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A review on the integrated disaster risk management strategies for wildfire outbreaks in the United State of America

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Abstract

Wildfires are becoming a near-annual occurrence in many regions globally as fire regimes are changing with warming temperatures and shifting precipitation patterns. The events have become a significant environmental and socio-economic challenge in the United States, where climate conditions, human activities, and land management practices contribute to their frequency and intensity. This review explores the key elements of Integrated Disaster Risk Management (IDRM) strategies in wildfire management in the USA with consideration on policies, technological advancements, community engagement, and environmental approach. The review suggested the need for a paradigm shift toward systems and structures that are more comprehensive and better address the interrelationships between communities and landscapes and between pre-fire mitigation, response, and post-fire recovery efforts.

Keywords: Wildfire; Integrated Disaster Risk Management (IDRM); Climate Change; Health Impacts; Pacific Northwest; Fire Regimes

1. Introduction

Natural disturbances (e.g., wildfires, floods, storms, insect outbreaks) play a central role in structuring ecosystems worldwide, but multiple disturbances can potentially interact in synergistic ways that alter ecosystem resilience (Harvey et al., 2014). Understanding these potential interactions and their consequences is critical for conserving and managing ecosystems in a period of increasing climate-driven disturbance activity (Harvey et al., 2014). According to International Federation of Red Cross and Red Crescent (IFRC), in its World Disaster Report 2018, has identified 3751 natural disasters such as floods, earthquakes, landslides, wildfire, tsunami, etc., over the last ten years with an estimated economic loss of $1.658 billion and about 2 billion human lives (Khan et al., 2020). Long-term negative consequences beyond the immediate loss of life and infrastructure in the form of public health issues, humanitarian crises, and environmental problems are predominantly observed for years to come (Khan et al., 2020).

Wildfires are becoming a near-annual occurrence in many regions globally as fire regimes are changing with warming temperatures and shifting precipitation patterns (Halofsky et al., 2020). The US Pacific Northwest (states of Washington, Oregon, Idaho, and western Montana, USA; hereafter the Northwest) is no exception. In 2014, the largest wildfire in recorded history for Washington State occurred, the 103,640 ha Carlton Complex Fire. In 2015, an extreme drought year with very low snowpack across the Northwest (Marlier et al. 2017), 688,000 ha burned in Oregon and Washington, with over 3.6 million ha burned in the western United States. Several fires in 2015 occurred in conifer forests on the west (i.e., wet) side of the Cascade Range, including a rare fire event in coastal temperate rainforest on the Olympic Peninsula (Halofsky et al., 2020).

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Wildfires have become a significant environmental and socio-economic challenge in the United States, where climate conditions, human activities, and land management practices contribute to their frequency and intensity. Integrated Disaster Risk Management (IDRM) strategies offer a holistic approach to mitigating, preparing for, responding to, and recovering from wildfires (Calkin et al., 2014). This review explores the key elements of IDRM in wildfire management in the USA, including policies, technological advancements, community engagement, and environmental considerations.

2. Understanding Wildfire Risks in the USA

2.1. Causes and Contributing Factors

Over the twentieth century in the Northwest, years with relatively warm and dry conditions have generally corresponded with larger fires and greater area burned (Westerling 2016; Kitzberger et al. 2017; Reilly et al. 2017; Holden et al. 2018; Halofsky et al., 2020). Decreasing fuel moisture and increasing duration of warm, dry weather creates large areas of dry fuels that are more likely to ignite and carry fire over a longer period of time (Littell et al. 2009). Wildfires are fuelled by multiple factors, including climate change, vegetation density, human encroachment into wildlands, and inadequate land management (Keeley & Syphard, 2016). Rising temperatures and prolonged droughts increase the likelihood of ignition and rapid-fire spread (Abatzoglou & Williams, 2016). Other contributing factors include wind patterns, lightning strikes, and unintentional human-induced ignitions such as power line failures (Mitchell et al., 2014). A warm climate will have profound effects on fire frequency, extent, and possibly severity in the Northwest. Increased temperatures are projected to lengthen fire and growing seasons, increase evaporative demand, decrease soil and fuel moisture, increase the likelihood of large fires, and increase area burned by wildfire (Westerling 2016). Decreased summer precipitation is also projected to increase area burned (Holden et al. 2018). Interactions between fire and other disturbance agents (e.g., drought, insect outbreaks) will likely catalyze ecosystem changes in a warming climate. Increased tree stress and interacting effects of drought may also contribute to increasing wildfire severity (damage to vegetation and soils) and area burned (Littell et al. 2016; Reilly et al. 2017). Climatic changes and associated stressors can interact with altered vegetation conditions (e.g., those resulting from historical management practices) to affect fire frequency, extent, and severity, as well as forest conditions in the future (Keeley and Syphard 2016). Human influence through domestic livestock grazing, road construction, conversion of land to agriculture, and urbanization in dry forests (Hessburg et al. 2005). Many larger, fire-resistant trees have been removed by selective logging.

