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Review Paper

Impacts of Wildfires on Human Health, Ecology, and Economy: An Overview

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Abstract

Wildfires have existed since prehistoric times occurring regularly as a natural phenomenon of the forest's ecosystems. The discovery of 440-million-year-old fossils of charred remains of plants show that the history of wildfires can be traced back to the Silurian period. Such fossil records became more frequent with the progression of geological time. Larger and sustained wildfires may negatively impact human health, environment, and economy. Conversely, wildfires are also vital for life cycles and the continued survival of some plant species. Thus, wildfires play an important role in the renewal of some ecosystems. In recent years, wildfires have become more frequent with escalated intensity and duration, and have been conjoined with massive health, ecologic, and economic consequences. Expanding anthropogenic activities and climate variability may have contributed to the current rise in the wildfire frequency, intensity, and duration. Studies indicate that wildfire smoke containing various gases and particulate matter may produce short- to long-term human health consequences, including death. If the frequency, amplitude, and duration of wildfires maintain or surpass the current course, it could produce drastic implications on human health, lifestyle, and the environment, and may affect the flora and fauna of various ecosystems. This paper focused on the impacts of wildfires on human health, ecology, and economy, as well as the impacts of shifting climatic conditions on the frequency and severity of wildfires.

Keywords: Wildfire, forest fire, climate change, health, ecological and economic consequences.

1.0 Introduction

Wildfires, also known as forest fires, are uncontrolled fires that burn wildland vegetation. Wildfires are a ubiquitous part of the Earth's ecosystem. For hundreds of millions of years, wildfires have been burning the forests, savannas, grasslands, and other wildland vegetation throughout the continents under varieties of climatic conditions. The United States Forest Service (USFS) has described wildfires as forces of nature which are nearly impossible to prevent and are as difficult to control (USFS, 2021).

The initiation of wildfires requires three basic elements – fuel, atmospheric oxygen, and ignition– which are referred as the fire triangle. Under favorable conditions such as low humidity and high temperature, both dead and living forest biomass could be used as fuel (Bond and Keane, 2017) and the ignition could be natural or anthropogenic in origin (Figure 1).

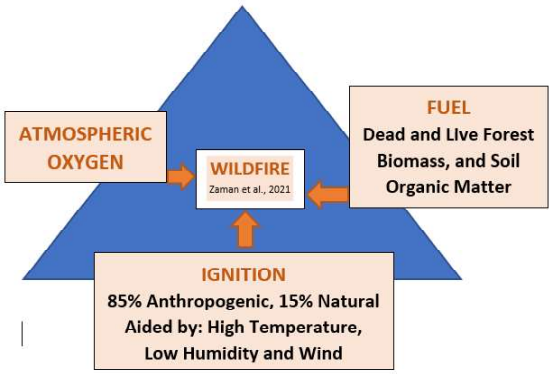

Figure 1: The three key elements of the "Fire Triangle" and the associated factors boosting the intensity and duration of wildfires.

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Wildfires may occur naturally such as a lightning strike, or due to an accidental or deliberate human made spark. According to National Park Service (NPS), in the U.S., about 85% of the wildfires are caused by human activities (NPS, 2021a). According to a National Geographic (NG) publication, forests remain most vulnerable to wildfires during the spring and summer months when long stretches of dry climates persist and dry and dead vegetations, fallen tree leaves, tree limbs, tree roots, grasses, and soil organic matter contribute to fuel such fires. Some plants such as, acacia, bamboo, chamise, cypress, Douglas fir, red cedar, juniper, palm, pampas grass, pine (Taylor, 2020) and plant parts containing resins (NG, 2019) are highly flammable and are capable of boosting wildfires (Figure 1).

