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If wildfire prevention doesn't work, what will be done?

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Abstract

Recently, natural disasters have increased significantly in the world, and one of the most important of these disasters is wildfires, so it has become necessary to work to reduce the risk of wildfires, so have to know and understand wildfire and what are factors affecting it, and most importantly, how to reduce wildfires before and after the occurrence of hazards (ignition). Therefore, strategies for suppression, reduction, and prevention of wildfires will be discussed in this review paper. The main objective of this paper is to discuss and find appropriate solutions to suppress the fire before the disaster occurs or to reduce the size of the disaster. It will concern the management of the forest and the management of what is on and below the surface of the soil of the forest, and this leads to the management of the fuels in the forest. In addition, knowing the factors affecting the spread of fire, whether direct or indirect factors, and knowledge of chemical, physical, and mechanical methods to reduce fire.

Keywords: Wildfire, Wildfire Causes, Wildfire Prevention, Wildfire Suppression, Fire Retardants

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إِذَا لَمْ تَنْجَحْ اَلْوِقَايَةُ مِنْ حَرَائِقِ اَلْغَابَاتِ، فَمَا اَلَّذِي يَجِبُ فِعْلُهُ؟

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المستخلص

في الأونة الأخيرة تزايدت الكوارث الطبيعية بشكل كبير في العالم، ومن أهم هذه الكوارث حرائق الغابات، لذلك أصبح من الضروري العمل على تقليل مخاطر حرائق الغابات، لذا يجب معرفة وفهم حرائق الغابات وما هي العوامل المؤثرة عليها والأهم من ذلك كيفية الحد من حرائق الغابات قبل وبعد حدوث الكارثة (الأشتعال). سيناقش استراتيجيات إخماد حرائق الغابات والحد منها والوقاية منها في ورقة المراجعة هذه. الهدف الرئيس من هذه الورقة هو مناقشة وإيجاد الحلول المناسبة لإخماد الحريق قبل وقوع الكارثة أو لتقليل حجم الكارثة فيما لو حصلت الكارثة. وسيهتم بإدارة الغابة وإدارة ما يوجد على سطح تربة الغابة وما تحته، وهذا يؤدي إلى إدارة الوقود في الغابة. بالإضافة إلى معرفة العوامل المؤثرة على إنتشار الحريق سواء كانت عوامل مباشرة أو غير مباشرة ومعرفة الطرائق الكيميائية والفيزيائية والميكانيكية للحد من حرائق الغابات.

الكلمات المفتاحية: حرائق الغابات، أسباب حرائق الغابات، الوقاية من حرائق الغابات، إخماد حرائق الغابات، مثبطات الحرائق

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Introduction

A wildfire may be defined as an unanticipated, unregulated, and capricious fire that occurs in regions with flammable vegetation, including in urban as well as rural areas [1 and 2]. Certain forest ecosystems rely on wildfires in their undisturbed condition [3]. A wildfire can be further categorized based on the specific flora it affects, such as forest fire, brush fire, bushfire (in Australia), desert fire, grass fire, hill fire, peat fire, prairie fire, vegetation fire, or veld fire [4]. Wildfires are inherently different from managed burns, which are intentional and beneficial applications of fire. However, it is worth noting that controlled burns have the potential to escalate into wildfires. The prevalence of wildfires across the course of terrestrial existence prompts speculation regarding the significant evolutionary impacts that fire may have exerted on the flora and fauna of various ecosystems. Factors such as the presence of carbon-rich vegetation, seasonally arid climates, atmospheric oxygen levels, and frequent occurrences of lightning and volcanic ignitions contribute to the favorable conditions for fires [5].

Wildfires are frequently categorized based on many attributes, including the ignition source, physical attributes, the kind of flammable material involved, and the influence of meteorological conditions on the fire [6]. The behavior and intensity of wildfires are influenced by a multitude of factors, including the presence of combustible materials, the geographical context, and meteorological conditions [7]. Climatic cycles characterized by alternating wet periods that facilitate the accumulation of significant fuel loads, followed by times of drought and elevated temperatures, frequently give rise to the occurrence of major wildfires [8]. The exacerbation of these cycles is attributed to the intensification of severe weather patterns resulting from climate change [9]. Wildfires have the capacity to inflict harm on both property and souls, notwithstanding their inherent occurrence in nature [10]. The occurrence of fire may potentially provide advantageous outcomes for indigenous flora, fauna, and ecological systems that have coevolved with this natural phenomenon [11]. The occurrence of high-severity wildfires gives rise to intricate early seral forest habitat, sometimes referred to as "snag forest habitat." This type of habitat frequently exhibits more species richness and variety compared to an unburned old-growth forest. Numerous plant species rely on the influence of fire to facilitate their development and reproductive processes [12]. Wildfires occurring in habitats where the occurrence of wildfire is infrequent or in the area under consideration where there has been an encroachment of non-native plants can potentially have significant adverse ecological consequences [6]. In a similar vein, fires may have significant consequences on human society, including several aspects such as the direct health effects stemming from smoke exposure, the damage of property, particularly in areas where wildland and urban environments intersect, the economic and ecological service losses incurred, and the polluting of water and soil [9].

