Proceedings of ICEGEE 2025 Symposium: Sensor Technology and Multimodal Data Analysis
DOI: 10.54254/2753-8818/2025.AU24388

Interaction Between Ecosystem and Wildfires in California under Climate Change

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Abstract. Modern high technology has brought about huge changes to people's lives, but the endless usage of natural resources has greatly increased carbon emissions, aggravated environmental pressures, and altered the earth's climate meanwhile. The occurrence of wildfires in California is an exemplary case of these serious consequences of environmental damage. This paper set out to study how the ecological environment and wildfires interact with each other under the circumstance of climate change. Caused by global warming, temperature, water and wind conditions to change, thus the combustibles-driven and wind-driven wild fires become more severe, with higher frequencies and larger impacts. The occurrence of wildfires changes the vegetation, soil and landforms. The vegetation type can switch, with a lower net coverage and biodiversity; the invasive species can benefit; the biotic availability of soil elements decreases and the soil ecosystem worse off; the landforms change with the sediment flow increases. This paper is of great significance since it fills the gap in explaining the relationships between ecosystems and wildfires conclusively, and future studies can be supported. The protection of natural environment is expected to be enhanced in California and similar regions.

Keywords: Climate change, wildfires, ecology, global warming

1. Introduction

Nowadays, great technological developments have brought great convenience to human life. However, as the global population upsurges and the scale of mechanized production increases, the emissions of greenhouse gases grow with each passing day. According to research, global CO2 emissions for 2023 have reached 35.8Gt and there’s a 67% possibility for the carbon budget to be depleted within 6 years [1]. The particles of greenhouse gases can absorb infrared radiation, undergo vibration, and emit some of the radiation to the surface of the Earth to increase global temperature. Thus, global warming is largely caused by the extreme temperature, precipitation and wind factors that occur more frequently, and the natural environment suffers. Great economic and social costs are established, noticing human beings that the situation is really serious. A notorious example is the wildfire in California, US. Known that wildfires occur most frequently in summer and autumn, it is proved in the following text that anthropogenic climate change is strongly related to the severe circumstances of California wildfires. As for the summer forest fires, the area burned annually grew to nearly eight times its original size from 1972 to 2018. Since the early 1970s, the hot days have

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been warmed about 1.4 degrees Celsius, and the deficit in atmospheric vapor pressure has augmented remarkably. These upwards trends are closely in line with the extent of summer wildfire burning area. For the fall forest fire, the warming background and substantial drying fuels may increase the wildfire events a great deal. Although the negative impacts of wildfires are numerous, simple data on economic costs was calculated in 2018 to quantify them. This statistic included impaired capital, costs for air pollution related health cares, and further consequential loss was approximately 148.5 billion dollars [2].

There has been plenty of kinds of literatures studying climate change, wildfires, and ecosystems. The prediction of future forest fires happening, the changes in temperature, precipitation, and wind have been studied to a deep extent, and the impacts on the ecological environment (including soil, vegetation, etc.) have been carefully studied through various research and experiments. However, current academic papers lack of studying the interaction between wildfires, and ecosystem under the context of global warming. This paper aims to fill this gap and explain the correlated relationships in detail, taking California as an exemplary district.

This study conducts an elaborate exploration of how climate change contributes to the escalation of wildfires, where climate change phenomena include extreme weather, El Niño and La Niña. Forest fires are analyzed in terms of two main types of fires: combustible-driven fires exacerbated by drought and wind-driven fires enhanced by wind and hydrologic conditions. The paper concludes with a discussion of the impacts on biotic and abiotic environmental factors, including vegetation, soils, and landforms. This paper hopes to inform the public about the critical importance of maintaining good spontaneous functioning of natural systems and to create awareness of the need to eliminate greenhouse gas emissions.

2. Climate change exacerbates wildfires

2.1. Extreme weathers

Under the background of continuously increasing carbon emissions, extreme weather has occurred more frequently while El Nino and La Nina are the two main factors of which. El Nino is an abnormal phenomenon, which means bringing opposite conditions and can deteriorate global warming. Take precipitation as an example, districts being flooded in the past may undergo drought in the years having El Nino. La Nina is the opposite of El Nino and will enhance the original situation, such as raising the flooding to an extraordinarily high level in commonly flooded areas. La Nina often alternates with El Nino, which can relatively alleviate global warming, and is a kind of adjustment mechanism of nature.

2.2. Drought and available combustibles

The positive correlation between drought and wildfires is supported by studies. Based on an assessment of ponderosa forests and canopy mixed conifer forests located in the Sierra Nevada of California, the two districts both showed higher fire activities in drought years [3]. When La Nina occurs, precipitation increases greatly so that the vegetation in the area is adequately supplied with water and grows vigorously to a large extent. After that, following the rule of alternative occurrence, El Nino may happen. Sudden droughts and high temperatures may occur in most districts in California. The increasing temperature in spring also contributes to a more rapid melting of snowpack, and the dry soils exist for a longer season [3].