The history of wildfires can be traced back to the Silurian period (about 444-419 million years ago) when terrestrial plants evolved, which is evident by observing fossils of 440 million years old charred remains of plants (Scott, 2000; Glasspool *et al.,* 2004). Wider buildup of charred materials (charcoals) appeared about 345 mya, in the late Paleozoic Era (Falcon-Lang, 2000; Scott, 2000; Keeley, 2009), which could be associated with a rise in atmospheric oxygen levels, facilitating the combustion processes. Oxygen started to build up in the atmosphere about 2 billion years ago (Bond and Keane, 2017) and during the Carboniferous Period (about 359 to 299 mya), the level reached a peak of 31% (Berner, 2006), compared to the current level of 21%. During the Permian Era (about 299-252 mya) and Triassic Periods (about 237-201 mya), the atmospheric oxygen level fell and so did the charred fossil materials (Keeley, 2009).

The number and the size of forest fires fluctuates from year to year. Data indicate that since the 1980s, the extent of areas burned due to wildfires have increased and between 1983-2020, an average of about 70,000 wildfires per year have been documented (EPA, 2020d). Climatic conditions such as rain, drought, wind, and temperature play major roles impacting the size and duration of wildfires (Borunda, 2020). The topography of forest lands may also play a role in the spread of wildfires (NG, 2019). Low intensity and balanced wildfires have beneficial effects on the forest ecology including removing invading plants, supporting seed germination and growth of conifer plant species, maintaining natural wood cycling, and providing soil nutrients. However, fires with higher frequencies and intensities can produce unwanted impacts on ecology, economy, and human health. Studies indicate that over the years, wildfire frequencies, duration and intensities have increased all over the world (Figures 2 and 3), and climate change models forecast that wildfire incidence and austerity will increase in the near future (Murphy *et al*., 2018). However, according to the National Oceanic and Atmospheric Administration (NOAA), the increases in temperature have not been ubiquitous and parts of the United States (particularly in the West) are more susceptible to wildfires (NOAA, 2021).

Larger wildfires produce substantial damages to natural resources, property, human health, ecology, and the environment. While the immediate and direct costs associated with fires could easily be determined, the long-term health and environmental consequences from wildfires and fire toxicants are subject to further studies.

2.0 Human Health Impacts

In recent years, stricter regulatory controls have improved the overall air quality in the USA. However, the increased frequency of wildfires tends to produce negative effects. Large fires consume huge amounts of oxygen, thus depleting oxygen in the surrounding environment. Wildfires typically produce huge amounts of heat and smoke, with the smoke containing various hazardous substances capable of causing adverse health effects. Such hazardous materials include aldehydes, benzene, carbon monoxide, nitrous oxide, polycyclic aromatic hydrocarbons, and various organic compounds (WHO, 1999).

Studies in 2012 indicated that smoke from wildfires contained over 50% methene and 20% particulate emissions (Black *et al*., 2017). Wakefield (2012) reported that smoke from wildfires may contain various toxicants that could be categorized into: (1) asphyxiant gases,