At the global scale, human activities have exacerbated the severity of wildfires beyond their normal occurrence, resulting in a twofold increase in the extent of land affected by such fires compared to natural levels. Human beings have made significant contributions to the exacerbation of wildfires through several means, including the amplification of hot and dry spells resulting from climate change. Additionally, Human actions that are conducted without intermediaries or indirect involvement, such as alterations in land use and the implementation of wildfire suppression strategies, have also played a role in this phenomenon. The escalation of fire incidents engenders a detrimental feedback mechanism that results in the release of carbon, which was previously sequestered naturally, back into the atmosphere. Consequently, this exacerbates the phenomenon of global warming [9]. The use of aggressive wildfire control strategies, with the intention of decreasing fire occurrences and discontinuing traditional land management practices employed by indigenous communities, has resulted in the accumulation of fuel loads. This, in turn, has heightened the probability of large-scale and catastrophic fires, particularly within specific colonial contexts such as the U.S. [13]. Contemporary forest management, adopting an ecological standpoint, employs controlled burns as a means to mitigate such hazards and facilitate the progression of natural forest life cycles.

The primary initiation of a fire is typically assessed in terms of natural or anthropogenic origins. The primary natural factors contributing to the occurrence of wildfires are a dry climate, lightning strikes, climate unpredictability, and volcanic eruptions [14]. In regions characterized by medium latitudes, the primary anthropogenic factors contributing to the occurrence of wildfires are the ignition of sparks generated by various types of equipment (chainsaws, grinders, mowers, etc.), the topics of discussion include overhead electricity wires and arson [15 and 16]. In tropical regions, it is common for farmers to employ the slash-and-burn technique as a means of field clearance, particularly during periods of low precipitation. When a significant number of farmers engage in this practice concurrently, a substantial portion of a continent can be observed from space as a unified conflagration [17]. The propagation of wildfires exhibits variability contingent upon factors such as the composition of combustible substances, their vertical disposition and moisture levels, as well as prevailing meteorological circumstances [18]. The fuel distribution and density are influenced, to some extent, by the topography of the land, as it plays a role in determining key aspects like sunshine availability and water availability for plant growth.

Wildfires transpire when the essential components of a fire triforce converge inside a vulnerable region: an ignition source encounters a flammable substance, such as vegetation, which is exposed to sufficient heat and possesses a sufficient oxygen supply derived from the surrounding atmosphere. Typically, a significant presence of moisture inhibits ignition and hinders the spread of fire, since it necessitates elevated temperatures to evaporate the water within the substance and raise the material's temperature to its ignition threshold [19]. Dense woods typically offer increased shading, leading to reduced ambient temperatures and higher humidity levels, thereby rendering them less prone to wildfires. Those with lower density, such as grasses and leaves, are more susceptible to ignition due to their reduced water content compared to those with higher density, such as branches and trunks [20].

Plants undergo a perpetual process of water loss through evapotranspiration; however, this loss is typically counterbalanced by the uptake of water from the soil, atmospheric humidity, or precipitation. When the equilibrium is disrupted, plants undergo desiccation, rendering them more susceptible to combustion, frequently as a result of prolonged periods of aridity [21]. The wildfire front refers to the segment of a fire that maintains a consistent and ongoing state of blazing combustion. This occurs at the interface where unburned material comes into contact with active flames, or in the smoldering region that marks the transition between unburned and burned material [22]. As the frontal system advances, the combustion process generates heat that is transferred to the adjacent air and woody substances via convection flow and radiation of heat. Initially, the wood undergoes a drying process wherein the moisture content is reduced through the evaporation of water at a specific temperature of 100° C (212° F). Subsequently, the thermal decomposition of firewood at a temperature of 230° C (450° F) results in the liberation of combustible gases. In conclusion, wood has the ability to undergo smoldering at a temperature of 380° C (720° F) or, under appropriate heating conditions, initiate combustion at a temperature of 590° C (1000° F) [18]. Prior to the arrival of a wildfire at a specific place, the propagation of heat from the leading edge of the wildfire raises the temperature of the surrounding air to around 800° C (1470° F). This elevated temperature serves to pre-heat and desiccate combustible substances, accelerating their ignition and facilitating the rapid expansion of the fire [20]. Surface wildfires that occur at high temperatures and persist for extended periods of time have the potential to promote flashover or torching phenomena. Flashover refers to the drying of tree canopies, followed by their igniting from the lower portions [23].