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Flora native to California possess characteristics of dehydration tolerance or dehydration avoidance to resist water stress during drought. Nevertheless, the hydraulic capabilities of many shrub species could be impaired once the time-span or fierceness of drought exceeds their adaptive thresholds and the xylem cavitation take place in stems [4]. Death of the stem and the whole plant can be caused in turn. As the environment moisture is reduced, the transpiration demand increases, causing the litter and dead materials to have a lower water content [3].

The moisture percentage of the living and dead fuel materials holds great significance and can affect the scope of wildfires significantly. As soon as the plants are ignited, they will spread the fire to a large range immediately. Thus, a higher possibility of fire spread and ignition may be promoted by the larger volume of dry herbaceous fuels. However, climate impacts on fuel moisture and volume are of varying importance in different vegetation types [5]. In the mixed conifer forests, the previous precipitation has little relationship with fires since the fire spread is dependent on litter. In the open ponderosa forest, the previous precipitation is strongly correlated with fires where fire spread is dependent on dried herbaceous fuels [3].

2.3. Wind and hydrological conditions

Due to the temporal coincidence of maximal annual vegetation dryness and desiccating offshore windstorms, the peak risk of severe fires usually happens in fall rather than warmer summers [6]. Offshore wind refers to the sporadic appearance of strong wind travel from land to sea, and the usually moist onshore wind across coastal California is reversed. It happens during the autumn for it is mainly driven by the intensive surface pressure gradients—generated by cold air masses above the Great Basin. Therefore, when the winds blow from the interior desert districts through the western declivities of California's mountain ranges heading towards the Pacific Ocean, they are largely dried and warmed [7].

Although the precipitation that occurs in spring and autumn contributes a small proportion to the annual precipitation, it has an important meaning in increasing the moisture of plants. The transpiration rate for plants is high during several months between spring and autumn, so without the supply of rainfall, the dryness of vegetation can become extremely high and is very dangerous. Even with a slight 2 percent to 5 percent increase in rainfall, the wildfires fanned by the winds can be strongly inhibited [7].

In recent years, affected by human activity, data showed that the narrow rainy seasons in California have become more acute. Based on observation from various stations from 1960 to 2019, the precipitation significantly decreased statistically. This was primarily driven by decreased precipitation in November while this is the most wet month. The drying trend is observed across South California and North California [8]. The shorter and deferred rainy season could stem from a tardy enhancement of the semi-permanent Aleutian Low and the ensuing southward migration of the mid-latitude storm course[7].

The delay of the raining season made an intense negative impact by increasing the synchronous occurrence between offshore wind period and plant desiccation. It is observed that the frequency of rainfall occurs during the peak of offshore wind or after that increases, and a higher possibility of wind-related wildfires happening presents [8]. It is noticeable that wind-related wildfires may be more destructive. The study showed that the wind velocity on the day of fire ignition was the top factor in the total costs. In communities with complicated road systems and terrain, the conservation of life and property is extremely hard while the strong offshore winds bring a high speed of spreading the wildfires. The intense winds can even preignite the combustibles across a range of distances since the heat and sparks are blown to the areas ahead. The sample in the 2018 Camp Fire

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provided strong evidence for the statement since the bushes and plants located several kilometers away from the combustion center were ignited by wind with a speed of over twenty-two meters per second [9].

3. Impacts of wildfire on the environment

3.1. Vegetation and plants

The conversion of ecosystems from one type to another is one notable consequence of planetary climate transformation. In South California, the vegetation shifts from woody shrublands to invasive annual grasslands, with the increasing occurrence of wildfires being one of the primary factors. The study driven by Alexandra et al, calculated the percentages of coverage for woody and herbaceous in South California from 1950s to 2019 using airscapes. It was observed that the net vegetation coverage (increase in herbaceous vegetation subtracts the decrease in woody vegetation) declined substantially while most changes occurred in the northern interior and southern coastal areas. Although the strong correlation between the occurrence of short-interval fires, degree of deviation from historical fires, and changes in vegetation is uncontroverted, they are not the only determining element as other factors including low soil mortality, the complexity of the terrain also have substantial effects on the changes of plantation in various regions [10].

The turning of the ecosystem in this case indicates that the large and whole forest areas decrease in space and also break into small pieces. The rate of fragmentization for the forests increases, and contributes to changes in interactions between fungal pathogens, insect herbivores and plants. An analysis studying how the fragmentation of forests affects the variation of natural enemies, and then decreases the plant species diversity is present. The researchers used biocides to inhibit the insects and fungi and observed significant changes in survival rates of trees in twenty-one blocks in the forest of the Western Ghats in India [11]. The result showed the change in forest scale has negative biotic processes on the diversity of plant species by interacting with other density-dependent biotic factors including fungal pathogens and insect herbivores.