These activities, along with active fire suppression, have resulted in increased forest density and fuel buildup in forests historically characterized by frequent, low severity and mixed-severity fires (Hessburg et al. 2005). Although landscape pattern and fuel limitations were key factors that limited fire size and severity historically, these limitations have been largely removed from many contemporary landscapes, thus increasing the potential for large high-severity fires, particularly in a warm climate.

2.2. Impacts of Wildfires

Wildfire poses severe threats to ecosystems, biodiversity, human health, and infrastructure. The 2018 Camp Fire in California, for example, was the deadliest and most destructive wildfire in state history, causing 85 fatalities and economic losses exceeding $16.5 billion (California Department of Forestry and Fire Protection, 2019). Additionally, wildfires contribute to air pollution, releasing significant amounts of carbon dioxide and particulate matter into the atmosphere, which exacerbates respiratory illnesses and climate change effects (Liu et al., 2016).

In addition to the risks and impacts of the fire itself, impacts to human health from inhalation of smoke emissions can have far-reaching and significant consequences. Inhalation of smoke or its by-products has been linked to a long list of conditions including respiratory and cardiovascular diseases, cancer, and mental health issues (Eisenman & Galway, 2022; Peterson et al, 2022). Smoke from fires in the built environment is of particular concern given the combustion of synthetic materials (United States Environmental Protection Agency [EPA], 2022). Though wildfire smoke is more prevalent in the West, recent research found that long-term smoke exposure is responsible for upwards of 6,000 additional deaths per year across the contiguous United States, the majority of which occur in the eastern half of the country (O'Dell et al., 2021). Firefighters in particular face prolonged exposure, the impacts of which are still poorly understood, as do agricultural workers and others who work outdoors (Navarro et al., 2019)

In the U.S., the nine most devastating fire seasons have occurred since 2005, when record keeping began (Grant & Runkle, 2022). To date, the record-setting 2020 and 2021 fire seasons in the western U.S. have resulted in 7.7 million acres burned and poor air quality across the nation (Grant & Runkle, 2022). Historically dry conditions brought on by drought and compounded by record-breaking heat wave events, all due to a changing climate, are responsible for fires spreading more quickly and burning more land area (Grant & Runkle, 2022). Considering the health-related impact, according to Fann et al. (2018), the estimated costs of long-term PM2.5-related premature deaths and hospital admissions were between $76B-$130B (2010 USD), with an estimated total net cost of $450B during the study period of 2008–2012. Neumann et al. (2021) estimated that the wildfire-attributable PM2.5-related mortality would translate to $29B-$36B (2015 USD) in annual total excess economic costs by the year 2090. Depending on fire intensity, severity, and frequency, fire events may significantly alter the soil's physical properties, such as soil gradation, soil structure and texture, plasticity, bulk density, porosity, soil water-repellence, infiltration rates, and water storage capacity (Grant & Runkle, 2022). The impacts of wildfire on the geo-environment are broad and diverse. Some of these impacts are not known or foreseen, and even for a large fraction of impacts that have been observed, or well-documented, quantitative evaluation of the impacts may not be available (Grant & Runkle, 2022).

3. Integrated Disaster Risk Management Framework for Wildfires

3.1. Prevention and Mitigation Strategies

Land Management and Vegetation Control: Controlled burns and fuel reduction treatments are critical in preventing large-scale wildfires. The U.S. Forest Service implements prescribed burns to manage forest density and reduce combustible materials (North et al., 2015).

Policy and Regulations: Federal policies, such as the National Cohesive Wildland Fire Management Strategy, aim to create fire-adapted communities and promote resilient landscapes (USDA Forest Service, 2021). Furthermore, local governments enforce building codes that require fire-resistant materials and defensible spaces around structures to reduce fire spread (Syphard et al., 2017).

Infrastructure Adaptation: Fire-resistant building materials, defensible spaces, and improved zoning regulations help reduce fire vulnerability in high-risk areas (Syphard et al., 2017). The implementation of underground power lines in wildfire-prone regions can reduce the risk of ignition from electrical failures (Mitchell et al., 2014).

3.2. Preparedness and Response Mechanisms

Early Warning Systems: Advanced satellite monitoring (e.g., NASA's MODIS and VIIRS sensors) and artificial intelligence-based predictive modeling enhance early wildfire detection and response (Davies et al., 2018). Fire behavior modeling and remote sensing technologies improve situational awareness and enable rapid deployment of firefighting resources (Finney et al., 2011).

Community Training and Engagement: Public education campaigns, such as the Ready, Set, Go! Program, provide communities with guidance on evacuation procedures and fire-resistant home modifications (NFPA, 2020). Community-based fire adaptation programs, such as Firewise USA, encourage property owners to take proactive measures to mitigate fire risk (Mockrin et al., 2018).

Emergency Response Coordination: Collaboration between federal, state, and local emergency response teams ensures efficient wildfire containment. The National Interagency Fire Center (NIFC) coordinates efforts among multiple agencies (National Interagency Fire Center, 2020). The use of specialized firefighting aircraft, such as water-dropping helicopters and air tankers, plays a critical role in suppressing wildfires in difficult terrains (Plucinski, 2019).

3.3. Recovery and Rehabilitation Strategies

Post-Fire Environmental Restoration: Strategies such as reforestation, erosion control, and soil stabilization help restore burned areas and prevent secondary disasters like landslides (Shive et al., 2018). Burned Area Emergency Response (BAER) teams assess post-fire landscapes and implement restoration measures to minimize long-term ecological damage (Robichaud et al., 2000).

Economic and Social Recovery: Federal assistance programs, including FEMA disaster relief and insurance initiatives, support affected communities in rebuilding efforts (FEMA, 2022). State-level initiatives, such as California's wildfire relief grants, provide additional financial support to homeowners and small businesses impacted by wildfires (CAL FIRE, 2021).

Policy Review and Adaptation: Continuous policy evaluation and adaptation based on recent wildfire events ensure improved management strategies (Stephens et al., 2019). Integrating Indigenous knowledge and traditional fire management practices can enhance resilience and reduce wildfire risks (Kimmerer & Lake, 2001).

4. Challenges and Future Directions

Despite advancements, wildfire management faces challenges such as insufficient funding, bureaucratic delays, and climate change exacerbation (Westerling, 2016). Limited access to resources and personnel constraints often hinder firefighting efforts, particularly in remote areas (Radeloff et al., 2018). Emerging technologies, including AI-driven fire prediction models and drone-based fire suppression techniques, offer promising solutions for improving wildfire response efficiency (Johnston et al., 2020). Additionally, fostering cross-agency collaboration and integrating Indigenous fire management practices can enhance wildfire resilience (Kimmerer & Lake, 2001). Expanding federal and state investment in wildfire prevention infrastructure, such as fuel break networks and community preparedness programs, can further strengthen wildfire management strategies (Stephens et al., 2020).

There is a need for a paradigm shift toward systems and structures that are more comprehensive and better address the interrelationships between communities and landscapes and between pre-fire mitigation, response, and post-fire recovery efforts. This includes greater integration between wildfire-related programs, procedures, policies, and workforces and incorporation of issues and sectors that have traditionally been set apart from the wild land fire discourse or handled disparately. Solutions should not and cannot be accomplished by federal agencies alone, but must involve individuals, entities, and jurisdictions at every level of society. A range of different approaches, including greater coordination, interoperability, collaboration, and, in some cases, simplification will be needed to accomplish these aims.

5. Conclusion

Integrated Disaster Risk Management strategies play a crucial role in mitigating wildfire risks, preparing communities, and ensuring efficient recovery. There is a need for continuous investing in advanced technologies, community-based resilience programs, and policy improvements to address the increasing wildfire threats. Successfully meeting the challenge of wildfire mitigation and management requires better involving all relevant entities and every scale of society. Governance systems and structures must become more inclusive and involve greater collaboration among federal agencies, and between federal agencies and non-federal governments, organizations, and communities. Such approaches are essential to building new relationships, creating more cohesive and holistic approaches, and removing the silos that limit effective wildfire risk reduction. In addition to and in support of greater collaboration, communities should be empowered – through capacity funding, program flexibilities, and other means – to identify, invest in, and implement their own solutions. Community assets and needs vary greatly, and federal programs should avoid one-size-fits-all strategies that create greater barriers to entry for some. Instead, it is imperative that federal programs provide opportunities for widespread participation in the spaces where decisions are made. Tribal participation and empowerment within the fire system are also essential and must be based upon the unique sovereign-to-sovereign relationships between the federal government and each federally recognized Tribe.

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