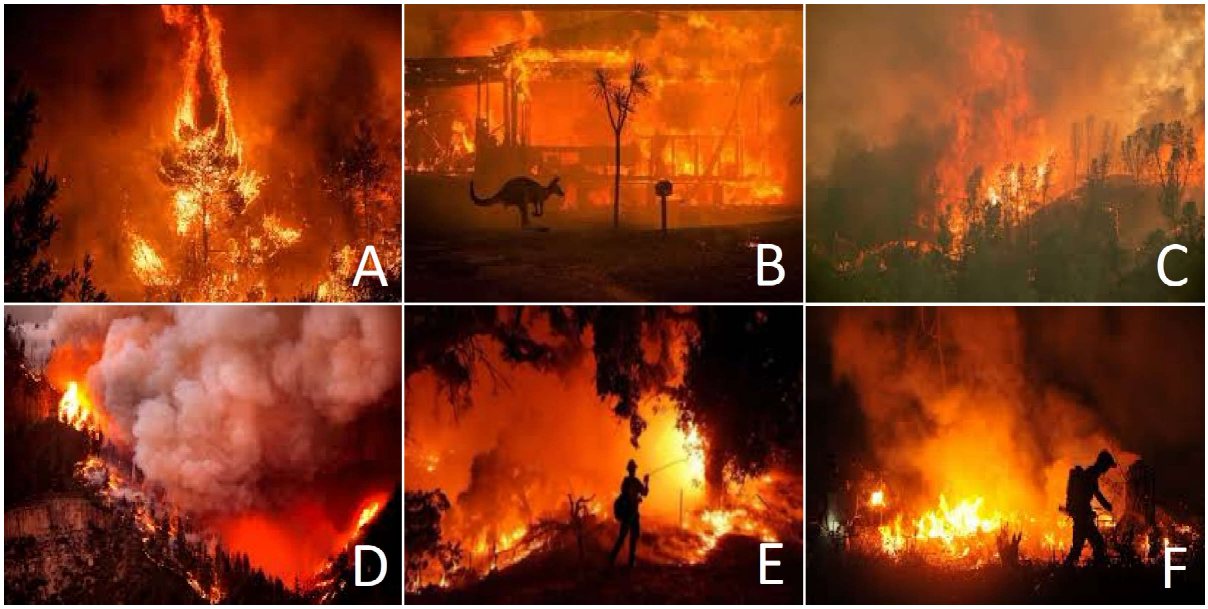

Figure 2: Pictures representing severe wildfires from different parts of the world: (A) Amazon Rainforest Fire, *vox.com*; (B) Australia Wildfire, *morningsidecenter.org*; (C) California Wildfire, *calmatters.org*; (D) Colorado wildfire, *peoplesworld.org*; (E) Northern Ireland wildfire, *wionews.com*; (F) Indonesia wildfire, *Aljazeera.com* (Source: Google).

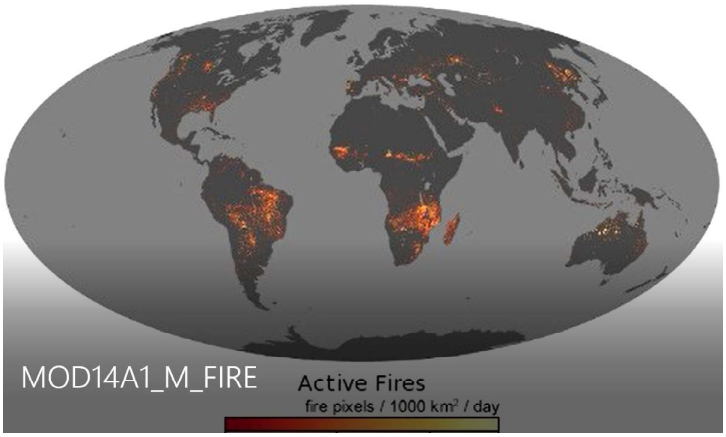

Figure 3: A Global Fire Map – created by NASA Earth Observatory. The link provided below will lead to an interactive Global Fire Map depicting the global wildfire pattern between 2000 and 2021. Source: https://earthobservatory.nasa.gov/global-maps/MOD14A1_M_FIRE

such as carbon monoxide, carbon dioxide, and hydrogen cyanide, and these asphyxiant gases can cause narcosis due to central nervous system dysfunction; (2) irritants, such as hydrogen chloride, hydrogen bromide, hydrogen fluoride, sulfur dioxide, phosphorus pentoxides, acrolein, formaldehyde, ammonia, chlorine, and phosgene which can cause sensory irritation and other injuries depending on the degree of exposure; and (3) complex molecules, such as polycyclic aromatic hydrocarbons, dioxins, isocyanates, and other particulate matters (PM). Additionally, metal oxides, such as chromium trioxide and arsenic trioxide may also be produced. All these substances have various deleterious health effects such as cancer, mutation, reproductive, endocrine, and respiratory dysfunctions, skin irritation and allergy (Kim *et al*., 2013; Kogevinas, 2001; Karol and Dean, 2008; Chu *et al*., 2019; Stevens, 2010).

Exposure to these combustion products, especially carbon dioxide, carbon monoxide, and hydrogen cyanide along with environmental oxygen depletion may cause tissue hypoxia leading to unconsciousness or death. Irritant products from fire mostly affect the eyes and the upper and lower respiratory systems. The extent of damage from such irritants may depend on the exposure duration along with the type and concentration of the irritant materials. Wakefield (2012) stated that the main health hazard from exposure to wildfires would be organic irritant gases. Smoldering wildfires, i.e., fire without flames, which occur due to incomplete combustion of forest materials have also been reported to produce toxins. However, since these toxins are low in concentration, they are unlikely to cause serious health concerns (Wakefield, 2012).