The kinds of literature showed that the local plant species and invasive plant species have different responses toward the occurrence of wildfires in different regions. It is suggested that wildfires have positive effects on the activity and composition of invasive plant species; have no significant effect on the composition of local species; have a negative effect on the activity of local species [12]. Furthermore, the responses of vegetation to wildfire vary in different ecosystems. A strong positive response for invasive species toward wildfires taking place in arid shrublands, temperate forests and heathlands is suggested.

3.2. Soil elements and ecosystem

Soil is a mixture of organic materials, mineral ions, gas and liquid, and is able to exchange elements actively with living organisms in various geological spheres [13]. Thus, soil is essential for the biological environment on earth. Studies have proved that the wildfires have significant effects on the soil. The properties of the soil in terms of biological, chemical, and physical aspects can all be changed to some extent after the wildfires. As these factors are changed, a situation where combinations of different factors that rarely appear at the same time exist, and promote the reactions that can’t happen in the original soil to take place. The movement, transportation and circular flow of some elements in the soil are also greatly affected by the fires. Based on studies using advanced analysis technologies such as X-ray absorption spectroscopy, it is proved that the state of the

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element—oxidation state, reduction state, and molecular shapes can be affected by the high temperature during the fires. In this process, the bioavailability of these elements can be changed, and even nutrients can be turned into pollutants. Take chromium, a redox-sensitive element as an example, it is considered to be a vital trace element in +III oxidation state, but can easily converted to +VI oxidation state during the fire. As a result, human health can be threatened while chromium can accumulate in the underground water [13]. Using phosphor- and neutral-lipid fatty acid, the soil biomass including major microbial groups is measured, and the food web structure in the soil is built to investigate its functions. Although the study showed that the total biomass stays the same over the gradient of different wildfire frequencies, the elasticity and stability of the soil biotic system is the lowest in 4-year wildfire frequency [14].

3.3. Landforms

Wildfire is the main factor in yields of mountainous and hillslope landscape dusts production. The fires can change the structure of soil, making it more hydrophobic and the permeability of rain to the soil is limited. The post-fire intense rainfall is also more likely to happen, leading to a higher possibility of debris flow. These factors cooperatively contribute to the higher transportation of sediments from mountains to rivers, and the downstream riparian habitats are influenced. Against the backdrop of planetary climate transformation, the frequency, extent and power of the fires and rainfalls will be further exacerbated, and worse situations of the environment are suggested [15]. An analysis studied the fresh data of the shoreline in Big Sur, California, and showed how the sediments affected the location of which. The wildfire occurred in 2016 with a record-breaking high precipitation increased yields of sediments in the Great Sul River while about thirty percent of these river sediments were inferred as littoral-grade sand. Subsequently, the widest satellite-documented beaches over the past thirty-seven years were formed since sands were integrated into the units along the sea [15].

4. Conclusion

This paper teased the intricate relationship between wildfires and the ecosystem in California under the backdrop of climate change. Through in-depth analysis, several key findings have emerged. Caused by global warming, temperature, precipitation and wind changed their patterns and have cooperatively increased the strength, duration and frequency of wildfires in California by promoting both combustibles-driven and wind-driven fires. After that, the occurrence of wildfires has profound impacts on the environment. It can change the vegetation type, and decrease the net vegetation coverage and biodiversity. Even local germplasm resources can be threatened as the invasive species benefit while the local species do not. The soil and base of an ecosystem are also disrupted, with alterations in soil properties creating the environment for abnormal reactions to take place, the biotic availability of elements, and the elasticity and stability of the soil ecosystem are decreased. Even landforms can be modified, while the increased sediment flow from mountain to river may change the downstream habitats and seashore. By providing a comprehensive understanding of the complex relationships, it is of great significance for scientists studying regional ecological changes. The results can also serve as a reference for policymakers to develop more targeted and effective fire management strategies and environmental protection policies. This study has its limitations, as although California is a complex small ecosystem separated by mountains and rivers, the climate varies to some extent across different geographic regions. This article mainly focuses on overall trends, but does not clearly explain the specific patterns of climate change in different regions, and

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the cycles of wildfires and climate change have not been fully explained. It can also discuss species living in California that have significant impacts on the entire ecosystem. Future research may focus on improving climate models to better predict extreme weather events and their impacts on wildfires. In conclusion, climate change is intensifying the wildfire situation in California. It is urgent to take measures to eliminate greenhouse gas emissions, and a collaborative effort from governments, scientists, and the public is crucial to mitigate the impacts of wildfires and protect the ecological balance.

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