Wildfires exhibit an extremely fast rate of forward spread (often referred to as FROS) when propagating across densely packed and continuous fuel sources [24]. In forested areas, their locomotion speed can reach up to 10.8 km hr^{-1} (6.7 mph), but in grasslands, they can achieve speeds of up to 22 km hr^{-1} (14 mph) [25]. Wildfires have the ability to progress in a direction that is parallel to the primary front, resulting in the formation of a flanking front. Additionally, they can also propagate in a direction opposite to the primary front, a phenomenon commonly referred to as backing [26]. Additionally, these fires have the potential to propagate through many means, such as jumping or spotting, facilitated by the movement of firebrands (i.e., heated wood embers) and other combustible materials carried by winds and vertical convection columns. This airborne transport can effectively overcome natural barriers like highways, rivers, and other potential firebreaks [27]. The occurrence of torching and fires within tree canopies has been shown to facilitate the process of spotting. Additionally, it has been observed that dry ground fuels surrounding a wildfire are particularly susceptible to igniting caused by firebrands. The act of spotting has the potential to generate spot fires, as the emission of hot embers and firebrands can initiate the ignition of combustible materials located in the downwind direction from the main fire. In the context of Australian bushfires, it has been observed that spot flames can manifest at distances of up to 20 km (12 mi) from the leading edge of the fire [28]. The occurrence of extreme temperatures, aridity, climate change such as El Niño, and local weather trends including high-pressure summits can substantially enhance the probability and alter the dynamics of wildfires [29]. The occurrence of prolonged periods of precipitation, along with subsequent warm climatic conditions, can foster the proliferation of fires on a larger scale and extend the duration of fire seasons [30]. The impact of temperature on wildfires is consistent in that it leads to desiccation of fuel sources, rendering them more susceptible to ignition and promoting increased flammability [31]. Since the mid-1980s, there has been a correlation between earlier snowmelt and the subsequent warming, resulting in an extended and intensified wildfire season, which represents the period of time with the most susceptibility to fires [32].

Global warming has the potential to amplify the severity and occurrence of droughts in numerous regions, hence engendering heightened and more regular occurrences of wildfires [6]. According to a study conducted in 2019, there is evidence suggesting that the escalation of fire risk in California could potentially be linked to climate variability caused by human activities [33]. The examination of alluvial sediment deposits spanning a time frame of more than 8000 years revealed that during warmer climate periods, there were instances of intense droughts and fires that resulted in the complete replacement of vegetation. Based on these findings, it can be inferred that climate exerted a significant influence on wildfires, to the extent that attempting to restore forest structure to its pre-human settlement state may prove unfeasible in a future characterized by elevated temperatures [34]. The level of intensity also experiences a rise during daylight hours. The combustion rates of smoldering logs exhibit up to a fivefold rise during daylight hours as a consequence of reduced humidity levels, elevated temperatures, and heightened wind velocities [35].

The ground is warmed by sunlight throughout the daytime, resulting in the generation of uphill air currents. During the nighttime, the ground undergoes a cooling process, resulting in the formation of downward air currents. Wildfires are propelled by these wind patterns and frequently trail the atmospheric streams through elevated terrain and through low-lying areas [36]. Frequent fire incidents in Europe are seen to transpire between 12:00 p.m. and 14:00 p.m. [37]. In the U.S., wildfire suppression efforts are structured around a 1-day *fire day*, commencing at 10:00 a.m., as this time is associated with a foreseeable escalation in fire severity due to diurnal temperature patterns [38].

In 2003, a wildfire occurred in the North Yorkshire Moors, resulting in the combustion of around 2.5 km^2 (600 acres) of heather vegetation and the peat layers that exist under the surface. Subsequently, the process of wind erosion ensued, leading to the removal of ash and the subsequent exposure of underlying soil, thereby unveiling archaeological remnants that can be traced back to the period of 10,000 BC [39]. Wildfires can exert an influence on climate variability by augmenting the quantity of carbon emissions discharged into the atmosphere and impeding the growth of vegetation, so impacting the overall capacity of plants to absorb carbon. The research conducted in Alaska has revealed that fire-event return intervals (FRIs) often exhibit a range of 150 to 200 years. It has been observed that dryer lowland regions experience more frequent occurrences of fire compared to wetter upland areas [40].