Finley *et al*., (2012) stated that the main pathways of human exposure to wildfires are: (1) heat, smoke and smoldering materials suspended in the air, (2) chemical products from burning vegetation, and (3) PM contaminated water from the fires. The authors also indicated that older people, pregnant women, and those with poor socio-economic status and/or predisposition to cardiac and respiratory disorders were more vulnerable and likely to suffer more from exposure to wildfire smoke.

PM are a major air pollutant contributed by burning forest vegetation, and according to the US EPA (Environmental Protection Agency), PM contained in smoke pose the biggest health threat (EPA, 2021a). These microscopic particles can affect the eye and the respiratory system. PM can pass through respiratory tracts and become deposited in the terminal bronchi and lung alveoli. An increase in PM concentration could be associated with higher mortality rates. An East European study indicated that elevated levels of PM from wildfires that affected about 64% of the population in Finland, caused an increase in daily all-cause mortality (Hanninen *et al*., 2008). An Australian study reported a 5% increase in non-accidental daily mortality rate caused by air pollution from bush fires (Johnson *et al*., 2011). Even with these data, the long-term health consequences from exposure to wildfire emission products is not fully understood and is subject to further investigations.

3.0 Ecological Impacts

3.1 Positive Impacts

Although wildfires are sometimes dangerous to humans and other animals, low intensity fires produce positive environmental effects. According to NG reports, many ecosystems benefit from periodic wildfires as fires are essential to revitalize forest ecology. Low intensity wildfires clean up debris on the forest floor, remove dead trees and competing vegetations, remove unhealthy plants, and kill insects and pests harmful to plants (NG, 2020). Remarkably, the animal fatalities from wildfires are low in many areas as animals escape the fires by moving to safer areas or burrowing into the grounds (NG, 2020).

The life cycle and sustained survival of some plant species vitally depends on wildfires. According to U.S. National Park Service (NPS), long-term survival of 33 plant species in Everglades National Park depends on fire (NPS, 2021b). Wildfires help the release and germination of seeds of certain plant species, such as scrub, chamise, jack pine, lodgepole pines, and certain types of lilies and lilacs (NPS, 2021b; NG, 2020). According to American Forest Foundation (AFF), fires support new growth of plant species and maintain the natural cycle of woods' growth and replenishment (AFF, 2021). Fires promote sprout of aspen, birch, and willow from their roots (NPS, 2021b). Planned or prescribed fires are often used to prevent future devastating wildfires that could occur by removing organic matter on forest floors serving as fuel.

Additionally, wildfires help provide soil nutrients, support growth for vegetation and provide food for herbivorous animals and birds. Barkley (2019) stated that wildfires can improve the fodder quality for wildlife for a few to many years following the fire occurrence. For a short

term, dead animals and burned plant materials provide food for scavengers and small animals. Bark beetle and other insect population growths are found to be supported by fires (Barkley, 2019; NG, 2020).

Fires also play an important role in supporting habitat requirements for the biota in the wetland ecosystems. Wetland hydrology is a complex system and is influenced by both the biotic and abiotic factors in the environment. Fires play significant role in maintaining hydrology, nutrient, soil chemistry, organic matter deposition, and flora and fauna composition of the wetlands (Neary *et al*., 2005). Wetlands are generally more shielded from wildfires and thus provide refuge for wildlife from fires (Barkley, 2019).

Wildfires are crucial for the vitality of boreal forests (Taiga) which represent about 30% of the global forest areas (IBFRA, 2021). Boreal forests grow in high-latitude environments where freezing temperatures exist for 6 to 8 months. The boreal ecozone is extended in parts of Russia, China, Japan, Norway, Sweden, Finland, Canada, and the United States (IBFRA, 2021). Boreal forests occupy about two-thirds of Eurasia, and in Russia, they cover about 12 million square kilometers, which is one of the largest biomes in the world. Wildfires play an important role in the thawing of the upper soil layers (active soil layers) in boreal forests during the summer months by removing the surface vegetation and organic soil layers, thus helping the vitality of the forest (Jafarov *et al*., 2013).

3.2 Negative Impacts

Wildfires are periodic phenomenon in most terrestrial ecosystems. Anthropogenic or deliberate fires are being used as tools to manage various forestlands. Such fires may produce a wide range of effects on soils, water, and the biota of the ecosystems (Neary *et al*., 2005). The forest ecosystems can be impacted by the frequency, severity, and the extent of the wildfires (Lesmeister, *et al*., 2019). Wildfires affect the soil quality, and consequently, can affect the flora and fauna. Fires can change soil texture, density, porosity, pH, and moisture content (Jhariya and Raj, 2014). Vegetation and organic matter that cover soil surface, helps prevent soil erosion. Fires that destroy these soil coverings, expose soils to direct weather which may lead to excessive soil erosion (Neary *et al*., 2005). Letey (2001) reported that high surface temperature from fires can incinerate soil organic matter and cause the soil to be hydrophobic. Such loss of soil consistency may lead to erosion and destruction of ecosystems and biodiversity. Fires can enhance carbon and nitrogen availability in soil which may cause increased microbial activity and decrease soil carbon sequestration (Wang *et al*., 2012). Conversely, fire may also reduce soil micro-organism biomass affecting the nutrient cycling and soil fertility (Swallow *et al*., 2009; Sun *et al*., 2011). Understandably, loss of soil productivity can affect the distribution of flora and fauna of the forestlands.

Fires may considerably impact wildlife by altering their habitats. In a short run, wildfires reduce the shrub density and promote the growth of herbs. As fires reduce the number of trees and allow more sunlight on forest floor, herbs flourish (Sheuyange *et al*., 2005). Fires also promote the growth of fire-tolerant plant species over the intolerant ones. Studies indicate that repeated fires can destroy forest flora and negatively impact the fauna including endangered species due to habitat modification and destruction. The extent of such impact depends on the extent of habitat change (Jhariya and Raj, 2014). Invertebrates, especially insect populations get severely affected by wildfires, while animals living in moist habitats such as amphibians and reptiles are least affected (Barkley, 2019).

Fish mortality in the wetlands and water bodies can also be linked to wildfires. Accumulation of debris from fires and application of fire retardants to control fires were found to be responsible for killing fish population during wildfires (Neary *et al*., 2005). Wildfires may also lead to the loss of nesting resources in birds. Loss of habitat and nesting resources following wildfires for swift parrots, a cavity nesting bird, have been reported, causing the birds to miss

reproduction opportunities (Stojanovic *et al*., 2016). Bosso *et al*., (2018) reported loss of habitats for bat species following a severe wildfire.

Ozone (O_3), a greenhouse gas, is known to produce negative effects on human health and ecosystems (Jaffe and Wilder, 2012). According to United States Environmental Protection Agency (EPA), while O_3 in the upper hemisphere provides shield against solar ultraviolet rays, O_3 produced at ground level is a health hazard (EPA, 2021b). Wildfire emissions and high temperature help form atmospheric O_3. Global wildfires are linked to approximately 3.5% of annual global tropospheric O_3 production. In the USA, the current permissible O_3 level in the air is 75 ppb (parts per billion) by volume. However, the increasing frequency of wildfires are likely to contribute to elevated levels of O_3 in the troposphere as has been recorded at monitoring sites (Jaffe and Wilder, 2012). Ozone is a major component in smog and may cause various respiratory problems such as throat irritation, coughing, inflammation of the bronchi, lung tissue damage, and reduced lung functions. Since O_3 can be carried by wind, it can affect distant areas (EPA, 2021b).

Ground level O_3 can enter plant leaves and alter photosynthesis. Reduction in photosynthetic activities affects plant's nutrient supply, causing sluggish plant growth, and makes plants weak and vulnerable to diseases. Such effects on plants may produce negative impacts on various ecosystems, resulting in loss of plant diversity and subsequent loss of animal, insect, and fish populations (EPA, 2021c).

3.3 Climate Change Impacts

Climate change is thought to be a long-term phenomenon which could be slowly shifting the Earth's weather pattern. A sizeable number of scientists acknowledge the concept of climate change which suggests the Earth has been gradually warming up. However, recent data from the NOAA indicate that the warming has not been ubiquitous across the United States. For example, temperatures in the Northern Plains and Upper Midwest have actually cooled from 1981-2010 to 1991-2020. Precipitation was another factor with those areas west of the Rocky Mountains being wetter while the Southwest was much drier (NOAA, 2021).

Thus, increased temperature in the west along with a drier climate has made that part of the U.S. more susceptible to wildfires with 2020 being a record setting year for fires in California (Cal Fire, 2021). Both anthropogenic activities such as those that produce greenhouse gases and non-anthropogenic activities such as volcanic eruption, and cosmological radiation may have been contributing to global warming. Furthermore, the increases in temperature appear to correlate with solar activity in the past, although recent years have not (Cubasch, *et al*., 1997; Xaio *et al*. 2017). Using theoretical methodologies, and mathematical and computer models, researchers predict that the Earth will continue to warm up in the upcoming centuries (Zaman, 2015; Gray, 2019).

Global warming is contributing to fast changing weather pattern, affecting various ecosystems, and may lead to widespread drought in the next 30-90 years (Dai, 2013). Such changes in weather pattern may have amplified drought in drying out forests and made them more vulnerable to wildfires (NG, 2020).

According to Union of Concerned Scientists (UCS), USA, the frequency, duration and intensity of wildfires are growing all over the world and affecting more communities (UCS, 2020). High temperatures and low humidity are two important factors in the ignition and sustainability of wildfires. Such conditions support both natural and anthropogenic-ignited fires. Lightning ignitions have increased since 1975 and lightning has been identified as the key factor in causing boreal wildfires in North America (Veraverbeke *et al*., 2017).

According to a report produced by National Aeronautics and Space Administration (NASA), over the past decade, the earth has gradually warmed up. Data indicate, that since 1880, the

earth's atmosphere has warmed up by 1.9^0 F and the fire seasons have extended across about 25% of the global forestlands (NASA, 2019). The past five years were recorded as the warmest years. This report also indicates that the increase in temperature has introduced added fuel in nature to ignite and speed up wildfires. The years 2017, 2018 and 2020 caused the most devastating wildfires in the history of California, and in 2019 wildfires burned millions of acres in Alaska and Siberia (Gray, 2019).

A 2021 report produced by Oregon Climate Change Research Institute (OCCRI), Oregon State University, stated that in Oregon, wildfire frequency and area burned were increased between 1984 and 2018. Since 1895, Oregon's annual temperature has increased by 2.2^0 F per century and projected to increase by 5^0 F by the 2050s. The report also projected a decrease in summer precipitation and an increase in winter precipitation (OCCRI, 2021). During the wildfire occurrences, the state of Oregon experienced moderate to severe drought and about 80% of the state experienced drought status (Burns, 2020).

Another measurement of increased wildfire activity is the increased levels of O_3 in the troposphere. As stated earlier, wildfires contribute about 3.5% of global tropospheric O_3, annually. Sites that monitor air quality increasingly show elevated levels of O_3, perhaps due to increases in the frequency of global wildfires (Jaffe and Wigder, 2012).

4.0 Economic Impacts

Economic factors associated with wildfires include both direct and indirect losses. The direct losses include loss of lives, physical injuries, psychological impacts, loss of infrastructures, and ecological impacts, such as loss of habitats, and agricultural losses. Indirect losses involve economic decline of community, destabilization of utility services and housing market, and health and environmental impacts from fire hazards and fire retardants (Thomas *et al.*, 2015). The economic costs from long-term health consequences due to wildfire pollution exposures are yet to be determined.

As stated earlier, there is a global rise in the frequency and amplitude of wildfires. