic.com/travel/article/volunteers-help-fight-invasive-buffelgrass-in-sonoran-desert-parks.

120 *Arizona Highways,* "Sparks From Vehicles Can Start Wildfires, Officials Warn," (blog), https://www.arizonahighways.com/blog/sparks-vehicles-can-start-wildfires-officials-warn.

was being dragged.[121] Hence, mitigating invasive plants near roadways and in forests is imperative to reducing wildfire spread and maintaining forest health.

In all, understanding the influences of wildfire scale and intensity, including the historical contexts of Arizona's forest, helps forest managers posture in implementing adaptive management and prioritize what is needed in forests.

2. Forestry Management

The Arizona Department of Forestry and Fire Management (DFFM) is responsible for preventing and suppressing wildland fire on 22 million acres of state land and private property.[122] DFFM receives its funding through a few avenues, including the state of Arizona, DOI, and the USFS.[123] In doing so, DFFM provides resources for fire prevention, response efforts, and grants. For instance, DFFM offers the Healthy Forest Initiative Grant (HFI), which provides fire departments, state, county, local, and tribal entities, schools, and nonprofits with funding for projects related to fire prevention, watershed restoration, fuels mitigation, and critical infrastructure protection.[124] Additionally, the HFI establishes a partnership with the Arizona Department of Corrections, allowing inmates to assist DFFM with wildfire mitigation and suppression, which is a common partnership in many western states.[125] Additionally, every 10 years, the agency updates the Forest Action Plan, which addresses issues, goals, and actions needed to meet compliance standards and maintain healthy forests.[126] In all, DFFM is the

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121 "377 Fire Burning Over 4,000 Acres, 70 Percent Contained," 12 News, June 9, 2018, sec. 12news,news,local,arizona,traffic, https://www.12news.com/article/news/local/arizona/377-fire-burning-over-4000-acres-70-percent-contained/75-562881065.

122 "Who We Are," Arizona Department of Forestry and Fire Management, accessed May 30, 2022, https://dffm.az.gov/about.

123 "Wildland Fire Hazardous Fuels Grants," Arizona Department of Forestry and Fire Management, accessed September 28, 2022, https://dffm.az.gov/resources/grant-programs/wildland-fire-fuels.

124 "Healthy Forest Initiative Grants," Arizona Department of Forestry and Fire Management, accessed May 30, 2022, https://dffm.az.gov/wildland-fire-hazardous-fuels-grants.

125 "Governor Ducey Signs Legislation To Promote Forest Health And Prevent Wildfires," Office of the Arizona Governor Doug Ducey, March 9, 2021, https://azgovernor.gov/governor/news/2021/03/governor-ducey-signs-legislation-promote-forest-health-and-prevent-wildfires.

126 Arizona Department of Forestry and Fire Management, *2020 Forest Action Plan* (Phoenix, AZ: Arizona Department of Forestry and Fire Management, 2020), https://dffm.az.gov/sites/default/files/media/2020%20Forest%20Action%20Plan%20FINAL.pdf.

primary state agency for forestry management and wildfire response on state and private lands that uses its budget for administrative funding and several grant programs related to forest health, community resilience, and local fire departments.[127]

Additionally, DFFM holds the authority to implement fire restrictions on state and private land, whereas the Bureau of Land Management (BLM) and the USFS have the authority on federal land.[128] Fire restrictions are set at two stages, with the third stage being the most extreme at full closure and no public access.[129] Stage 1 allows small fires in a designated area, whereas Stage 2 has stricter regulations that prohibit campfires.[130] Fire restrictions are set in place to prevent large wildfires since it is related to the fire danger in the given area.[131] Regarding infrastructure, under DFFM, the Office of the State Fire Marshal is responsible for inspections, fire investigations, and public education on fire codes under Arizona Revised Statute 37–1381.[132] In sum, Arizona's regulations and policies grant DFFM the responsibility to collaborate with stakeholders, protect forests, mitigate the threat of wildfires, and fund operations.

BLM is responsible for 245 million miles of public land throughout the West, including Alaska.[133] In Arizona, BLM manages 12.1 million acres.[134] Still, for fire

127 "Grant Programs," Arizona Department of Forestry and Fire Management, accessed September 28, 2022, https://dffm.az.gov/grants.

128 "Fire Activity and Dry Conditions Trigger Fire Restrictions in Portions of Western, Central, and Northern Arizona," Bureau of Land Management, May 2, 2022, https://www.blm.gov/press-release/fire-activity-and-dry-conditions-trigger-fire-restrictions-portions-western-central; Arizona Secretary of State, "Arizona Department of Forestry and Fire Management," Arizona State Library, Archives, and Public Records, September 22, 2021, https://azlibrary.gov/sla/agency_histories/arizona-department-forestry-fire-management.

129 "Fire Restrictions," Arizona Department of Forestry and Fire Management, accessed September 28, 2022, https://dffm.az.gov/fire-restrictions.

130 Arizona Department of Forestry and Fire Management.

131 Arizona Department of Forestry and Fire Management.

132 "AZ State Statute and Fire Code," Arizona Department of Forestry and Fire Management, accessed September 28, 2022, https://dffm.az.gov/az-state-statute-and-fire-code.

133 "BLM Arizona Issues Policy to Reduce Wildfire Risk Around Power Lines on Public Lands," Bureau of Land Management, December 12, 2019, https://www.blm.gov/press-release/blm-arizona-issues-policy-reduce-wildfire-risk-around-power-lines-public-lands.

134 "Arizona Fire Program," Bureau of Land Management, accessed May 30, 2022, https://www.blm.gov/programs/public-safety-and-fire/fire/regional-info/arizona.

protection, BLM is responsible for 14.6 million acres after protection agreements with the Bureau of Indian Affairs (BIA), Bureau of Reclamation , and the Department of Defense (DOD).[135] These acres are divided into four zones, including the Arizona Strip District Fire Zone, Colorado River District Fire Zone, Gila District Fire Zone, and the Phoenix District Fire Zone.[136] Some initiatives for BLM include the Federal Land Policy and Management Act, which reduces fuel loads around power lines and opens a line of collaboration with utility companies to prevent wildfire.[137] In addition, BLM has led a Healthy Lands program to combat invasive species.[138] Likewise, BLM's Healthy Lands program is similar to DFFM's HFI grant in that it focuses on restoring watersheds and mitigating fuel loads in forests.[139] In all, BLM is responsible for public lands throughout Arizona, including those areas with which they have made protection agreements.

The USFS preserves and protects six national forests throughout Arizona, totaling 11.25 million acres.[140] The largest park is the Tonto National Forest (2.9 million acres), which is also in the nation's top-10 most visited forests.[141] The USFS combines Arizona and New Mexico for Region 3, in which the regional priorities for this area are relationships, recreation, and restoration.[142] USFS initiatives in the state include the Four Forest Restoration Initiative (4FRI), which focuses on restoring the ponderosa pine ecosystem in the Kaibab, Coconino, Apache-Sitgreaves, and Tonto National Forests.[143]

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[135] Bureau of Land Management.

[136] Bureau of Land Management.

[137] Bureau of Land Management, "BLM Arizona Issues Policy."

[138] Bureau of Land Management, "Shared Conservation Strategies," Bureau of Land Management, accessed May 30, 2022, https://www.blm.gov/about/how-we-manage/shared-conservation-strategies.

[139] Bureau of Land Management.

[140] "Region 3 - Regional Overview," USDA Forest Service, accessed May 30, 2022, https://www.fs.usda.gov/main/r3/about-region/overview.

[141] U.S. Forest Service.

[142] "Regional Priorities- R3's 3 Rs," USDA Forest Service, accessed May 30, 2022, https://www.fs.usda.gov/detail/r3/about-region/overview/?cid=fseprd567522.

[143] "Four Forest Restoration Initiative," USDA Forest Service, accessed May 30, 2022, https://www.fs.usda.gov/4fri.

The 4FRI is the USFS's most extensive and longest-running restoration project.[144] One reporter revealed that the 4FRI's goal of completing thinning projects in Arizona has been thwarted by the lack of loggers in the area.[145] For instance, in Coconino County, the 89 Mesa project received a notice to proceed by the USFS in July 2015 but had not begun as of July 2022, in which some of the project areas burned in the 2022 Tunnel and Pipeline Fire.[146] Nonetheless, the USFS funded an additional $54 million in November 2021 to support the goals of 4FRI, including solving the lack of the logging industry in the area.[147] In sum, the USFS is responsible for national forest land throughout Arizona.

In addition to state and federal forestry management stakeholders, tribes are also a critical component to the national wildfire management and mitigation structure. Arizona consists of 22 federally recognized tribes that span 19.8 million acres.[148] Tribal nations can manage their own wildland fire programs with services and funding with assistance from the Bureau of Indian Affairs (BIA).[149] Additionally, DFFM collaborates with tribes to meet goals and objectives in preserving the land.[150] The White Mountain Apache Tribe (WMAT) maintains their own forestry department in partnership with the BIA.[151] Historically, the tribe would use prescribed burns to manage the big game population and

144 Andrew Onodera, "Lack of Loggers Is Hobbling Arizona Forest-Thinning Projects That Could Have Slowed This Year's Devastating Wildfires," Inside Climate News (blog), July 8, 2022, https://insideclimatenews.org/news/08072022/arizona-wildfire-forest-thinning/.

145 Onodera.

146 Onodera.

147 Onodera.

148 "Tribal Lands & Casinos," Arizona Indian Gaming Association, accessed May 30, 2022, https://www.azindiangaming.org/members/tribal-land-casinos/.

149 "Improving Wildland Fire Management Across Tribal and Federal Lands," U.S. Department of the Interior, November 2021, https://www.doi.gov/wildlandfire/improving-wildland-fire-management-across-tribal-and-federal-lands.

150 Arizona Department of Forestry and Fire Management, *Tribal Outreach and Activities Annual Report 2021* (Phoenix, AZ: Arizona Department of Forestry and Fire Management, 2021), https://gotr.azgovernor.gov/file/38593/download?token=meItuwkB.

151 Debra Utacia Krol, "As Fires Rage Across the West, White Mountain Apache Forests Show a Balance of Tradition, Economy," The Arizona Republic, September 22, 2020, https://www.azcentral.com/story/news/local/arizona-environment/2020/09/22/white-mountain-apache-tribe-forestry-environmental-protection/3475797001/.

timber harvesting for profit and to allow grass to grow for big game.[152] Naturally, WMAT has thousands of years' worth of experience in supporting a healthy ecosystem and utilizing forestry management practices that support their economy, big game, and protect cultural sites.[153] Similarly, the San Carlos Apache Tribe (SCAT) has a strong history of traditional fire and ecological knowledge.[154] In recent years, SCAT has been working to return to their traditional fire regime pre-European settlement, which has proved challenging after their practices were changed when BIA intervened with aggressive wildfire suppression from the 1900s to 1930s.[155] Nonetheless, efforts have been made to align tribal forestry management traditions with BIA forestry management objectives to ensure the resilience of ponderosa pine in and near tribal nations.[156] On Arizona tribal lands, most tribes maintain their own forestry department, but for the most part, all tribes collaborate with the BIA to ensure compliance and to meet forestry management goals and objectives.

Forestry management in Arizona involves key stakeholders at all levels of government including BLM, USFS, BIA, DFFM, local fire departments, and community members. At each level, all stakeholders are responsible for maintaining healthy forests and responding to wildfires.

[152] Krol.

[153] Krol.

[154] Marvin Victor, "Fire Management of the San Carlos Apache Tribe: A Case Study in Southeastern Arizona" (Flagstaff, AZ, Northern Arizona University, 2014), https://nau.edu/wp-content/uploads/sites/140/2014.MarvinVictor.FireManagementSanCarlosApache.pdf.

[155] Victor.

[156] Wildland Fire Management, "Fort Apache Fuels Crew Receives the Prestigious Pulaski Award," U.S. Department of the Interior Indian Affairs, June 2019, https://www.bia.gov/bia/ots/dfwfm/bwfm/forestry-fire-management-stories/fort-apache-fuels-crew-receives-prestigious.

3. Summary

Of the 18.6 million acres of forest in Arizona, ponderosa pine is the dominant forest type in Arizona.[157] For instance, in northern Arizona, the Coconino National Forest is considered the largest ponderosa pine forest globally.[158] Located near and within Arizona's forests are the state's most valuable resources and critical infrastructure, including water, communities, power lines, military bases, and cultural sites.[159] The wildfire scale and intensity shift occurred in the post-1900s due to climate change, human activity, and other factors.[160] The increase in wildfire scale and intensity is apparent in listing the top three wildfires recorded in Arizona, which all occurred in or around a period of drought.[161] Additionally, the top three wildfire list demonstrates concerns about human activity and the growing WUI. Another factor to wildfire scale and frequency includes invasive species, ranging from the bark beetle to buffel grass, which will continue to persist if drought and extreme heat remain.[162] As a result, it is critical to evaluate and implement mitigation efforts to prevent the further spread of invasive species. Assessing the historical context of Arizona's forests and wildfire regimes provides forestry managers with the means to determine if a landscape can go back to the original regime or if it is necessary to implement adaptive management. Responsibility for wildfire prevention and suppression include Arizona's largest landowners, the federal and state governments, and Native American tribes. Nonetheless, it is the federal, state, county, local, tribal, and individuals' responsibility to mitigate fuel loads that contribute to wildfire scale. Understanding key stakeholders and their initiatives and goals provide a means to ensure unified objectives are aligned in addressing wildfires.

157 Shaw et al., *Arizona's Forest Resources*.

158 Arizona Tourism, "The Largest Stand of Ponderosa Pines."

159 Roudaut and Eden, "Water Resources Protection."

160 Swetnam, *Fire History and Climate*.

161 Roudaut and Eden, "Water Resources Protection."

162 Negrón et al., "Bark Beetle."

B. SOUTHERN CALIFORNIA: CHAPARRAL

In its totality, California is home to 33 million acres of forest.[163] The USFS publicly owns 60%, and 40% is privately owned (timber companies own one-third, and individuals and tribes own two-thirds).[164] Four national forests are located within Southern California, totaling 3.5 million acres, which include the Angeles, Cleveland, Los Padres, and San Bernardino.[165] Southern California counties covered in this section include Los Angeles, Imperial, Riverside, Orange, San Bernardino, Santa Barbara, San Diego, and Ventura. This section primarily focuses on Southern California and the chaparral area that covers 15.3 million acres of California.[166]

As the third-largest state in the country, California maintains significant critical infrastructure and resources that support the state and the nation.[167] For instance, the Sierra Nevada Mountain range in Northern California is an essential water source for the entire state, including the southern portion, as it provides 60% of the state's fresh water and mitigates drought impact.[168] Specifically in Southern California, two of the country's largest container ports are Los Angeles and Long Beach, where the Long Beach port alone generates $5 billion a year in U.S. Customs revenue and $46.6 billion a year in tax revenue for local, state, and federal governments.[169] Agriculture and power/utility

163 U.S. Department of Agriculture, "Focus on Forestlands in California," USDA Climate Hubs, accessed June 1, 2022, https://www.climatehubs.usda.gov/hubs/california/topic/focus-forestlands-california.

164 U.S. Department of Agriculture.

165 "Southern California Forests," Center for Biological Diversity, accessed June 1, 2022, https://www.biologicaldiversity.org/programs/public_lands/forests/southern_california_forests/index.html.

166 Wrangle, "North American Chaparral," World Rangeland Learning Experience, accessed June 1, 2022, https://wrangle.org/ecotype/north-american-california-chaparral.

167 Cal OES, "About Cal OES," Cal OES Governor's Office of Emergency Services, accessed June 1, 2022, https://www.caloes.ca.gov:443/cal-oes-divisions/about-cal-oes.

168 Katharine Davis Reich et al., "Climate Change in the Sierra Nevada: California's Water Future" (Los Angeles, CA: UCLA Center for Climate Science, April 2018), 1, https://www.ioes.ucla.edu/wp-content/uploads/UCLA-CCS-Climate-Change-Sierra-Nevada.pdf.

169 "Port Facts & FAQs," Port of Long Beach, accessed June 1, 2022, https://polb.com/port-info/port-facts-faqs/#facts-at-a-glance.

companies are also a large sector in Southern California.[170] Additionally, approximately 27 military bases and DOD facilities are in Southern California, including the most prominent: Naval Base San Diego and Marine Corps Base Camp Pendleton.[171] In comparison to the 1940s, the WUI has become significantly denser in recent years throughout the southern portion of the state, which is increasing fire frequency and spread of invasive species in the area.[172] Before the 2018–2020 wildfire seasons, Bob Eisele, a retired member of the San Diego County Fire Authority, noted that the 2003 Cedar Fire in San Diego County held state's record for the most acres burned (273,250 acres) and most destroyed homes (4,847).[173] In turn, maintaining WUI and forest health throughout Southern California is critical for protecting critical infrastructure, including communities.

Chaparral is a prominent vegetation type found throughout the hills and woodland areas of Southern California's landscape, as shown in Figure 4.[174] Generally, chaparral areas are characterized as short, woody shrubs commonly found in Mediterranean climates.[175] While chaparral stabilizes slopes and provides a habitat for wildlife, it is difficult and costly to remove and can be very flammable in drought conditions.[176] In the

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170 CAL OES, "Critical Infrastructure Protection," Cal OES Governor's Office of Emergency Services, accessed June 1, 2022, https://www.caloes.ca.gov:443/cal-oes-divisions/law-enforcement/critical-infrastructure-protection.

171 "California Military Installations and Operational Areas," Office of Governor Gavin Newsom, accessed June 1, 2022, https://militarycouncil.ca.gov/s_californiamilitarybases/.

172 Alexandra D. Syphard, Teresa J. Brennan, and Jon E. Keeley, "Chaparral Landscape Conversion in Southern California," *Springer International Publishing, Environmental Management*, April 2018, 329, https://doi.org/10.1007/978-3-319-68303-4_12.

173 Bob Eisele, *An Analysis of Large Chaparral Fires in San Diego County, California*, RMRS-P-73 (Fort Collins, CO: Department of Agriculture, 2015), 77, https://www.fs.fed.us/rm/pubs/rmrs_p073/rmrs_p073_077_079.pdf.

174 Charles L. Boisinger, *Shrubs of California's Chaparral, Timberland, and Wood Land: Area, Ownership, and Stand Characteristics*, PNW-RB-160 (Portland, OR: Department of Agriculture, 1988), 25, https://www.fs.usda.gov/treesearch/pubs/5113; Jeremy S. Fried, Charles L. Bolsinger, and Debby Beardsley, *Chaparral in Southern and Central Coastal California in the Mid-1990s: Area, Ownership, Condition, and Change*, PNW-RB-240 (Portland, OR: U.S. Department of Agriculture, 2004), 21, https://doi.org/10.2737/PNW-RB-240.

175 Active Wild, "The Chaparral Biome Facts, Pictures & In-Depth Information," Active Wild, accessed June 2, 2022, https://www.activewild.com/chaparral/.

176 Boisinger, *Shrubs of California's Chaparral*, 1.

United States, chaparral is relatively unique to the western portion of the nation. Outside of Marin County and down Southern California, it can be found in southern Oregon, including the southern Cascades and Klamath Mountains.[177] As a result, conserving chaparral landscapes is necessary to maintain the uniqueness it offers the West Coast and protect surrounding infrastructure and habitats.

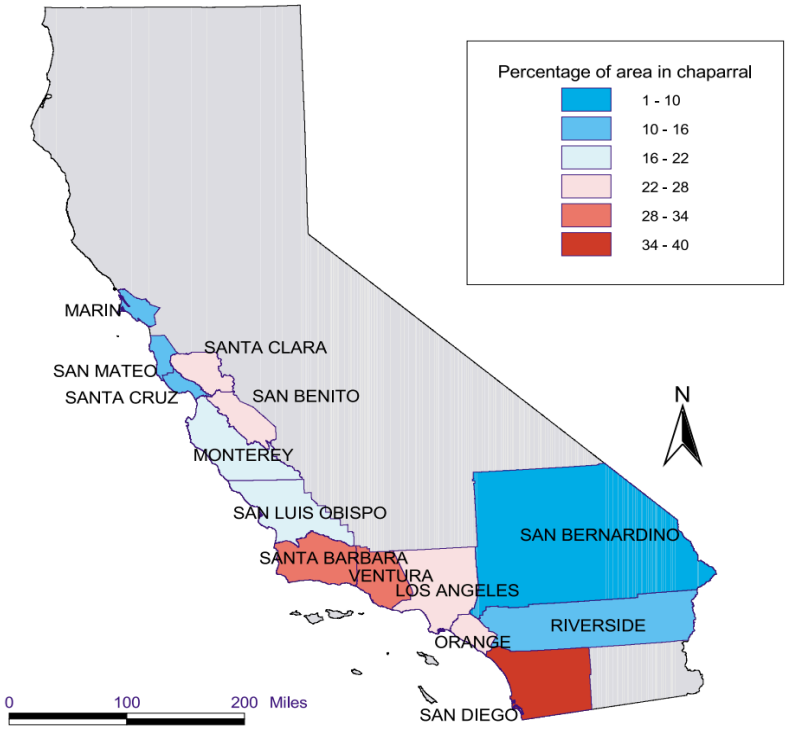

Figure 4. Chaparral in California[178]

[177] U.S. Forest Service, "Fire in Chaparral Ecosystems," U.S. Forest Service Pacific Southwest Research Station, accessed June 2, 2022, https://www.fs.fed.us/psw/topics/fire_science/ecosystems/chaparral.shtml.

[178] Source: Fried, Bolsinger, and Beardsley, *Chaparral in Southern and Central Coastal California in the Mid-1990s,* 21.

1. Historical Context

Historically, California has experienced large and intense fires since the 19th century.[179] For instance, in compiling and analyzing USFS fire records, newspaper accounts, and drought records from 1860 to 2020, Keeley and Syphard identified the 1920s, 2007, and 2008 as peak years in fire frequency.[180] Additionally, Kelly and Syphard also identified 2018 and 2020 as recent peak years in fire frequency for the state.[181] In a USFS report, Eisele shared similar findings as Keeley and Syphard in that the San Diego region began to experience large fires more often in the 1920s.[182] Eisele conveyed that Santa Ana winds, which bring hot and dry air to the area and persistent heatwaves may contribute to large-scale fires.[183] Furthermore, Eisele found that fire intensity in the chaparral is dependent on the age of the vegetation and climate. For instance, young chaparral can limit fire spread and is responsive to fire suppression unless there are Santa Ana winds.[184] On the other hand, mature chaparral is resistant to fire suppression and holds dead fuel, thus contributing more to fire intensity as it is more flammable than young chaparral.[185] Per USFS 1991 findings, there is little consensus on the natural fire cycle for chaparral.[186] The fire cycle range is every 65 years for coastal areas and every 30 to 35 years or possibly 10 to 50 years farther inland.[187] Moreover, Barro and Conard posited that forestry management practices of suppression in the 1990s

[179] Jon E. Keeley and Alexandra D. Syphard, "Large California Wildfires: 2020 Fires in Historical Context," *Fire Ecology* 17, no. 1 (2021): 3, https://doi.org/10.1186/s42408-021-00110-7.

[180] Keeley and Syphard, 6.

[181] Keeley and Syphard, 6.

[182] Eisele, *An Analysis of Large Chaparral Fires,* 78.

[183] Eisele, 79.

[184] Eisele, 80 and 87.

[185] Eisele, 80 and 87.

[186] S.C. Barro and S.G. Conard, "Fire Effects on California Chaparral Systems: An Overview," *Environment International* 17, no. 2–3 (1991): 135–49, https://doi.org/10.1016/0160-4120(91)90096-9.

[187] Barro and Conard, 137.

altered the chaparral's natural fire pattern, resulting in a decrease in the number of fires but an increase in the size of fires.[188] Nonetheless, despite the wide range of chaparral's fire cycle, it is beneficial to understand what contributes to fire intensity and scale in the chaparral and fire frequency peak years in Southern California. In turn, the historical background of the chaparral provides a foundation for understanding how chaparral naturally acts and how forestry management practices have contributed to or mitigated fire frequency, scale, and intensity in the area. With this understanding, forestry management practices can be addressed to improve the balance between maintaining the chaparral environment and protecting the surrounding critical infrastructure.

The following sections list the top three largest wildfires in California's history to illustrate the state's increase in wildfire scale, intensity, and devastation. Each fire provides the location, type of forest, severity, and total cost. As a result, each fire elaborates the point made by researchers' that recent wildfires in California have become more significant and devastating to critical infrastructure and surrounding communities.

a. August Complex Fire

The August Complex Fire is California's largest wildfire in history, which coined the term "'gigafire" after burning 1,032,648 acres on national forest, BIA, BLM, state, and private lands.[189] The fire burned for three months from August 16, 2020, to November 12, 2020, in Mendocino, Humboldt, Trinity, Tehama, Glenn, Lake, and Colusa Counties, including three national forests: Mendocino, Shasta-Trinity, and Six Rivers.[190]

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188 Barro and Conard, 146.

189 U.S. Forest Service, *Burned-Area Report August Complex (North Area),* FS-2500-8 (Washington, DC: U.S. Department of Agriculture, 2020), https://inciweb.nwcg.gov/photos/CAMNF/2020-10-02-1804-August-Complex-PostFire-BAER/related_files/pict20210306-194049-0.pdf; Harmeet Kaur, "California Fire Is Now a 'Gigafire,' a Rare Designation for a Blaze That Burns at Least a Million Acres," CNN, October 6, 2020, https://www.cnn.com/2020/10/06/us/gigafire-california-august-complex-trnd/index.html.

190 National Weather Service, "August Complex, Northern California," ArcGIS StoryMaps, January 31, 2021, https://storymaps.arcgis.com/stories/056a3a9520274896aa4146a57ea9f506; U.S. Department of Agriculture, August Complex Vegetation and Resource Rapid Assessment (Washington, DC: U.S. Department of Agriculture, 2020), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd865429.pdf.

Type of forest: The three national forests predominantly consist of hard chaparral, Pacific Douglas-fir, Pacific ponderosa pine, and Sierra Nevada mixed conifer.[191]

Cause: Thirty-eight individual lightning strikes sparked multiple fires that converged.[192]

Severity: According to Burned Area Emergency Response (BAER) assessments of the northern area of the burn, the fire burned at high and moderate severity, "approximately 61% of the 551,493 acres analyzed by the BAER team is either unburned/very low (32%) or low (29%) soil burn severity, while 31% sustained a moderate soil burn severity, and only 8% burned at high soil burn severity."[193]

Critical Infrastructure: 935 structures were damaged or destroyed.[194]

Lives lost: One life was unfortunately lost in this fire.[195]

Cost: Suppression cost of the August Complex Fire was $115.5 million.[196]

b. Dixie Fire

The state's second largest fire, the Dixie Fire, burned 963,309 acres from July 13, 2021, to October 30, 2021, in Butte, Plumas, Lassen, Shasta, and Tehama Counties, including Plumas National Forest, Lassen National Forest, and Lassen Volcanic National Park.[197]

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191 U.S. Forest Service, *Burned Area Report.*

192 National Weather Service, "August Complex, Northern California."

193 National Wildfire Coordinating Group, "August Complex-North Post-Fire BAER Soil Burn Severity Map Released," InciWeb, October 21, 2020, https://inciweb.nwcg.gov/incident/article/7228/58330/; U.S. Forest Service, Burned Area Report.

194 National Weather Service, "August Complex, Northern California."

195 National Weather Service.

196 Alaska Interagency Coordination Center, "National Large Incident Year-to-Date Report," Wayback Machine, December 21, 2020, https://web.archive.org/web/20201229021815/https://gacc.nifc.gov/sacc/predictive/intelligence/NationalLargeIncidentYTDReport.pdf.

197 National Wildfire Coordinating Group, "Dixie Fire (CA) Information," InciWeb, October 26, 2021, https://inciweb.nwcg.gov/incident/7690/.

Type of forest: The national forests are primarily mixed conifer, chaparral, and ponderosa pine.[198]

Cause: Powerlines near trees ignited the fire.[199]

Severity: One-third (33%) of affected areas burned at high severity.[200]

Critical Infrastructure/WUI: 1,329 structures were damaged or destroyed.[201]

Lives lost: One life was unfortunately lost.[202]

Cost: Suppression cost approximately $624 million.[203] Total cost of destruction in the area was $1.15 billion.[204] Commercial timber companies lost $1 billion in supply.[205]

c. Mendocino Complex/ Ranch Fire

California's third largest wildfire began as the Ranch Fire and then combined with the River Fire, resulting in the name the Mendocino Complex Fire.[206] The fire burned 459,123 acres for over a month from July 27, 2018, to September 1, 2018, in Colusa,

198 U.S. Forest Service, *Burned-Area Report: Dixie Fire BAER Assessment Phase 1,* FS-2500-8 (Washington, DC: Department of Agriculture, 2021), https://inciweb.nwcg.gov/photos/CALNF/2021-08-17-2149-Dixie-PostFire-BAER/related_files/pict20211123-185601-0.pdf; *U.S. Forest Service, Burned-Area Report: Dixie Fire BAER Assessment Phase 2,* FS-2500-8 (Washington, DC: U.S. Department of Agriculture, 2021), https://inciweb.nwcg.gov/photos/CALNF/2021-08-17-2149-Dixie-PostFire-BAER/related_files/pict20211123-185457-0.pdf.

199 Marisa Iati, "PG&E Faces Federal Probe in Dixie Fire, Estimates $1.15 Billion in Losses from the Blaze," *Washington Post,* November 2, 2021, https://www.washingtonpost.com/nation/2021/11/02/pge-dixie-fire-inquiry-california/.

200 "Dixie Fire," National Park Service, October 4, 2022, https://www.nps.gov/lavo/learn/nature/dixie-fire.htm.

201 National Wildfire Coordinating Group, "Dixie Fire (CA) Information."

202 "Dixie Fire Incident Report," CAL FIRE, October 25, 2021, https://www.fire.ca.gov/incidents/2021/7/13/dixie-fire/.

203 U.S. Forest Service, *Burned-Area Report*, FS-2500-8 (Washington, DC: U.S. Department of Agriculture, 2021), https://inciweb.nwcg.gov/incident-information/calnf-dixie-fire-ca.

204 Iati, "PG&E Faces Federal Probe in Dixie Fire, Estimates $1.15 Billion in Losses from the Blaze."

205 National Wildfire Coordinating Group, "Dixie Fire (CA) Information."

206 "The Mendocino Complex Fire - Causes, History & Statistics," Frontline Wildfire Defense, February 2021, https://www.frontlinewildfire.com/wildfire-news-and-resources/mendocino-complex-fire/.

Lake, Mendocino, and Glenn Counties, as well as the southern portion of the Mendocino National Forest.[207]

Type of forest: The prominent forest type in the areas include chaparral, coniferous trees, and woody plants[208]

Cause: The fire was human related, due to an individual that put a metal stake into the ground with a hammer, causing a spark, which initiated the fire.[209]

Severity: The fire burned at 46% low severity, 31% moderate severity, and 3% high severity.[210]

Critical Infrastructure: 280 structures were damaged or destroyed.[211]

Lives lost: One life was unfortunately lost.[212]

Cost: $203 million was spent in suppression costs, but the total losses amounted to $56 million.[213]

The listed top three wildfires demonstrate how extensive and destructive wildfires have been in recent years to California's forests and communities in the WUI. Out of the 20 largest wildfires in California's history, nine occurred between 2020–2021, two years

207 Frank A. Aebly, "Mendocino Complex / Ranch Fire 2018" (presentation, Blue Ribbon Commission Meeting, Upper Lake, CA, December 20, 2018), https://resources.ca.gov/CNRALegacyFiles/wp-content/uploads/2019/01/USFS-Mendocino-Complex-BAER-Presentation-20181220.pdf; Hilda Flores, "Cal Fire Investigators Release Cause of 2018 Ranch Fire," KCRA, June 6, 2019, https://www.kcra.com/article/cal-fire-investigators-release-cause-2017-ranch-mendocino-fire/27793658.

208 "Woody Plants of the Mendocino National Forest," USDA Forest Service, accessed June 5, 2022, https://www.fs.usda.gov/detailfull/mendocino/learning/nature-science/?cid=stelprdb5143325&width=full.

209 Flores, "Cal Fire Investigators."

210 Aebly, "Mendocino Complex / Ranch Fire 2018."

211 Flores, "Cal Fire Investigators."

212 Flores.

213 Aebly, "Mendocino Complex / Ranch Fire 2018"; Hannah Beausang, "Mendocino Complex Fire Tallies $56m in Insured Losses," *North Bay Business Journal*, September 6, 2018, https://www.northbaybusinessjournal.com/article/industry-news/mendocino-complex-wildfires-cause-56-million-of-insured-losses/.

in which Santa Ana winds were prevalent.[214] Two fires in the 20th century remain on the top 20 list, including the 1932 Matilija Fire and the 1977 Marble Cone Fire.[215] The rest of the fires have occurred in the 21st century due to lightning, human activity, or powerlines.[216] Aside from climate concerns, the list also suggests an additional situation California forestry managers and communities face: powerlines igniting fires.[217] A notable fire in southern California includes the eighth-largest wildfire in California's history, the 2017 Thomas Fire, which burned 281,893 acres in Ventura and Santa Barbara Counties.[218] The fire, ignited by powerlines, burned chaparral, coastal sage scrub, and oak woodland at 65% moderate severity and 1% high severity.[219] As a result, two lives were lost, and 1,063 structures were destroyed or damaged, costing $204.5 million in suppression, totaling $1.8 billion in damages.[220] Overall, human activity, climate change, and the build-up of fuels throughout California's forests and WUI communities continue to contribute to wildfire activity; thus, it is critical to evaluate additional contributing factors and means to mitigate wildfires.

An additional factor in California's forest health and fire frequency includes invasive species. Southern California invasive species in the chaparral include wild oats,

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214 Doyle Rice, "17M Under Threat of Wildfire in Southern California as Ferocious Santa Ana Winds Blow," USA TODAY, November 26, 2021, https://www.usatoday.com/story/news/nation/2021/11/26/santa-ana-winds-wildfire-red-flag-warnings-southern-california/8766122002/; Associated Press, "Strong Santa Ana Winds Blow Through Southern California," KPBS Public Media, November 28, 2020, https://www.kpbs.org/news/environment/2020/11/28/strong-santa-ana-winds-blow-southern-california.