The majority of the Earth's weather patterns and air pollutants are concentrated within the troposphere, which encompasses the region of the atmosphere extending from the planet's surface up to approximately 10 km (6 mi) in altitude. The vertical updraft of a violent thunderstorm or pyro cumulonimbus can experience augmentation within the vicinity of a substantial wildfire, propelling smoke, soot, and other small particles to elevations reaching the lower stratosphere [41]. In the past, the dominant scientific hypothesis posited that the majority of particles present in the stratosphere originated from volcanic activities. However, recent observations have identified the presence of smoke and other emissions resulting from wildfires in the lower stratospheric region [42]. Pyro cumulus clouds have the potential to attain altitudes of up to 6100 m (20000 ft) over areas affected by wildfires [43]. The utilization of satellite technology for the purpose of observing smoke plumes originating from wildfires has provided evidence indicating that these plumes can be followed over considerable distances surpassing 1600 km (1000 mi) without significant fragmentation [44]. Computer-aided models, such as CALPUFF, have the potential to assist in the prediction of the dimensions and trajectory of smoke plumes generated by wildfires through the utilization of atmospheric dispersion modeling techniques [45].

Wildfire prevention include proactive strategies designed to mitigate the likelihood of fires, as well as mitigate their intensity and rate of propagation [46]. The primary objective of prevention approaches is to effectively regulate and control air quality, uphold ecological equilibrium, and safeguard valuable resources [47]., and to have an impact on subsequent fire incidents [48]. In North America, firefighting regulations allow for the intentional allowance of naturally occurring fires to persist in order to preserve their biological function, as long as measures are taken to minimize the potential for these fires to spread into regions of significant value [49]. Nevertheless, it is imperative for preventative programs to acknowledge the significant contribution of human activities to wildfires. This is exemplified by the fact that around 95% of wildfires occurring in Europe may be attributed to human participation [50]. Human-caused fires can stem from various sources, including deliberate acts of arson, unintentional ignition, or the unregulated utilization of fire for land clearance and agricultural purposes, such as the prevalent practice of slash-and-burn farming observed in Southeast Asia [51].

Prevention

Wildfire avoidance initiatives implemented globally often incorporate strategies such as fire wildland usage (WFU) and planned or controlled fires [52]. The term "wildland fire use" pertains to the deliberate monitoring and permissive burning of fires caused by natural factors. Controlled burns, also known as prescribed burns, are deliberate fires initiated by governmental entities under meteorological circumstances that pose lower risks [53].

The approaches employed in the prevention, detection, control, and suppression of wildfires have exhibited a range of variations throughout the years. Controlled burning is a widely employed and cost-effective strategy for mitigating the threat of uncontrolled wildfires. This technique involves deliberately initiating smaller and less intense burns with the aim of reducing the quantity of combustible materials that could potentially fuel a wildfire [54]. Periodic burning of vegetation can be employed as a strategy to mitigate the buildup of plant matter and other combustible detritus, whilst simultaneously promoting the preservation of a rich variety of species [55]. Jan Van Wagtendonk posits that wildfires are the most effective means of reducing the rate of spread, intensity of firelines, length of flames, and heat per unit of land [56]. While some individuals argue that implementing controlled burns and adopting a policy of allowing certain wildfires to burn is a cost-effective approach and ecologically suitable for numerous forests, they often overlook the economic implications associated with the loss of resources, particularly marketable timber [8]. Several studies have reached the conclusion that although logging activities can potentially reduce fuels, thinning treatments may not be sufficiently successful in mitigating fire intensity during periods of extreme meteorological conditions [57].

In the Philippines, local communities use a practice of establishing fire lines that span a width of 5 - 10 m (16 - 33 ft) between the forested areas and their respective villages. These fire lines are diligently monitored and patrolled by community members, particularly during the summer months or periods characterized by dry weather conditions [58]. The criticism has been directed towards the ongoing expansion of residential development in regions susceptible to wildfires, as well as the reconstruction efforts aimed at replacing structures that have been destroyed by such fires [59]. The prompt and efficient identification plays a crucial role in the mitigation of wildfires. The primary emphasis of early detection initiatives revolved around prompt reaction, precise outcomes throughout both diurnal and nocturnal periods, and the capacity to assign priority to fire hazards [60]. During the early 20th century in the U.S., fire lookout towers were employed as a means of fire detection. Various methods were utilized to report fires, including telephones, carrier pigeons, and heliographs [61]. During the 1950s, the practice of employing instant cameras for both aerial and ground photography was prevalent. However, the advent of infrared scanning in the 1960s revolutionized fire detection techniques, rendering the former method obsolete. Nevertheless, the dissemination and interpretation of information were frequently impeded by the constraints imposed by communication technology. In the initial stages of satellite-derived fire analysis, manual techniques were employed to depict the data on maps at a distant location. These maps were subsequently dispatched to the fire manager by overnight postal services. At now, the early detection of wildfires can be facilitated through the utilization of many methods, including public helplines, fire lookouts stationed in towers, as well as ground and aircraft patrols. Nevertheless, the precision of human observation could potentially be constrained by factors such as operator tiredness, temporal variables including time of day and time of year, as well as spatial considerations such as geographic location. In recent years, there has been a surge in the adoption of electronic systems as a potential solution to mitigate human operator mistake. According to a government study regarding a recent trial conducted in Australia, it was determined that the automated camera fire detection systems exhibited slower and less dependable detection capabilities compared to those of a proficient human observer. These systems have the potential to be either partially or completely automated and utilize methodologies that are determined by the level of risk and the extent of human involvement, as indicated by the analysis of Geographic Information Systems (GIS) data. The utilization of an integrated methodology involving numerous systems enables the amalgamation of satellite data, aerial photography, and personnel position using the Global Positioning System (GPS). This amalgamation results in a comprehensive entity that can be promptly accessed by wireless Incident Command Centers for near-realtime purposes [62].

A local sensor network can be employed to monitor a limited geographical region characterized by dense vegetation, significant human activity, or proximity to a crucial urban area, hence posing a heightened level of danger. Detection systems may include sensor networks with wireless connections that operate as automated weather systems, enabling the identification of temperature, humidity, and smoke levels [63 and 64]. These devices have the capability to be powered by batteries, solar energy, or the capacity to recharge their battery systems through the utilization of minute electrical currents inherent in plant matter [47]. In order to monitor larger areas with medium-risk levels, it is possible to employ scanning towers equipped with fixed cameras and sensors. These instruments possess the capability to detect smoke and other pertinent constituents, including the infrared signal of greenhouse gases (especially CO_2) released by fires. Sensor arrays can also be enhanced with supplementary features, such as nocturnal vision, luminance detection, and hue detection [65 and 66]. It is imperative to acknowledge that satellite detection is susceptible to offset errors, ranging from 2 to 3 km (1 to 2 mi) for MODIS and AVHRR data, and up to 12 km (7.5 mi) for GOES data [67]. Satellites situated in geostationary orbits possess the potential to experience operational incapacitation, while satellites occupying polar orbits are frequently constrained by their restricted duration of observational opportunity. The efficacy of satellite images can be constrained by cloud cover and the image resolution as well [68].

Suppression

Wildfire suppression encompasses a variety of firefighting approaches and strategies employed to quell the spread of wildfires. The mitigation of fires in wildland areas necessitates distinct methodologies, specialized equipment, and specific training, in contrast to the conventional structural firefighting practices commonly employed in densely populated regions. In collaboration with specifically engineered aerial firefighting aircraft, these wildfire-trained firefighters effectively mitigate the spread of fires, establish fire containment boundaries, and quell flames and areas of high temperature to safeguard valuable assets and pristine natural environments. Wildfire suppression efforts also encompass the concerns associated with the wildland-urban interface, which refers to the places where human settlements abut natural landscapes. The implementation of aggressive wildfire control strategies to decrease fire occurrences has resulted in the building of fuel weights, thereby augmenting the likelihood of extensive in scope or magnitude and disastrous fires [69; 70 and 71].

The effectiveness of wildfire suppression is contingent upon the technological resources accessible inside the geographical region where the wildfire transpires. In underdeveloped countries, the methods employed may involve rudimentary actions such as the application of sand or the utilization of sticks or palm fronds to extinguish the fire [72]. In developed countries, the strategies employed to suppress certain activities or behaviors differ as a result of enhanced technological capabilities. The utilization of silver iodide has been found to have the potential to stimulate the occurrence of snowfall [73]. drones, planes, and helicopters have the capability to deploy flame retardants and water onto fires [74]. The notion of achieving 100% fire suppression is no more seen feasible, however a significant proportion of wildfires are frequently contained before they escalate beyond manageable levels. The majority of the 10,000 annual new wildfires are successfully controlled, with a containment rate above 99%. However, in cases when wildfires manage to escape under severe weather conditions, their suppression becomes challenging unless there is a shift in the prevailing weather patterns. On an annual basis, wildfires in Canada and the U.S. collectively consume an estimated average area of 54,500 km^2 (equivalent to 13,000,000 acres) [75].

Primarily, combating wildfires has the potential to result in fatalities. The propagation of a wildfire's blazing front has the potential to exhibit unforeseen alterations in direction, hence exhibiting the ability to traverse fire breaks. The combination of elevated temperatures and the presence of smoke can result in a state of disorientation and a diminished ability to accurately perceive the location of a fire, hence exacerbating the hazardous nature of flames. As an illustration, in the context of the event that occurred in Mann Gulch, the U.S. state of Montana in 1949, it was observed that a tragic outcome ensued as thirteen smokejumpers perished due to the loss of their communication links, subsequent disorientation, and eventual engulfment by the fire [76]. The February 2009 Victorian bushfires in Australia resulted in a minimum of 173 fatalities, along with the destruction of around 2,029 residences and 3,500 structures due to their complete engulfment by wildfire [77]. The mitigation of uncontrolled wildfires constitutes a significant proportion of a nation's gross domestic product, hence exerting a direct impact on the country's economic landscape. The expenditure for wildfire suppression in the U.S. fluctuates significantly every year, contingent upon the intensity of each fire season. However, it is noteworthy that local, state, federal, and tribal organizations collectively allocate billions of U.S. dollars each year towards the mitigation of wildfires. According to reports, an estimated $6 billion was expended in the U.S. from 2004 to 2008 to mitigate wildfires within the country [78]. In the state of California, the U.S. Forest Service allocates around $200 million annually towards the containment of 98% of wildfires, while reserving up to $1 billion for the suppression of the remaining 2% of fires that manage to evade initial control measures and escalate into larger-scale incidents [79]. Wildland fire fighters encounter a multitude of perilous risks, encompassing heat stress, exhaustion, smoke, and dust inhalation, alongside the potential for sustaining various injuries, including burns, lacerations, abrasions, animal bites, and even rhabdomyolysis [80]. From 2000 to 2016, a total of over 350 wildland firefighters lost their lives while performing their duties. In a typical year, Canada has a significant number of wildfires, totaling more than 9,000 occurrences. These wildfires collectively consume an average land area of approximately 25,000 km^2. The incidence of fires and the extent of burned areas exhibit significant interannual variability. The annual average expenditure on suppression amounts to a range of $500 million to $1 billion [81].

The attacking strategies that used to suppress wildfire [82]:

Strategy - Direct Attack

Direct attack refers to the application of various treatments directly to the burning fuel in order to mitigate the fire. These treatments include soaking, stopping the fire, or putting out the fire with chemicals, as well as physically separating the fuel that is burning from the fuel that is not burning. This includes using fire trucks, firefighters, and airplanes to put water or other fire-stopping substances directly on the fuel that is on fire. The primary goal of the majority of agencies is to establish a fireline around all fires intended for suppression.

Advantages

- The extent of burned area is minimized, with no deliberate expansion of the affected region.
- The most secure working environment is typically found in the profession of firefighting, as firefighters possess the ability to retreat into the area that has been affected by fire.
- The reduction or elimination of uncertainty associated with firing operations is possible.

Disadvantages

- Firefighters may encounter obstacles such as elevated temperatures, smoke emissions, and the presence of flames, which might impede their operations.
- Control lines may exhibit significant length and irregularity.
- The combustion of material has the potential to rapidly propagate along mid-slope lines.
- The utilization of natural or pre-existing obstacles may pose limitations.
- Additional mop-up and patrol activities are typically necessary.

Strategy - Indirect attack

Indirect suppression tactics/strategies, which are implemented at a certain distance from the approaching fire, are classified as preparatory measures. Firelines can also be constructed in this fashion. Examples of fuel reduction methods in fire management include indirect firelines, contingency firelines, backburning, and watering unburnt fuels. This approach has the potential to facilitate enhanced planning efficiency. The utilization of natural barriers to fire may facilitate the establishment of strategically positioned firelines within lighter fuels, hence enhancing fire management practices. This approach can contribute to the creation of safer working conditions for firefighters, characterized by reduced smoke exposure and cooler ambient temperatures. Nevertheless, it could also result in an increase in the extent of land consumed by fire, larger and more intense burns, and the potential for unproductive allocation of resources towards the construction of firelines that ultimately go unused.

Advantages

- Control lines can be identified by utilizing advantageous topographical conditions.
- Natural or pre-existing barriers have the potential to be utilized.
- Firefighters may not be required to perform their duties in environments characterized by smoke and elevated temperatures.
- Control lines have the potential to be created using lighter fuels.
- There is a potential decrease in the risk of slopes.

Disadvantages

- It is anticipated that a larger expanse of land will be subject to combustion.
- In order to establish and activate a line, one must possess the ability to exchange time and space.
- Firefighters may face increased risks due to their spatial separation from the fire and the presence of unburned fuels in the intervening space.
- There exist potential hazards associated with firing activities.
- Firing procedures have the potential to result in the presence of unburned regions of fuel.
- It is possible that the existing control line may not be usable.

Fire retardants

Initially, it is essential to understand that fire-retardant gels are composed of superabsorbent polymer slurries, with a viscosity akin to that of petroleum jelly. Fire-retardant gels may also manifest as slurries, comprising a blend of water, starch, and clay [83]. Fire retardants are commonly employed for the purpose of safeguarding structures and for directly combating wildfires. Fire-retardant gels, which are commonly employed using ground equipment, serve as temporary fire suppressants [84].

Fire retardants are employed with the purpose of impeding the progress of wildfires by the suppression of combustion. The substances in question are solutions composed of ammonium phosphates $(NH_4)_3PO_4$ and ammonium sulfates $(NH_4)_2SO_4$, which are dissolved in water. Additionally, these solutions contain thickening agents [85]. The determination of whether to utilize retardant is contingent upon factors such as the scale, geographical placement, and severity of the wildfire. In specific cases, the use of fire retardant may also serve as a proactive step for fire prevention. Fire retardants commonly consist of similar compounds to those found in fertilizers. The potential impact of fire retardants on water quality can manifest through many mechanisms, including leaching, eutrophication, or misapplication. The impact of fire retardants on the quality of drinking water has yet to be definitively determined. Various elements, such as the size of the water body, amount of rainfall, and velocity of water flow, contribute to the dilution of fire retardant, hence reducing its concentration and effectiveness. The presence of wildfire waste, including ash and sediment, can lead to the obstruction of rivers and reservoirs, so elevating the potential for floods and erosion. Consequently, these phenomena can impede the functionality of water treatment systems, causing them to operate at a reduced pace or sustain damage [86]. There persists a prevailing worry regarding the impact of fire retardants on terrestrial and aquatic ecosystems, including wildlife habitats and the quality of watersheds. Consequently, further investigation is necessary in order to comprehensively understand these consequences. Nevertheless, it is worth noting that fire retardant, particularly its nitrogen N and phosphorus P constituents, has demonstrated the ability to enhance the fertility of nutrient-deficient soils, resulting in a transient augmentation of vegetation.

According to the prevailing protocol established by the U.S. Department of Agriculture (USDA), it is mandated that the aerial dispersion of fire retardant inside the country adhere to a minimum clearance distance of 300 feet from waterways. This requirement is implemented with the aim of safeguarding against any potential adverse impacts arising from the runoff of the fire retardant substance. The utilization of fire retardants using aerial means necessitates the avoidance of their application in close proximity to waterways and habitats of endangered species, both flora and fauna. Following any occurrence of fire retardant misapplication, it is mandatory for the U.S. Forest Service to ensure that reporting and assessment of the resulting impacts are conducted. These evaluations are crucial in order to ascertain the appropriate measures for mitigation, remediation, and potential restrictions on future utilization of retardants within the affected region.

Chemical additives are extensively employed in conjunction with water for the purpose of combating wildfires in North America, Australia, and the countries situated within the Mediterranean basin. There are two primary categories of products that can be classified based on their method of action: water additives and long-term retardants. The initial category comprises foams and water enhancers, specifically gels. The water's ability to moisten and cover fuels is enhanced by the reduction of surface tension and the modification of viscosity, respectively. The aforementioned additives are administered directly onto the combusting fuel in order to mitigate the flames. The efficacy of the solution persists until the complete evaporation of water. The primary constituents of these goods consist of surfactants, which are responsible for generating foams, and superabsorbent polymers, which contribute to the formation of gels. Additionally, these products incorporate several other compounds, including stabilizers, solvents, thickening agents, and corrosion inhibitors. In the second category, referred to as long-term retardants, the water present in the prepared solution assumes a secondary function as it serves as the carrier medium facilitating the delivery of the retardant product to the fuel. These items have the ability to suppress the flame and modify the process of combustion, exhibiting sustained efficacy even after the evaporation of water. Consequently, these measures are typically implemented in advance of the advancing fire front. The primary constituents of these products consist of inorganic salts, specifically $(NH_4)_3PO_4$ and $(NH_4)_2SO_4$. However, commercial formulations may also incorporate additional substances such as thickening agents, coloring agents, and corrosion inhibitors [74].

As per the information provided on the official website of the state of Oregon [84], both long-term and short-term retardants have been identified as having detrimental effects. However, it is noteworthy that long-term retardants exhibit a significantly greater degree of harm. Specifically, long-term retardants possess acidic properties and include elevated concentrations of nutrients, hence posing a substantial risk to the health and well-being of landscape plants. It is advisable to promptly cleanse plants that have been treated with fire retardant in order to mitigate the risk of potential chemical burns to their leaves. The presence of these substances may result in detrimental effects on the quality of water and the well-being of aquatic organisms, including fish and other species. It is recommended that washwater be discharged onto a suitable surface, such as a grass, which facilitates the absorption of retardant and ash particles present in the washwater.

The conventional long-term retardant, which is a red-colored slurry obtained from fertilizer, has the ability to decelerate the propagation of fire. However, it has the drawback of depositing a residue that possesses toxicity to wildlife and can contaminate water sources. According to testing conducted by the U.S. Forest Service, FireIce has been shown to be non-toxic, non-corrosive, and devoid of any adverse effects on aquatic or terrestrial wildlife. The estimated cost of the aircraft employed in combatting the Spring Glade Fire is projected to be approximately $100,000. One limitation of FireIce in comparison to conventional retardants is its limited effectiveness, lasting around 24 hours, after which the water-bubble blanket undergoes evaporation. The proposed method of deploying a line of FireIce at a considerable distance from a fire in order to impede its propagation seems unlikely to be effective. In contrast, aircraft disperse the gel substance in a targeted manner right onto the conflagration (Marmaduke, 2017).

From the previous summary, the following complementary methodological steps can be suggested:

Procedures before and after/during the fire

Before the Fire

- Have to explore and analyze the soil and find out its components from peat, coal, tree roots, and other buried organic matter. This reduces the incidence of Ground Fire-type wildfire.
- Knowing the type of vegetation, the number of trees, the remains of trees on the soil, and the growth stage of trees, this reduces the incidence of Surface fire-type wildfire. It may indirectly contribute to reducing the occurrence of a Crown Fire-type wildfire.

Note: It is often observed that trees possessing leaves, commonly referred to as deciduous trees, exhibit a significantly lower rate of combustion and intensity compared to trees characterized by needle-like foliage, known as coniferous trees. There exists a minor exception to this rule. During the early spring period, deciduous trees have the potential to exhibit high flammability levels shortly before the emergence of their new leaves. During this temporal interval, the moisture content within the trees exhibits a diminished state, hence augmenting their susceptibility to combustion till the emergence of their foliage.

Knowing the type of vegetation: Forest fuels can be categorized into four distinct classifications:

- Ground fuels encompass various components, including fine fuels often known as the litter layer, fine fuels in the initial stages of decomposition known as the fermentation layer, and undifferentiated organic matter referred to as the humus layer.
- The components of surface fuels include coarse woody debris and ground-level plant biomass.
- The understory fuels encompass both the biomass of live and dead shrubs and saplings.
- The presence of overstory fuels, which include both live and dead standing trees, is a significant factor to consider.

- Triage of dead and dying trees to making “green” (live) forests more resilient.
- Study the age of trees.
- When performing the tree cutting technique, trees with a thick diameter must be preserved, as mentioned by [88] the probability of survival was higher in larger-diameter trees, which is associated with the thickness of the bark.

Note: We can say that it includes survey or study above and below the surface of the soil.

- Soil analysis and knowing the volume of organic matter in the soil and the moisture in it.
- Knowing the moisture content of the soil, studying the humidity of the forest throughout the year, and trying to make the forest more humid, which leads to an increase in the vitality of the forest (more resilient), and to make the fuel in the forest more moist, which leads to a decrease in the occurrence of fire and preventing an increase in the continuity of fire.

After/During the Fire

- The type of fire must be known if it is: Ground Fire, Surface Fire or Crown Fire.
- Studying climate indicators, especially wind speed and direction to reduce the intensity of the Crown Fire type.
- Know the type of fuel in the forest and its volume.

- Investigation of the size of tree diameters and the age stage of the tree.
- Follow the necessary procedures and various methods known to suppress the fire.

Recommendations and Suggestions

- It's important to recognize that not all wildfires are the same.
- The manipulation of the fire environment can significantly influence the possibility for fire behavior management.
- When cutting forests, the height of the trees must be taken into account, and the highest height of the trees should be taken into consideration. On this basis, the thickness of the cutting belt is as if the height of the trees is 50 m. A belt is made with a distance of 60 m in the middle of the forest (more like a dirt road without trees). This leads to cutting off the continuity of fire and giving extra time to put out the fire at this interval (belt).
- If conditions permit, make the belt more humid in hot weather by providing the belt with appropriate irrigation systems.
- Use of fire retardants rich in phosphorus and nitrogen.

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