215 "Top 20 Largest California Wildfires," CAL FIRE, January 13, 2022, https://www.fire.ca.gov/media/4jandlhh/top20_acres.pdf.

216 CAL FIRE.

217 Herman K. Trabish, "Record Wildfire Threats Mean California Must Pick When and Where to Fight, Utilities, Analysts, CalFire Agree," Utility Dive, May 27, 2021, https://www.utilitydive.com/news/record-wildfire-threats-mean-california-must-pick-when-and-where-to-fight/599405/.

218 CAL FIRE, "Top 20 Largest California Wildfires."

219 U.S. Forest Service, *Thomas Burned Area Report,* FS-2500-8 (Washington, DC: Department of Agriculture, 2018), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd573382.pdf; CAL FIRE, "Top 20 Largest California Wildfires."

220 Annette Ding, "Charting the Financial Damage of the Thomas Fire - The Bottom Line UCSB," *The Bottom Line University of California Santa Barbara* (blog), April 10, 2018, https://thebottomline.as.ucsb.edu/2018/04/charting-the-financial-damage-of-the-thomas-fire; Nicole Santa Cruz, "Trump Approves Disaster Funds for Thomas Fire Victims," *Los Angeles Times,* January 2, 2018, https://www.latimes.com/local/california/la-me-trump-wildfire-relief-20180102-story.html; CAL FIRE, "Top 20 Largest California Wildfires."

ryegrasses, giant reed, crimson fountain grass, and salt cedar.[221] Invasive species are problematic; high-severity fires in the chaparral increase invasive plants' abundance rather than getting rid of them.[222] Post-fire, common invasive plants include bull thistle, salsify, cheatgrass, and scotch broom.[223] At high densities, invasive plants can alter the fire regime, resulting in high-frequency and high-severity fires in Southern California; thus, it is critical to mitigate these invasive species in forests and the WUI.[224] Aside from invasive plants, wild pigs are also problematic in chaparral areas as they eat the native plants and regenerating trees, disrupt the soil, and contaminate the water.[225] Southern California faces concerns with bark beetles, specifically the western pine beetle, which also disrupt ponderosa pine. One of the most severe outbreaks of western pine beetle ever recorded occurred mainly in the San Bernardino National Forest between 2001 and 2004.[226] As a result, with the combination of drought, some of the largest and most damaging wildfires broke out in southern California in 2003 and 2007.[227] Therefore, mitigating invasive species is vital in maintaining forest health and reducing fire frequency and severity in chaparral areas.

Overall, the historical context of Southern California's fire regime in the chaparral depicts the contributing factors to fire frequency, scale, and intensity, which is essential

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221 Carl E Bell, Joseph M Ditomaso, and Matthew L Brooks, *Invasive Plants and Wildfires in Southern California* (Oakland, CA: University of California, Agriculture and Natural Resources, 2009), https://doi.org/10.3733/ucanr.8397.

222 "Invasive Plants and Fire," U.S. Forest Service Pacific Southwest Research Station, accessed June 5, 2022, https://www.fs.fed.us/psw/topics/fire_science/ecosystems/invasiveplants.shtml.

223 U.S. Forest Service.

224 U.S. Forest Service.

225 "Wild Pig Management Program," California Department of Fish and Wildlife, accessed June 5, 2022, https://wildlife.ca.gov/Conservation/Mammals/Wild-Pig; David Van Cleve et al., "An Assessment of the Known and Potential Impacts of Feral Pigs (Sus Scrofa) in and near San Diego County with Management Recommendations" (Corvallis, OR: Conservation Biology Institute, October 2009), https://d2k78bk4kdhbpr.cloudfront.net/media/reports/files/Feral_pig_report_Oct_2009_with_figures-11.pdf.

226 Christopher . Fettig, "Socioecological Impacts of the Western Pine Beetle Outbreak in Southern California: Lessons for The Future," *Journal of Forestry* 117, no. 2 (July 27, 2018): 139, https://doi.org/10.1093/jofore/fvy029.

227 Fettig, 140.

for forestry managers and others responsible for land management and wildfire prevention.

2. Forestry Management

The California Department of Forestry and Fire Protection (CAL FIRE) is the state agency responsible for preventing and suppressing the state's 31 million acres of private and public forests.[228] Like most state fire agencies, CAL FIRE receives its funding through the state, DOI, and the USFS. With its budget, CAL FIRE is able to uphold its legislative mandates and provide resources to forestry and fire stakeholders. For instance, the Forest Practice Regulations establish the state's standards for varying land management practices, including erosion control, burning brush, logging rules, and specific county and area policies.[229] Three notable legislative mandates in the state include the California Forest Improvement Act of 1978, the California Urban Forestry Act of 1978, and the California Forest Legacy Act of 2008.[230] These acts are focused on forest resources and grants for forest conversation. Like Arizona, CAL FIRE cooperates with the Los Angeles County Fire Department under the Conservation Camp Program to allow inmates to assist with fire suppression and mitigation.[231] In 2020, Assembly Bill 2147 was signed to provide inmates with a pathway to seek a career with CAL FIRE, USFS, or interagency hotshot crews.[232] In turn, CAL FIRE is the primary state agency for forestry management on state and private lands that provides grants to local fire agencies and other programs focused on forest health.[233]

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228 "About Us," CAL FIRE, accessed June 5, 2022, https://www.fire.ca.gov/about-us/; "Partnering Agencies," Ready for Wildfire CAL FIRE, accessed June 5, 2022, https://www.readyforwildfire.org/more/cal-fire-partners/.

229 The California Department of Forestry and Fire Protection, *California Forest Practice Rules* (Sacramento, CA: CAL FIRE, 2020), https://bof.fire.ca.gov/media/9478/2020-forest-practice-rules-and-act_final_ada.pdf.

230 "Wildfire Protection," CAL FIRE Office of the State Fire Marshal, accessed September 28, 2022, https://osfm.fire.ca.gov/divisions/code-development-and-analysis/wildfire-protection/.

231 "Conservation (Fire) Camps," California Department of Corrections and Rehabilitation, accessed September 28, 2022, https://www.cdcr.ca.gov/facility-locator/conservation-camps/.

232 California Department of Corrections and Rehabilitation.

233 "CAL FIRE Grants," CAL FIRE, accessed September 28, 2022, https://www.fire.ca.gov/grants/.

In addition to prevention and suppression, under California law, CAL FIRE is responsible for enforcing forest and fire laws throughout the state.[234] In areas where CAL FIRE has primary financial responsibility for the prevention and suppression of wildland fires, also known as State Responsibility Area (SRA), CAL FIRE requires homeowners to establish defensible space around their homes, clear flammable materials, and use fire-resistant materials when building a new home.[235] Additionally, under state law, CAL FIRE is responsible for designating Fire Hazard Severity Zones, which are areas at risk from fire hazards, including fuels, terrain, and weather.[236] Zones are identified from moderate to very high and landowners must abide by the same standards as SRA locations.[237] In all, California's regulations and policies grant CAL FIRE the responsibility to enforce forest and fire laws and suppress and mitigate wildfires on state and private lands.

CAL FIRE also formed the California Fire Safe Council to educate California residents on wildfires.[238] Additionally, the Rural County Representatives of California advocate policy for rural counties.[239] CAL FIRE's *January 2019 Strategic Plan* covers four goals in efforts to improve capabilities, operations, and the health and wellness of the community and workforce.[240] In 2019, Governor Newsom signed Executive Order (EO) N-05-19 to address destructive wildfires in 2018 that saw 1.8 million acres burned, including the 2018 Camp Fire, the deadliest fire in California's history with 86 lives

234 "CAL FIRE Law Enforcement Program," CAL FIRE, accessed September 28, 2022, https://www.fire.ca.gov/programs/fire-protection/law-enforcement-civil-cost-recovery/.

235 "Fire Safety Laws," CAL FIRE, accessed September 28, 2022, https://www.readyforwildfire.org/more/fire-safety-laws/; California Department of Forestry and Fire Protection, "California State Responsibility Areas," ArcGIS, September 19, 2022, https://www.arcgis.com/home/item.html?id=5ac1dae3cb2544629a845d9a19e83991.

236 CAL FIRE Office of the State Fire Marshal, "Wildfire Protection."

237 CAL FIRE Office of the State Fire Marshal.

238 CAL FIRE, "Partnering Agencies."

239 CAL FIRE.

240 California Department of Forestry and Fire Protection, *January 2019 Strategic Plan (*Sacramento, CA: California Department of Forestry and Fire Protection, 2019), https://www.fire.ca.gov/media/bo2fdzfs/strategicplan2019-final.pdf.

lost.[241] Ultimately, the EO assigned CAL FIRE to provide a report covering recommendations the governor can implement to manage wildfires. The 19 recommendations provided by CAL FIRE included addressing regulatory requirements for fuels reduction projects, creating incentives for private landowners, and community engagement.[242] CAL FIRE is the state agency responsible for forestry management and wildfire suppression on state and private lands, alongside other councils collaborating with residents to meet forestry management objectives.

BLM is responsible for 15 million acres of public lands in California; 9.5 million of those acres are primarily in the desert of Southern California.[243] BLM maintains recreation areas and renewable energy sites throughout the state, including San Gorgonio Pass Wind Farm.[244] In sum, BLM is one of the federal agencies in California focused on protecting public lands throughout the state. An additional federal agency includes USFS, which manages 20 million acres of national forest in California.[245] Southern California is home to four national parks (Angeles, Cleveland, Los Padres, and San Bernardino), totaling 3.5 million acres.[246] California is considered Region 5, the Pacific Southwest, with the USFS, including Hawaii and U.S. Affiliated Pacific Islands.[247] The 2022 strategic priorities for Region 5 involve disaster relief assistance for post-fire recovery and a 10-year strategy for fuel reduction and improving forest resiliency.[248] Additionally, the USFS and CAL FIRE signed the Shared Stewardship Agreement

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241 Gavin Newsom, Exec. Order No. N-05-19 (2019), https://www.gov.ca.gov/wp-content/uploads/2019/01/1.8.19-EO-N-05-19.pdf.

242 California Department of Forestry and Fire Protection, *Community Wildfire Prevention & Mitigation Report* (Sacramento, CA: California Department of Forestry and Fire Protection, 2019), https://www.fire.ca.gov/media/5584/45-day-report-final.pdf.

243 Sierra Club, "BLM Wilderness Areas of California," *Sierra Club Hundred Peaks Section* (blog), June 1995, http://www.hundredpeaks.org/guides/blmmaps.htm.

244 Bureau of Land Management, *California Public Lands: National System of Public Lands* (Sacramento, CA: Bureau of Land Management, 2021), https://www.blm.gov/sites/blm.gov/files/docs/2021-08/Public%20Lands%202020_508.pdf.

245 "Region 5," USDA Forest Service, accessed June 5, 2022, https://www.fs.usda.gov/r5.

246 Center for Biological Diversity, "Southern California Forests."

247 U.S. Forest Service, "Region 5."

248 "Regional Strategic Priorities," USDA Forest Service, accessed June 5, 2022, https://www.fs.usda.gov/detail/r5/about-region/?cid=STELPRDB5150117.

together, a long-term plan to treat one million acres of forest land per year to minimize wildfire impacts.[249] Overall, the USFS is responsible for national forest land throughout California. Alongside state entities, like CAL FIRE, BLM and the USFS are heavily involved in improving collaboration to meet forestry management goals and reduce wildfire impacts on forest health and communities.

In addition to state and federal forestry management partners, tribes are an integral component to forestry and fire management practices. There are about 110 federally recognized tribes in California, the highest Native American population in the country.[250] BIA's Pacific Region's Branch of Forestry and Wildland Fire Management is responsible for the protection and response of over 500,000 acres of Indian trust land in California.[251] Some tribal nations have their own fire departments to combat wildland fires.[252] Historically, tribes would burn chaparral in the fall and spring to create new plant growth.[253] In recent years, traditional tribal fire management practices, such as cultural burning, have been incorporated with modern-day fire management to clear built-up fuels and reintroduce fire to critical areas.[254] Throughout California, tribal nations and BIA are responsible for land management and wildfire mitigation on tribal lands.

Forestry management in California is the responsibility of all stakeholders at all levels, including CAL FIRE, BLM, the USFS, tribal nations, and residents. All agencies collaborate on the Wildfire and Forest Resilience Task Force, which reviews and

249 "California, U.S. Forest Service Establish Shared Long-Term Strategy to Manage Forests and Rangelands," Office of Governor Gavin Newsom, August 13, 2020, https://www.gov.ca.gov/2020/08/13/california-u-s-forest-service-establish-shared-long-term-strategy-to-manage-forests-and-rangelands/.

250 "Frequently Asked Questions: Indian Tribes and Tribal Communities in California," California Tribal Court-State Court Forum, accessed June 5, 2022, https://www.courts.ca.gov/documents/TribalFAQs.pdf.

251 "Branch of Wildland Fire," U.S. Department of the Interior Indian Affairs, accessed June 5, 2022, https://www.bia.gov/regional-offices/pacific/programs-and-services/wildland-fire.

252 Jeanine Pfeiffer, "California Tribes Support Each Other and Seek Inclusion in State Wildfire Response," *KCET* (blog), October 21, 2021, https://www.kcet.org/news-community/california-tribes-support-each-other-and-seek-more-inclusion-in-state-wildfire-response.

253 Barro and Conard, "Fire Effects on California Chaparral," 137.

254 Lauren Sommer, "To Manage Wildfire, California Looks To What Tribes Have Known All Along," NPR, August 24, 2020, https://www.npr.org/2020/08/24/899422710/to-manage-wildfire-california-looks-to-what-tribes-have-known-all-along.

establishes the *California's Wildfire and Forest Resilience Action Plan*.[255] The plan encompasses frameworks and programs for all key stakeholders to improve forest health, protect communities, and reduce climate change impacts.[256] Every stakeholder is responsible for maintaining forest health and mitigating wildfire impacts at all levels.

3. Summary

Out of California's 33 million acres of forest, 15.3 million of those acres include the chaparral landscape in Southern California.[257] Located in and around the chaparral regions are the state's and nation's vital resources and critical infrastructure—for example, the port of Long Beach, DOD facilities and military bases, and agriculture.[258] Additionally, Southern California is home to many residents living in the WUI, which is continuing to expand.[259] Wildfire scale and frequency in Southern California began to occur more often in the 1920s.[260] Santa Ana winds contribute to large-scale fires as it brings dry and hot air to the area.[261] Additionally, old-growth chaparral contributes to an increase in wildfire scale and intensity while young chaparral does not.[262] In recent years, wildfire scale and intensity have increased since the 1920s, as demonstrated in the listing of California's largest and most destructive wildfires in history.[263] Additional contributing factors to southern California's wildfire scale and intensity include human activity, climate change, built-up fuels, and invasive species. In turn, assessing the

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255 "Governor's Wildfire and Forest Resilience Task Force Announces Forest Health Grants and Smoke Spotter App," California Natural Resources Agency, May 20, 2021, https://resources.ca.gov/Newsroom/Page-Content/News-List/Governors-Wildfire-and-Forest-Resilience-Task-Force.

256 California Forest Management Task Force, *California's Wildfire and Forest Resilience Action Plan: Recommendations of the Governor's Forest Management Task Force* (Sacramento, CA: California Forest Management Task Force, 2021), https://fmtf.fire.ca.gov/media/cjwfpckz/californiawildfireandforestresilienceactionplan.pdf.

257 U.S. Department of Agriculture, "Focus on Forestlands in California"; Wrangle, "North American Chaparral."

258 Cal OES, "About Cal OES."

259 Syphard, Brennan, and Keeley, "Chaparral Landscape."

260 Eisele, *An Analysis of Large Chaparral Fires.*

261 Eisele; Associated Press, "Strong Santa Ana Winds Blow Through Southern California."

262 Eisele, *An Analysis of Large Chaparral Fires.*

263 CAL FIRE, "Top 20 Largest California Wildfires."

historical context and factors of wildfire scale and intensity provides key stakeholders with the ability to determine effective measures that mitigate the negative impacts of unhealthy forests and wildfires.

C. ALASKA: TUNDRA

Alaska maintains approximately 126 million acres of forest that range from boreal forests to coastal rainforests.[264] Of the 10 largest national forests in the United States, seven are in Alaska.[265] One noteworthy forest in Alaska is the Tongass National Forest, the largest old-growth forest in the nation, which claims 17 million acres in southeast Alaska's panhandle.[266] The BLM is the largest owner of land in Alaska, responsible for 82 million acres.[267] Under the Alaska Native Claims Settlement Act, BIA manages 45 million acres.[268] The USFS manages two national forests, totaling 21.9 million acres.[269] With three state-designated forests (Haines, Tanana Valley, and Southeast), the state owns more than 1.8 million acres.[270] It is estimated that 413,000 acres are privately owned.[271] Uniquely, Alaska is home to two types of tundra: the alpine, which can be found in southwest Alaska in Lake Clark National Park and Preserve, and the Arctic,

264 Alaska Division of Forestry, Statewide Assessment of Forest Resources (Juneau, AK: Alaska Division of Forestry, 2010), 1, http://forestry.alaska.gov/Assets/pdfs/home/FOR%20assessment%202010%20Master%20lores.pdf; Patricia Cochran et al., "Alaska," Climate Change Impacts in the United States: The Third National Climate Assessment (Washington, DC: U.S. Global Change Research Program, 2014), https://doi.org/10.7930/J00Z7150.

265 *National Park Foundation*, "The Size of the Largest National Parks Will Blow Your Mind," (blog), accessed June 5, 2022, https://www.nationalparks.org/connect/blog/size-largest-national-parks-will-blow-your-mind.

266 "Tongass National Forest - About the Forest," USDA Forest Service, accessed June 5, 2022, https://www.fs.usda.gov/main/tongass/about-forest.

267 Alaska Division of Forestry, *Statewide Assessment of Forest Resources*, 7.

268 Tana Fitzpatrick, *Alaska Native Lands and the Alaska Native Claims Settlement Act (ANCSA): Overview and Selected Issues for Congress*, CRS Report No. R46997 (Washington, DC: Congressional Research Service, 2021), https://sgp.fas.org/crs/misc/R46997.pdf.

269 "Region 10 - About the Area," USDA Forest Service, accessed June 5, 2022, https://www.fs.usda.gov/main/r10/about-region.

270 Alaska Department of Natural Resources Division of Forestry, "Alaska's State Forests," The Great State of Alaska, accessed June 5, 2022, http://forestry.alaska.gov/stateforests.htm.

271 Alaska Division of Forestry, Statewide Assessment of Forest Resources, 11.

which is in the northern part of the state, near the Arctic Circle.[272] Tundra regions are vital for Earth as they feature permafrost—frozen ground—that scientists use to study climate change impacts and is considered the planet's carbon sink.[273] This section primarily focuses on Alaska's tundra regions, covering approximately 20 million acres in the state, as shown in Figure 5.[274] Translated from the Finnish word *Tunturi*, tundra means treeless heights.[275] Although the tundra is considered a treeless zone, and this thesis is focused on forests, the tundra biome is a large part of western U.S. geography and is an imperative component of the environment and to homeland security.[276]

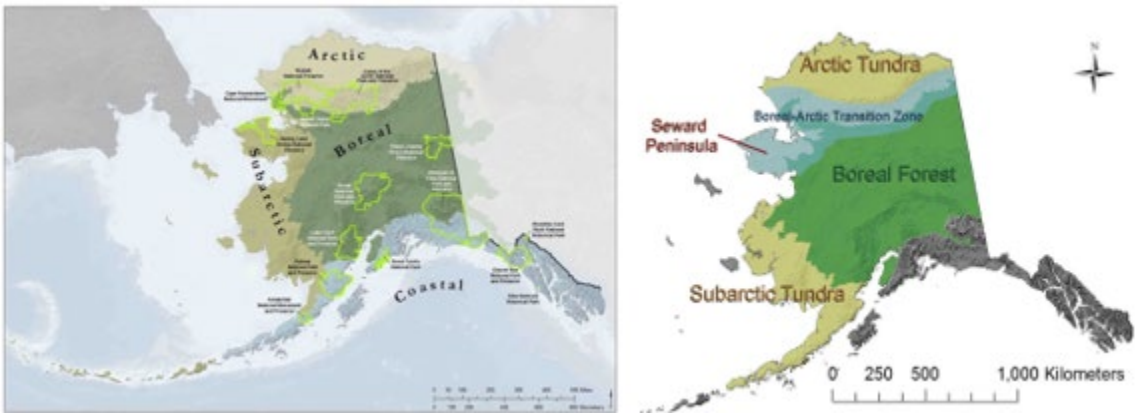

Figure 5. Alaska Tundra Regions[277]

[272] "Tundra - Lake Clark National Park & Preserve," National Park Service, February 15, 2018, https://www.nps.gov/lacl/learn/nature/tundra.htm.

[273] Pot, "Why Is the Tundra So Important?," *Sciencing,* September 30, 2021, https://sciencing.com/tundra-important-5329435.html.

[274] Jennifer Errick, "Parks in the Arctic," *National Parks Conservation Association* (blog), February 3, 2022, https://www.npca.org/articles/389-parks-in-the-arctic; "Park Statistics," National Park Service, March 8, 2022, https://www.nps.gov/lacl/learn/management/statistics.htm.

[275] "Tundra," Alaska Department of Fish and Game, accessed August 15, 2022, https://www.adfg.alaska.gov/index.cfm?adfg=tundra.main.

[276] G.J Wolken et al., "Glacier and Permafrost Hazards," NOAA Arctic Report Card, January 5, 2021, https://doi.org/10.25923/v40r-0956; National Park Service, "Tundra."

[277] Adapted from National Park Service, "About the Region," National Park Service, December 17, 2019, https://www.nps.gov/subjects/aknatureandscience/about.htm; Hugh Edwards et al., "Alaskan Tundra Project," *Alaskan Tundra* (blog), November 22, 2015, http://alaskantundrageo5.blogspot.com/2015/11/alaskan-tundra-project-geography-5-lab.html.

Natural resources and critical infrastructure are prevalent in Alaska, where some are located near or in forests, including tundra regions. For instance, several military bases in Alaska's Arctic areas are strategically located to defend against attacks from Russia and China, including the possibility of new shipping lanes in the Arctic.[278] As of April 2022, the Office of Inspector General found that five military bases in Alaska's Arctic and sub-Artic have not sufficiently prepared for climate change impacts, such as flooding, wildfires, etc.[279] Thus, to meet the DOD's *Arctic Strategy* and *National Defense Strategy* priorities, it is critical to address and mitigate concerns that will improve the nation's resiliency against adversaries and create opportunities for available natural resources as the Arctic sea ice melts.[280] Overall, the DOD manages more than 1.6 million acres in Alaska in coordination with BLM.[281] Some of Alaska's most critical and abundant natural resources include timber, minerals, oil, and coal, which support the state's communities and the nation.[282] Specifically, the tundra provides freshwater sources, abundant minerals, including coal, iron, zinc, lead, and nickel, and rocks and stones used for construction projects.[283] Concerning residents living in the WUI, the Alaska Division of Forestry estimates that about 80% of citizens live in communities at

278 Claire Stremple, "Alaska Military Bases Fall Short on Climate Readiness, Federal Report Says," KTOO, April 27, 2022, https://www.ktoo.org/2022/04/27/alaska-military-bases-fall-short-on-climate-readiness/.

279 U.S. Department of Defense, *Evaluation of the Department of Defense's Efforts to Address the Climate Resilience of U.S. Military Installations in the Arctic and Sub-Arctic,* DODIG-2022-083 (Washington, DC: U.S. Department of Defense, 2022), 15, https://media.defense.gov/2022/Apr/15/2002977604/-1/-1/1/DODIG-2022-083.PDF.

280 U.S. Department of Defense, 6, 7; Rhemi Marlatt, "The Intersection of U.S. Military Infrastructure & Alaskan Permafrost Through the 21st Century," *The Arctic Institute Center for Circumpolar Security Studies* (blog), October 27, 2020, https://www.thearcticinstitute.org/intersection-military-infrastructure-alaskan-permafrost-21st-century/.

281 Alaska Division of Forestry, *2020 Alaska Forest Action Plan* (Anchorage, AK: State of Alaska Department of Natural Resources Division of Forestry, 2020), 18, https://www.stateforesters.org/wp-content/uploads/2021/02/FINAL-2020-Alaska-Forest-Action-Plan-2020-02-01-reduced-file-size.pdf.

282 Alaska Division of Forestry, *Annual Report to the Board of Forestry: 2020 Forest Practices Act Effectiveness* (Anchorage, AK: Alaska Department of Natural Resources, 2021), http://forestry.alaska.gov/Assets/pdfs/alaskaboardforestry/2021/DNR%20report%202020.pdf; "Region 10 - Regional Overview," USDA Forest Service, accessed June 5, 2022, https://www.fs.usda.gov/detail/r10/about-region/overview/?cid=fsbdev2_038640.

283 "Arctic Natural Resources," National Ocean Economics Program, August 22, 2017, https://www.oceaneconomics.org/arctic/NaturalResources/; Kirstynn Joseph, "Alpine Tundra," World Biomes, accessed August 15, 2022, https://thewildclassroom.com/biomes/alpine-tundra/.

risk from wildfires.[284] For thousands of years, the indigenous people of the Aleut, Alutiiq, Inupiat, Central Yup'ik, and Siberian Yupik have lived in Alaska's tundra.[285] The tundra serves Alaskan natives culturally and economically.[286] In the northwest portion of the state, the two largest indigenous populations, the Kotzebue and Barrow, with about 10,500 people, live in the Arctic tundra.[287] Therefore, addressing wildfire concerns in the tundra is necessary to ensure that Alaska's critical infrastructure, communities, and natural resources are protected from wildland fire.

This section offers a different perspective on fire regimes in a different climate in the western United States. Analyzing Alaska's tundra can provide insight into climate change impacts and other considerations for areas such as Colorado, which also has an alpine tundra.[288] Alaska's alpine tundra consists of shrubs, including the dwarf willow, dwarf birch, heath plants (i.e., blueberry and cranberry), cotton grass, and mosses.[289] Alaska's Arctic tundra similarly consists mainly of dwarf shrubs and grasses.[290] Despite its cold climate, wildfires are a routine process in the tundra that regulate the permafrost but the fires have grown larger and more frequent in recent years.[291] For instance, in June 2022, the East Fork Fire became the largest documented wildfire in southwest Alaska's Yukon–Kuskokwim Delta, burning 166,587 acres and forcing two Alaska

284 Alaska Division of Forestry, *2020 Alaska Forest Action Plan,* 44.

285 Alaska Department of Fish and Game, "Tundra."

286 Alex Whiting, "The Economic and Cultural Benefits of Northwest Alaska Wilderness," National Park Service, October 30, 2021, https://www.nps.gov/articles/aps-v13-i1-c5.htm.

287 "Far North," Alaska Web, 2015, http://alaskaweb.org/region-farnorth.html.

288 "Alpine Tundra Ecosystem," National Park Service, July 22, 2020, https://www.nps.gov/romo/learn/nature/alpine_tundra_ecosystem.htm.

289 Reed Noss, "Interior Alaska-Yukon Alpine Tundra," *One Earth* (blog), accessed August 15, 2022, https://www.oneearth.org/ecoregions/interior-alaska-yukon-alpine-tundra/.

290 "Featured Species-Associated Tundra Habitats: Arctic, Alpine and Maritime Tundra," Alaska Department of Fish and Game, 1, https://www.adfg.alaska.gov/static/species/wildlife_action_plan/appendix5_tundra_habitats.pdf.

291 "Wildfire in the Arctic," National Park Service, August 13, 2019, https://www.nps.gov/subjects/arctic/wildfire.htm.

Native villages to evacuate.[292] In all, it is beneficial to learn the forestry management practices, understand the importance of what Alaska's tundra offers, and address the concerns posed by wildfires and climate change in the region to protect indigenous communities, critical infrastructure, and improve the homeland's resiliency.

1. Historical Context

Similar to the rest of the western United States, the state of Alaska has experienced longer fire seasons and larger, more severe, and more frequent wildfires.[293] Based on 65 years of data collected on Alaska's wildfires, Climate Central finds that fires larger than 1,000 acres began to increase in the 1990s and 2000s.[294] Scholars Todd and Jewkes, with the University of Alaska Fairbanks, maintained that tundra fires were common in the late 1800s and the beginning of the 1900s.[295] Historically, fires in the tundra are from May to August but commonly occur in June or July and tend to be ignited by lightning.[296] The USFS suggested that due to the sparse population in the tundra, current fire regimes may not differ drastically from historical regimes.[297] The USFS does note that human-caused fires have become more frequent than in the past.[298] On the other hand, the National Park Service (NPS) suggested that the shift in warm, dry

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[292] National Wildfire Coordinating Group, "East Fork Fire Information," InciWeb, July 29, 2022, https://inciweb.nwcg.gov/incident/8148/; Olivia Ebertz, "Smoky Conditions Persist on the Lower Yukon River as Some Evacuees Return Home," KYUK, June 17, 2022, https://www.kyuk.org/public-safety/2022-06-17/smoky-conditions-persist-on-the-lower-yukon-river-as-some-evacuees-return-home; Lisa Phu, "Yukon-Kuskokwim Delta Wildfires, Part of a New Pattern, Push Alaska to Early Season Milestone," *Alaska Public Media* (blog), June 21, 2022, https://alaskapublic.org/2022/06/21/yukon-kuskokwim-delta-wildfires-part-of-a-new-pattern-push-alaska-to-early-season-milestone/.

[293] Alison York and Randi Jandt, "Wildfire Is Transforming Alaska and Amplifying Climate Change," *Scientific American,* October 1, 2021, https://www.scientificamerican.com/article/wildfire-is-transforming-alaska-and-amplifying-climate-change/.

[294] Todd Sanford, Regina Wang, and Alyson Kenward, "The Age of Alaskan Wildfires" (Princeton, NJ: Climate Central, 2015), 3, http://assets.climatecentral.org/pdfs/AgeofAlaskanWildfires.pdf.

[295] Susan K Todd and Holly Ann Jewkes, "Wildland Fire in Alaska: A History of Organized Fire Suppression and Management in the Last Frontier" (master's thesis, Fairbanks, AK, University of Alaska, 2022), 9, https://scholarworks.alaska.edu/bitstream/handle/11122/1313/Bulletin114.pdf?sequence=1.

[296] Robin J. Innes, "Fire Regimes of Alaskan Tundra Communities," USDA Forest Service, 2013, https://www.fs.fed.us/database/feis/fire_regimes/AK_tundra/all.html.

[297] Innes.

[298] Innes.

weather conditions due to climate change in the past 60 years has resulted in more than 5.4 million acres of tundra being burned.[299] Similarly, the USFS concurred that warmer temperatures result in longer, larger, more frequent, and severe fire seasons due to melting snow, vegetation changes, and loss of permafrost.[300] From the late 1800s to the early 1900s, it is suspected that wildfire prevention and suppression throughout Alaska were limited.[301] According to Todd and Jewkes, the first documented wildfire prevention in the tundra occurred in 1926 when two Alaskan natives were sentenced to 90 days in jail for igniting a wildfire near the village of Napamute.[302] Overall, the historical context of Alaska's wildfires illustrates that fire has been relatively common in the tundra regions but has recently grown in frequency, scale, and intensity due to climate change and human activity.

Alaska's wildfire activity is demonstrated in the following list of the three largest wildfires in the state's history. Each fire details the location and amount of destruction, including total cost, lives lost, and critical infrastructure impacted.

a. Taylor Complex Fire

Alaska's largest wildfire, the Taylor Complex Fire, was formed by seven other fires that occurred in the same area that eventually merged.[303] The most prominent fires included in the complex were the Billy Creek, Chicken, Wall Street, and Porcupine Fires.[304] The initial fire began June 12, 2004, and ended November 9, 2004, which

299 "The Burning Tundra: A Look Back at the Last 6,000 Years of Fire in the Noatak National Preserve, Northwestern Alaska," National Park Service, October 26, 2021, https://www.nps.gov/articles/aps-v10-i1-c9.htm; "In Alaskan Arctic, Tundra Wildfire Drives Large Loss of Nutrients from Terrestrial to Aquatic Ecosystems," National Park Service, February 18, 2021, https://www.nps.gov/articles/000/tundrafirec.htm.

300 Innes, "Fire Regimes of Alaskan Tundra Communities."

301 Todd and Jewkes, "Wildland Fire in Alaska," 10.

302 Todd and Jewkes, 10.

303 Sarah A. Lewis et al., "Using Hyperspectral Imagery to Estimate Forest Floor Consumption from Wildfire in Boreal Forests of Alaska, USA," *International Journal of Wildland Fire* 20, no. 2 (January 2011): 257, https://doi.org/10.1071/WF09081.

304 Bureau of Land Management, *Alaska Fire Season 2004* (Anchorage, AK: Bureau of Land Management, 2004), 6, https://fire.ak.blm.gov/content/aicc/Statistics%20Directory/Previous%20Years%20Data%20and%20FFR%20Handouts/Annual%20Reports%202004%20-%202014/2004.pdf.

burned 1,303,358 acres in the eastern portion of the state, including the Tok area, Northway, near Chicken, and north of Tanacross.[305] From 1977 to 2007, the Taylor Complex Fire was the largest wildfire, by acreage, in U.S. history.[306]

Type of forest: Each fire that was part of the Taylor Complex Fire burned in the state's interior boreal forest, which includes black spruce, white spruce, quaking aspen, and feather moss.[307] Near the Tok area, the fire burned portions of the tundra.[308]

Cause: Six of the seven fires were ignited by lightning.[309]

Severity: Analyzing information collected from sites within the Chicken, Wall Street, and Porcupine Fires, Lewis et. al. found that black spruce sites burned at moderately high severity whereas white spruce sites burned at moderate severity and high severity.[310] Additionally, in areas with high moisture, there were some sites that burned at a low severity.[311]

Critical Infrastructure: One uninhabited structure was lost, but the fire threatened campsites, cabins, and motor homes, and closed the Taylor Highway for weeks.[312]

Lives lost: No reports on deaths were found.

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[305] Bureau of Land Management, 6; Lewis et al., "Using Hyperspectral Imagery," 257.

[306] Z. Grabinski and H.R. McFarland, "Alaska's Changing Wildfire Environment," University of Alaska Fairbanks: International Arctic Research Center, 2020, 5, https://uaf-iarc.org/alaskas-changing-wildfire-environment/.

[307] Lewis et al., "Using Hyperspectral Imagery," 257–58.

[308] National Interagency Fire Center, "Incident Management Situation Report" (Boise, ID: National Interagency Fire Center, July 31, 2004), 3, https://www.predictiveservices.nifc.gov/IMSR/2004/20040731IMSR.pdf.

[309] Darcy H. Hammond et al., "Boreal Forest Vegetation and Fuel Conditions 12 Years After the 2004 Taylor Complex Fires in Alaska, USA," Fire Ecology 15, no. 32 (December 2019): 5, https://doi.org/10.1186/s42408-019-0049-5; Bureau of Land Management, Alaska Fire Season 2004, 6.

[310] Lewis et al., "Using Hyperspectral Imagery," 266.

[311] Lewis et al., 266.

[312] Bureau of Land Management, *Alaska Fire Season 2004*, 6.

Cost: The total cost of suppression in the Chicken Fire was $1.6 million.[313] For the entire complex, the cost of suppression was more than $5.9 million.[314]

b. Ruby Fire

The Ruby Fire, also known as the Ruby-Poorman, was ignited June 18, 1940, and burned 1.25 million acres till sometime in August.[315] Given that the fire occurred in 1940, fire records and additional details regarding damage, burn severity, and cost are limited. Since the early 1900s, the towns of Ruby and Poorman are in a remote area along the Yukon River that can only be accessed by airplane or riverboat.[316]

Type of forest: The town of Ruby is nestled in the Kilbuck-Kuskokwim Mountains, which is characterized as a boreal forest that consists of black spruce, white spruce, birch, and alder shrubs.[317] Additionally, permafrost is consistent under the lowlands and high mountains of the region, ranging from thin to moderate thickness, but is not found in the forested portions.[318]

Cause: From 1940–1942, lightning-ignited fires were not reported as it was not considered a cause of fire, thus the ignition of the Ruby Fire is unknown.[319]

Severity: No reports were found on the fire's burn severity.

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313 Bureau of Land Management, 6.

314 National Interagency Fire Center, "Incident Management Situation Report," 3.

315 Harold John Lutz, *Ecological Effects of Forest Fires in the Interior of Alaska*, 1133 (Washington, DC: U.S. Government Printing Office, 1956), 16, https://books.google.com/books?hl=en&lr=&id=GrQXAAAAYAAJ&oi=fnd&pg=PA78&dq=alaska+1940+ruby+fire&ots=dECEQ0s12D&sig=65CQh8gJPHKj73VcxhGWiSI3Yb8#v=onepage&q=Ruby&f=false; Alaska Division of Forestry, "When It Comes to Big Fires, 2015 Has Room to Grow," Alaska Wildland Fire Information, July 17, 2015, https://akfireinfo.com/2015/07/17/when-it-comes-to-big-fires-2015-has-room-to-grow/.

316 Robert M. Chapman, Robert R. Coats, and Thomas G. Payne, *Placer Tin Deposits in Central Alaska, Open-File Report* (Washington, D.C.: U.S. Department of the Interior Geological Survey, 1963), 36, https://pubs.usgs.gov/of/1963/0015/report.pdf; "Ruby," Travel Alaska, accessed August 28, 2022, https://www.travelalaska.com/Destinations/Cities-Towns/Ruby.

317 Alaska Department of Fish and Game, *Ecological Framework: The Lands and Waters That Produce Our Fish and Wildlife (*Anchorage, AK: Alaska Department of Fish and Game), 45, accessed August 28, 2022, https://www.adfg.alaska.gov/static/species/wildlife_action_plan/section3b.pdf.

318 Alaska Department of Fish and Game, 45.

319 Todd and Jewkes, "Wildland Fire in Alaska," 19.

Critical Infrastructure: The town of Ruby was popular in the early 1900s with more than 3,000 residents.[320] Ruby was nicknamed "The Gem of the Yukon" since many people got lucky and struck gold.[321] In 1939, a year before the Ruby Fire, about 139 people remained in Ruby after World War I and significant natural disasters occurred in the area.[322] It is unknown if the fire damaged any parts of the town. Additionally, for thousands of years, the Athabascan people have lived in Ruby.[323]

Lives lost: No reports on deaths were found.

Cost: The cost of damages is unknown. Regarding the cost of suppression, it is likely that no resources or personnel were used to suppress the fire given the area's remoteness.[324]

c. Kateel River #5 Fire

Located north of Koyukuk, the Kateel River #5 Fire consisted of five fires that combined, which burned 1,161,200 acres of boreal forest.[325] Lighting ignited the fires in the area on June 10, 1957.[326] Since the fire occurred in remote area, there was no concern of the fire impeding on critical infrastructure or communities, thus not a lot of

320 Senior Downing Bill, "Ruby Was Once the Gem of the Yukon," *Senior Voice* (blog), May 1, 2018, https://www.seniorvoicealaska.com/story/2018/05/01/columns/ruby-was-once-the-gem-of-the-yukon/1694.html.

321 Downing Bill.

322 Downing Bill.

323 Tanana Chiefs Conference, Inx., "Forest Resources: Ruby Village/Yukon River Watershed" (Anchorage, AK: Tanana Chiefs Conference, INC., 1987), 4, https://publicdocushare.tananachiefs.org/docushare/dsweb/Get/Document-3347/ruby_inventory.PDF.

324 Todd and Jewkes, "Wildland Fire in Alaska," 19.

325 Alaska Division of Forestry, "When It Comes to Big Fires"; Melanie Miller, *Fire Occurrence in the Central Yukon Planning Area, 1956–1982*, 14 (Anchorage, AK: Bureau of Land Management, 1985), 4, https://ia600703.us.archive.org/24/items/fireoccurrencein4480mill/fireoccurrencein4480mill.pdf; Ken Marsh, "Moose Luck: A Hunt in One of the Planet's Last, Best Wilderness Regions," Alaska Department of Fish and Game, February 2014, https://www.adfg.alaska.gov/index.cfm?adfg=wildlifenews.view_article&articles_id=644.

326 Miller, *Fire Occurrence in the Central Yukon,* 6.

information was recorded on the duration of the fire and burn severity.[327] Regarding costs, only $888 was spent to conduct aerial observations.[328]

The listed top three wildfires demonstrate the concern of climate change impacts such as warmer temperatures and low snowpack on forests that are used to a lot of moisture.[329] Alaska's largest fire seasons occurred in 1957, 2004, and 2015, and BLM determined that 2022 is also a record fire season.[330] Thus far, the record fire season was in 2004 with over 6.5 million acres burned throughout the state.[331] Each of the notable fire seasons are contributed to low snowpack and a warm spring that dried fuels.[332] Although most fires in Alaska occur in remote areas with sparse populations and are, in turn, left to burn, it is beneficial to understand the evolution of Alaska's wildfires as it still impacts the environment and surrounding communities.[333]

In the tundra, the most notable fire season occurred in 2007 with the Anaktuvuk River Fire (ARF), which was ignited by lightning.[334] The fire burned 256,000 acres at uncharacteristically high severity for three months from June to October, mainly on a

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[327] Miller, 8.

[328] Miller, 8.

[329] Lewis et al., "Using Hyperspectral Imagery," 269.

[330] Bureau of Land Management, "Alaska Wildfire Number of Fires and Acres Burned Since 1950," Alaska Fire History Chart, 2022, https://fire.ak.blm.gov/content/aicc/Statistics%20Directory/Alaska%20Fire%20History%20Chart.pdf.

[331] Bureau of Land Management.

[332] Bureau of Land Management, *Alaska Fire Season 2004*; Grabinski and McFarland, "Alaska's Changing Wildfire Environment"; Heidi Strader and Sharon Alden, *2015 Fire Season Weather Summary* (Washington, DC: Bureau of Land Management, 2015), https://fire.ak.blm.gov/content/Weather%20Folder/Fire%20Season%20Summaries/2015%20Fire%20Season.pdf.

[333] Alaska Division of Forestry, "When It Comes to Big Fires"; Grabinski and McFarland, "Alaska's Changing Wildfire Environment."

[334] Yereth Rosen, "Lower Yukon River Wildfire Is Among Alaska's Largest Tundra Fires on Record," *ArcticToday* (blog), June 15, 2022, https://www.arctictoday.com/lower-yukon-river-wildfire-is-among-alaskas-largest-tundra-fires-on-record/; Benjamin M. Jones et al., "Fire Behavior, Weather, and Burn Severity of the 2007 Anaktuvuk River Tundra Fire, North Slope, Alaska," *Arctic, Antarctic, and Alpine Research* 41, no. 3 (August 2009): 311, https://doi.org/10.1657/1938-4246-41.3.309.

mixture of BLM, native, and state land.[335] Scientists discovered that the ARF burned deep and thawed the permafrost, stating the fire "spewed a volume of carbon into the air equivalent to the average amount of carbon absorbed annually in the 20th century by all the world's Arctic tundra habitats."[336] Contributing factors to the 2007 wildfire season included warmer than average temperatures, below-normal precipitation, and low soil moisture that stressed the vegetation in the area.[337] As a result, the ARF is considered the longest-burning recorded tundra fire in the area and the largest tundra fire recorded in the state.[338] Most wildfires in Alaska are due to human activity, lightning, and climate change impacts, similar to fires in much of the western United States. In Alaska, lightning-induced fires commonly burn more acres, but historically, humans have caused more fires throughout the state.[339] According to USFS findings, while tundra regions accumulate fuels faster than boreal forests, tundra regions have fewer fires than boreal forests.[340] Within the past few years, the effects of an increasingly warmer climate and below-normal precipitation has become alarming in tundra regions as wildfires have become more frequent, larger, and more intense.[341] Early into the 2022 fire season, Alaska reached the one-million-acre threshold of fires throughout the state, including the tundra.[342] Overall, it is essential to address climate change impacts and human activity to reduce wildfire threats in Alaska's tundra.

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[335] Randi R. Jandt, Eric A. Miller, and Benjamin M. Jones, *Fire Effects 10 Years After the Anaktuvuk River Tundra Fires*, 64 (Washington, D.C.: U.S. Department of the Interior, 2021), 3 and 9, https://www.blm.gov/sites/blm.gov/files/docs/2021-06/BLM_AK_TR_64.pdf; E J Trammell et al., eds., *North Slope Rapid Ecoregional Assessment* (Anchorage, AK: U.S. Department of the Interior, 2015), 69, https://landscape.blm.gov/REA_General_Docs/NOS_REA_Report.pdf; Jones et al., "Fire Behavior, Weather, and Burn Severity," 309.

[336] Rosen, "Lower Yukon River Wildfire Is Among Alaska's Largest Tundra Fires on Record."

[337] Jones et al., "Fire Behavior, Weather, and Burn Severity," 313.

[338] Jones et al., 309.

[339] Grabinski and McFarland, "Alaska's Changing Wildfire Environment."

[340] Innes, "Fire Regimes of Alaskan Tundra Communities."

[341] Jandt, Miller, and Jones, *Fire Effects 10 Years After.*

[342] Phu, "Yukon-Kuskokwim Delta Wildfires."

Regarding invasive species, Alaska's tundra does not face the same impact from invasive plants compared to other regions, such as the boreal forests.[343] For example,, the spruce beetle is native to the state but, at times of outbreak, can be very destructive in attacking mature spruce trees, reducing forest health.[344] For instance, in 2019, the USFS surveyed 24.4 million acres of forest in the state, identifying 1.1 million damaged and diseased acres from insects, including spruce beetle.[345] In the tundra, climate change has impacted native Arctic animals, such as the caribou, as the climate has increased the number of parasites and disease that damage food sources.[346] Additionally, animals like the red fox are beginning to move into the tundra and competing with the native Arctic fox.[347] National Geographic suggested that climate change poses higher risks for invasive species to take root in the Arctic tundra.[348] Invasive plant species in Alaska include reed canary grass, orange hawkweed, and bull thistle.[349] Invasive plants tend to be located where humans pass through, including on trails and along highways. These plants pose concerns for the native environment and, in drought conditions, can offer fuel for wildfires, which is critical to consider with human activity in the tundra.[350]

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343 Therese M. Poland et al., eds., *Invasive Species in Forests and Rangelands of the United States: A Comprehensive Science Synthesis for the U.S. Forest Sector* (Springer International Publishing, 2021), xiii, https://doi.org/10.1007/978-3-030-45367-1.

344 U.S. Forest Service, Insects and Disease (Washington, DC: Department of Agriculture, 2014), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprd3856099.pdf; "What's Bugging Alaska's Forests? Spruce Beetle Facts and Figures," Alaska Department of Natural Resources Division of Forestry, accessed June 6, 2022, http://forestry.alaska.gov/insects/sprucebeetle.

345 Grabinski and McFarland, "Alaska's Changing Wildfire Environment."

346 Christina Nunez, "Tundra Threats Explained," National Geographic Society, May 19, 2022, https://education.nationalgeographic.org/resource/tundra-threats-explained.

347 Nunez.

348 Nunez.

349 "Alaska - Invasive & Non-Native Species," National Park Service, February 24, 2022, https://www.nps.gov/subjects/invasive/ak.htm; U.S. Forest Service, "Tongass National Forest High Priority Invasive Plants," Department of Agriculture, accessed June 6, 2022, https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd529961.pdf.

350 U.S. Forest Service, *Invasive Species Pocket Guide for Alaska Firefighters,* R10-TP-162 (Juneau, AK: U.S. Department of Agriculture, 2018), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd605385.pdf; Matthew L Carlson, Irina Lapina, and Julie A Michaelson, "Invasive Non-Native Plants in the Arctic: The Intersection of Natural and Anthropogenic Disturbance," University of Alaska Anchorage, accessed August 15, 2022, https://accs.uaa.alaska.edu/wp-content/uploads/Invasive_Non-Native_Plants_in_the_Arctic.pdf.

Thus, to ensure forest health and reduce fire fuel, addressing invasive species in Alaska's forests is critical.

Alaska is one of the most abundant permafrost locations in the United States, as 85% of permafrost is located beneath the state's surface.[351] The Alaska Department of Natural Resources, Division of Geological and Geophysical Surveys, defines permafrost as "ground with a temperature that remains at or below freezing (32° F or 0° C) for two or more consecutive years [and] provides a stable foundation for structures and infrastructure in cold-climate regions as long as the temperature of the frozen ground is well below freezing."[352] In other words, permafrost is a mixture of soil, gravel, and sand, bounded by ice, that creates a permanently frozen layer.[353] As there are two types of tundra regions, alpine and Arctic, there are two types of permafrost, alpine and Arctic.[354] Essentially, location is the primary differentiation between alpine permafrost and Arctic permafrost. For instance, alpine permafrost is in high elevations closer to the equator in places like Mount Washington in New Hampshire, Mauna Kea in Hawaii, and the Colorado Rocky Mountains.[355] On the other hand, Arctic permafrost is in Arctic regions in the Northern Hemisphere, including places like Canada, Greenland, and Russia.[356] Ultimately, permafrost makes the ground watertight; therefore, it maintains the wetlands and lakes throughout the Arctic and acts as a carbon sink, as it holds frozen plants and

351 Ronald P. Daanen, "Permafrost and Periglacial Hazards," Alaska Department of Natural Resources Geological and Geophysical Surveys, accessed November 12, 2022, https://dggs.alaska.gov/hazards/permafrost.html.

352 Daanen.

353 Kim Rutledge et al., "Permafrost," National Geographic, May 19, 2022, https://education.nationalgeographic.org/resource/permafrost.

354 Siraj Ul. Islam and Stephen Dery, "Arctic and Alpine Permafrost" (presentation, University of Northern British Columbia, Prince George BC, Canada, 2020), https://cyclone.unbc.ca/454/week7/Week7_2020.pdf.

355 Mikayla Mace Kelley, "Fast-Melting Alpine Permafrost May Contribute to Rising Global Temperatures," *University of Arizona News* (blog), March 14, 2022, https://news.arizona.edu/story/fast-melting-alpine-permafrost-may-contribute-rising-global-temperatures; T.E. Osterkamp and M.T. Jorgenson, "Permafrost Conditions and Processes," Geological Society of America, 2009, 205–27, https://doi.org/10.1130/2009.monitoring(09); Jack D. Ives and Barry D. Fahey, "Permafrost Occurrence in the Front Range, Colorado Rocky Mountains, U.S.A.," *Journal of Glaciology* 10, no. 58 (1971): 105–11, https://doi.org/10.3189/S0022143000013034.

356 Rutledge et al., "Permafrost."

animals with carbon-based remains.[357] Geologists with the USGS found that approximately 1,400 billion metric tons of carbon are stored in Alaska's permafrost, which is significantly more carbon than has ever been released by fossil fuel combustion.[358] There is significant concern around thawing permafrost for, ultimately, two reasons. First as permafrost thawing increases, more methane and carbon dioxide are emitted into the atmosphere, contributing to climate change impacts.[359] Second, permafrost thawing becomes a geologic hazard for Alaska as it causes landslides, flooding, and erosion, which may damage critical infrastructure.[360] In short, the thawing and loss of permafrost can significantly impact the planet's water and carbon cycle.[361] Some scholars have revealed that alpine permafrost is predicted to begin melting faster than Arctic permafrost, which may increase global temperatures.[362] Additionally, other scholars have found that recent tundra fires and other events that rapidly thaw permafrost (i.e., above-average temperatures) have increased carbon emissions in the Arctic tundra.[363] Maintaining and preserving permafrost in Alaska's tundra is vital as it is a significant part of the Arctic ecosystem that influences the global environment and poses obvious homeland security implications to the United States.

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[357] Center for Biological Diversity, "Thawing Permafrost," Center for Biological Diversity, accessed November 12, 2022, https://www.biologicaldiversity.org/programs/climate_law_institute/the_arctic_meltdown/slideshow_text/thawing_permafrost.html; Renee Cho, "Why Thawing Permafrost Matters," State of the Planet (blog), January 11, 2018, https://news.climate.columbia.edu/2018/01/11/thawing-permafrost-matters/.

[358] U.S. Geological Survey, "A Disappearing Act in Alaska,," July 19, 2022, https://www.usgs.gov/news/featured-story/disappearing-act-alaska#:~:text=Permafrost%20also%20happens%20to%20store,of%20years%2C%E2%80%9D%20Jones%20said.

[359] "Climate Change Indicators: Permafrost," U.S. Environmental Protection Agency, April 2021, https://www.epa.gov/climate-indicators/climate-change-indicators-permafrost.

[360] Daanen, "Permafrost and Periglacial Hazards"; U.S. Environmental Protection Agency, "Climate Change Indicators."

[361] National Snow and Ice Data Center, "Why Frozen Ground Matters," National Snow and Ice Data Center, accessed November 12, 2022, https://nsidc.org/learn/parts-cryosphere/frozen-ground-permafrost/why-frozen-ground-matters.

[362] Kelley, "Fast-Melting Alpine Permafrost May Contribute to Rising Global Temperatures"; "Thawing Permafrost in the Colorado Rockies Is Releasing Carbon Dioxide," Colorado Public Radio, April 3, 2019, https://www.cpr.org/2019/04/03/thawing-permafrost-in-the-colorado-rockies-is-releasing-carbon-dioxide/.

[363] Melissa Denchak, "Permafrost: Everything You Need to Know," Natural Resources Defense Council, June 26, 2018, https://www.nrdc.org/stories/permafrost-everything-you-need-know.

In turn, factoring wildfire scale, intensity, frequency influences, and historical context of Alaska's tundra provide key stakeholders with the ability to address preventable factors and climate change impacts.

2. Forestry Management

Under the Alaska Department of Natural Resources, the Alaska Division of Forestry (DOF) is the state entity responsible for managing and suppressing fires and timber management in three forests.[364] The DOF's 2020 *Alaska Forest Action Plan* involves all stakeholders at every level of government.[365] It prioritizes conservation, protection from threats including WUI and invasive species, and "enhancing public benefits from trees and forests."[366] Regarding fire suppression, the Alaska Interagency Wildland Fire Management Plan establishes shared management priorities of suppression resources between federal, state, and tribal land managers by designating four protection levels.[367] In other words, the plan is a guide to deciding between letting a fire burn or implementing suppression methods in forests and tundra regions. Additionally, the plan acknowledges the impact of climate change on Alaska's forests and tundra as it may result in melting permafrost, vegetation change, and increased wildfires.[368] Primarily, DOF is the state entity responsible for 1.8 million acres of the Haines, Tanana Valley, and Southeast Forests.[369]

364 Alaska Department of Natural Resources Division of Forestry, "Alaska's State Forests."

365 Alaska Division of Forestry, 2020 Alaska Forest Action Plan.

366 Alaska Division of Forestry, 58.

367 Alaska Division of Forestry, 43.

368 Alaska Wildland Fire Coordinating Group, Alaska Interagency Wildland Fire Management Plan (Anchorage, AK: Alaska Wildland Fire Coordinating Group, 2020), 40, https://fire.ak.blm.gov/content/aicc/Alaska%20Statewide%20Master%20Agreement/3.%20Alaska%20Interagency%20WIldland%20Fire%20Managment%20Plan%20(AIWFMP)/B.%20Previous%20AIWFMPs/2020%20AIWFMP.pdf.

369 Alaska Department of Natural Resources Division of Forestry, "Alaska's State Forests."

Under Alaska's statute, DOF upholds the laws on burning, mitigating, and protecting state and private land, and is the lead agency for wildfire management.[370] Ultimately, the Alaska Wildland Fire Protection Statutes and Regulations govern DOF's fire activities.[371] Additionally, the Alaska Forest Resources and Practices Act declares that "forest resources of Alaska are among the most valuable natural resources of the state" and details regulatory measures to preserve the forest resources and the power and duties of the commissioner.[372] Alaska's DOF receives funding from the USFS for community programs that promote healthy trees and forests.[373] Aside from USFS funding, DOF gets funding from the DOI and the state, like all forest departments in the United States, including timber sales.[374] DOF's funding is allocated between the coastal region, northern region, and statewide for programs that involve management costs, preparedness, response, and mitigation. Considering that DOF is responsible for most WUI areas, many programs are dedicated to forest preservation against the threat of wildfires and invasive species. For instance, through State Fire Assistance and Volunteer Fire Assistance from the USFS, DOF was able to allocate funds to train and hire more firefighters and establish programs that educate the community on wildfire threats and preparedness.[375] In all, Alaska's state regulations and policies are focused on forest preservation and health.

370 Alaska Division of Forestry and Fire Protection, Alaska Wildland Fire Protection Statutes and Regulations Booklet (Anchorage, AK: Alaska Department of Natural Resources Division of Forestry, 2019), http://forestry.alaska.gov/Assets/pdfs/statutes/Fire_regulations_PINK%20BOOK_5_30_2019.pdf.

371 Alaska Division of Forestry and Fire Protection.

372 Alaska Division of Forestry, Alaska Forest Resources & Practices Act (Anchorage, AK: Alaska Department of Natural Resources Division of Forestry, 2018), 1, http://forestry.alaska.gov/Assets/pdfs/forestpractices/Forest%20Resources%20&%20Practices%20Act%20text%20-%20update%20Mar%202018.pdf.

373 "Alaska Community Forestry," Alaska Department of Natural Resources Division of Forestry and Fire Protection, accessed September 28, 2022, http://forestry.alaska.gov/community/.

374 Alaska Department of Natural Resources Division of Forestry, *2020 Annual Report* (Anchorage, AK: Alaska Department of Natural Resources Division of Forestry, 2020), http://forestry.alaska.gov/Assets/pdfs/overview/2020AnnualReport.pdf.

375 U.S. Forest Service, "State and Private Forestry Fact Sheet - Alaska 2022" (Washington, DC: U.S. Department of Agriculture, Forest Service, November 10, 2022), https://apps.fs.usda.gov/nicportal/temppdf/sfs/naweb/ak_std.pdf.

At the federal level, the BLM Alaska Fire Service manages 82 million acres through fire prevention, fire suppression, fire ecology research, and managing the Alaska Interagency Coordination Center, where resources and logistics are coordinated.[376] BLM is a significant steward of the tundra in Alaska and is responsible for monitoring, suppressing, and protecting their responsible regions.[377] BLM's fire protection area is focused on the northern half of the state, including Galena, Tanana, the Upper Yukon Zone, and military areas.[378] DOF is concentrated in the central part, and the USFS is assigned to the south. The fire protection area is solely for the efficient use of fire-related resources. USFS, Region 10, manages the 21.9 million acres of the two largest national parks in the country, Tongass National Forest and Chugach National Forest.[379] An additional notable federal agency includes NPS, which is responsible for more than four million acres of the Lake Clark National Park and Preserve in southwest Alaska.[380] As previously mentioned, the tundra is a vital cultural and economic resource to Alaskan natives.[381] The indigenous peoples of Alaska use the land for food and income via hunting, fishing, fur production, and culturally through traditions, notable landmarks, and ancestral history.[382] NPS highlights the social challenge of managing the tundra in balancing federal and nonlocal priorities with local customs and practices.[383] Nonetheless, the BIA manages tribal areas and provides opportunities for tribes to "mitigate wildfire risk by managing wildfire fuels in and around their communities with

376 "Alaska Fire Service," Bureau of Land Management, accessed June 6, 2022, https://www.blm.gov/programs/fire-and-aviation/regional-info/alaska-fire-service; Alaska Interagency Coordination Center, "Alaska Interagency Coordination Center," Alaska Interagency Coordination Center, accessed June 6, 2022, https://fire.ak.blm.gov/aicc.php.

377 "Alaska Fire Service: Fire Management," Bureau of Land Management, accessed June 6, 2022, https://www.blm.gov/programs/fire-and-aviation-/state-information/alaska-fire-service/fire-management.

378 Bureau of Land Management.

379 "Alaska Region," USDA Forest Service, accessed June 6, 2022, https://www.fs.usda.gov/wildflowers/regions/alaska/index.php; U.S. Forest Service, "Region 10 - About the Area."

380 National Park Service, "Park Statistics."

381 Whiting, "The Economic and Cultural Benefits."

382 Whiting.

383 Whiting.

BIA funding."[384] In terms of traditional fire management practices in the tundra, the USFS finds that it was historically rare for Alaskan natives to conduct prescribed burns in the tundra.[385] In sum, the BLM, NPS, and BIA are some of the prominent federal agencies in the state responsible for forestry management, tundra preservation, and wildfire suppression in their designated area.

3. Summary

Alaska's alpine and Arctic tundra covers one third of the state. It is scenic and a critical component of the Earth's environment as it maintains a portion of its permafrost.[386] Natural resources and location near and within Alaska's national forests and tundra are vital to the state, communities and tribes, and the nation.[387] The state began to experience an increase in larger fires in the 1990s and 2000s in the boreal and tundra regions.[388] Wildfires are becoming more likely and severe due to climate change and human activity, especially in June and July.[389] Alaska's top three wildfires, including notable fire seasons, demonstrate the concern of climate change impacts such as warmer temperatures and low snowpack. In turn, key stakeholders, such as the BLM, USFS, and DOF, can utilize the historical context of Alaska's tundra and wildfire frequency, scale, and severity influencers to improve forest management practices and maintain tundra health.

384 "Wildland Fire Management," U.S. Department of the Interior Indian Affairs, accessed June 6, 2022, https://www.bia.gov/regional-offices/alaska/natural-resources/wildland-fire-management.

385 Innes, "Fire Regimes of Alaskan Tundra Communities."

386 Jandt, Miller, and Jones, *Fire Effects 10 Years After,* 3.

387 U.S. Forest Service, "Region 10 - Regional Overview."

388 Sanford, Wang, and Kenward, "The Age of Alaskan Wildfires."

389 Kristin Zouhar, *Fire Regimes in Alaskan Pacific Maritime Ecosystems* (Rocky Mountain Research Station: Department of Agriculture, 2017), https://www.fs.fed.us/database/feis/fire_regimes/AK_Pacific_maritime/all.html#FuelCharacteristics.

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III. IMAGINE IF …

This chapter uses the areas and information presented in the second chapter to illustrate the impact of the West's current forest and fire conditions on wildland fire growth near communities and critical infrastructure. To note, Alaska is not included in this section. Although tundra fires have a large impact on the environment and surrounding tribal villages, the simulations did not have the same effect as the Arizona and California scenarios. Nonetheless, each section discusses the current conditions of each forest, presents a fictional scenario that includes models, and concludes with a summary that discusses the scenario's findings and current challenges each state faces. As a result, each fictional scenario demonstrates the similarities and differences between western states' current forest conditions and forestry and fire management practices.

The modeling intertwined into each fictional scenario is through FARSITE, a tool offered by the USFS to produce fire growth simulations.[390] FARSITE utilizes data provided from weather reports and the LandFire interface for landscape and fuel characteristics.[391] Hence, each fictional scenario and model presented depicts the status quo of forestry and fire management practices, visualizes the factors that contribute to wildfire scale and intensity, and shows that simulations quantify how mitigation measures significantly changes fire growth dynamics. The use of FARSITE also illustrates how computer simulations of fire behavior can be used to inform off-season forest treatments that reduce the rate of fire growth, as simulations can be run in regions of interest. In running FARSITE simulations, it is acknowledged that mitigation measures must also preserve natural spaces and provide recreation activities to the public. The competing needs of a variety of stakeholders is precisely why simulation is so important: the effect of mitigation measures can be quantified to help educate skeptical constituents and engage diverse partners in better-informed forest management practices. Additional details regarding the simulation process are included in the appendix.

[390] M. Finney, "FARSITE," U.S. Forest Service, December 19, 2012, https://www.fs.usda.gov/rmrs/tools/farsite.

[391] Finney.

Furthermore, the fictional scenarios portray the influence of natural and human-caused ignitions, climate change conditions, and the impact wildfires have on communities. Addressing the difficulties posed to communities, wildland firefighters, and forestry managers allows key stakeholders to suggest and implement solutions to improve forest health and mitigate wildfire scale, frequency, and intensity. Ultimately, this chapter is to serve as a cautionary tale to communities in the West. For policymakers, this chapter is to emphasize the status of forest's health and how that poses challenges to protecting our communities and critical infrastructure. Last, for land managers, this chapter is to demonstrate the importance of incorporating simulations into mitigation planning.

A. ARIZONA

Since the 1900s, Arizona's 18.6 million acres of forest have experienced an increase in wildfire scale, intensity, and frequency.[392] Scholars have contributed this increase to drought and human activity.[393] Additional factors to Arizona's wildfires include growing WUI zones and invasive species.[394] Forestry management experts have shared concerns with ponderosa pine regeneration and note high tree mortality rate in Arizona and New Mexico due to increasing wildfires, bark beetle attacks, and climate change impacts.[395] The experts noted that ponderosa pine regeneration has been slow after environmental disturbances (i.e., wildfire, drought, invasive species) and predict threats to ponderosa pine forests will increase.[396] Nonetheless, the experts suggested with the help of nursery cultural practices and tree-seedling production facilities,

[392] Swetnam, Fire History and Climate.

[393] Roudaut and Eden, "Water Resources Protection"; Jennifer K. Balch et al., "Human-Started Wildfires Expand the Fire Niche Across the United States," *Proceedings of the National Academy of Sciences* 114, no. 11 (January 6, 2017): 2946, https://doi.org/10.1073/pnas.1617394114.

[394] Balch et al., "Human-Started Wildfires," 2950; Negrón et al., "Bark Beetle"; Fusco et al., "Invasive Grasses Increase Fire Occurrence."

[395] Thomas Kolb, Aalap Dixit, and Owen Burney, "Challenges and Opportunities for Maintaining Ponderosa Pine Forests in the Southwestern United States," *Tree Planters' Notes* 62, no. 1 (2019): 104, https://www.researchgate.net/profile/Aalap-Dixit/publication/339338811_Challenges_and_Opportunities_for_Maintaining_Ponderosa_Pine_Forests_in_the_Southwestern_United_States/links/5e4c1c8f299bf1cdb93554bb/Challenges-and-Opportunities-for-Maintaining-Ponderosa-Pine-Forests-in-the-Southwestern-United-States.pdf.

[396] Kolb, Dixit, and Burney, 105.

ponderosa pine forests may be restored.[397] Overall, the current and predicted state of Arizona's ponderosa pine forests offer a grim outlook that is further exacerbated by wildfires.

Due to the lack of precipitation in the winter months, and drought proceeding, the NIFC predicted "above normal fire potential" in Arizona, beginning in late May 2022.[398] In other words, the NIFC indicated an increase in high-severity fires throughout the area.[399] The Arizona 2022 fire season started in early April with seven fires burning over 50,000 acres throughout the state.[400] The Tunnel Fire was the most notable of the seven, which burned 19,088 acres near Flagstaff from April 17 to June 3.[401] The Tunnel Fire burned ponderosa pine, and due to the combination of drought, high winds, and built-up fuel, the fire increased in size quickly.[402] As a result, 25 structures were burned.[403] Shortly after the Tunnel Fire was contained, the Pipeline Fire was ignited on June 12 by a man that lit toilet paper on fire.[404] The Pipeline Fire burned on the west and north sides of the Tunnel Fire burn scar and reached containment on July 28.[405] Thus far, the Pipeline Fire was the second largest fire in Arizona's 2022 wildfire season, burning a

397 Kolb, Dixit, and Burney, 109.

398 National Interagency Fire Center, "National Significant Wildland Fire Potential Outlook" (Boise, ID: Predictive Services National Interagency Fire Center, June 1, 2022), https://www.predictiveservices.nifc.gov/outlooks/monthly_seasonal_outlook.pdf.

399 Alisa R. Keyser and A. LeRoy Westerling, "Predicting Increasing High Severity Area Burned for Three Forested Regions in the Western United States Using Extreme Value Theory," *Forest Ecology and Management* 432 (January 15, 2019): 694–706, https://doi.org/10.1016/j.foreco.2018.09.027.

400 "Wildfire Map: Track Where Fires Are Burning in Arizona in 2022," The Arizona Republic, August 12, 2022, https://www.azcentral.com/story/news/local/arizona-wildfires/2022/04/20/arizona-wildfires-2022-map-track-where-fires-burning-now/7383488001/.

401 National Wildfire Coordinating Group, "Tunnel Fire BAER Information," InciWeb, June 13, 2022, https://inciweb.nwcg.gov/incident/8088/.

402 National Wildfire Coordinating Group.

403 "Arizona Tunnel Fire Burns More Than 19,000 Acres, Prompting Evacuations," CBS News, April 20, 2022, https://www.cbsnews.com/news/arizona-tunnel-wildfire-evacuations/.

404 National Wildfire Coordinating Group, "Pipeline Fire Information," InciWeb, August 2, 2022, https://inciweb.nwcg.gov/incident/8152/; Justin Lum et al., "Pipeline Fire: Man Pleads Guilty to Starting Wildfire Near Flagstaff," FOX 10 Phoenix, July 14, 2022, https://www.fox10phoenix.com/news/pipeline-fire-man-pleads-guilty-starting-wildfire-flagstaff.

405 National Wildfire Coordinating Group, "Pipeline Fire Information"; The Arizona Republic, "Wildfire Map."

total of 26,532 acres in the Coconino National Forest.[406] As of September 2022, Arizona's 2022 wildfire season consisted of 22 wildfires that burned more than 134,000 acres throughout the state.[407] In all, wildfire season in Arizona is expected to become more frequent and damaging to forest health and surrounding communities.[408]

1. Scenario: Pumphouse Wash Fire

This scenario mimics the Wallow Fire, Arizona's largest wildfire in history.[409] Additionally, the location of this scenario was selected based on its proximity to communities and critical infrastructure. Evacuations are discussed in the scenario and are based on the "Ready, Set, Go!" campaign, which is the dominant nationwide approach adopted by local, state, and tribal entities for wildfire evacuations.[410] In other words, "Ready" means to create and maintain a defensible space around property, "Set" means to prepare to evacuate, and "Go" means it is time to evacuate.[411] No research or articles were found to suggest mitigation efforts have been conducted in the area surrounding the site. Therefore, the scenario and modeling may suggest if adaptive management is necessary in this area. Additionally, the acres burned in this scenario is based on the FARSITE simulation shown in Figure 9 and the plot shown in Figure 12, given that spotting is relatively common fire behavior.[412]

406 The Arizona Republic, "Wildfire Map"; National Wildfire Coordinating Group, "Pipeline Fire Information."

407 The Arizona Republic, "Wildfire Map."

408 Climate Central, "Arizona Wildfires," States At Risk, accessed June 19, 2022, http://statesatrisk.org/arizona/wildfires.

409 Crigler, "The Rancher and the Wallow Fire."

410 Mass Evacuation Incident Annex (Washington, DC: Federal Emergency Management Agency, 2008), https://www.fema.gov/pdf/emergency/nrf/nrf_massevacuationincidentannex.pdf; "Ready, Set, Go!," Arizona Emergency information Network, n.d., https://ein.az.gov/ready-set-go.

411 CAL FIRE, "Ready, Set, Go!," Prepare for Wildfire, accessed October 12, 2022, https://www.readyforwildfire.org/prepare-for-wildfire/ready-set-go/.

412 "Spotting Fire Behavior," National Wildfire Coordinating Group, July 8, 2021, https://www.nwcg.gov/publications/pms437/crown-fire/spotting-fire-behavior.

This fictional wildfire is located at Pumphouse Wash (FR 237) Dispersed Camping Area, near State Route 89A in the Coconino National Forest, which is 11 miles south of Flagstaff, five miles north of Oak Creek Canyon, and 18 miles north of Sedona, shown in Figure 6.[413] Fire restrictions have been implemented throughout the Coconino National Forest due to the lack of rain from monsoon season, low snowmelt in the previous winter, and high temperatures, making fuels in the area are very dry.[414] Additionally, weather predictions for the summer forecast calm winds with the possibility of high wind gusts due to monsoonal activity.[415] Overall, the forest surrounding the camping site is at a high fire danger rating.[416]

On August 1, some campers arrived at their campsite in the late afternoon and wanted to begin cooking lunch, so they started a fire, despite the fire restrictions, in an undesignated spot near their site. After eating lunch, the campers wanted to take an early evening stroll, so they put out the fire and went on their way. Unfortunately, the fire was not properly put out and it caught the nearby brush and began to spread. Before a forest ranger could catch it, the fire began to spread into the Coconino National Forest toward Flagstaff.

413 "Pumphouse Wash (FR 237) Dispersed Camping Area," U.S. Forest Service, accessed October 12, 2022, https://www.fs.usda.gov/recarea/coconino/recarea/?recid=81580.

414 "Fire Restriction Stages Explained," U.S. Forest Service, accessed October 12, 2022, https://www.fs.usda.gov/detail/coconino/fire/?cid=fseprd891645.

415 "Climate and Average Weather Year Round in Flagstaff," Weather Spark, accessed October 12, 2022, https://weatherspark.com/y/2636/Average-Weather-in-Flagstaff-Arizona-United-States-Year-Round; Sean Golightly, "'We Can't Let Our Guard Down': Heavy Rain, Flash Flood Threats Remain in Northern Arizona Forecast," Arizona Daily Sun, September 19, 2021, https://azdailysun.com/news/local/weather/we-can-t-let-our-guard-down-heavy-rain-flash-flood-threats-remain-in-northern/article_ed5aa560-385d-11ed-ab41-370f3a01e438.html.

416 "National Fire Danger Rating System," U.S. Forest Service, accessed October 12, 2022, https://www.fs.usda.gov/detail/inyo/home/?cid=stelprdb5173311.

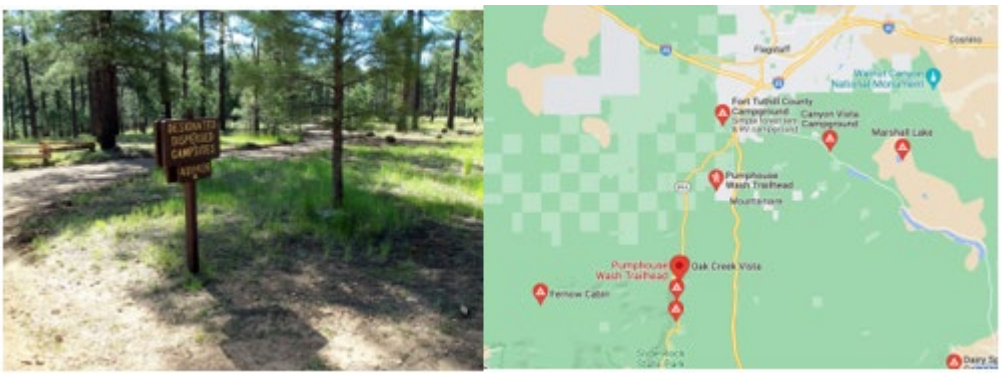

Figure 6. Pumphouse Wash (FR 237) Dispersed Camping Area[417]

Due to dry fuels and winds, the fire jumped to several hundred acres by the end of the first day. As a result, Oak Creek Canyon, consisting of more than 300 people and tourists, is immediately evacuated and thousands of residents and tourists in southern Flagstaff are in "Ready" status for evacuations.[418] After five days, the fire has burned more than 3,500 acres. On the 10th day, at 13, 271 acres, the fire is now about to impose on the city of Flagstaff. Some communities are put into "Set" status for evacuations. As winds are pushing the fire north, smoke is beginning to blanket the city and surrounding communities, resulting in poor air quality, posing concerns for children and people with asthma and other health concerns.[419]

[417] Adapted from U.S. Forest Service, "Pumphouse Wash (FR 237) Dispersed Camping Area"; Google, "Pumphouse Wash Trailhead," Google Maps, accessed October 12, 2022, https://www.google.com/maps/place/Pumphouse+Wash+Trailhead/@35.0927512,-111.6938815,11z/data=!4m10!1m2!2m1!1spumphouse+wash+dispersed+camping!3m6!1s0x872d99673e229385:0xd5a61bbff75038ef!8m2!3d35.0242679!4d-111.7362282!15sCiBwdW1waG91c2Ugd2FzaCBkaXNwZXJzZWQgY2FtcGluZ5IBC2hpa2luZ19hcmVh4AEA!16s%2Fg%2F11g9qv_8jm.

[418] "Oak Creek Canyon Demographics," Arizona Demographics, March 2022, https://www.arizona-demographics.com/oak-creek-canyon-demographics; "Flagstaff, Arizona," U.S. Census Bureau, July 1, 2021, https://www.census.gov/quickfacts/flagstaffcityarizona.

[419] "Wildfire Smoke," Centers for Disease Control and Prevention, July 11, 2022, https://www.cdc.gov/air/wildfire-smoke/default.htm.

In all, ignited by a campfire in an undesignated spot while fire restrictions were in place, the wildfire burned 13,271 acres at the end of the 10th day, August 10. After burning for more than a week, the avoidable fire threatened people and tourists, homes, and wildlife. Damages caused by this fictional fire include some homes, campgrounds, and critical infrastructure such as State Route 89 and I-17. In using a real-life fire that burned the same amount of acreage, suppression cost for the Pumphouse Wash Fire is estimated at approximately $2.1 million in just the first ten days.[420]

2. Pumphouse Wash (FR 237) Dispersed Camping Area Model

For this scenario, the information presented on acres burned, wind, etc., is based on the simulation run through FARSITE, shown in Figure 7. The landscape and fuel characteristics were downloaded using the LandFire interface, while historical weather data was downloaded from the National Weather Service using the Flagstaff Station #20209, at roughly 35 latitude and -111 longitude.[421] The current downloadable historical data range for the area spans from 2001 to 2018. As the scenario alluded, the simulation ran for 10 days spanning August 1 through August 10, using weather data from 2018. The weather data is tabulated in hourly increments and the fire growth front appears as contour lines for each hour superimposed onto the landscape map. In all, the model and scenario demonstrate the status quo of forest conditions and forest health of the Pumphouse Wash Camping Area near the Coconino National Forest.

[420] Dennis Webb, "Oil Springs Fire Suppression Cost Tops $2 Million as Acreage Holds," *The Grand Junction Daily Sentinel,* June 29, 2021, https://www.gjsentinel.com/news/oil-springs-fire-suppression-cost-tops-2-million-as-acreage-holds/article_fe392a02-d82b-11eb-a956-77ad7ec891cf.html.

[421] "NWS Forecast Office Flagstaff, AZ," National Weather Service National Oceanic and Atmospheric Administration, accessed October 12, 2022, https://www.weather.gov/fgz/.

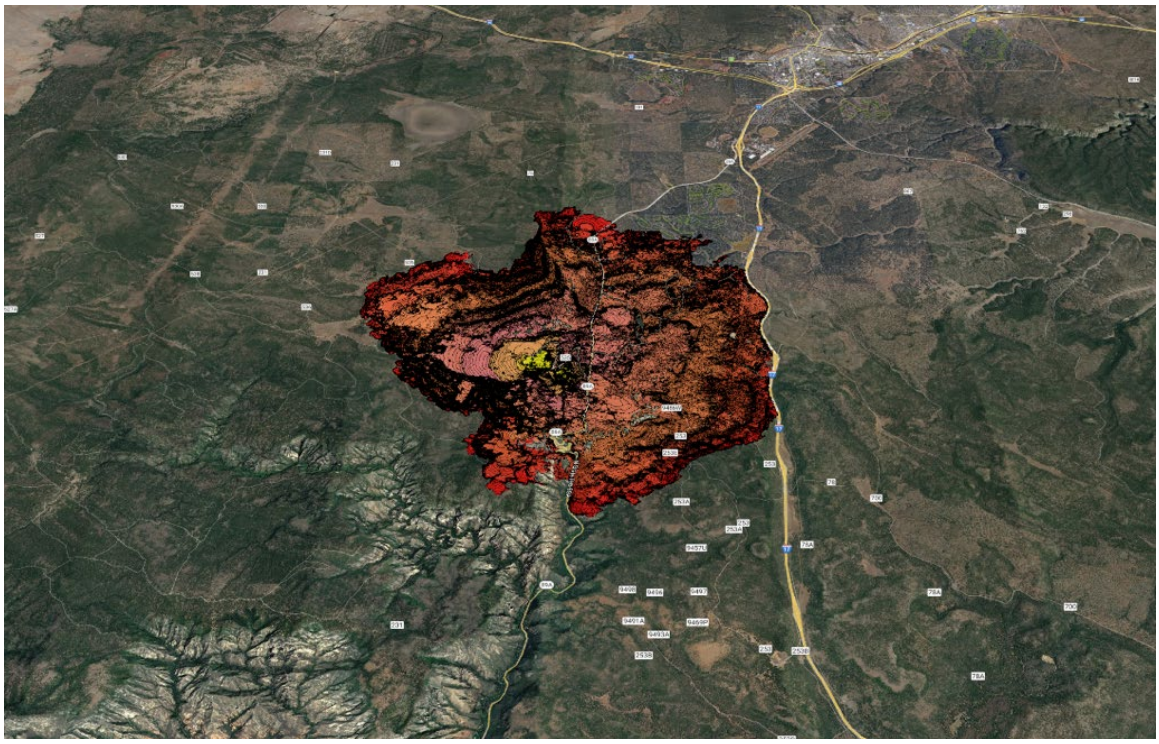

Figure 7. Contour Lines of Hourly Flame-Front Growth from a Single Campfire Ignition in Pumphouse Wash Camping Area; for This Simulation, the Fire Covers 13,271 Acres after 10 Days.[422]

Figure 8 presents a simulation over 10 days using 40% fuel moisture content, the same historical weather data as described earlier, a fuel bed model from the LandFire website, and assumed no spotting. The fire daily growth contour lines are placed onto a Google Map of the area. Under these conditions, the fire grows to span 9,940 acres in 10 days.

[422] Source: FARSITE simulation model created by Dr. Tom Mackin, provided to author via email on November 15, 2022.

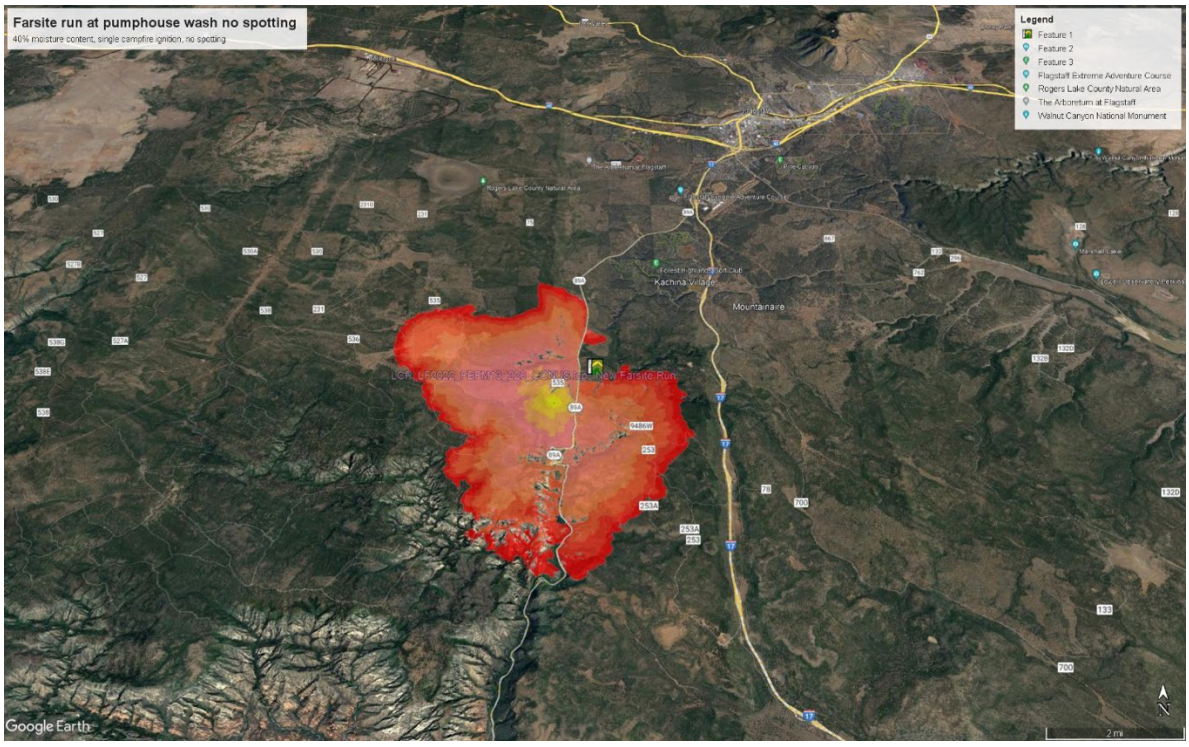

Figure 8. Fire Burn Area, Starting from the Campsite in the Dispersed Camping Area, Covers 9940 Acres over 10 Days from August 1 to August 10.[423]

FARSITE can also simulate the importance of spotting by running another simulation under the same conditions and allowing a 3% probability for spot fires, shown in Figure 9. Under identical weather and fuel moisture conditions, spotting spreads the fire to 13,271 acres over the same 10-day period. To provide visualization, Figure 10 overlays the two burn areas, with and without spotting.

[423] Source: FARSITE simulation model created by Dr. Tom Mackin, provided to author via email on November 15, 2022.

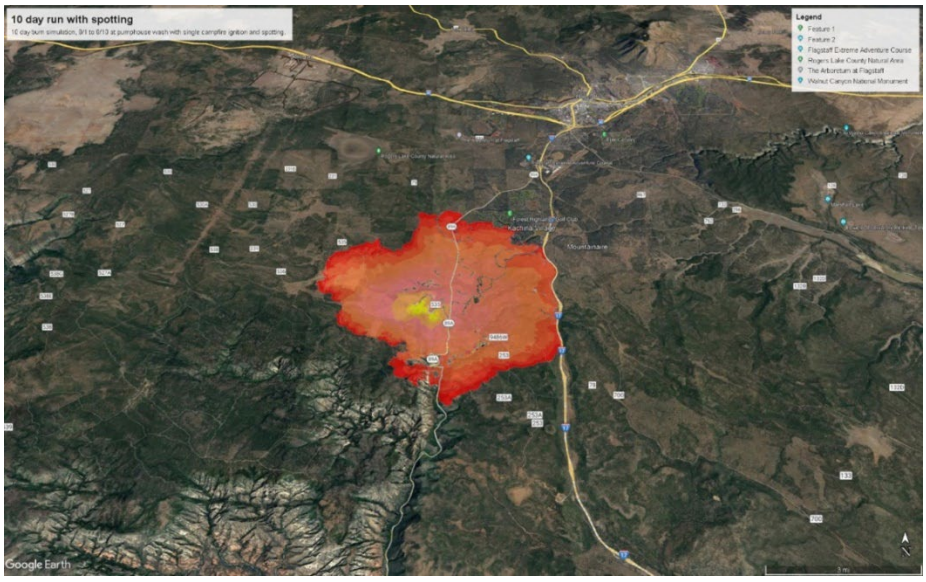

Figure 9. If Spotting Is Permitted, the Fire Grows to 13,271 Acres over the Same 10-Day Burn Period.[424]

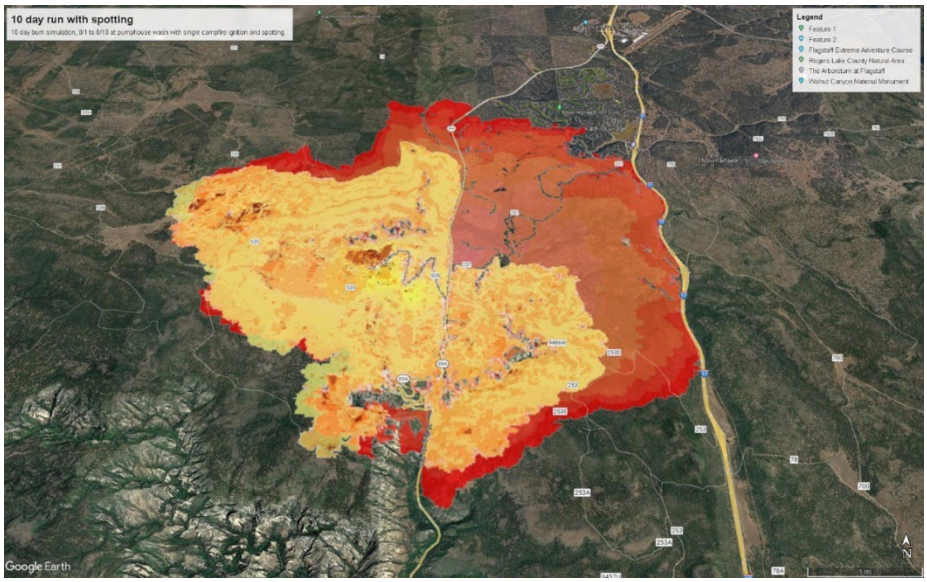

Figure 10. Overlay of the Fire Simulations with (red) and without (yellow) Spotting.[425]

424 Source: FARSITE simulation model created by Dr. Tom Mackin, provided to author via email on November 15, 2022.

425 Source: FARSITE simulation model created by Dr. Tom Mackin, provided to author via email on November 15, 2022.

FARSITE can also be utilized to assess the impact of mitigation and adaptive management measures that ultimately changes the availability of fuels, thus changing the fire dynamics.[426] For instance, establishing a clear-cut perimeter or fuel break around communities can restrict fire growth into undesired areas, in which a successful case study is detailed in the Community Involvement section in Chapter VI. For the Pumphouse Wash Camping Area, a clear-cut perimeter was implemented into the fire simulation, around the campsite, shown as a red polygon in Figure 11. In this simulation, the barrier reduces the progress of the fire, resulting in 3,153 acres burned. The fire does jump the fire break but grows at a much slower rate and does not reach I-17 over the 10-day period. Thus, the fire break would buy time for firefighting efforts.

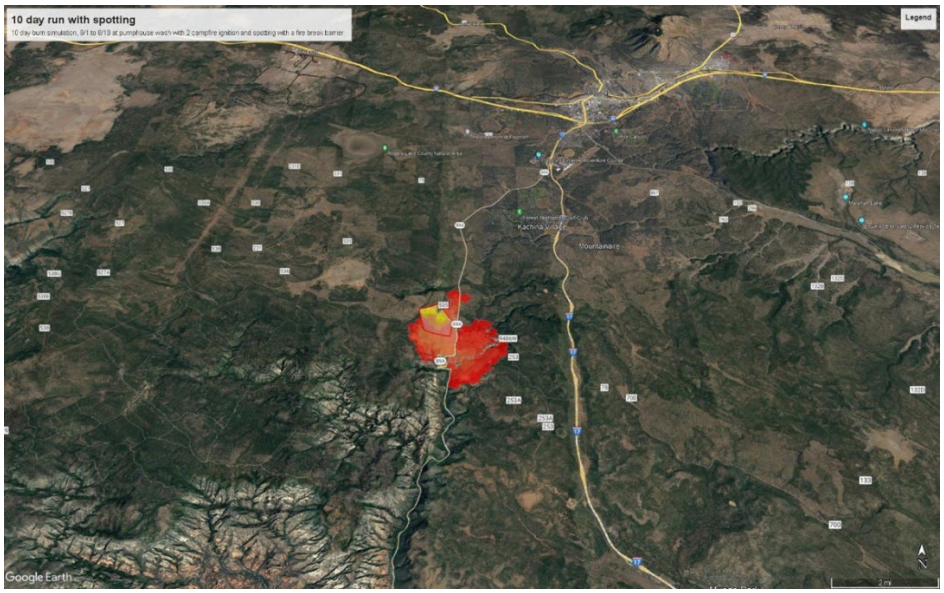

Figure 11. The Polygonal Fire Break Reduces the Rate of Fire Growth but Does Not Stop It Completely; 3,153 Acres Are Burned in This Simulation.[427]

Figure 12 plots the acres consumed for each hour over the 10-day simulation period to allow a visual comparison of the simulation conditions.

426 Finney, "FARSITE."

427 Source: FARSITE simulation model created by Dr. Tom Mackin, provided to author via email on November 15, 2022.

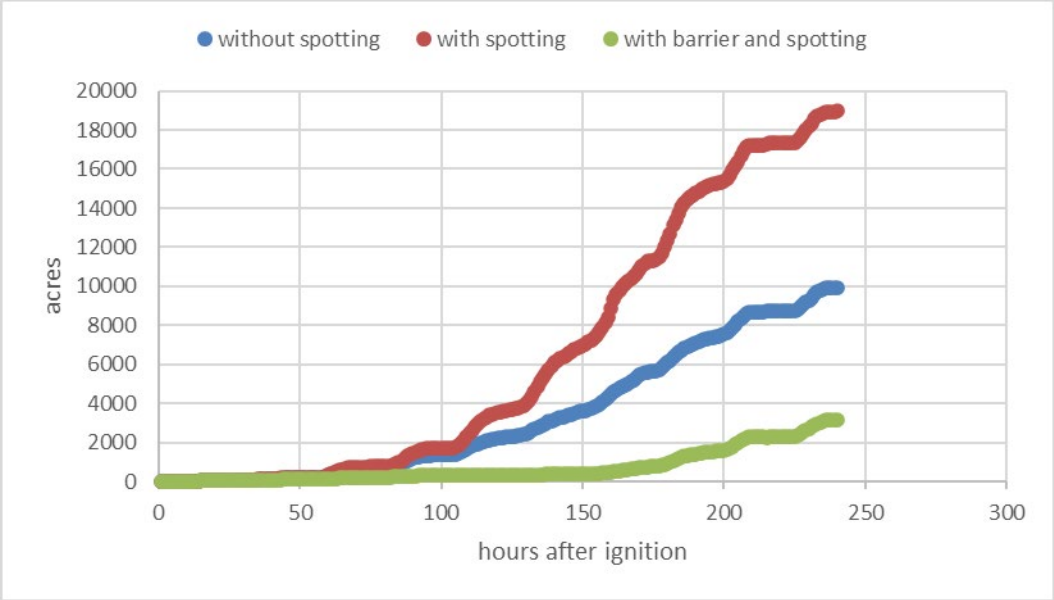

Figure 12. Plots of Burnt Acreage by Hour for the Three Simulation Conditions.[428]

There are a few limitations in the scenario and simulation. For one, historical data for 2019–2022 was not available to download into the simulation. Second, the simulation spanned 10 days, so the fire's full potential and resulting impact on communities and critical infrastructure was not fully encompassed. Nonetheless, the full potential of a wildfire's impact should be assumed given the historical data of Arizona's largest wildfires offered in Chapter II. Additionally, there are more programs offered to run fire simulations other than FARSITE, but it was the best, publicly available tool to utilize for the purpose of this thesis. Consequently, the FARSITE tool is helpful in visualizing wildfire growth in current forest conditions and details the benefits of establishing fuel breaks around communities.

3. Summary

The Arizona wildfire scenario demonstrates how quickly a fire can spread and threaten communities. Additionally, the scenario stresses the impact of human activity. Aside from lightning, human activity is the leading cause of wildfires, as nearly 85% of

[428] Source: Plot created by Dr. Tom Mackin, provided to author via email on November 30, 2022.

wildfires in the United States are ignited by people.[429] On the other hand, human activity can reduce wildfire impacts through collaboration with key stakeholders to implement fire adaptation measures.[430] In turn, communities that create defensible spaces around homes, establish fuel breaks, and take all necessary precautions have a better chance at limiting wildfire growth, as demonstrated in Figure 9.[431]

In Arizona, there is a pressing concern about firefighting staffing shortages, impacting controlled burns and wildfire suppression.[432] Water has also become a very scarce resource for fire suppression; wildfires impact watersheds within Arizona's forests that help the state's water supply.[433] Aside from water scarcity, post-fire floods are a serious concern for communities in and near the WUI. After a wildfire has been contained, BAER teams assess the damage, including burn area severity, watershed damage, and necessary emergency stabilization actions, which is critical information needed to determine forest health and how post-fire floods will impact surrounding communities and critical infrastructure.[434] For instance, BAER teams assessed the Pipeline Fire and found that approximately 1% of the fire area was unburned, 56% had

[429] National Park Service, "Wildfire Causes and Evaluations," March 8, 2022.

[430] "Fire Adapted Communities," U.S. Forest Service, accessed October 12, 2022, https://www.fs.usda.gov/managing-land/fire/fac; "10 Tips to Prevent Wildfires," U.S. Department of the Interior, May 4, 2022, https://www.doi.gov/blog/10-tips-prevent-wildfires.

[431] U.S. Forest Service, "'Living on the Edge': The Prescott Wildland Urban Interface Commission," Success Stories from the Western Region (Washington, DC: U.S. Forest Service, November 3, 2012), https://www.forestsandrangelands.gov/documents/strategy/rsc/west/stories/WRSC-Nov-2012-Success-story-PAWUIC.pdf; Tom DeGomez and Chris Jones, "Creating Wildfire-Defensible Spaces for Your Home and Property" (Tucson, AZ: University of Arizona College of Agriculture and Life Sciences, February 2013), https://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1290.pdf; Laura Petersen, "A Fighting Chance: Shaded Fuel Break Helps in Fight Against Wildfire in Grass Valley," The Union, June 2, 2022, https://www.theunion.com/news/a-fighting-chance-shaded-fuel-break-helps-in-fight-against-wildfire-in-grass-valley/.

[432] Nicole Grigg, "Another Challenge for Arizona Wildfire Season 2022: Getting More Wildland Firefighters," abc15 Arizona, March 31, 2022, https://www.abc15.com/news/state/another-challenge-for-arizona-wildfire-season-2022-getting-more-wildland-firefighters.

[433] Brian Webb and Justin Lum, "As Fire Crews Face Water Shortages, Arizona Lawmakers Detail Water Contingency Plans," FOX 10 Phoenix, June 16, 2021, https://www.fox10phoenix.com/news/as-fire-crews-face-water-problems-officials-detail-water-contingency-plans.

[434] "Burned Area Emergency Response (BAER) Team," National Wildfire Coordinating Group, accessed October 12, 2022, https://www.nwcg.gov/term/glossary/burned-area-emergency-response-baer-team; "BAER," Burned Area Emergency Response, accessed October 12, 2022, https://burnseverity.cr.usgs.gov/baer/.

low burn severity, 34% had moderate burn severity, and less approximately 5% had high burn severity.[435] Coconino County Flood Control District reviewed the BAER report findings and revealed that there is a high possibility for post-fire flooding in communities.[436] When monsoon season rolled into Flagstaff, predictions for flooding came to fruition, shown in Figure 13, resulting in 31 damaged homes, immediate emergency protective actions, and calls for mitigation projects that are expected to cost more than $125 million.[437] Predictors of worsening fire conditions suggest scenarios like the one mentioned, or worse, may occur more frequently. Thus, it is critical to address controllable factors to mitigate wildfire scale, frequency, and intensity.

Figure 13. Flagstaff Floods from Pipeline Fire Burn Scars.[438]

[435] U.S. Forest Service, Pipeline Fire Burned Area Emergency Response (BAER) Executive Summary (Coconino National Forest, AZ: U.S. Department of Agriculture, Forest Service, 2022), https://inciweb.nwcg.gov/photos/AZCOF/2022-06-22-0726-Pipeline-Fire-BAER/related_files/pict20220622-163121-0.pdf; "BAER Team Completes Soil Burn Severity Map for Pipeline Fire," Arizona Emergency Information Network, June 24, 2022, https://ein.az.gov/emergency-information/emergency-bulletin/baer-team-completes-soil-burn-severity-map-pipeline-fire.

[436] Sean Golightly, "'Heightened Flood Risk' and Rain in the Forecast Following Pipeline Fire," Arizona Daily Sun, June 17, 2022, https://azdailysun.com/news/local/heightened-flood-risk-and-rain-in-the-forecast-following-pipeline-fire/article_f387e086-edb4-11ec-b93b-57135c053a78.html.

[437] Lacey Latch, "Flagstaff Hit With More Flash Flooding; Federal Officials Touring Area Had to Flee Raging Waters," The Arizona Republic, August 20, 2022, https://www.azcentral.com/story/news/local/arizona-weather/2022/08/17/flagstaffs-pipeline-east-hit-more-flash-flooding-aid-expected/10352188002/; AZFamily Digital News Staff, "Monsoon Flooding Leaves Behind Muddy Mess Near Flagstaff," Arizona's Family, July 14, 2022, https://www.azfamily.com/2022/07/14/flagstaff-area-residents-asked-seek-shelter-flash-flooding-expected-pipeline-fire-burn-scar/.

[438] Source: Sean Golightly and Sierra Ferguson, "Heavy Rains on Pipeline Fire Burn Scar Cause Flooding, Brief Closure of Highway East of Flagstaff," Arizona Daily Sun, July 14, 2022, https://azdailysun.com/news/local/heavy-rains-on-pipeline-fire-burn-scar-cause-flooding-brief-closure-of-highway-east-of/article_3225815c-03ce-11ed-9b77-5f154a2e1341.html; "Pipeline Fire," Arizona's Family, June 12, 2022, https://www.azfamily.com/gallery/2022/06/12/pipeline-fire/.

B. SOUTHERN CALIFORNIA

Since the 1920s, southern California's 15.3 million acres of chaparral forests have experienced increased wildfire scale and intensity due to varying factors, including drought, Santa Ana winds, vegetation age, invasive species, and built-up fuels.[439] Forestry management professionals and scholars note that chaparral is one of the more resilient vegetation types in the state.[440] Still, its resilience has declined due to wildfires, drought, invasive species, and WUI impacts.[441] Allen et al. highlight that "active restoration" (i.e., stabilizing soil, weeding, and planting) has not been prevalent in the area; instead, "passive restoration" (i.e., removal of vegetation and invasive species) has been the dominant restoration method.[442] Hence, the scholars advocate for a mixture of active and passive restoration in areas that are in critical need and other techniques that stabilize the soil and improve regeneration post-fire.[443] Similar to Arizona, California's current and predicted state of chaparral suggests a grim outlook further exacerbated by wildfires.

For the 2022 fire season, the NIFC predicted the fire potential to be slightly above average based on multiple factors including moderate to severe drought, reduced, and quickly melting snowpack in the Sierra Nevada mountains.[444] The snowpack in the Sierra Nevada is critical to all California residents, especially communities in Southern California, as it provides 75% of the state's fresh water and helps combat drought impacts.[445] The Sierra Nevada mountains are also an essential water source for Arizona,

439 Eisele, *An Analysis of Large Chaparral Fires*, 78; U.S. Forest Service, "Invasive Plants and Fire."

440 Edith B. Allen et al., "Chaparral Restoration," in *Valuing Chaparral,* ed. Emma C. Underwood et al. (Springer International Publishing, 2018), 347, http://link.springer.com/10.1007/978-3-319-68303-4_13.

441 Allen et al., 347.

442 Allen et al., 347.

443 Allen et al., 348.

444 National Interagency Fire Center, "National Significant Wildland Fire Potential Outlook" (Boise, ID: National Interagency Fire Center, June 1, 2022), 5.

445 Sierra Nevada Conservancy, "Water Supply," State of California, accessed November 27, 2022, https://sierranevada.ca.gov/what-we-do/water-supply/.

New Mexico, and Nevada.[446] The California 2022 fire season started January 21 with the Colorado Fire in Monterey County, burning 647 acres.[447] The most notable 2022 fire in California was the Mosquito Fire that burned 76,788 acres in El Dorado and Placer Counties from September 6 to October 27.[448] As a result, more than 70 structures were damaged or destroyed, and unhealthy air quality remained over Northern California and parts of Nevada.[449] In all, California's 2022 wildfire season consisted of 7,400 fires that burned 362,436 acres throughout the state, including nine fatalities and 876 damaged or destroyed structures.[450] As drought and other climate change conditions persist, the Southern California wildfire season is expected to continue frequently and threaten critical infrastructure.

1. Scenario: Mission Trails Regional Park

This scenario mimics the 2020 El Dorado fire in Yucaipa, California, near the San Bernardino National Forest, which burned over 22,000 acres due to a firework for a gender-reveal party. The location of this fictional scenario takes place in San Diego, specifically near the neighborhood on Mission Vista Drive. This neighborhood is in a very high Fire Hazard Severity Zone in a Local Responsibility Area, meaning the local government has the financial responsibility for wildland fire protection.[451] Additionally, this neighborhood borders the Mission Trails Regional Park and is near the Marine Corps Air Station Miramar as well as other communities and parks. It is August 1, fire

446 Denise Chow, "Sierra Nevada Snowpack, a Crucial Water Resource, Could Disappear in 25 Years," NBC News, December 2, 2021, https://www.nbcnews.com/science/environment/sierra-nevada-snowpack-crucial-water-resource-disappear-25-years-rcna7220.

447 "Colorado Fire Incident," CAL FIRE, February 3, 2022, https://www.fire.ca.gov/incidents/2022/1/21/colorado-fire/.

448 "Mosquito Fire Incident," CAL FIRE, October 27, 2022, https://www.fire.ca.gov/incidents/2022/9/6/mosquito-fire/.

449 Thao Nguyen, "Mosquito Fire Becomes California's Largest Blaze This Year, Scorching Over 63k Acres," USA TODAY, September 14, 2022, https://www.usatoday.com/story/news/nation/2022/09/14/mosquito-fire-california-largest-wildfire-2022-evacuations/10383178002/.

450 "2022 Incident Archive," CAL FIRE, accessed November 27, 2022, https://www.fire.ca.gov/incidents/2022/.

451 "FHSZ Viewer," CAL FIRE, accessed November 26, 2022, https://egis.fire.ca.gov/FHSZ/.

restrictions are in place, and fireworks are illegal in San Diego County.[452] Weather conditions have resulted in red flag warnings for extreme fire conditions due to a record heatwave, drought, moderate wind, and dry fuels. The acres burned in this scenario is based on the FARSITE simulation shown in Figure 16 and plot shown in Figure 18, given spotting is relatively common fire behavior.[453]

Nonetheless, some partygoers celebrated their gender-reveal party by shooting off illegal fireworks near the entrance of Mission Trails Regional Park. As a result, the sparks ignited the area's dry fuels, resulting in a fast-spreading wildfire. Immediate calls for evacuation occurred. Due to the immediate proximity to homes, evacuations were complex, as residents did not have a significant lead team to prepare and leave. The local fire department arrived on the scene, but the fire has already escaped into rugged terrain, threatening more homes and critical infrastructure in the area. Within the first day, the fire jumped to 2,278 acres, damaging homes, and endangering the Marine Corps base. As a result of the fast-moving fire and threat to communities and critical infrastructure, San Diego County Fire Department arrived to assist with wildfire suppression and home defense. Over a few weeks, the fire finally reached full containment. On day 10, at 2,627 acres, the fire continued to impose on communities and destroy homes. As winds continued to push the fire, smoke continued to blanket the San Diego area, resulting in poor air quality.

In all, ignited by an illegal firework while fire restrictions were in place, the wildfire burned 2,627 acres and several homes in the WUI at the end of the 10th day, August 10. The preventable fire burned for more than a week and threatened people, tourists, wildlife, homes, and critical infrastructure. An estimate for suppression costs for the first 10 days of the Mission Trails Fire is difficult to conclude, as similar real-life fires

[452] Fire-Rescue Department, "Fireworks," The City of San Diego, accessed November 27, 2022, https://www.sandiego.gov/fire/safety/tips/fireworks.

[453] National Wildfire Coordinating Group, "Spotting Fire Behavior."

could not be found in research. However, it can be assumed this fire would cost a significant amount in suppression and damages, given the proximity to homes.[454]

2. Mission Trails Regional Park Model

For this scenario, the information presented on acres burned, wind, etc., in Mission Trails Regional Park in San Diego, CA, is based on the simulation ran through FARSITE, shown in Figure 14. Once again, LandFire vegetation, landscape and fuel bed models were imported into FlamMap, a fire behavior mapping and analysis program, for the FARSITE simulation. Hourly weather data from 1998 through 2017 was available through the Weather Information Management System (WIMS) site, using a weather station near the park. Initial moisture conditions were set identical to that used in the Pumphouse Wash simulation. The simulation was run from August 1 through August 10^{t} using weather data from 2017.

Figure 14. Subject Burn Area Surrounding the Mission Trails Regional Park in San Diego, CA.[455]

[454] Alex Parijanlar and Cody Welch, "What Are the Costs of Fighting Wildfires?," Exploring the Past to Understand the Future, 2012, https://serc.carleton.edu/NZFires/megafires/cost.html.

[455] Adapted from Google Maps; FARSITE simulation model created by Dr. Tom Mackin, provided to author via email on November 17, 2022.

Results of fire growth simulation, using FlamMap, are shown in Figure 15. In this simulation, the fire was initiated from a single point ignition near the main entrance to the park and allowed to burn, without spotting, over the course of 10 days. As a result, the fire burned a total of 2,965 acres over the 10-day period, after which it encountered natural barriers that hindered any further growth. As shown, the fire growth is stunted by the San Clemente Canyon freeway on the north and by neighborhoods to the South and East.

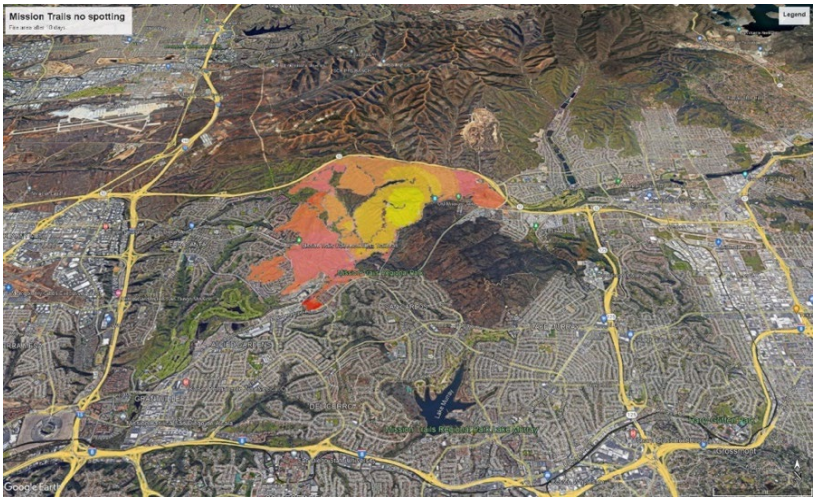

Figure 15. Fire Growth Simulation for Mission Trails Using Representative Weather Data and Soil Moistures; 2,965 Acres Were Burned in This Simulation.[456]

A new simulation was run to include a 3% probability of spot fire formation, shown in Figure 16. The total burn area is slighting smaller and moved more toward the southwest, burning a total of 2,627 acres.

[456] Source: FARSITE simulation model created by Dr. Tom Mackin, provided to author via email on November 17, 2022.

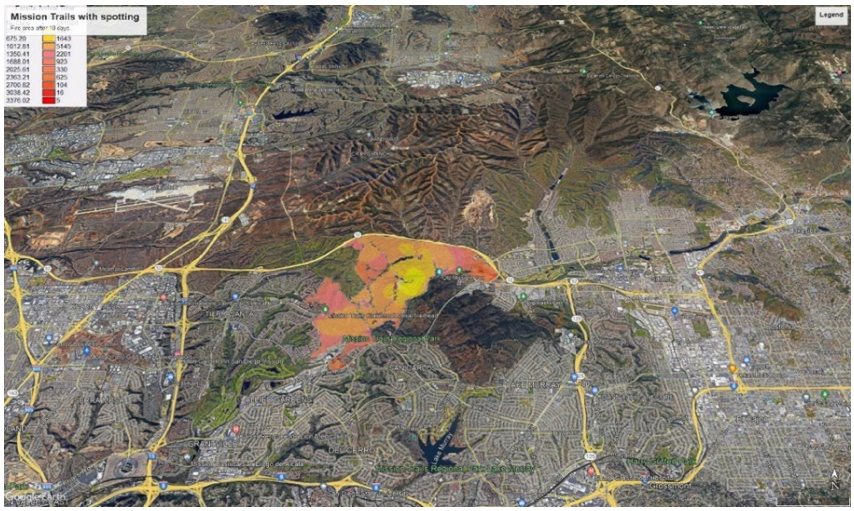

Figure 16. Fire Growth Simulation for Mission Trails, including a 3% Spotting Probability; 2,627 Acres Were Burned in This Simulation.[457]

As previously discussed, implementing fire breaks can change growth dynamics of a fire. In this simulation, Figure 17 included a fire break (shown as a blue line) that was placed along the northern region of the park, south of the San Clemente Canyon Freeway. The fire break suppressed growth north of the barrier but fire growth continued to the southeast. As such, the barrier changed the fire growth, but was not optimally located.

[457] Source: FARSITE simulation model created by Dr. Tom Mackin, provided to author via email on November 17, 2022.N.d.

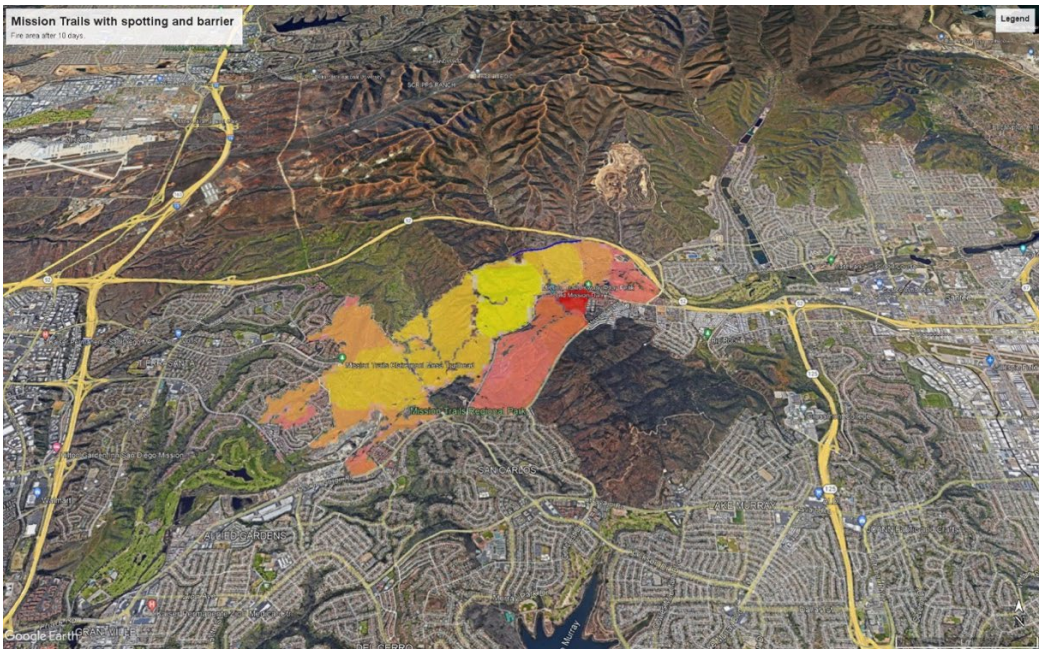

Figure 17. Simulated Burn Area with Spotting and a Barrier Placed Along and Just South of the San Clemente Canyon Freeway.[458]

Figure 17 shows plots of the acres burned as a function of hours since ignition. The plot reveals that the total burn acreage is not strongly influenced by spotting under the given wind conditions. However, the rate of fire growth is strongly influenced by spotting. The existence of a barrier, in this case, shows no difference from that of the unmitigated fire. As a result, it is clear that pre-season mitigation should be done deliberately, not randomly.

[458] Source: FARSITE simulation model created by Dr. Tom Mackin, provided to author via email on November 17, 2022.

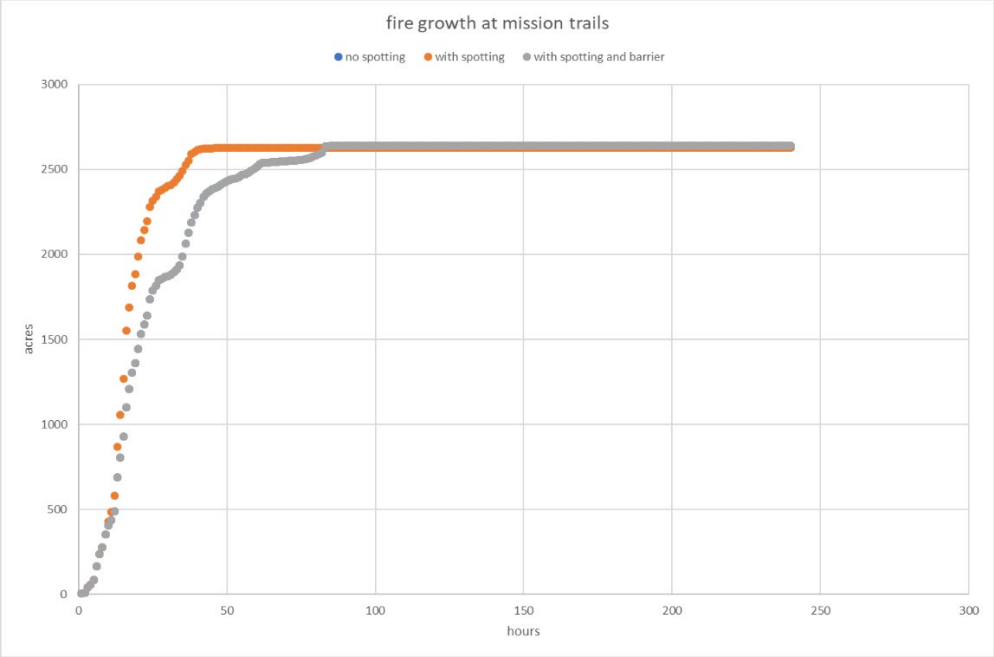

Figure 18. Plot of Acres Burned as a Function of Hours after Ignition Shows Increase in Burn Rate with Spotting as Well as the Importance of Barrier Location.[459]

To identify the most effective area to establish a fire break in efforts to obstruct spot fire formation, wind field data should be overlayed onto the unmitigated fire growth simulation. Thus, in Figure 19, a line barrier was placed along the southern flank but remained within the park boundaries. As a result, the fire dynamics significantly changed, resulting in a smaller burned area of 1,934 acres. This difference is made clear in the burn acreage plots of Figure 18, where the southern barrier placement proves much more effective at decreasing the maximum burn size. In all, fire break locations and size should be strategically located and factor in fuels, wind, and built infrastructure. In all, fire simulation plays an integral role in locating these barriers.

[459] Source: Plot created by Dr. Tom Mackin, provided to author via email on November 17, 2022.

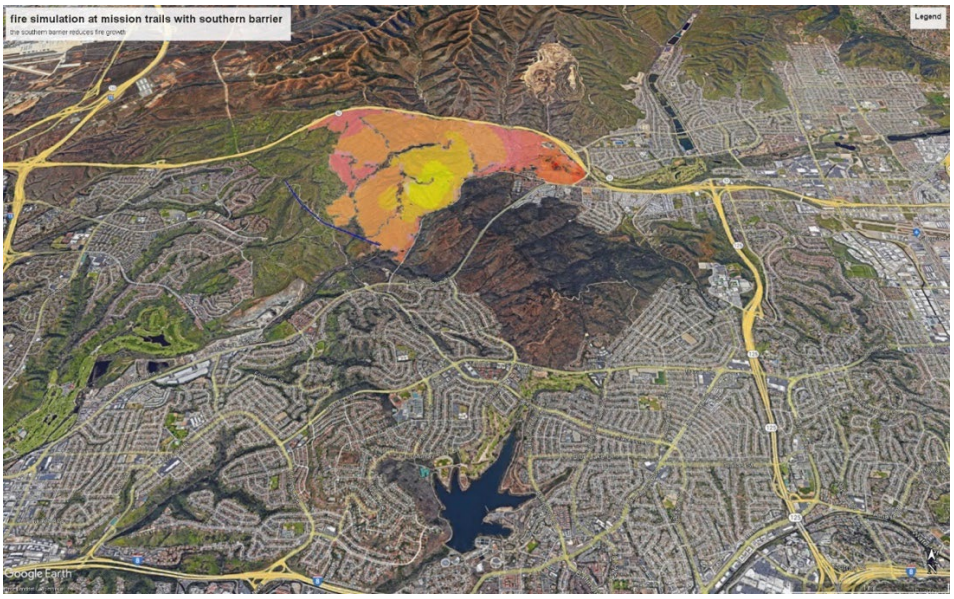

Figure 19. A Barrier Located Along the Southwestern Edge (Blue Line) Arrests Spot Fire Ignition and Reduces Both the Rate of Fire Growth and the Total Acreage Burned.[460]

As mentioned in the Arizona section, there are a few limitations in this scenario and simulation. For one, historical data for 2019–2022 was not available to download into the simulation. Second, the simulation spanned 10 days, so the fire's full potential and resulting impact on communities and critical infrastructure was not fully encompassed. Nonetheless, the full potential of a wildfire's impact should be assumed given the historical data of California's largest wildfires offered in Chapter II. Additionally, there are more programs offered to run fire simulations other than FARSITE, but it was the best, publicly available tool to utilize for the purpose of this thesis. Consequently, the FARSITE tool is helpful in visualizing wildfire growth in current forest conditions and the benefits of establishing fuel breaks around communities.

3. Summary

The scenario posed highlights the danger of human activity when rules are not followed in an area surrounding large communities with dry fuels. Fires within the WUI

[460] Source: FARSITE simulation model created by Dr. Tom Mackin, provided to author via email on November 17, 2022.

are widespread and expected to occur, which further emphasizes the importance of clearing fuels, establishing a defensible space, and using fire-resistant materials.[461] Like most western states, including Arizona, California has faced concerns regarding personnel shortages and water scarcity.[462] Predictors of worsening fire conditions suggest scenarios like the one mentioned, or worse, may occur more frequently. Thus, it is critical to address controllable factors to mitigate wildfire scale, frequency, and intensity.

461 Federal Emergency Management Agency and U.S. Fire Administration, *Wildland Urban Interface: A Look at Issues and Resolutions.*

462 Zach Urness, "Labor Shortage Leaves U.S. Struggling to Hire Firefighters Despite Record Wildfire Funding," *Statesman Journal*, May 11, 2022, https://www.statesmanjournal.com/story/news/nation/2022/05/11/worker-shortage-western-drought-wildfire-season-2022-wildland-firefighter-hirings/65354018007/; Chow, "Sierra Nevada Snowpack."

IV. COMPARATIVE ANALYSIS

This chapter compares costs, key factors, and resources associated with prescribed fires and wildfires. Additionally, this chapter analyzes the costs, and resources committed to wildfire response efforts compared to mitigation efforts. Comparing these costly efforts capture the effectiveness, benefits, and difficulties posed to communities, forestry managers, firefighters, and other key stakeholders. As a result, an informed decision can be made on which efforts should be prioritized and implemented to restore forest health and reduce wildfire impact on communities and critical infrastructure.

A. PRESCRIBED FIRES VS. WILDFIRES

Forestry and fire management practices have changed significantly throughout the decades.[463] In the early 1900s, fire suppression was extreme and was essentially the only management tool in all forests.[464] Still, the importance of controlled burns became apparent in the 1960s.[465] As highlighted in Chapter II, Native American tribes have historically used controlled burns for cultural and agricultural purposes.[466] Looking at the Smokey the Bear campaign, the longest-running public service campaign in U.S. history, the slogan in 1947 used to be "Remember ... Only YOU Can Prevent Forest Fires."[467] Now Smokey the Bear says, "Only You Can Prevent Wildfires," to reiterate the point that fires are natural, but unplanned fires should be prevented.[468] The generational back and forth of fire and forestry management practices and current climate conditions have resulted in the fire regimes we see today. In a documentary produced by the University of Arizona, one expert stated, "We put out every fire we can, so we only

463 Jan W. van Wagtendonk, "The History and Evolution of Wildland Fire Use," *Fire Ecology* 3, no. 2 (December 2007): 3–17, https://doi.org/10.4996/fireecology.0302003.

464 van Wagtendonk, 4.

465 van Wagtendonk, 3.

466 Krol, "As Fires Rage Across the West"; Sommer, "To Manage Wildfire, California Looks To What Tribes Have Known All Along."

467 "About the Campaign," Smokey Bear, accessed October 19, 2022, https://smokeybear.com/en/smokeys-history/about-the-campaign.

468 Smokey Bear.

get fire behavior associated with fires we can't put out."[469] To address the concern of problematic fire behavior, examining the trade-offs between prescribed burns and wildfires is essential to determine which is more effective and where resources and budgets should be prioritized.

As defined by NPS, prescribed fires or controlled burns are a critical tool to manage fires by establishing a scientific prescription for the area given to reduce fuel loads, restore the natural environment, and manage the landscape in a controlled setting.[470] Ultimately, prescribed fires fill the role of low-intensity fires that should naturally occur in an environment.[471] Several methods are used to ignite a prescribed fire, including drip torches, a plastic sphere dispenser (PSD) for remote areas, and flare guns.[472] A wide variety of factors are involved when planning for a controlled burn. First, management objectives should be clear; then, it is critical to evaluate temperature, humidity, wind, moisture of the vegetation, and smoke dispersal.[473] Additionally, firebreaks and fire escapes should be established.[474] The cost of prescribed burns varies depending on the area. Still, roughly speaking, in Arizona, controlled burns in wilderness areas cost $5 per acre, whereas it costs $50 per acre near communities.[475] Generally, it takes at least three to four people for each prescribed burn: one to ignite, one to two to

469 Wallowa Resources, "The West Is Burning," The West Is Burning, accessed October 19, 2022, https://westisburning.org.

470 "Wildland Fire: What Is a Prescribed Fire?," National Park Service, March 19, 2020, https://www.nps.gov/articles/what-is-a-prescribed-fire.htm.

471 NC State University College of Natural Resources News, "Ask an Expert: Why Is Prescribed Fire Important?," *Forestry and Environmental Resources Research* (blog), November 22, 2021, https://cnr.ncsu.edu/news/2021/11/ask-an-expert-why-is-prescribed-fire-important/.

472 National Park Service, "Wildland Fire."

473 "Prescribed Fire," USDA Forest Service, December 2016, https://www.fs.usda.gov/managing-land/prescribed-fire.

474 Jarred Brooke, "Prescribed Fire: 6 Things to Consider Before You Ignite," *Purdue Extension Forestry & Natural Resources* (blog), April 4, 2017, https://www.purdue.edu/fnr/extension/prescribed-fire/.

475 Sean Holstege, "Wildfire Experts Call for More Controlled Burns," USA TODAY, July 7, 2013, https://www.usatoday.com/story/news/nation/2013/07/07/fire-experts-call-for-more-controlled-burns-to-stem-wildfires/2495873/.

control the line, and a floater.[476] Overall, critical components to consider before and during a controlled or prescribed burn includes a substantial amount of planning, evaluation of factors, and sufficient resources.

Benefits of prescribed burns include minimizing the spread of disease, promoting new vegetation growth, and clearing built-up fuels.[477] Moreover, prescribed burns are a more practical solution to clearing fuels near WUI zones, given that it is planned and more controlled than wildfires.[478] Researchers from Penn State, USFS, and NPS evaluated the combined benefits of wildfire suppression and prescribed burning and discovered that the combination of the two reduced tree mortality by 72%.[479] Additionally, one researcher stated, "prescribed fires have a strong moderating effect and help to provide good anchor points for operations during a wildfire."[480] However, controversially, a 14-year study conducted by UC Berkeley researchers in Yosemite Valley advocated for wildfire management rather than fire suppression.[481] The researchers suggested that allowing lightning-induced fires to burn creates increased streamflow and soil moisture, establishes natural firebreaks and a landscape more resistant to catastrophic wildfires, and increases vegetation diversification.[482] The researchers also argued that allowing fires to burn eliminates the need to conduct prescribed burns and noted that suppression is only necessary when fire and smoke are

476 Indiana Division of Fish and Wildlife, "Prescribed Burns," Habitat Management Fact Sheet (Indianapolis, IN: Indiana Department of Natural Resources, March 2005), 6, https://www.in.gov/dnr/fish-and-wildlife/files/HMFSPrescribedBurn.pdf.

477 NC State University College of Natural Resources News, "Ask an Expert: Why Is Prescribed Fire Important?"

478 Kari Cobb, "A Prescription for Safety: Burning in the Wildland Urban Interface," U.S. Department of the Interior, August 18, 2020, https://www.doi.gov/wildlandfire/prescription-safety-burning-wildland-urban-interface.

479 Francisco Tutella, "Fire Operations-Prescribed Burning Combo Reduces Wildfire Severity up to 72%," Penn State, July 14, 2021, https://www.psu.edu/news/research/story/fire-operations-prescribed-burning-combo-reduces-wildfire-severity-72/.

480 Tutella.

481 Robert Sanders, "Wildfire Management Vs. Fire Suppression Benefits Forest and Watershed," UC Berkeley News, October 24, 2016, sec. Research, Science and Environment, https://news.berkeley.edu/2016/10/24/wildfire-management-vs-suppression-benefits-forest-and-watershed/.

482 Sanders.

near communities.[483] Thus, depending on the severity, natural wildfires benefit the landscape and aid in improving forest health.[484] Nonetheless, the ability to manage a wildfire only applies to remote areas and not WUI zones given the lack of control near property and concerns with smoke.[485] In all, prescribed fires and some wildfires offer many benefits for improving forest health, but prescribed fires are more manageable near WUI zones and reduce the risk of high-severity wildfires.[486]

Smoke emissions from prescribed burns and wildfires are a critical factor to evaluate, given the communal and environmental impacts of smoke. Thus, comparing the smoke emitted from prescribed burns and wildfires may prove beneficial in identifying which is more effective in avoiding poor air quality associated with fires. Smoke emissions from forest fires depend strongly on fuel type, density, and burning conditions.[487] For instance, a wildfire in Northern California will produce significant emissions as it is a heavily forested area compared to rangelands in Nevada or Arizona.[488] Wildfires have contributed immensely to poor air quality throughout the United States. Countless articles have shown smoke from large fires in the West making its way across the nation to the East Coast to states like New York and Rhode Island.[489] Fortunately, prescribed fires do not make the same emissions as wildfires.[490] For

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483 Sanders.

484 Andrew Burchill, "Are Wildfires Bad?," Arizona State University School of Life Sciences, May 5, 2021, https://askabiologist.asu.edu/explore/wildfires.

485 Nathan Rott, "Fire Ecologists Say More Fires Should Be Left To Burn. So Why Aren't They?," NPR, September 27, 2018, https://www.npr.org/2018/09/27/649649316/fire-ecologists-say-more-fires-should-be-left-to-burn-so-why-arent-they.

486 NC State University College of Natural Resources News, "Ask an Expert: Why Is Prescribed Fire Important?"

487 Daniel A. Jaffe et al., "Wildfire and Prescribed Burning Impacts on Air Quality in the United States," *Journal of the Air & Waste Management Association* 70, no. 6 (June 4, 2020): 586, https://doi.org/10.1080/10962247.2020.1749731.

488 Jaffe et al., 592.

489 Gillian Flaccus and Sara Cline, "Wildfire Smoke from the West Clouds Sky, Hurts Air Quality on East Coast," *Los Angeles Times*, July 21, 2021, sec. World & Nation, https://www.latimes.com/world-nation/story/2021-07-21/bootleg-fire-smoke-hurts-air-quality-east-coast.

490 Xiaoxi Liu et al., "Airborne Measurements of Western U.S. Wildfire Emissions: Comparison with Prescribed Burning and Air Quality Implications," *Journal of Geophysical Research: Atmospheres* 122, no. 11 (June 14, 2017): 6108–29, https://doi.org/10.1002/2016JD026315.

example, Liu et al. found that wildfires produce two times more particulate matter than prescribed fires.[491] Also, considering that controlled burns are planned, wind directions are factored in to avoid heavily impacting surrounding neighborhoods, and residents are typically notified ahead of time.[492] Some studies have suggested that public opinion in the western United States disfavors smoke pollution from prescribed fires.[493] However, Mark Melvin, the spokesperson for the Coalition of Prescribed Fire Councils, shared that public perception and acceptance of prescribed burns have improved tremendously.[494] Ultimately, in discussions regarding reducing emissions and addressing wildfire impacts, as one scholar posed, "The question is, really, how do you want your smoke delivered? [495] In sum, to avoid hazardous air quality that is commonly associated with wildfires, prescribed fires are an effective tool in reducing fuels that create smoke pollutants.[496]

Regarding personnel, most state fire entities and all federal fire entities require intensive training before being able to conduct a controlled burn.[497] Therefore, there is an established standard and structure for personnel conducting controlled burns on state and federal lands. On the other hand, western states have different standards and

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[491] Liu et al.

[492] Natural Resources Conservation Service, "Prescribed Burning Fact Sheet" (North Dakota: U.S. Department of Agriculture, February 2012), https://efotg.sc.egov.usda.gov/references/public/ND/prescribed_burning_fact_sheet.pdf.

[493] Emily Williams, "Reimagining Exceptional Events: Regulating Wildfires Through the Clean Air Act," *Washington Law Review* 96, no. 2 (June 1, 2021): 776, https://digitalcommons.law.uw.edu/cgi/viewcontent.cgi?article=5176&context=wlr.

[494] Felicity Barringer, "Gaining in Public Acceptance, Can Prescribed Fires Head Off Devastating Wildfires?," Stanford University Bill Lane Center for the American West, July 18, 2019, https://andthewest.stanford.edu/2019/gaining-in-public-acceptance-can-prescribed-fires-head-off-devastating-wildfires/.

[495] Jennifer Hijazi, "Wildfires Highlight What's 'Gone Wrong' in Pollution Mitigation," *Bloomberg Law* (blog), August 11, 2021, https://news.bloomberglaw.com/environment-and-energy/wildfires-highlight-whats-gone-wrong-in-pollution-mitigation.

[496] Marshall Burke, Sam Heft-Neal, and Michael Wara, *Managing the Growing Cost of Wildfire* (Stanford, CA: Stanford Institute for Economic Policy Research, 2020), https://siepr.stanford.edu/publications/policy-brief/managing-growing-cost-wildfire.

[497] "Prescribed Fire Burn Boss Type 1," National Wildfire Coordinating Group, January 18, 2022, https://www.nwcg.gov/positions/rxb1/position-qualification-requirements; Arizona Department of Transportation, "ADOT Vegetation Management Guidelines - Prescribed Burning" (Phoenix, AZ: Arizona Department of Transportation), accessed October 30, 2022, https://azdot.gov/sites/default/files/2019/09/RVMG-Prescribed-Burning.pdf.

programs for prescribed burns on private lands, which poses challenges in encouraging private landowners to conduct beneficial forestry management practices. For instance, New Mexico offers a certification program and has a clear standard and process for private landowners to conduct their own prescribed burn, which includes a standard of liability for damages.[498] In contrast, Arizona does not have a certification program but does require landowners to get approval from Arizona State Land Department and the Arizona Department of Environmental Quality.[499] For states like Arizona that lack a certification program, there are concerns pertaining to liability for damage, which consequently deters landowners from seeking approval for a controlled burn.[500] To establish a unified approach among federal, state, and private landowners in efforts to improve forest health, it may be beneficial for western states to establish a certification program for private landowners to conduct prescribed burns.

Additionally, federal and state fire entities have struggled with hiring, which has posed challenges in having a workforce that can accomplish fuel treatment goals, such as the USFS's goal of treating 30 million acres in the West over a 10-year period.[501] In 2021, the USFS had to suspend prescribed burns due to the overwhelming number of wildfires threatening communities, fires that required most of their workforce.[502] This dilemma sparked a debate among politicians and forest managers, but it ultimately

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498 Michelle Lujan Grisham, "Gov. Signs Bipartisan Measure to Improve Forest Management, Help N.M. Avoid Catastrophic Fires," Office of the Governor Michelle Lujan Grisham, March 18, 2021, https://www.governor.state.nm.us/2021/03/18/gov-signs-bipartisan-measure-to-improve-forest-management-help-n-m-avoid-catastrophic-fires/; Prescribed Burning Act, Pub. L. No. HB0057 (2021), https://nmrxfire.nmsu.edu/documents/hb0057.pdf.

499 Jeff Eisenberg and Anne Gondor, "Prescribed Burning on Arizona Private Land: Policy Issues," The University of Arizona, June 24, 2021, https://westernlandsblog.arizona.edu/prescribed-burning-arizona-private-land-policy-issues.

500 Eisenberg and Gondor.

501 U.S. Forest Service, *Confronting the Wildfire Crisis: A 10-Year Implementation Plan,* FS-1187b (Washington, DC: U.S. Department of Agriculture, 2022), 1, https://www.fs.usda.gov/sites/default/files/Wildfire-Crisis-Implementation-Plan.pdf; Ximena Bustillo, "'Pretty Brutal': Hiring Woes Plague Biden Effort to Contain Wildfires," POLITICO, March 15, 2022, sec. Agriculture, https://www.politico.com/news/2022/03/15/bidens-effort-to-contain-wildfires-threatened-by-staffing-woes-00016419; Grigg, "Another Challenge for Arizona Wildfire Season 2022: Getting More Wildland Firefighters."

502 Lauren Sommer, "With Extreme Fires Burning, Forest Service Stops 'Good Fires' Too," NPR, August 10, 2021, https://www.npr.org/2021/08/09/1026137249/with-extreme-fires-burning-forest-service-stops-good-fires-too.

highlights the concern of stressed resources. In all, personnel at the federal, state, and private levels are a critical component to ensuring enough prescribed burns can be conducted to clear fuels and improve forest health.

When evaluating the cost associated with prescribed fires and wildfires, controlled burns are more cost-effective considering fewer resources are necessary.[503] As previously mentioned, the cost of prescribed burns varies on the area, but generally, in western states like Arizona, controlled burns cost around $5 per acre in wilderness areas, $50 per acre near communities, and $500 per acre when including mechanical thinning operations.[504] Wildfires require significant resources, including equipment, personnel, and funds. According to the NIFC, wildfires on federal land used to average $425 million annually from 1985 to 1999.[505] From 2000 to 2019, the annual average increased to $1.6 billion.[506] Looking at state suppression costs, California has doubled costs within the past decade. For instance, for 2019–2020, CAL FIRE spent nearly $700 million just in suppression.[507] In the case studies presented in Chapter II, each fire details suppression costs. Given that controlled burns can limit wildfire growth, it is possible to assume that more strategic controlled burns in areas with high fuels can reduce the cost and effort that is associated with large wildfires.[508] Additionally, since managing wildfires is not the most probable solution near WUI zones throughout the West, controlled burns are one of

503 Arun Regmi et al., "Prescribed Fire: Does It Have a Place on My Land?," Penn State Extension, October 1, 2020, https://extension.psu.edu/prescribed-fire-does-it-have-a-place-on-my-land.

504 Holstege, "Wildfire Experts Call for More Controlled Burns."

505 Jesse Roman, Angelo Verzoni, and Scott Sutherland, "The Wildfire Crisis," *NFPA Journal,* November 1, 2020, http://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2020/November-December-2020/Features/Wildfire.

506 Roman, Verzoni, and Sutherland.

507 Roman, Verzoni, and Sutherland.

508 Tutella, "Fire Operations-Prescribed Burning Combo Reduces Wildfire Severity up to 72%"; John Loomis et al., "Do Fuel Treatments Reduce Wildfire Suppression Costs and Property Damages? Analysis of Suppression Costs and Property Damages in U.S. National Forests," *Proceedings of the Fifth International Symposium on Fire Economics, Planning, and Policy: Ecosystem Services and Wildfires* (Pacific Southwest Research Station: U.S. Forest Service, January 11, 2018), 83, https://www.montana.edu/econ/documents/LoomisPaper030718.pdf.

the more cost-effective tools in reducing catastrophic wildfires if sufficient resources are dedicated to it (i.e., funding, personnel, and equipment).[509]

Ultimately, prescribed burns are one of the most effective tools available to forestry managers and private landowners to improve forest health, reduce high-severity wildfires, and protect WUI zones, especially when it is combined with mechanical thinning.[510] Recently, there has been a large initiative at the federal level to increase controlled burns in the West, but it is important to note that the proper policies, funding, and resources also need to be invested for prescribed burns to prove its effectiveness.[511] There have been a few instances of a controlled burn escaping and impeding on a community, which highlights the need for safety and management but does not minimize the benefits that come from controlled burns, as escapes are rare.[512] Some scholars have argued that current climate conditions no longer favor prescribed burns, as the fuel is incredibly dry due to severe drought and extreme weather.[513] Nonetheless, with any prescribed burn plan, it is essential to evaluate the condition of the forest prior to

509 Samuel Poza, "Controlled Burns; the Solution to California's Wildfire Problem," *Debating Science* (blog), December 5, 2018, https://blogs.umass.edu/natsci397a-eross/controlled-burns-the-solution-to-californias-wildfire-problem/.

510 Sherri Eng, "Prescribed Burning and Mechanical Thinning Pose Little Risk to Forest Ecology," U.S. Department of Agriculture, February 21, 2017, https://www.usda.gov/media/blog/2012/07/26/prescribed-burning-and-mechanical-thinning-pose-little-risk-forest-ecology; NC State University College of Natural Resources News, "Ask an Expert: Why Is Prescribed Fire Important?"

511 Matthew Brown, "Biden Administration Plans to Increase Controlled Burns in Western States at Risk for Wildfires," PBS NewsHour, January 18, 2022, sec. Nation, https://www.pbs.org/newshour/nation/biden-administration-plans-to-increase-controlled-burns-in-western-states-at-risk-for-wildfires; Ezra David Romero, "Federal Bill Could Increase Prescribed Burns In California, Incentivize State To Burn At A Larger Scale," podcast, CapRadio Presents: Environment, accessed October 30, 2022, https://www.capradio.org/157090.

512 John R Weir et al., "Prescribed Fire: Understanding Liability, Laws and Risks," Oklahoma Cooperative Extension Service (Oklahoma State University Division of Agricultural Sciences and Natural Resources, March 2020), 2, https://extension.okstate.edu/fact-sheets/print-publications/nrem/prescribed-fire-understanding-liability-laws-and-risk-nrem-2905.pdf; Eric Westervelt, "Ecologists Say Federal Wildfire Plans Are Dangerously Out of Step with Climate Change," NPR, July 3, 2022, sec. National, https://www.npr.org/2022/07/03/1108748259/ecologists-wildfire-plans-climate-change; Alisa Chang, "Prescribed Burns Started a Wildfire, But Experts Say They're A Crucial Tool," NPR, October 5, 2022, sec. Consider This From NPR, https://www.npr.org/2022/10/05/1126912268/prescribed-burns-started-a-wildfire-but-experts-say-theyre-a-crucial-tool.

513 Westervelt, "Ecologists Say Federal Wildfire Plans Are Dangerously Out of Step with Climate Change."

conducting any fuel treatments.[514] In all, prescribed burns effectively clear built-up fuels in forests and are significantly less costly than wildfires.[515] It is critical to consider and implement controlled burns to reduce wildfire impact, especially in WUI areas.[516]

B. SUPPRESSION VS. MITIGATION

As highlighted in the previous section, wildfire response is quite costly and damages accrued require immense resources. On the other hand, mitigation projects are also expensive and sometimes need significant time, personnel, and resources. Politicians, land managers, and researchers have debated increasing investments and adjusting policies to allow for more mitigation projects than wildfire suppression and response.[517] This section compares wildfire response and mitigation efforts to demonstrate the investment and results of each line of effort. As a result, key stakeholders can better understand the return on investment between the two efforts.

1. Suppression

Wildfire suppression encompasses many resources ranging from boots-on-the-ground firefighters to aviation support and equipment. As highlighted in the previous section, response efforts are extraordinarily costly and have risen recently. Suppression has become more complex due to a nationwide shortage of firefighters and limited aviation support due to periodic fuel shortages and prioritization of fires across the

514 National Wildfire Coordinating Group, *NWCG Standards for Prescribed Fire Planning and Implementation*, PMS 484 (Washington, DC: National Wildfire Coordinating Group, 2022), 12, https://www.nwcg.gov/sites/default/files/publications/pms484.pdf.

515 Loomis et al., "Do Fuel Treatments Reduce Wildfire Suppression Costs and Property Damages?"

516 Loomis et al., 83.

517 "Reduce Wildfire Risks or Pay More for Fire Disasters," International Association of Wildland Fire, 2015, https://www.iawfonline.org/article/reduce-wildfire-risks-or-pay-more-for-fire-disasters/; "Secretary Haaland Highlights Bipartisan Infrastructure Law Wildfire Response Investments in Colorado," U.S. Department of the Interior, April 11, 2022, https://www.doi.gov/pressreleases/secretary-haaland-highlights-bipartisan-infrastructure-law-wildfire-response; Gabe Kohler and Alexander Evans, "Investing in Wildfire Prevention" (Santa Fe, NM: Forest Stewards Guild, May 2021), https://foreststewardsguild.org/wp-content/uploads/2021/05/InvestingInWildfirePrevention.pdf.

West.[518] Outside of immediate wildfire suppression, evacuations, disaster relief response, and recovery are also critical components to wildfire response.[519] Each component involves some degree of disruption to everyday life, displaces communities, and requires significant costs and time. Disaster relief and recovery includes economic recovery of infrastructure and private property as well as ecological recovery for the rehabilitation and restoration of the burned area.[520] For instance, in assessing California's 2020 August Complex Fire, discussed in Chapter II, suppression cost alone was $115.5 million for a three-month response period that included 4,337 total personnel, 45 aircraft, and 388 engines.[521] Amid the response, more than 60,000 people had to evacuate, which overwhelmed some evacuation shelters and required additional deployed resources from nonprofits to accommodate displaced residents.[522] Additionally, approximately 935 structures were damaged or destroyed. While there was no information was found on the exact estimated damage cost, 2,912 California residents were awarded over $23 million through the Federal Emergency Management Agency's (FEMA) Individual Assistance in response to California's 2020 wildfires.[523] After the fire, recovery efforts can begin, in which rapid assessment teams (i.e., BAER teams) can

518 Urness, "Labor Shortage Leaves U.S. Struggling to Hire Firefighters Despite Record Wildfire Funding," May 11, 2022; Ximena Bustillo, "Federal Firefighters Are Waiting for Pay Raises They Hope Will Help Fill Their Ranks," NPR, June 11, 2022, https://www.npr.org/2022/06/11/1103982837/federal-firefighters-waiting-for-pay-raises-they-hope-will-help-fill-their-ranks; Troy Oppie, "A Shortage Of Aviation Fuel Temporarily Grounds Some Firefighting Efforts," NPR, July 23, 2021, https://www.npr.org/2021/07/23/1019610989/a-shortage-of-aviation-fuel-temporarily-grounds-some-firefighting-efforts.

519 Katie Hoover, *Federal Assistance for Wildfire Response and Recovery,* CRS Report No. IF10732 (Washington, DC: Congressional Research Service, 2022), https://sgp.fas.org/crs/homesec/IF10732.pdf.

520 Hoover, 2.

521 George Morris III and Carrie Dennis, *2020 Fire Siege* (Sacramento, CA: California Department of Forestry and Fire Protection, 2020), 64, https://www.fire.ca.gov/media/hsviuuv3/cal-fire-2020-fire-siege.pdf; National Weather Service, "August Complex, Northern California"; Alaska Interagency Coordination Center, "National Large Incident."

522 Stephanie Sierra, "Evacuation Center Full as CZU August Lightning Complex Fire Scorches More Than 50,000 Acres," ABC7 San Francisco, August 21, 2020, https://abc7news.com/santa-cruz-evacuation-centers-bay-area-wildfires-czu-august-lightning-complex-update-on-fire/6383053/; Elinor Aspegren and Doyle Rice, "At Least 5 Dead in Massive California Wildfires; More Than 60,000 Flee, Thousands of Homes Threatened," USA TODAY, August 21, 2020, sec. Nation, https://www.usatoday.com/story/news/nation/2020/08/20/california-wildfires-thousands-homes-threatened/5616288002/; United Way, "Resources - CZU August Lightning Complex Fires," United Way of Santa Cruz County, accessed November 2, 2022, https://www.unitedwaysc.org/2020wildfireresources.

523 "California Wildfires," Federal Emergency Management Agency, October 27, 2022, https://www.fema.gov/disaster/4558; National Weather Service, "August Complex, Northern California."

deploy to evaluate the wildfire's impact on areas including vegetation, hydrology, and wildlife to determine emergency stabilization actions.[524] As a result, the USFS was able to begin large-scale projects, in a phased approach, to restore the impacted forests.[525] In total, FEMA awarded the state $407 million for emergency and permanent work projects as well as $20 million for hazard mitigation projects in affected areas.[526] Bottom line: wildfire response is a multifaceted, costly, and reactive endeavor that includes personnel and equipment, aviation resources, resources for displaced evacuees, and emergency stabilization actions to restore forests and communities.

2. Mitigation

Mitigation projects are a proactive response to reduce wildfire impacts on communities, forests, and critical infrastructure. CAL FIRE shared its lessons learned from the August Complex Fire and emphasized the importance of fuel reduction treatments, as it influences fire behavior.[527] For example, CAL FIRE shared that in treated areas where the fire burned, the fire behavior was primarily surface fires, as the treatments reduced the risk of crown fires (fires that move through treetops), which reduced tree mortality in the area.[528] Generally, wildfire mitigation includes various measures to minimize wildfire impacts and post-fire floods, in which these measures include fuel treatments with controlled burns, mechanical thinning, reforestation, culvert

524 "August Complex Restoration," U.S. Forest Service, accessed November 2, 2022, https://www.fs.usda.gov/detail/mendocino/home/?cid=FSEPRD860382; U.S. Department of Agriculture, August Complex Vegetation and Resource Rapid Assessment (Washington, DC: U.S. Department of Agriculture, 2020), https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fseprd865429.pdf; "August Complex Post-Fire BAER Information," InciWeb- Incident Information System, November 5, 2020, https://web.archive.org/web/20201206165856/https://inciweb.nwcg.gov/incident/7228/.

525 U.S. Forest Service, "August Complex Restoration."

526 Federal Emergency Management Agency, "California Wildfires."

527 Matthew Nobert, "August Complex Fire Provides Lessons in Fire Mitigation," FOX40 News, September 2, 2022, https://fox40.com/news/wildfire-watch/august-complex-fire-provides-lessons-in-fire-mitigation/.

528 Nobert.

and watershed restoration, and creating fire-resistant structures.[529] On average, FEMA disaster mitigation projects take around seven years to complete, including the time to apply for grant money, receive funds, and begin work.[530] The lengthy time span can be problematic for jurisdictions that want to begin preventative measures immediately, but cannot due to the insurmountable price tag that sometimes come with these projects. To accommodate the long wait time, some states have established their own fund to complete critical projects within several months to a few years.[531] For instance, in Arizona, a $100 million wildfire relief package was signed in 2021, granting DFFM with $36 million for mitigation projects related to post-fire floods, $10 million for public and private landowners needing financial assistance for infrastructure repairs, $29 million for wildfire suppression activities, and $25 million for the Healthy Forest Initiative.[532] Similarly, California has proposed $1.2 billion over two years for forest and WUI mitigation.[533] Several case studies have revealed that effective mitigation projects often have a positive return on investment for private residents in WUI and state and federal landowners. For instance, in the WUI, FEMA states that investments in fire-resistant windows and doors, non-combustible roofs, and clearing fuels around the home and

529 "Wildfire Mitigation," Boulder County, accessed October 19, 2022, https://bouldercounty.gov/disasters/wildfires/mitigation/; Federal Emergency Management Agency, "Avoiding Wildfire Damage: A Checklist for Homeowners" (Washington, DC: Federal Emergency Management Agency), accessed October 19, 2022, https://www.fema.gov/pdf/hazard/wildfire/wdfrdam.pdf; "Restore Healthy Forests-Reduce Wildfire Risk," Washington Forest Protection Association, accessed October 19, 2022, https://www.wfpa.org/sustainable-forestry/restore-healthy-forests-reduce-wildfire-risk/.

530 Hannah Dreier and Andrew Ba Tran, "The Ring in the Ashes," *Washington Post,* November 15, 2021, sec. National, https://www.washingtonpost.com/nation/2021/11/15/fema-hazard-mitigation-funding/.

531 "Funding Available for Post-Wildfire Infrastructure Repair Assistance," Arizona Department of Forestry and Fire Management, August 20, 2021, https://dffm.az.gov/funding-available-post-wildfire-infrastructure-repair-assistance.

532 "Governor Ducey Signs $100 Million Bipartisan Wildfire Relief Package," Office of the Arizona Governor, June 18, 2021, https://azgovernor.gov/governor/news/2021/06/governor-ducey-signs-100-million-bipartisan-wildfire-relief-package; "Funding to Help Arizonans Under HB 2001," Arizona Department of Forestry and Fire Management, August 12, 2021, https://dffm.az.gov/funding-help-arizonans-under-hb-2001-august-12-2021.

533 Legislative Analyst's Office, The 2022–23 Budget: Wildfire and Forest Resilience Package (Sacramento, CA: The California Legislature's Nonpartisan Fiscal and Policy Advisor, 2022), https://lao.ca.gov/Publications/Report/4495.

property is typically less than 5% of the cost of a home and the items inside.[534] Additionally, FEMA summarizes that every $1 spent on mitigation measures should save $6 on future disaster losses.[535] For forests, studies conducted in Denver, Colorado, have revealed that fuel treatments and watershed investments have a positive financial return in reducing wildfire impacts and protecting watershed health.[536] In sum, although mitigation projects take time and funding, it is critical to focus on these initiatives as they decrease wildfire impacts on communities, forests, and critical infrastructure.

In conclusion, wildfire response and mitigation efforts are costly, time consuming, and can require a significant number of resources. Investment in response and mitigation efforts is necessary to protect communities and critical infrastructure. Nonetheless, it is important to stress the importance of mitigation projects considering proactive efforts to reduce fuels, protect watersheds, and maintain forest health are all essential elements in reducing wildfire intensity and impacts. Last, investing in mitigation projects offers forestry and fire agencies and private landowners a positive return on investment, whereas wildfire suppression does not. Mitigation projects have and will continue to save lives, homes, and wildlife and reduce the costs associated with catastrophic wildfires throughout the West.

534 Federal Emergency Management Agency, "Natural Hazard Mitigation Saves Interim Report" (Washington, DC: Federal Emergency Management Agency, June 2018), 2, https://www.fema.gov/sites/default/files/2020-07/fema_mitsaves-factsheet_2018.pdf.

535 Federal Emergency Management Agency, 2.

536 Kelly W. Jones et al., "Return on Investment from Fuel Treatments to Reduce Severe Wildfire and Erosion in a Watershed Investment Program in Colorado," *Journal of Environmental Management* 198 (May 6, 2017): 75, https://doi.org/10.1016/j.jenvman.2017.05.023; Kelly Jones et al., "A Cost-Benefit Analysis of Denver's Forests to Faucets Program, 2011–2019" (Fort Collins, CO: Colorado State University, January 2021), https://cfri.colostate.edu/wp-content/uploads/sites/22/2021/02/Jones-et-al-F2F-ROI-Final.pdf.

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V. POLICY AND CONSIDERATIONS

This chapter covers federal landmark cases and recent initiatives that relate to and impact land management and wildfires to analyze the benefits or potential challenges they pose for forestry managers. Additionally, this chapter highlights policies and funding for post-wildfire recovery in the WUI, which is vital to ensuring communities can improve resiliency to recover from natural disasters now and in the future. The final section of this chapter highlights state and local concerns and considerations for forestry managers and the residents. Analyzing efforts to improve collaboration among different landowners to mitigate wildfire scale, frequency, and impacts is essential. Regarding the WUI, this chapter highlights community involvement programs that improve community resiliency and mitigate wildfire scale. Last, this chapter addresses wildfire insurance, which has been an area of concern for homeowners since insurance companies have declined continued or new coverage.

A. FEDERAL POLICIES

Federal policies on forestry and fire management are critical in establishing unified goals and objectives across all levels of government. At times, policies can be polarizing and spark significant debates, as there are often misconceptions on the policy's intentions and what it means for forest health.[537] For instance, in the early to mid-1900s, policies and common perception of fires among forestry managers and the public was that all fires are destructive.[538] Now, there is a general understanding that fires are often beneficial to the environment.[539] Therefore, it is vital to consider scientific findings for developing policies and evaluating their impact on wildfire mitigation and forest health.

537 "U.S. Forest Service Fire Policy," Forest History Society, accessed November 3, 2022, https://foresthistory.org/research-explore/us-forest-service-history/policy-and-law/fire-u-s-forest-service/u-s-forest-service-fire-policy/.

538 "The 1910 Fires," Forest History Society, accessed November 3, 2022, https://foresthistory.org/research-explore/us-forest-service-history/policy-and-law/fire-u-s-forest-service/famous-fires/the-1910-fires/.

539 U.S. Forest Service, "Fire Effects on the Environment," U.S. Forest Service Pacific Southwest Research Station, accessed November 4, 2022, https://www.fs.usda.gov/pnw/page/fire-effects-environment.

1. Landmark Legislation

Landmark legislation is commonly referenced when discussing laws that hold significant historical and/or cultural meaning that shape aspects of the nation's way of life, to include liberties and the environment. Regarding forestry and fire management, the National Environmental Policy Act (NEPA) and the Clean Air Act (CAA) are two notable laws that influence forestry and fire management operations. Inversely, wildfires tend to impact the intentions and goals set forth by these laws.[540] NEPA was signed into law on January 1, 1970, and was the first major environmental law in the nation.[541] NEPA requires federal agencies to examine the environmental impacts of their proposed plans and actions before taking significant action.[542] Overall, as stated in Section 101, the objective of NEPA is "to use all practicable means and measures, including financial and technical assistance, in a manner calculated to foster and promote the general welfare, to create and maintain conditions under which man and nature can exist in productive harmony, and fulfill the social, economic, and other requirements of present and future generations of Americans."[543] The Clean Air Act was Enacted in 1970 and amended in 1990 and regulates emissions to protect and improve the nation's air quality.[544] One of the stated purposes of CAA is, "to protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the productive capacity of its population."[545] Additionally, CAA establishes the U.S. Environmental Protection Agency (EPA) as the responsible agency for regulating the

[540] Mira Rojanasakul, "Wildfire Smoke Is Erasing Progress on Clean Air," *New York Times*, September 25, 2022, sec. Climate, ProQuest.

[541] Executive Office of the President of the United States, "National Environmental Policy Act," National Environmental Policy Act, accessed November 3, 2022, https://ceq.doe.gov/.

[542] "What Is the National Environmental Policy Act?," U.S. Environmental Protection Agency, October 26, 2022, https://www.epa.gov/nepa/what-national-environmental-policy-act.

[543] Executive Office of the President of the United States, "National Environmental Policy Act."

[544] "Clean Air Act Text," U.S. Environmental Protection Agency, May 4, 2022, https://www.epa.gov/clean-air-act-overview/clean-air-act-text; "EPA History: Clean Air Act of 1970/1977," U.S. Environmental Protection Agency, September 30, 2022, https://www.epa.gov/history/epa-history-clean-air-act-19701977; "EPA History: Clean Air Act Amendments of 1990," U.S. Environmental Protection Agency, June 27, 2022, https://www.epa.gov/history/epa-history-clean-air-act-amendments-1990.

[545] The Public Health and Welfare, 42 U.S.C. § 7401 (1990), https://www.govinfo.gov/content/pkg/USCODE-2013-title42/html/USCODE-2013-title42-chap85-subchapI-partA-sec7401.htm.

National Ambient Air Quality Standards (NAAQS).[546] The six air pollutants regulated by NAAQS include carbon monoxide, lead, ground-level ozone, particulate matter, nitrogen dioxide, and sulfur dioxide. Most pollutants can reach extreme levels during a wildfire.[547] In turn, NEPA and CAA are two federal landmark policies that are fundamental to preserving the nation's environment and have a direct influence on forestry and fire management operations.

Due to its involvement with land management, the USFS conducts the most NEPA analyses out of all federal agencies.[548] NEPA requires the Council on Environmental Quality (CEQ) and the public to be consulted before building new roads, trails, campgrounds, etc.[549] Section 102 of NEPA states that "actions significantly affecting the quality of the human environment" require a detailed statement.[550] Per Section 102, the statement should include

> (1) the environmental impact of the proposed action; (2) any adverse effects that cannot be avoided; (3) alternatives to the proposed action; (4) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity; and (5) any irreversible and irretrievable commitments of resources that would be involved in the proposed action.[551]

In other words, if the project has significant ecological impacts, an environmental impact statement (EIS) will need to be drafted for CEQ to decide.[552] Dominantly, categorical

546 "Summary of the Clean Air Act," U.S. Environmental Protection Agency, September 12, 2022, https://www.epa.gov/laws-regulations/summary-clean-air-act.

547 U.S. Environmental Protection Agency, *Environments and Contaminants: Criteria Air Pollutants, 3rd ed., America's Children and the Environment* (Washington, DC: U.S. Environmental Protection Agency, 2015), 16, https://www.epa.gov/sites/default/files/2015-10/documents/ace3_criteria_air_pollutants.pdf.

548 Forrest Fleischman et al., "US Forest Service Implementation of the National Environmental Policy Act: Fast, Variable, Rarely Litigated, and Declining," *Journal of Forestry* 118, no. 4 (March 12, 2020): 405, https://doi.org/10.1093/jofore/fvaa016.

549 "USDA Forest Service Announces Key Changes to NEPA Procedures," U.S. Forest Service, November 18, 2020, https://www.fs.usda.gov/news/releases/usda-forest-service-announces-key-changes-nepa-procedures.

550 Executive Office of the President of the United States, "National Environmental Policy Act."

551 Executive Office of the President of the United States.

552 Fleischman et al., "US Forest Service Implementation of the National Environmental Policy Act," 405.

exclusions (CE) and environmental assessments (EA) are the majority of NEPA analyses submitted by USFS, which are not as time-consuming as an EIS.[553] According to Fleischman et al., between 2005–2018, the USFS submitted 33,976 decisions in which 82.3% were CEs, 15.8% were EAs, and 1.9% were EISs.[554] Generally, the NEPA process for the USFS takes about 105 days for CEs, one year for EAs, and 2.5 years for an EIS.[555] In 2020, a revision to the NEPA process was made to improve the process and add CEs, which has sparked debates on the effectiveness of NEPA.[556] Diane Katz, a research fellow in regulatory policy, argued that the high number of categorical exclusions resulted in NEPA becoming "pointless."[557] Among environmental groups, the addition of CEs, such as allowing logging up to 2,800 acres, has resulted in lawsuits against USFS, stating the new amendment would "cause significant harm to publicly owned national forests across the country and to members of the public who use those lands."[558] Nonetheless, the case, *Wild Virginia et al. v. Council on Environmental Quality et al.*, was thrown out due to lack of standing.[559] Regardless, NEPA is a beneficial process for all stakeholders involved, since it requires the consideration of diverse perspectives on forest health and preservation projects. In all, NEPA is a proactive, instrumental law that influences forestry mitigation more so than wildfires. It is critical to ensure that the balance between practical forestry management projects and public consideration is maintained and considered.

Large wildfires produce a significant number of pollutants, such as carbon monoxide, which creates poor air quality that threatens younger children, the elderly, and

553 Fleischman et al., 404.

554 Fleischman et al., 403.

555 Fleischman et al., 412.

556 U.S. Forest Service, "USDA Forest Service Announces Key Changes to NEPA Procedures."

557 Diane Katz, "Time to Repeal the Obsolete National Environmental Policy Act (NEPA)," The Heritage Foundation, March 14, 2018, https://www.heritage.org/government-regulation/report/time-repeal-the-obsolete-national-environmental-policy-act-nepa.

558 Sarah Vogelsong, "Fight Over Environmental Review by Forest Service Continues in Courts," *Virginia Mercury* (blog), April 25, 2022, https://www.virginiamercury.com/2022/04/25/fight-over-environmental-review-by-forest-service-continues-in-courts/.

559 Vogelsong.

people with health-related issues (i.e., asthma).[560] Additionally, wildfire smoke in the western United States travels and impacts other countries and states, like New York, air quality, as well as the planet's ground-level ozone.[561] The CAA considers wildfires an "exceptional event"; thus, when the air quality exceeds EPA limits, it does not hinder the states' EPA compliance.[562] Nonetheless, wildfires impede states' goals of reducing emissions. For instance, researchers with the University of Chicago found that California's 2020 wildfire season nulled 18 years of the state's reduction in emissions.[563] Thus, it is critical to evaluate smoke management (i.e., monitoring, forecasting, and communication) to aid and improve public health.[564]

The ultimate dilemma regarding wildfire smoke is between significant events that blanket the nation with pollutants or managed and planned smoke. As discussed in the previous chapter, critical forestry and fire management strategies, like controlled burns, improve forest health conditions and reduces wildfire air pollution over time.[565] Aside from personnel, funding, and time, conducting prescribed burns faces challenges with CAA compliance.[566] In 2016, the EPA included prescribed burns as an exceptional event, yet as of March 2020, no state has submitted documentation for an exception to the

560 "Which Populations Experience Greater Risks of Adverse Health Effects Resulting from Wildfire Smoke Exposure?," U.S. Environmental Protection Agency, October 20, 2022, https://www.epa.gov/wildfire-smoke-course/which-populations-experience-greater-risks-adverse-health-effects-resulting.

561 Nadja Popovich and Josh Katz, "See How Wildfire Smoke Spread Across America," *New York Times*, July 21, 2021, sec. Climate, https://www.nytimes.com/interactive/2021/07/21/climate/wildfire-smoke-map.html; Kate C. Shouse, *Wildfire Smoke: Air Quality Concerns and Management,* CRS Report No. IN11528 (Washington, DC: Congressional Research Service, 2021), https://crsreports.congress.gov/product/pdf/IN/IN11528#:~:text=Additional%20pollutants%20of%20concern%20from,liquid%20droplets%20in%20the%20atmosphere.

562 Air Quality Monitoring, 42 U.S.C. § 7619 (1977), https://uscode.house.gov/view.xhtml?req=(title:42%20section:7619%20edition:prelim)%20OR%20(granuleid:USC-prelim-title42-section7619)&f=treesort&edition=prelim&num=0&jumpTo=true.

563 Thomas Catenacci, "One Year of California Wildfires Negated 18 Years of Emissions Reductions from State Climate Policies: Study," Fox News, October 19, 2022, https://www.foxnews.com/politics/one-year-california-wildfires-negated-18-years-emissions-reductions-state-climate-policies-study.

564 Shouse, *Wildfire Smoke: Air Quality Concerns and Management.*

565 Williams, "Reimagining Exceptional Events: Regulating Wildfires Through the Clean Air Act," 776.

566 Courtney Schultz et al., "Prescribed Fire Policy Barriers and Opportunities: A Diversity of Challenges and Strategies Across the West" (Eugene, OR: University of Oregon, 2018), 1, https://ewp.uoregon.edu/sites/ewp.uoregon.edu/files/WP_86.pdf.

EPA.[567] The lack of documentation suggests that the regulation may not be effective. One scholar suggested that states are wary of exceeding NAAQS standards and not receiving approval from EPA for the exceptional event, thus states conduct limited prescribed burn operations.[568] In other words, CAA does not incentivize prescribed burns due to the imposed administrative burdens.[569] As suggested by the director of the Climate and Energy Policy Program at Stanford, the solution to improving air quality due to wildfire air pollution is the "use of prescribed burns, indigenous burning practices and mechanical fuel treatments."[570] In all, the CAA has improved the nation's air quality significantly since its implementation, but further consideration of how the policy translates to the reality of wildfires and controlled burn operations may be necessary.

2. Recent Initiatives

This section covers two recent federal initiatives—the Bipartisan Infrastructure Law and Wildfire Emergency Act—that address forestry and fire management. Furthermore, this section highlights the opportunities and potential challenges posed by the new legislation, as it will most likely influence forestry management operations in the West.

The Bipartisan Infrastructure Law is a $1 trillion investment for the nation's infrastructure, including roads, transportation, environment, power, and water.[571] More specifically, the DOI received funding for water and drought resilience ($8.3 billion), wildfire resilience ($1.5 billion), ecosystem restoration ($1.4 billion), and tribal infrastructure ($466 million) to support DOI entities such as NPS, USFS, tribes, and other

567 Williams, "Reimagining Exceptional Events: Regulating Wildfires Through the Clean Air Act," 788.

568 Williams, 788.

569 Williams, 799.

570 Josie Garthwaite, "The Shifting Burden of Wildfires in the United States," *Stanford News* (blog), January 12, 2021, https://news.stanford.edu/2021/01/12/shifting-burden-wildfires-united-states/.

571 "President Biden's Bipartisan Infrastructure Law," The White House, accessed July 15, 2022, https://www.whitehouse.gov/bipartisan-infrastructure-law/.

federal, state, and local entities.[572] The environmental objectives of the infrastructure law align with the USDA Forest Service's 10-Year Wildfire Crisis Strategy, which is centered around collaboration with partners to treat (i.e., mechanical thinning, prescribed burns, removing invasive species) 20 million acres in national forests and 30 million acres on state, tribal, and private lands.[573] Additionally, the infrastructure law provides funding for programs focused on addressing firefighters' mental health, forestry and fire management research, and wildfire risk mapping.[574] Furthermore, under the infrastructure law, the National Wildland Fire Risk Reduction Program Act will support and fund research and development on wildfire prediction, improving WUI resilience, and technology.[575] A year since the law was signed on November 15, 2021, guidance has yet been provided to states seeking to acquire the funds for much-needed projects.[576] Regardless, the funds provided through the Bipartisan Infrastructure Law offers states and local jurisdictions with some financial relief in wildfire mitigation, restoration efforts, and improving resilience overall.

The Wildfire Emergency Act, introduced into Congress on May 2021 by Congressman Jimmy Panetta and Senator Dianne Feinstein of California, proposes funding for forest restoration, critical infrastructure protection, training, and support for

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572 "Interior Department Celebrates Passage of the Bipartisan Infrastructure Deal," U.S. Department of the Interior, November 8, 2021, https://www.doi.gov/pressreleases/interior-department-celebrates-passage-bipartisan-infrastructure-deal.

573 U.S. Forest Service, *Confronting the Wildfire Crisis,* FS-1187a (Washington, DC: U.S. Department of Agriculture, Forest Service, 2022), 4, https://www.fs.usda.gov/sites/default/files/Confronting-Wildfire-Crisis.pdf.

574 "President Biden's Bipartisan Infrastructure Law to Provide $103 Million for Wildfire Mitigation and Resilience," U.S. Department of the Interior, June 17, 2022, https://www.doi.gov/pressreleases/president-bidens-bipartisan-infrastructure-law-provide-103-million-wildfire-mitigation.

575 "Western Science Committee Dems Introduce Comprehensive Authorization Bill to Improve U.S. Preparedness, Resilience & Response to Wildfires," The House Committee on Science, Space and Technology, October 29, 2021, https://science.house.gov/news/press-releases/western-science-committee-dems-introduce-comprehensive-authorization-bill-to-improve-us-preparedness-resilience-and-response-to-wildfires.

576 John LaConte, "Colorado Democrats Urge Forest Service to Create Spending Plan for $10B in Funds," Post Independent, November 2, 2022, https://www.postindependent.com/news/colorado-democrats-urge-forest-service-to-create-spending-plan-for-10b-in-funds/.

disadvantaged communities in the West.[577] As of November 2022, the bill has not yet been voted on, but hearings were held on October 2022 before the Senate Committee on Energy and Natural Resources.[578] To note, the bill is supported by several stakeholders including the California Farm Bureau, Sierra Club, Idaho Conservation League, Western Environmental Law Center, and PG&E Corporation, to name a few.[579] More specifically, the bill proposes the authorization of $250 million to the USFS for 20 forest restoration projects (i.e., controlled burns and dead tree and invasive species removal) that are at least 100,000 acres each, with the federal cost-share at the maximum of 60% per project.[580] If the bill were to become law, it is critical to acknowledge that the continuous maintenance that comes with forest restoration requires continuous funding. For instance, to address invasive plants that span 200,000 acres of land under the Pima County Natural Resources, Parks and Recreation Department in Arizona, the county has had to collaborate with several stakeholders to acquire significant funds from different funding streams since 2010.[581] In 2020 alone, the county was awarded $360,000 from DFFM, requested an additional $280,000 from DFFM, and has submitted additional grants to FEMA.[582] Before 2020, the county had contributed approximately $600,000 since 2010.[583] The county's efforts from 2010–2019 have primarily relied on volunteer work to manually remove and spray herbicide on invasive plants, in which the financial

[577] Wildfire Emergency Act of 2021, H.R.3534, 117th Cong. § (2021), http://www.congress.gov/; United States Senator for California Dianne Feinstein, "New Bill Would Reduce Risk for Catastrophic Wildfires, Increase Preparedness," United States Senator for California Dianne Feinstein, May 26, 2021, https://www.feinstein.senate.gov/public/index.cfm/2021/5/new-bill-would-reduce-risk-for-catastrophic-wildfires-increase-preparedness.

[578] "All Information (Except Text) for S.2806 - Wildfire Emergency Act of 2021," Congress.gov, October 21, 2021, http://www.congress.gov/.

[579] Congressman Panetta, Senator Feinstein Introduce Bill to Reduce Wildfire Risk, Increase Preparedness," Congressman Jimmy Panetta, May 26, 2021, https://panetta.house.gov/media/press-releases/congressman-panetta-senator-feinstein-introduce-bill-reduce-wildfire-risk.

[580] Congressman Jimmy Panetta.

[581] Brian Powell, *NRPR Invasive Plant Program History, Accomplishments, and Future Directions* (Pima County, Arizona: Pima County Natural Resources, Parks and Recreation Department, 2021), 2, 12, https://webcms.pima.gov/UserFiles/Servers/Server_6/File/Government/Administration/CHHmemosFor%20Web/2021/April/Update%20on%20Invasive%20Species%20Management%20Process.pdf.

[582] Powell, 1.

[583] Powell, 11.

value of volunteer work is estimated at over $1.1 million.[584] From 2001–2019, the county completed 4,275 invasive species treatments on 9,810 acres of land.[585] In sum, in combining grants, county funds, and volunteer support, Pima County has invested $2.34 million on 9,810 out of 200,000 acres of land in Arizona. This case study is shared to emphasize the continuous funds required to address forest restoration and the importance of personnel and resources in these efforts. Nonetheless, if the bill were to become a law, it may prove effective in addressing pressing concerns and providing financial relief to forestry managers throughout the West.

All in all, the Bipartisan Infrastructure Law and proposed Wildfire Emergency Act offer western forestry managers and key stakeholders the financial opportunity to focus on initiatives that will improve forest health and reduce wildfire impacts on communities and critical infrastructure. On the other hand, the main concerns surrounding both initiatives include the delay of passing the law and the need to create a structure to release funding immediately. To note, with the 2022 mid-term election and shift of power within Congress, the Wildfire Emergency Act will have to be reintroduced and face the possibility of not passing.[586] Additionally, longevity should be considered, as most projects require continuous funds for maintenance to ensure these large-scaled projects continue to prove effective.

3. Post-Wildfire Recovery

Recovery is critical in maintaining the homeland's resiliency.[587] Recovery includes restoring communities and repairing environmental damage.[588] Post-wildfire

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584 Powell, 16.

585 Powell, 15.

586 Shane Goldmacher, "Republicans Capture Control of the House After Falling Short of Midterm Expectations," *New York Times*, November 17, 2022, sec. U.S, https://www.nytimes.com/2022/11/16/us/politics/house-control-congress.html.

587 U.S. Department of Homeland Security, *DHS Resilience Framework: Providing a Roadmap for the Department in Operational Resilience and Readiness* (Washington, DC: U.S. Department of Homeland Security, 2018), 2, https://www.dhs.gov/sites/default/files/publications/dhs_resilience_framework_july_2018_508.pdf.

588 "Mission Areas and Core Capabilities," Federal Emergency Management Agency, July 20, 2020, https://www.fema.gov/emergency-managers/national-preparedness/mission-core-capabilities.

recovery is important to not only enhance and restore community resiliency but also to mitigate post-fire floods, debris flow, and landslides.[589] Recovery of the WUI community can take months to years, depending on the damage.[590] In December 2021, the Marshall Fire destroyed 1,084 homes in Boulder, Colorado.[591] Boulder County began debris removal in April 2022, but architects predict that rebuilding the homes will take one to two years.[592] Whereas, depending on the severity, forest regrowth and recovery can take months to years to decades.[593] In 2012, ecologists with the University of Nevada, Las Vegas, determined that full recovery of Southwest deserts may take 65 years (2077).[594] On the other hand, researchers with the University of Colorado, Boulder, predicted that ponderosa pine and Douglas fir forests in the Southern Rocky Mountains may not recover from wildfires in a few decades and then will convert to grasslands.[595] Therefore, restoration and mitigation efforts are critical to reducing wildfire impacts and ensuring forest health. Since not all wildfires are preventable, ensuring effective and efficient recovery efforts is vital to restoring communities and forests.

589 "Post-Wildfire Recovery: What to Expect After a Wildfire," CAL FIRE, accessed November 8, 2022, https://www.readyforwildfire.org/post-wildfire/after-a-wildfire/.

590 "Post-Wildfire Recovery," U.S. Fire Administration, October 22, 2020, https://www.usfa.fema.gov/blog/ci-102220.html.

591 "Update: 1,084 Homes and 7 Businesses Destroyed in Marshall Fire," KUVO Public Radio (Denver, CO), accessed July 16, 2022, https://www.kuvo.org/update-1084-homes-and-7-businesses-destroyed-in-marshall-fire/.

592 "Marshall Fire Debris Removal Program Underway in Superior and Louisville," Boulder County, April 19, 2022, https://bouldercounty.gov/news/marshall-fire-debris-removal-program-underway-in-superior-and-louisville/; Kelly Reinke, "Rebuilding a Home After the Marshall Fire Could Take 12 Months at Minimum, Architect Says," 9 News, April 3, 2022, sec. Marshall Fire, https://www.9news.com/article/news/local/wildfire/marshall-fire/rebuilding-home-after-marshall-fire/73-2c6016b9-9836-467e-897f-1a3b57430cb8.

593 *Frontline Wildfire Defense*, "Forest After Fire: The Forest's Restoration & Regrowth After Wildfire," (blog), accessed July 16, 2022, https://www.frontlinewildfire.com/wildfire-news-and-resources/how-forest-recovers-wildfire/.

594 Tony Allen, "UNLV Study: Southwest Desert Ecosystems Can Take Decades To Recover from Wildfires," University of Nevada, Las Vegas, January 3, 2012, https://www.unlv.edu/news/article/unlv-study-southwest-desert-ecosystems-can-take-decades-recover-wildfires.

595 Kyle C. Rodman et al., "A Changing Climate Is Snuffing Out Post-Fire Recovery in Montane Forests," *Global Ecology and Biogeography* 29, no. 11 (August 17, 2020): 2039–51, https://doi.org/10.1111/geb.13174; Lisa Marshall, "Forests Scorched by Wildfire Unlikely to Recover, May Convert to Grasslands," CU Boulder Today (blog), August 25, 2020, https://www.colorado.edu/today/2020/08/25/forests-scorched-wildfire-unlikely-recover-may-convert-grasslands.

Regarding post-fire financial assistance, FEMA offers Public Assistance (PA) and Individual Assistance (IA) programs when natural events receive a presidential disaster declaration, which is not always expected. Between 2021 to 2022, New Mexico and California received presidential disaster declarations for their catastrophic wildfires.[596] PA provides a 75% reimbursement for state and local governments to conduct debris removal, infrastructure repairs, and additional protective measures.[597] IA is the funding source for individuals and families that have been affected by wildfires.[598] The IA process has become controversial, as it has been revealed that FEMA has recently denied more claims and filtered out requests deemed fraudulent, even though residents were adamant that their documentation was correct.[599] For instance, NPR found that about 70% of claims from Oregon residents did not get approved and 86% of claims from California residents were not approved.[600] However, for the 2020 Oregon fire season, FEMA provided $160 million in IA.[601] Federal hearings have been held to address FEMA's IA process.[602] Considering that FEMA IA is not always guaranteed further

596 "President Joseph R. Biden, Jr. Approves California Disaster Declaration," The White House, August 14, 2021, https://www.whitehouse.gov/briefing-room/statements-releases/2021/08/24/president-joseph-r-biden-jr-approves-california-disaster-declaration/; "FACT SHEET: The Biden Administration Responds to Early Wildfires in New Mexico," The White House, May 7, 2022, https://www.whitehouse.gov/briefing-room/statements-releases/2022/05/07/fact-sheet-the-biden-administration-responds-to-early-wildfires-in-new-mexico/.

597 "Understanding Individual Assistance and Public Assistance," Federal Emergency Management Agency, October 12, 2017, https://www.fema.gov/press-release/20210318/understanding-individual-assistance-and-public-assistance.

598 Federal Emergency Management Agency.

599 U.S. Congress. Senate, Are FEMA's Assistance Programs Adequately Designed to Assist Communities Before, During, and After Wildfire?, Senate, 117th Cong., 1st sess., October 26, 2021, https://www.congress.gov/event/117th-congress/house-event/LC67922/text?s=1&r=83; Sean McMinn and April Ehrlich, "As Western Wildfires Worsen, FEMA Is Denying Most People Who Ask For Help," NPR, July 1, 2021, https://www.npr.org/2021/07/01/1010897265/as-western-wildfires-worsen-fema-is-denying-most-people-who-ask-for-help.

600 McMinn and Ehrlich, "As Western Wildfires Worsen, FEMA Is Denying Most People Who Ask For Help."

601 Wildfire Recovery: Federal Assistance to Individuals and Households Tops $160 Million," Federal Emergency Management Agency, July 6, 2021, https://www.fema.gov/press-release/4562/20210706/wildfire-recovery-federal-assistance-individuals-households-tops-160-m.

602 U.S. Congress. Senate, October 26, 2021; Chris Currie, Wildfire Disasters: FEMA Could Take Additional Actions to Address Unique Response and Recovery Challenges, GAO-20-5 (Washington, DC: Government Accountability Office, 2019), https://www.gao.gov/assets/gao-20-5.pdf.

emphasizes the importance of implementing mitigation measures on and around private property.

Post-wildfire, it is critical to ensure recovery efforts reduce the future risk of the wildfire threat in the WUI and forests, thus implementing policies that improve resiliency may be necessary at the state and local levels. Recently, a group of scholars found that California's post-wildfire rebuilding efforts have not adapted to reduce the wildfire risk.[603] Kramer et al. suggested building new developments in low-risk fire areas to prevent devastation.[604] Unfortunately, families building homes in the western United States are not always told about the wildfire risk.[605] California and Oregon are the only western states that require wildfire risk to be shared with homebuyers.[606] In some areas, rebuilding or renovating homes that are wildfire resistant is (perhaps surprisingly) the same cost as traditional home construction.[607] For instance, in response to the 2018 Camp Fire in California that devastated the town of Paradise, the local government decided to adopt more robust building codes that required homes to be rebuilt with fire-resistant materials.[608] As a result, the community significantly improved its resilience and has since avoided disaster due to catastrophic wildfires nearby. On the other hand, some residents of Paradise decided to not rebuild due to a variety of factors including limited availability of contractors and high rebuilding costs.[609] Overall, factoring in wildfire risk is vital when rebuilding or purchasing a home. Additionally, investment in

603 H. Anu Kramer et al., "Post-Wildfire Rebuilding and New Development in California Indicates Minimal Adaptation to Fire Risk," *Land Use Policy* 107, no. 105502 (April 24, 2021): 7, https://doi.org/10.1016/j.landusepol.2021.105502.

604 Kramer et al., 7.

605 Lauren Sommer, "Millions Of Homes Are At Risk Of Wildfires, But It's Rarely Disclosed," NPR, October 2020, sec. Climate Risk Hits Home, https://www.npr.org/2020/10/21/924507691/millions-of-homes-are-at-risk-of-wildfires-but-its-rarely-disclosed.

606 Sommer.

607 "Cost Of Fire-Resistant Homes Comparable To Traditional Construction, Study Says," Montana Public Radio, November 30, 2018, https://www.mtpr.org/montana-news/2018-11-30/cost-of-fire-resistant-homes-comparable-to-traditional-construction-study-says.

608 Daniel Cusick, "A Rebuilt Paradise Nervously Watches Wildfire on the Horizon," Scientific American, September 14, 2020, sec. Climate Change, https://www.scientificamerican.com/article/a-rebuilt-paradise-nervously-watches-wildfire-on-the-horizon/.

609 Debra Kamin, "Hounded by Wildfires, Californians Rethink Their Willingness to Rebuild," *New York Times*, January 15, 2021, ProQuest.

renovating homes with fire resistant materials and clearing debris around properties has proved effective in minimizing wildfire impacts, as demonstrated in the town of Paradise. In sum, federal, state, and local policies should be reviewed, considered, and implemented to ensure communities are resilient against wildfire threats and can efficiently recover.

B. STATE, LOCAL, AND OTHER CONSIDERATIONS

This section discusses patchwork ownership and community involvement as it influences wildfire impacts throughout the western United States, and insurance coverage for wildfires. It is important to highlight these topics as they pose some challenges and opportunities for state and local forestry managers and citizens preparing for and recovering from wildfires.

1. Patchwork Ownership and Community Involvement

Patchwork ownership is one significant barrier to implementing unified land management objectives.[610] Most of the land throughout the West has multiple owners, including federal and state governments, utilities, private companies, individuals, etc., which, when zoomed out, looks like a checkerboard, as depicted in Figure 19.[611] Multiple owners in a given landscape make implementing solutions more complex and take longer as some entities have to balance public and private interests.[612] The USFS suggested that when the land is managed collaboratively, "landowners, the larger public, and local economies reap tangible benefits such as cleaner air and water, increased

[610] Andy Castillo, "Patchwork of Land Management Adds Complexity in the Fight Against Wildfire," *American City and County* (blog), July 28, 2021, https://www.americancityandcounty.com/2021/07/28/patchwork-of-land-management-adds-complexity-in-the-fight-against-wildfire/.

[611] Deanna H. Olson and Nobuya Suzuki, "Options for Biodiversity Conservation in Managed Forest Landscapes of Multiple Ownerships in Oregon and Washington, USA," *Biodiversity and Conservation* 17, no. 5 (October 2007): 1021, https://doi.org/10.1007/s10531-007-9301-4; Julie Turkewitz, "Covering Land and Power in the American West: Times Insider," *New York Times,* June 23, 2019, ProQuest; Andrew Avitt, "Incentivizing Long-Term Forest Ownership," U.S. Forest Service, March 31, 2021, https://www.fs.usda.gov/features/incentivizing-long-term-forest-ownership-pays-dividends-increases-forest-health.

[612] Castillo, "Patchwork of Land Management Adds Complexity in the Fight Against Wildfire."

recreation opportunities, and sustainable timber and fuel production. They also lower their community's risk of catastrophic wildfire."[613]

Figure 20. Patchwork Ownership in the Pacific Northwest.[614]

Thus, community involvement and collaboration are vital in addressing patchwork ownership concerns and mitigating wildfire impacts.[615] In addition to community involvement, interaction with wildfire stakeholders (i.e., state and federal land managers) is crucial for education on mitigation and preparedness efforts.[616] A study focused on the understanding and perception of wildfire risk among groups that have and have not experienced wildfires revealed that those with direct experience only had an enhanced understanding of basic information (i.e., defining WUI), not improved

613 Avitt, "Incentivizing Long-Term Forest Ownership."

614 Source: Olson and Suzuki, "Options for Biodiversity Conservation," 1021.

615 "Fire Adapted Communities," U.S. Forest Service, December 2016, https://www.fs.usda.gov/managing-land/fire/fac.

616 Erika A. Lang, Kristen C. Nelson, and Pamela Jakes, "Working with Community Leadership to Promote Wildfire Preparedness," The Public and Wildland Fire Management, 2006, 137–49, https://co-co.org/wp-content/uploads/2020/06/Lang-and-Jakes.-Working-with-community-leadership-to-promote-wildfire-preparedness..pdf.

preparedness measures.[617] On the other hand, the study did reveal that all groups (those that have and have not experienced direct wildfires) are interested in getting more information on wildfire preparedness, mitigation, and impacts.[618] However, the study concluded: "It is therefore clear that the level of information of those who should provide it (e.g., the scientific community, responsible bodies) is perceived to be insufficient."[619] Given that the perception is insufficient, it is critical for respected community leaders to engage all critical stakeholders in educating and encouraging community involvement in wildfire preparedness to reduce wildfire impacts.

To improve community collaboration and support for rural residents and firefighters, the Australia Department of Fire and Emergency Services (DFES) built the Bushfire Centre of Excellence in 2020 as an education hub to train rural firefighters, volunteers, and locals on bushfire threats, how to stay and defend, safety awareness, and how to mitigate fire impacts.[620] In Australia, Stay and Defend or Leave Early (SDLE) is an approach to wildfire response that allows residents to prepare and train in wildfire suppression and serves as an alternative if there is no time to evacuate.[621] Although the United States does not practice SDLE, having a one-stop-shop for residents and forestry and fire professionals to gather and learn has proved effective in Australia. The Bushfire Centre of Excellence offers classes such as Rural Fire Awareness to teach bushfire behavior and survival procedures as well as training sessions with Aboriginal Australians

617 Giuseppina Spano et al., "Is Experience the Best Teacher? Knowledge, Perceptions, and Awareness of Wildfire Risk," *International Journal of Environmental Research and Public Health* 18, no. 16 (August 2021): 9, https://doi.org/10.3390/ijerph18168385.

618 Spano et al., 8.

619 Spano et al., 9.

620 "Bushfire Centre of Excellence," Australia Department of Fire and Emergency Services, accessed November 12, 2022, https://dfes.wa.gov.au/hazard-information/bushfire/bcoe.

621 U.S. Forest Service, "What Can the U.S. Learn from the Australian Stay-and-Defend-or-Leave-Early Approach to Fighting Wildfires?," U.S. Department of Agriculture, October 18, 2010, https://www.nrs.fs.fed.us/disturbance/fire/australia_policy/; Sarah M McCaffrey and Alan Rhodes, "Public Response to Wildfire: Is the Australian 'Stay and Defend or Leave Early' Approach an Option for Wildfire Management in the United States?," *Journal of Forestry* 107, no. 1 (January 2009): 9–15, https://www.nrs.fs.fed.us/pubs/jrnl/2009/nrs_2009_mccaffrey_001.pdf.

to discuss traditional fire management practices.[622] Additionally, DFES recommends that residents contact their local bushfire brigade for a visit to their property, review their evacuation plan, and attend local community bushfire awareness events.[623] Implementing events and training opportunities at local community or recreational centers in the United States could prove effective in encouraging communities to get involved and improve education on effective mitigation measures.

One program that has been effective in encouraging community involved within the United States has been the Firewise USA program, which is administered by the National Fire Protection Association (NFPA) and the USDA Forest Service. The Firewise USA program is a robust strategy and accreditation program encouraging citizen participation in establishing fire-adapted communities.[624] The program evaluates communities' wildfire risk assessments, plans, and efforts to reduce fuels and risks.[625] Overall, the Firewise USA program is a grassroots effort that brings communities together to understand the wildfire risk and continuously take active steps toward reducing those risks.[626] Michele Steinberg, a Firewise program manager, contributes eight challenges that communities face in maintaining Firewise status: "1) focusing on areas outside homeowner control; 2) lack of financial capacity; 3) lack of communication about wildfire risk assessment; 4) conflicting community agendas; 5) lack of community cohesion; 6) lack of outside help; 7) emphasis on legal mandates vs. voluntary action; and

622 Australia Department of Fire and Emergency Services, "Course Catalogue: Bushfire Centre of Excellence Training Products" (Perth, Australia: Australia Department of Fire and Emergency Services, January 2022), https://publications.dfes.wa.gov.au/publications/bushfire-centre-of-excellence-course-catalogue.

623 "FAQ," Australia Department of Fire and Emergency Services, accessed November 12, 2022, https://mybushfireplan.wa.gov.au/faq.

624 "How to Become a Firewise USA Site," National Fire Protection Association, accessed July 30, 2022, https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Firewise-USA/Become-a-Firewise-USA-site?utm_source=hootsuite&utm_medium=&utm_term=&utm_content=&utm_campaign=.

625 National Fire Protection Association.

626 Michele Steinberg, "Firewise Forever? Voluntary Community Participation and Retention in Firewise Programs," *Proceedings of the Second Conference on the Human Dimensions of Wildland Fire* (Northern Research Station: U.S. Department of Agriculture, Forest Service, 2011), 82, https://www.nrs.fs.usda.gov/pubs/gtr/gtr-nrs-p-84papers/11steinberg-p-84.pdf.

8) difficulty completing paperwork."[627] Thus, as suggested by the USFS, it is essential to understand your community characteristics to engage in wildfire preparedness, set goals, and keep the momentum going.[628] A successful case study was demonstrated near the Los Padres National Forest in California when the San Luis Obispo Toro Creek Fire broke out near communities due to an off-road vehicle igniting built-up fuels.[629] Before the fire, residents and local fire units collaborated on establishing a fuel break and creating a detailed pre-attach plan map.[630] As a result, the fire only grew to 51 acres and no homes were damaged.[631] In all, community involvement, alongside forestry management professionals, is a critical component of reducing wildfire impacts and addressing patchwork ownership concerns.

2. Insurance

Wildfire insurance has become more expensive and challenging to acquire, especially in California.[632] According to the *Insurance Journal*, within the past two years, insured losses due to wildfire totaled $176 billion, the highest two-year total in U.S. history.[633] The threat of increasing losses has left insurance companies wanting to factor climate change into disaster-related coverage, which suggests higher premiums.[634] To mitigate the challenges with acquiring and maintaining wildfire insurance in

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627 Steinberg, 84.

628 Dan Williams, Travis Paveglio, and Matthew Carroll, "Living with Fire: How Social Scientists Are Helping Wildland-Urban Interface Communities Reduce Wildfire Risk," U.S. Forest Service Rocky Mountain Research Station, accessed July 31, 2022, https://www.fs.usda.gov/rmrs/living-fire-how-social-scientists-are-helping-wildland-urban-interface-communities-reduce-wildfire.

629 "Success Stories," CAL FIRE Office of the State Fire Marshal, accessed July 31, 2022, https://osfm.fire.ca.gov/divisions/community-wildfire-preparedness-and-mitigation/fire-plan/success-stories/.

630 CAL FIRE Office of the State Fire Marshal.

631 CAL FIRE Office of the State Fire Marshal.

632 Carlos Granda, "For California Homeowners, Wildfire Insurance Is Getting More Expensive and Becoming Harder to Find," ABC7 Los Angeles, July 13, 2022, https://abc7.com/california-wildfire-insurance-fair-plan/12050254/.

633 Don Jergler, "Insurers Increasingly Concerned for Western U.S. Wildfire Season," *Insurance Journal*, June 14, 2022, https://www.insurancejournal.com/news/west/2022/06/14/671813.htm.

634 Granda, "For California Homeowners, Wildfire Insurance Is Getting More Expensive and Becoming Harder to Find."

California, since some private insurance companies that covered wildfires have left the state, Senate Bill 824 was recently implemented to prevent insurance companies from canceling or not renewing policies for one year after a state of emergency is declared for a wildfire.[635] Some residents have been left with joining a state-established insurance company, Fair Plan, which residents have complained is too expensive and has poor coverage.[636] Yet, it is the only plan serving high-risk properties. Finding the balance between sufficient coverage and adapting to wildfires is crucial.[637] Recently, The Nature Conservancy revealed in its Wildfire Resilience Insurance project that efforts to reduce risk and loss of property could lower premiums for commercial and residential insurance.[638] In turn, The Nature Conservancy found that the money saved can be applied to funding for forest treatments.[639] Overall, as more communities expand into WUI zones, it is important to evaluate insurance concerns to establish a model that protects communities, allows them to rebuild, and creates more resilient communities.

An additional component to wildfire insurance in California includes recent tensions surrounding the use of private firefighters. In the Golden State, insurance companies have begun hiring private fire crews to conduct mitigation efforts, often on wealthy individuals' property, and defending those properties when evacuation orders have been implemented, which poses several liabilities to government firefighters.[640] Liabilities include disrupting government firefighting operations and possibly

635 Hanh Truong, "Misunderstood California Law Could Protect Your Home's Fire Insurance. How Does It Work?," *Sacramento Bee*, May 31, 2022, sec. Fires, https://www.sacbee.com/news/california/fires/article261831275.html; Granda, "For California Homeowners, Wildfire Insurance Is Getting More Expensive and Becoming Harder to Find."

636 Granda, "For California Homeowners, Wildfire Insurance Is Getting More Expensive and Becoming Harder to Find."

637 Miranda Green, "Should Homeowners Pay for Climate Change?," *CAL Matters* (blog), June 30, 2021, http://calmatters.org/economy/2021/06/california-wildfire-insurance-climate-change/; Sophie Quinton, "As Wildfire Risk Increases, Home Insurance Is Harder to Find," Pew Research Center, January 3, 2019, https://pew.org/2QXyd6E.

638 Andrew Avitt, "Innovating Wildfire Insurance," U.S. Forest Service, August 3, 2021, https://www.fs.usda.gov/features/innovating-wildfire-insurance.

639 Avitt.

640 Susie Cagle and Vivian Ho, "'Not Our Mission': Private Fire Crews Protect the Insured, Not the Public," The Guardian, November 3, 2019, sec. U.S. News, https://www.theguardian.com/us-news/2019/nov/03/not-our-mission-private-fire-crews-protect-the-insured-not-the-public.

accelerating a fire.[641] In response, California implemented AB 2380 in 2018 to restrict private crews from operating in evacuated zones.[642] Nonetheless, there have been several instances in which private-for-profit crews have disregarded California's law and evacuation orders.[643] The National Wildfire Suppression Association revealed to Reuters that more than 280 private companies are working throughout the western U.S. in preventing and suppressing wildfires.[644] The use of private firefighters ultimately, as mentioned by Ulmer, "underscores the inequity of who receives protection," as wealthy landowners can ensure the protection of their property whereas other homeowners are struggling to insure theirs.[645]

Insurance dilemmas in California provide a glimpse at what can occur in other western states battling wildfires in the WUI. For instance, in February 2022, Colorado lawmakers proposed a bill to have insurance companies increase the upfront payout amount and extend the home rebuild time for victims.[646] All in all, sufficient insurance coverage is vital for residents living in and near the WUI, as it provides residents with the means to restore their home and daily life.

641 Alexandra Ulmer, "Private Firefighters Fuel Tensions While Saving California Vineyards and Mansions," Reuters, May 14, 2021, sec. United States, https://www.reuters.com/world/us/private-firefighters-fuel-tensions-while-saving-california-vineyards-mansions-2021-05-14/.

642 "Historic Legislative Wins," California Professional Firefighters, accessed November 8, 2022, https://www.cpf.org/advocacy/our-legislation/historic-wins.

643 Ulmer, "Private Firefighters Fuel Tensions."

644 Ulmer.

645 Ulmer.

646 Hannah Metzger, "Colorado Lawmakers Propose Changes to Insurance Coverage of Wildfire Losses," Colorado Politics, February 11, 2022, https://www.coloradopolitics.com/legislature/colorado-lawmakers-propose-changes-to-insurance-coverage-of-wildfire-losses/article_aa2863d6-8b65-11ec-90b0-3bade9da5f20.html.

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VI. CONCLUSION

In 1901, President Theodore Roosevelt put conservation at the forefront of the nation's agenda and created the United States Forest Service to preserve and protect the wondrous landscape that lies between the Atlantic and the Pacific Oceans.[647] Roosevelt once stated, "Of all the questions which can come before this nation, short of the actual preservation of its existence in a great war, there is none which compares in importance with the great central task of leaving this land even a better land for our descendants than it is for us."[648] The responsibility of preserving the land and forests throughout the western United States is not solely dependent on the USFS; rather, it is the unification of all individuals that live, use, visit, and love the nation's scenery. Wildfires have been and will continue to be a natural part of the planet's ecosystem, but the increasing threat to communities, critical infrastructure, and forest health due to climate change impacts and human activity is problematic. The increased scale and frequency of wildfires since the 1900s, even more so in recent years, is a direct threat to homeland security. Thus, to leave the western United States even better for future generations, to ensure the safety of generations living today, and to protect critical infrastructure, a unified effort must be made to become more resilient against wildfires.

Through a comparative analysis approach, the research presented in this thesis showcased western states' historical and current forestry and fire trends to convey wildfire impacts on forest health, communities, and critical infrastructure. Also, this thesis offered two fictional scenarios based on real events to illustrate wildfire impacts on communities and forest health. The fictional scenarios were intertwined with simulation models via FARSITE to visualize the effectiveness of mitigation efforts on wildfire growth and express the usefulness of simulation tools to inform off-season forest treatments. The comparison and contrast of the factors, resources, and costs associated

647 National Park Service, "Theodore Roosevelt and Conservation," National Park Service, November 16, 2017, https://www.nps.gov/thro/learn/historyculture/theodore-roosevelt-and-conservation.htm.

648 "Theodore Roosevelt Quotes," National Park Service, April 10, 2015, https://www.nps.gov/thro/learn/historyculture/theodore-roosevelt-quotes.htm.

with prescribed burns and wildfires as well as wildfire suppression and mitigation provide decision-makers and citizens with the effects behind each action and advocate for the prioritization and investment for prescribed burns and mitigation projects. Highlighting landmark legislation and recent federal initiatives that relate to and influence forestry and fire management showcases the opportunities and potential challenges posed to forestry managers. Furthermore, the discussion surrounding post-wildfire hazards and recovery efforts, including insurance dilemmas and the need for community involvement, demonstrates the critical components of maintaining resilient communities and further emphasizes wildfire impacts. In all, the intention behind this thesis and the research is to bring the conversation of the West's wildfires to the forefront of the nation's agenda to advocate for a unified approach, as catastrophic wildfires impact the country every year.

Highlighting three western states (Arizona, California, and Alaska) offers forestry and fire stakeholders (firefighters, forestry managers, policymakers, citizens, etc.) throughout the West a vital understanding of the wildfire threat and provides ways to become more resilient against it. The outcome of each case study, including the fictional scenarios, reveals a few common denominators faced by all states in the West. For one, climate change impacts (i.e., drought and extreme heat) have significantly impacted wildfire scale and frequency.[649] Additionally, across the West, there has been a significant increase in people living in the WUI as well as personnel shortages for wildfire suppression and mitigation.[650] Similarities challenges faced by Arizona and California include built-up fuels on forest floors, human activity, and invasive species. Identifying the Alaskan tundra was necessary for this thesis for a few reasons. Alaska is a critical, strategic state within the western United States from a military, economic, and national security perspective, given the availability of natural resources and geographic

649 Jessica E. Halofsky, David L. Peterson, and Brian J. Harvey, "Changing Wildfire, Changing Forests: The Effects of Climate Change on Fire Regimes and Vegetation in the Pacific Northwest, USA," *Fire Ecology 16*, no. 1 (2020): 1–26, https://doi.org/10.1186/s42408-019-0062-8.

650 Federal Emergency Management Agency and U.S. Fire Administration, Wildland Urban Interface: A Look at Issues and Resolutions, 6; Urness, "Labor Shortage Leaves U.S. Struggling to Hire Firefighters Despite Record Wildfire Funding," May 11, 2022.

location in the Arctic.[651] Moreover, the state is home to most of the largest national forests in the nation and features a vast amount of permafrost in the tundra.[652] The inclusion of Alaska further emphasizes the impact of climate change on forest and tundra health conditions that eventually fuel and influence wildfire behavior. Overall, showcasing the three western states offers a glimpse at similar wildfire behavior and impacts across the West. Thus, the research provided in this thesis applies to most western states and underscores the point that resiliency against wildfires is imperative to ensuring the protection of the nation's natural resources, communities, and critical infrastructure.

The first research question asks, how has the difference between western states' forestry and fire management practices affected wildland fire response? The bottom line is that forestry and fire management operations at the federal and state levels are not negatively impacting wildland fire response. The primary differentiation among state forestry management agencies is the organizational structure. Still, they all share a similar mission, conduct mitigation projects, and receive and distribute funding to reduce the wildfire threat in their states. However, the primary drivers affecting wildland fire response in each state are climate conditions, human activity, invasive species, the availability of personnel and resources during and off-season, and the expansion of the WUI. Aside from climate change impacts and human activity, it is important to note that historical forestry and fire management methods have influenced the fire regimes we see today. For instance, as discussed in the Arizona section of Chapter II, the San Carlos Apache Tribe has found it challenging to return to their traditional fire regime pre-European settlement due to aggressive wildfire suppression that was introduced from the 1900s to 1930s.[653] Therefore, returning to fire regimes before the 1900s, including low-

651 Kathleen A. Cooper, "'North to Alaska': The Geostrategic Importance of the Last Frontier" (Maxwell Air Force Base, Alabama, Air University School of Advanced Air and Space Studies, 2012), https://apps.dtic.mil/sti/pdfs/AD1019442.pdf; Michael J. Forsyth, "Why Alaska and the Arctic Are Critical to the National Security of the United States," *Army University Press* (blog), February 2018, https://www.armyupress.army.mil/Journals/Military-Review/English-Edition-Archives/January-February-2018/Why-Alaska-and-the-Arctic-are-Critical-to-the-National-Security-of-the-United-States/.

652 Jandt, Miller, and Jones, *Fire Effects 10 Years After*, 3; U.S. Forest Service, "Alaska Region."

653 Victor, "Fire Management of the San Carlos Apache Tribe."

severity fires that occurred at a recurring frequency and manageable size, may prove to be incredibly challenging today. Nonetheless, current forest health conditions and fire regimes can be improved. Regardless, human activity, including the expansion into WUI zones, is one of the key factors influencing wildfire behavior and response today. After all, humans are the leading ignitors of wildfires throughout the United States, as 85% of wildfires are caused by humans.[654] Furthermore, WUI zones throughout the West continue to grow and encroach on forest areas.[655] Thus, it is an individual, federal, state, and local responsibility to positively influence wildland fire response by minimizing factors affecting wildfire scale and impacts on homes and critical infrastructure. Overall, the unification of the whole community will affect wildfire scale, frequency, and response throughout the West.

With the prolonged wildfire season at hand, solutions and the means to reduce wildfire impacts cannot be stalled. Natural disasters such as wildfires should be an apolitical issue that requires bipartisan action, as wildfires know no political parties and have no boundaries. Thus, forestry managers, policymakers, and citizens must work together to identify, assess, and implement solutions to improve the West's resiliency against wildfires. To safeguard the American people and the homeland, U.S. homeland security leaders must strive to unite the whole community in efforts to improve preparedness and response for the long term.[656] Much is already being done within the forestry management, scientific, and scholarly communities to assess and mitigate wildfire impacts. Nonetheless, the unification of all stakeholders and the process of approving legislation to action is lacking. In turn, there should be a harmonious efficiency in motivating all stakeholders, implementing effective adaptive management projects, and creating legislation that ensures action is taken and gaps are filled.

654 "Wildfire Causes and Evaluations," National Park Service, March 8, 2022, https://www.nps.gov/articles/wildfire-causes-and-evaluation.htm.

655 Federal Emergency Management Agency and U.S. Fire Administration, *Wildland Urban Interface: A Look at Issues and Resolutions.*

656 Department of Homeland Security, "Mission," Department of Homeland Security, October 4, 2022, https://www.dhs.gov/mission.

A. RECOMMENDATIONS

There is no single answer to reducing wildfire impacts and improving the West's resiliency against wildfires. Nonetheless, steps can be made among all stakeholders to address the wildfire threat. Thus, the following sections answer the second question posed in this thesis: How can forestry and fire management stakeholders address wildfire scale and frequency in the western United States? The following four recommendations encompass apparent solutions to any disaster and critical steps that have been overlooked. These actions require collaboration and would aid forestry managers in their mission "to sustain the health, diversity, and productivity of the nation's forests and grasslands to meet the needs of present and future generations."[657] As a result, forests, communities, and critical infrastructure will reap the benefits of decisive action for years to come.

1. Community Involvement

Community involvement is at the crux of any natural and man-made disaster preparedness initiative. As mentioned in Chapter V, patchwork ownership has made it difficult to implement unified land management objectives, as there are sometimes competing goals. However, addressing multiple owners with varying objectives in a given area is critical to mitigating wildfire impacts. Although a landscape may physically look like a patched quilt, the management and work behind the scenes does not have to be so. Thus, at the core of community involvement, there are two key initiatives that must be considered as solutions to wildfires in the West. First, community education with direct involvement from community leaders and federal and state forestry management professionals is paramount. Second, the development and long-term maintenance of the Firewise program must be accepted and respected in all WUI areas. As a result, these two initiatives will unify all key stakeholders in protecting the West's communities and critical infrastructure while improving and maintaining forest health.

Chapter V offered a study that revealed that those with direct wildfire experience did not translate into improved preparedness measures, only an enhanced understanding

657 "Meet the Forest Service," U.S. Forest Service, February 1, 2016, https://www.fs.usda.gov/about-agency/meet-forest-service.

of basic information (i.e., defining WUI). Additionally, the study stated that groups providing citizens with information (i.e., scholars and forestry management agencies) are insufficient. Therefore, community engagement is key to translating direct wildfire experience into improved preparedness measures and providing citizens with sufficient information. One way to do so is to utilize community centers for public events to connect the forestry and fire community to residents, similar to the Bushfire Centre of Excellence in Australia. Currently, federal and state forestry and fire agencies offer online material, including Public Service Announcement videos, reports, and youth education, but there is no information online suggesting a public event.[658] However, the NIFC shares that every May (Wildfire Awareness Month), the BLM partners with Maverik (an established convenience store and gas station) to meet with residents and discuss wildfire preparedness.[659] An additional essential factor that will be unique to each community is to identify a community leader that is respected to lead the initiative on gathering residents. During these events, residents can ask questions, learn more, share concerns, and meet their local forestry and fire crews. In the same vein, tribal leaders and tribal forestry and fire professionals should be a part of these events to understand the land and historical tribal fire management practices. To take it a step further, federal and state forestry and fire entities should establish a process for residents to submit their fire plans for review. In addition, a process should be established for residents to request a professional assessment of their property to ensure resiliency and obtain any recommendations on improving preparedness measures. To note, nonprofit entities are available to assist communities with conducting wildfire risk assessments and implementing preparedness measures.[660] As a result, there would be symmetry, connection, and balance among forestry management professionals and citizens.

658 "Fire Prevention," Arizona Department of Forestry and Fire Management, accessed November 26, 2022, https://dffm.az.gov/fire/prevention.

659 "Fire Prevention, Education and Mitigation," National Interagency Fire Center, accessed November 26, 2022, https://www.nifc.gov/fire-information/fire-prevention-education-mitigation.

660 "Community Wildfire Planning Center," Community Wildfire Planning Center, accessed November 26, 2022, https://www.communitywildfire.org/; Wildfire Research Center, "The WiRē Approach," WiRē - Wildfire Research (blog), February 7, 2017, https://wildfireresearchcenter.org/approach/.

Another way to connect forestry management professionals and citizens and enhance citizen education includes the availability of open-source information that specifically pertains to residential areas. For instance, California's Office of the State Fire Marshal offers an interactive GIS map that details the fire hazard severity of a given area.[661] In tandem with the map, CAL FIRE offers several handouts that walk residents through the process of conducting their own "Defensible Space Assessment."[662] Similarly, in Arizona, DFFM lists at-risk communities on its website.[663] The DOI shares that open-source information on wildfire data drives innovation in the private sector to deliver useful products to all stakeholders and ultimately improves public safety across the board.[664] In turn, open-source information and interactive GIS maps are useful in improving situational awareness and citizen education.

In all, community involvement in taking actions to reduce wildfire impacts is paramount, as forestry management entities cannot do it alone. Recently, a story was released that shared communities have been conducting "micro-prescribed burns" (less than a few acres) on private land.[665] The article suggests that this initiative may aid in the acceptance of controlled burns and improve awareness and education on improving defensible spaces around homes.[666] Thus, this may allude to the fact that communities and private landowners are concerned about the wildfire risk and are open to implementing solutions that mitigate risk. In other words, the climate in engaging communities may be apt. Regardless, whole community involvement is critical to address

661 CAL FIRE, "FHSZ Viewer."

662 CAL FIRE, "Defensible Space," CAL FIRE, accessed November 26, 2022, https://www.fire.ca.gov/dspace/.

663 "Arizona At Risk Communities," Arizona Department of Forestry and Fire Management, accessed November 26, 2022, https://dffm.az.gov/fire/prevention/arizona-at-risk.

664 Office of Wildland Fire, "Wildfire Open Data Is Driving Innovation and Improving Public Safety," U.S. Department of the Interior, November 10, 2021, https://www.doi.gov/wildlandfire/wildfire-open-data-driving-innovation-and-improving-public-safety.

665 Bill Gabbert, "PBS Covers the Growing Trend of Micro-Prescribed Fires on Private Land," *Wildfire Today* (blog), March 29, 2022, https://wildfiretoday.com/2022/03/29/pbs-covers-the-growing-trend-of-micro-prescribed-fires-on-private-land/.

666 Gabbert.

wildfire impacts on communities and critical infrastructure and should be a recurring, long-term engagement.

2. Allocation and Utilization of Resources

The availability of resources and personnel is essential to forestry mitigation projects and wildfire suppression. Resources range from equipment, aviation support, funding, and technology. All three western states covered in this thesis face concerns with the availability of firefighters. More specifically, the USFS has struggled with offering competitive wages compared to state and private firefighting agencies, despite the significant investment made at the federal level for wildfire support.[667] Firefighter and support positions staffing shortages at the federal level are problematic, given most wildfires in the West (80%) are on federal lands.[668] In addition to those fighting the flames, the function that supports these groups has also faced major staffing shortages. Incident Management Teams (IMTs) are often deployed for large-scale, complex wildfires to provide firefighting crews with logistical, operational, and planning support.[669] As a result of staffing shortages, these teams must be prioritized nationally during wildfire season.[670] With a significant amount of funding now available through the Bipartisan Infrastructure Law, it will be critical to explore ways to increase the wages of firefighters and IMTs, as they are necessary for combating wildfires.

Alongside staffing shortages, there is a nationwide shortage of air tankers, specifically the DC-10, that is used to drop fire retardant on flames. Nationwide, only four tankers are available, two of which are on an exclusive contract with the USFS,

667 Zach Urness, "Labor Shortage Leaves U.S. Struggling to Hire Firefighters Despite Record Wildfire Funding," *Statesman Journal*, May 11, 2022, https://www.statesmanjournal.com/story/news/nation/2022/05/11/worker-shortage-western-drought-wildfire-season-2022-wildland-firefighter-hirings/65354018007/; The White House, "President Biden's Bipartisan Infrastructure Law."

668 Hoover and Hanson, *Wildfire Statistics*, 2022.

669 "Incident Management Teams," National Interagency Fire Center, accessed November 26, 2022, https://www.nifc.gov/resources/firefighters/incident-management-teams.

670 National Multi-Agency Coordinating Group, "Incident Management Team Rationale" (Boise, ID: National Multi-Agency Coordinating Group, July 18, 2021), https://www.nifc.gov/nicc/administrative/nmac/NMAC2021-23.pdf.

meaning two tankers are available for other firefighting agencies.[671] Obviously, this shortage leads to extreme competition between federal and state firefighting entities. At times, the USFS will contract all four tankers, leaving none available for state and local agencies, but the USFS has been known to share the resource if possible.[672] As a result, state entities are left with finding alternative solutions like working with the DOD to equip C-130s with fire retardant capabilities and equipping Blackhawks (UH-60s) with Bambi buckets.[673] Although states like California have expressed the need for more DC-10s, the company that exclusively owns DC-10s, 10 Tanker, shares that it is not economically feasible.[674] The chief executive officer of 10 Tanker shared that annual government contracts do not grant enough funds to support the endeavor of retrofitting DC-10s.[675] In tandem with the DC-10 shortage, there is also a shortage of pilots available to fly them, as these aircraft require extensive training.[676] Nonetheless, the USFS has worked with the RAND Corporation to identify the ideal aviation fleet that is cost-effective and effective at wildfire suppression.[677] As a result, in 2012, the RAND Corporation identified an optimal fleet for the national and local levels. For the national level, an optimal fleet for the USFS would be eight 3,000-gallon air tankers (i.e., C-130, P-3 Orion, DC-7) and 48 1,600-gallon scoopers (i.e., CL-215).[678] An optimal fleet at the local level includes one 3,000-gallon air tanker, two 2,700-gallon helicopters (i.e., CH-

671 Aaron Mak, "The Reason We Don't Have Enough Airplanes to Put Out Wildfires," Slate, August 28, 2021, https://slate.com/business/2021/08/california-wildfires-airplanes-dc10-shortage.html.

672 Mak.

673 "Airtankers," National Interagency Fire Center, accessed November 26, 2022, https://www.nifc.gov/resources/aircraft/airtankers; Mak, "The Reason We Don't Have Enough Airplanes to Put Out Wildfires."

674 Mak, "The Reason We Don't Have Enough Airplanes to Put Out Wildfires."

675 Mak.

676 Mak.

677 Edward G. Keating et al., "Identifying a Cost-Effective Aviation Fleet for the U.S. Forest Service" (Santa Monica, CA: RAND Corporation, 2012), https://www.rand.org/pubs/research_briefs/RB9676.html; Edward G. Keating et al., "Air Attack Against Wildfires: Understanding U.S. Forest Service Requirements for Large Aircraft" (Santa Monica, CA: RAND Corporation, 2012), https://www.rand.org/pubs/monographs/MG1234.html.

678 Keating et al., "Identifying a Cost-Effective Aviation Fleet for the U.S. Forest Service"; CAL FIRE, "Firefighting Aircraft Recognition Guide" (Sacramento, CA: California Department of Forestry and Fire Protection), accessed November 26, 2022, https://gacc.nifc.gov/swcc/dc/azpdc/operations/documents/aircraft/links/Aircraft%20Recognition%20Guide.pdf.

47), and 15 1,600-gallon scoopers.[679] For the future, it would be beneficial to reexamine what an optimal fleet would look like for federal and state entities facing the current fire regimes. Again, with a significant amount of funding now available through the Bipartisan Infrastructure Law, it will be critical to explore ways to increase the availability of aviation support, as they are integral to supporting firefighting crews in combating wildfires.[680]

To readily support local jurisdictions in conducting mitigation efforts, state funding streams may prove effective for critical projects that are not applicable for FEMA funds. For instance, Arizona's Post Wildfire Infrastructure Program is a notable program that allows DFFM to allocate funds to state, county, local, and private entities impacted by post-wildfire floods. Although the fund is centered on post-fire floods, it allows agencies and residents to restore property after a disaster and complete immediate mitigation projects. States that want to implement a similar program need to recognize that it will be critical to ensure the program is in alignment with other state and federal grant programs to avoid overlap. Thus, policymakers should meet with emergency managers and forestry professionals to guarantee the program fills a critical gap, without eliminating other available funding streams. Given the program was introduced in June 2021, there are no case studies available to demonstrate the success of the program in mitigating wildfire impacts. Nonetheless, the fact that the state is investing in supporting local agencies and residents and filling the gap that the federal government cannot meet is commendable in making an effort to address wildfire concerns.

Now more than ever, technology development has created an incredible opportunity for forestry management professionals. The challenge is utilizing it and ensuring every agency at the state and local levels has the personnel capable of utilizing any technology and implementing it during and off-season. Chapter III showcased the use

679 Keating et al., "Identifying a Cost-Effective Aviation Fleet for the U.S. Forest Service"; Billings Flying Service, "Chinook Helicopter Fire Fighting: The Best Way To Fight Wildfires," *Aerial Firefighting* (blog), September 6, 2021, https://billingsflyingservice.com/chinook-helicopter-fire-fighting/.

680 *Frontline Wildfire Defense,* "Aerial Firefighters & Fire Fighting: Dangerous… But Effective?," (blog), October 18, 2016, https://www.frontlinewildfire.com/wildfire-news-and-resources/aerial-wildfire-fighting-how-effective-is-it/.

of FARSITE, one simulation tool that can be used in any given area to demonstrate the effects of mitigation projects on wildfire growth. As a result, utilizing simulation tools informs strategic mitigation projects as well as citizens on the success mitigation projects can offer. All in all, in addition to community involvement, resource allocation and sustainment are critical to wildfire prevention and suppression.

3. Action!

As mentioned in this research, many initiatives at the federal and state levels are being made to support forestry and fire management agencies. The one dilemma is the time it takes from being words on a page and putting it in to action. For instance, the Bipartisan Infrastructure Law was passed on November 2021 and as of November 2022, funds have not been released.[681] Additionally, the establishment of a new 2022 Congress may pose some challenges to legislation pertaining to wildfires, especially regarding the Wildfire Emergency Act.[682] Thus, at the federal and state levels, time is of the essence, and bipartisan action needs to be taken. Alongside time, state legislation can effectively support local and private entities with prescribed burn operations, insurance concerns, and address gaps like the lack of loggers.

Regarding prescribed burns, there needs to be more consistency throughout western states regarding the standards and policies that grant private landowners the ability to conduct prescribed burns, as highlighted in Chapter III. One notable structure that can be adopted among all western states is New Mexico's Prescribed Burning Act, which establishes a certification program that includes a straightforward process to acquire certification and liability standard for private landowners.[683] The act also establishes a partnership between New Mexico State University and New Mexico's Forestry Division to offer training and certification.[684] In doing so, New Mexico extends

681 LaConte, "Colorado Democrats Urge Forest Service to Create Spending Plan for $10B in Funds."

682 Goldmacher, "Republicans Capture Control of the House After Falling Short of Midterm Expectations."

683 The Prescribed Burning Act, HB0057 § 68, 5 Stat. 1 (2021), https://www.emnrd.nm.gov/sfd/wp-content/uploads/sites/4/2021-Prescribed-Burning-Act-Final-HB57.pdf.

684 "Prescribed Burning," New Mexico Energy, Minerals, and Natural Resources Department, accessed November 26, 2022, https://www.emnrd.nm.gov/sfd/prescribed-burning/.

the partnership among private landowners, students, and forestry professionals. Furthermore, the legislation incentivizes prescribed burns, which is more cost-effective than mechanical thinning and wildfire suppression.[685] As of February 2022, California implemented a similar law to New Mexico that covers liability but does not include state training.[686] States lacking prescribed burn laws for private landowners include Arizona, Idaho, Montana, and Wyoming. These four western states mandate permits through the Department of Environmental Quality, but no information was found on official training programs and liability coverage for residents.[687] Therefore, to encourage prescribed burns on private land, establishing a prescribed burn program that provides training, certification, and liability coverage is necessary.

State policymakers should be aware of the growing trend in private firefighters and the insurance concerns of those living in the WUI. Regarding insurance, western states should be aware of wildfire insurance premiums and the availability of insurance agencies to ensure residents have reasonable coverage to rebuild. In the event that states want to implement state insurance, like California, it is critical to ensure it has sufficient coverage. The Nature Conservancy offers a possible sufficient solution with the Wildfire Resilience Insurance project that encourages mitigation efforts and uses saved funds for forest treatments. Regarding private firefighters, a framework should be established among private entities and government forestry and fire professionals to reduce the concern of liabilities and identify means to have a unified approach.

In this research, some gaps were identified in the chain of forestry mitigation projects and wildfire suppression operations. Thus, these gaps must be addressed to

685 New Mexico Energy, Minerals, and Natural Resources Department.

686 Alexa Bertola, "New California Law Makes It Easier for Private Landowners to Conduct Prescribed Burns," KSBY News, February 9, 2022, https://www.ksby.com/news/in-depth/new-california-law-makes-it-easier-for-private-landowners-to-conduct-prescribed-burns.

687 "Open Burning," Montana Official State website, accessed November 26, 2022, https://deq.mt.gov/air/Programs/burning; "Open Burning," Wyoming Department of Environmental Quality, accessed November 26, 2022, http://deq.wyoming.gov/aqd/smoke-management-and-open-burning/open-burning/; "Prescribed Fire," Idaho Department of Environmental Quality, January 202AD, https://www.deq.idaho.gov/air-quality/smoke-and-burning/prescribed-fire/; "Why Do I Need an Open Burn Permit?," Arizona Department of Environmental Quality, November 15, 2021, https://azdeq.gov/OpenBurn.

ensure an efficient process of clearing built-up fuels in forests and providing crews with ample support. For one, some forest mitigation projects (i.e., mechanical thinning) have been delayed due to the lack of loggers in the area.[688] As mentioned in Chapter II, the 89 Mesa project in Coconino County, Arizona, has been delayed because much of the logging industry no longer exists.[689] Similarly, California has experienced the same shortage as Arizona, as 25 mills are operating in the state.[690] During the Trump administration, there was a significant push for the USFS to increase logging, but the industry was met with controversy from those that believe the logging industry could harm forests' health and wildlife.[691] Regardless, the logging industry is necessary for forest mitigation to decrease fire severity and allow forest regrowth.[692] For instance, Colorado has begun to reembrace logging to get rid of infested trees and, overall, improve forest health.[693] Oregon, Washington, and Alaska have long embraced the logging industry to maintain healthy forests and timber sales.[694] Ultimately, identifying ways to incentivize public-private partnerships would be beneficial to increase logging operations in western states. In doing so, Oregon, Washington, and Alaska may offer a beneficial framework for supporting logging operations to aid forestry management. With

688 Onodera, "Lack of Loggers Is Hobbling Arizona Forest."

689 Onodera.

690 Steve Wilnet, "California: Lots of Logs with Nowhere to Go," *The Smokey Wire: National Forest News and Views* (blog), September 8, 2019, https://forestpolicypub.com/2019/09/08/california-lots-of-logs-with-nowhere-to-go/.

691 Sophie Quinton, "Battles Over Logging, Funding Delay Wildfire Mitigation Projects," *Treesource* (blog), March 4, 2019, https://treesource.org/news/management-and-policy/wildfire-mitigation/; Keith Schubert, "Conservation Groups Sue U.S. Forest Service Over Logging Project in Northern Montana," *Daily Montanan* (blog), July 1, 2022, https://dailymontanan.com/2022/07/01/conservation-groups-sue-u-s-forest-service-over-logging-project-in-northern-montana/.

692 *Future Forest Consulting,* "Six Benefits of Logging Forests," (blog), February 4, 2016, https://www.futureforestinc.com/six-benefits-of-logging-forests/.

693 Bruce Finley, "Colorado Looks to Logging to Help Re-Balance Forests in an Era of Climate-Triggered Megafires," The Denver Post, December 7, 2020, https://www.denverpost.com/2020/12/07/colorado-logging-forests-wildfires/.

694 Bureau of Land Management, "Timber Sales," U.S. Department of the Interior, accessed November 26, 2022, https://www.blm.gov/programs/natural-resources/forests-and-woodlands/timber-sales; *World Forestry Center*, "Tracing Oregon's Timber Culture," (blog), September 9, 2021, https://www.worldforestry.org/tracing-oregons-timber-culture/; "Sustainable Forestry," Washington Forest Protection Association, accessed November 26, 2022, https://www.wfpa.org/sustainable-forestry/; "Alaska Forest Facts," Alaska Forest Association, accessed November 26, 2022, https://www.akforest.org/facts.htm.

appropriate oversight, strategic logging can aid forestry management and help control the spread of wildfires. In all, the logging industry offers western forests the means to create more resilient forests and support forest managers in maintaining healthy forests and protecting communities and critical infrastructure. The intention is not to cut away national forests for good but to preserve and maintain them.

In all, time is of the essence to protect communities, critical infrastructure, and forest health. Thus, action among all stakeholders is vital.

4. Examine Alternative Solutions

More unique alternative solutions are becoming available to forestry managers in the scholarly and scientific realms. This recommendation aims to highlight a few strategies but ultimately stresses the importance of exploring alternative solutions and being open to implementing them. The following strategies include utilizing beavers to minimize wildfire growth, exploring available and developing technology for forest and fire agencies, and providing a final emphasis on partnerships.

First, in the search for identifying ways to mitigate extreme wildfires, Emily Fairfax and Andrew Whittle, two environmental science scholars, have researched and advocated for introducing "Smokey the Beaver" to western forests.[695] The scholars found that beaver ponds create a natural firebreak, as a wildfire will not burn wet vegetation.[696] Hence, introducing and allowing beavers to do their thing can limit wildfire growth and mitigate drought impacts, as shown in Figure 20.[697] Additionally, the scholars noted that beaver dams are "a low-tech, low-cost strategy to build climate resiliency at the landscape scale."[698] In their research, Fairfax used remote sensing via Google Earth and other platforms to identify beaver dams throughout the West. She

695 Emily Fairfax and Andrew Whittle, "Smokey the Beaver: Beaver-Dammed Riparian Corridors Stay Green During Wildfire Throughout the Western United States," *Ecological Applications* 30, no. 8 (September 2020), https://doi.org/10.1002/eap.2225.

696 Emily Fairfax, "Beavers and Wildfire," Emily Fairfax Science, April 13, 2020, https://emilyfairfaxscience.com/research/firebeavers/.

697 Fairfax.

698 Fairfax and Whittle, "Smokey the Beaver."

recommended in areas that prohibit beavers, conducting basic stream restoration to support beaver habitats may prove beneficial.[699] Fairfax and Whittle found that "Smokey the Beaver" can establish and maintain fire-resistant landscapes, provide temporary habitat for wildlife during a fire, and mitigate drought impacts.[700] Thus, utilizing beavers may prove effective for forestry managers in improving forest health and reducing wildfire scale.

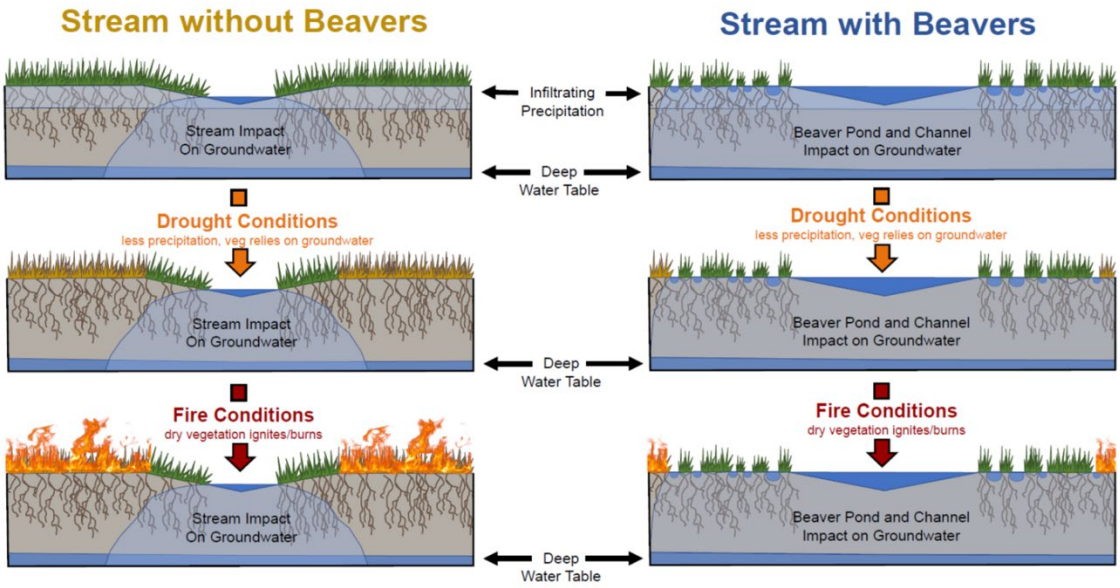

Figure 21. Comparison between Drought and Wildfire Conditions without and with Beavers.[701]

Second, with the advancements in technology, it is critical for forestry and fire management professionals to keep an open mind. In aviation and marine environments, articles have been shared expressing that professionals have felt undermined by

699 Ann Cameron Siegal, "Beavers Offer Natural Solution to Fighting Wildfires," *Washington Post,* October 4, 2022, https://www.washingtonpost.com/kidspost/2022/10/04/beavers-help-fight-forest-fires/.

700 Fairfax and Whittle, "Smokey the Beaver."

701 Fairfax and Whittle.

technology—specifically autonomous tech.[702] Recent technological advancements in the wildfire industry include autonomous vehicles, artificial intelligence (AI), augmented reality, and the internet of things.[703] One notable development includes Project Vesta, a technology package that extends firefighting capabilities and support, including surveillance, AI, and autonomous support.[704] Throughout 2022, the Project Vesta team has been conducting experiments to improve performance and demonstrate the potential benefits to forestry and fire stakeholders.[705] Technology such as Project Vesta provides forestry and fire stakeholders with a considerable opportunity to enhance wildfire preparedness, mitigation, and suppression capabilities. As community involvement is paramount, so are partnerships at all levels of government. Partnerships drive many of the operations behind wildfire mitigation, suppression, and recovery. Thus, it is important to keep the door open and explore new partners that can aid in any gaps (i.e., personnel, equipment, etc.).

Last, as community involvement is paramount, so are partnerships at all levels of government, including the private sector. Partnerships drive many of the operations behind wildfire mitigation, suppression, and recovery. Thus, it is crucial to keep the door open and explore new partners that can aid in any gaps (i.e., personnel, equipment), whether with private entities, communities, and tribal nations. All forestry and fire stakeholders can offer practical solutions, historical backgrounds, and technological advancements to address the unified goal of reducing wildfire frequency and scale and impacts on communities, critical infrastructure, and forest health.

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[702] Sarah Clark, "Unmanned Future Threatens Pilot Identity," *Proceedings*, September 2022, https://www.usni.org/magazines/proceedings/2022/september/unmanned-future-threatens-pilot-identity-0.

[703] SafetyNow, "Nine Technologies That Will Help Transform the Fire Service," *Safety Now & Next* (blog), February 1, 2021, https://www.3m.com/blog/en_US/safety-now/science-of-safety/9-technologies-that-will-help-transform-the-fire-service/.

[704] kassmcrostie, "Supporting the Wildfire Response Common Operational Picture with Project Vesta," SoCal Tech Bridge, February 16, 2022, https://www.socaltechbridge.org/post/supporting-the-wildfire-response-common-operational-picture-with-project-vesta.

[705] "Project Vesta," SoCal Tech Bridge, accessed November 27, 2022, https://www.socaltechbridge.org/project-vesta.

B. FUTURE RESEARCH

Concerning the information presented in this thesis, future research is necessary to continue adapting and overcoming wildfire threats in the West. Future research may be needed on the recommendations offered to identify practical means to implement them at all levels of government. Additionally, it will be critical to analyze how the western landscape develops in the years to come. Researching new technology and other adaptive solutions may prove beneficial in bringing unique solutions to the wildfire threat to forestry and fire management stakeholders. Lastly, examining wildfire data in each western state may help identify key concerns and solutions. All in all, the wildfire threat will continue to evolve in the United States, especially in the West, so it is vital that action is taken and solutions are identified for years to come to mitigate wildfire impacts on forests, communities, and critical infrastructure.

In conclusion, John Muir once said, "The battle for conservation must go on endlessly. It is part of the universal warfare between right and wrong."[706] To win this battle, all western forestry and fire stakeholders must unite to protect and preserve the nation's forests, communities, and critical infrastructure. Thus, discussion, action, and research must continue to evolve to ensure we show the United States is worthy of the good fortune that our forests offer.

706 "John Muir," National Park Service, last updated October 28, 2022, https://www.nps.gov/jomu/learn/historyculture/people.htm.

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APPENDIX. SIMULATION PROCESS

FlamMap 6 was used to run dynamic fire growth simulations in the Pumphouse Wash Dispersed Camping Area near State Route 89A in Arizona and the Mission Trails Regional Park in San Diego California. The landscape and fuel characteristics for each location were downloaded using the LandFire interface, while historical weather data was downloaded from the National Weather Service using the Flagstaff station #20209, at roughly 35 latitude and -111 longitude for the pumphouse wash and a weather station near the Mission Trails Park. Any location can be located and identified using the interface provided through the weather information management system (https://www.wfas.net/nfdrs2016/maps/). Simply find the nearest station to the area of interest, then click on the link to save that data to your local computer. Weather files download as fw13 files must be converted into ASCII files for use in FlamMap and FARSITE. Weather file format conversion was carried out using the Fire Family + software package, which can be used to load fw13 files and save those files as ASCII formatted files for use in other programs. The current downloadable historical data range spans 2001 to 2018. We ran the simulation for 10 days from August 1 thru August 10, using weather data from 2018. The weather data is tabulated in hourly increments and the fire growth front appears as contour lines for each hour superimposed onto the landscape map using the "pointer" tool in FARSITE. The basic steps to run these simulations follow.

Simulation Procedure

The simulation process consists of the following steps:

(1) Identify a location of interest.

(2) Use the LandFire interface (https://landfire.gov/getdata.php) to locate and identify a region in the U.S. for data download.

(3) Choose your area coverage around the location of interest and transform the data to true north (UTM NAD83) using the best fit option in LandFire

(4) Download a file that contains a full description of the landscape, including elevation, slope, aspect, fuel types and canopy cover.

(5) Import these files into FlamMap.

(6) Use the weather station identifier map through the WIMS site to get a weather record for the region of interest.

(7) The WIMS data must be converted to ASCII for import into Flam Map using the Fire Family Plus software and export the WIMS data to a FARSITE readable format.

(8) Import the data into the FARSITE simulator in FlamMap.

(9) Determine an ignition location using the point or polygon tool in FlamMap. Create an ignition file from that location for download into FlamMap

(10) Determine a barrier geometry for a mitigation geometry of interest.

(11) Run the simulation for the number of days of interest.

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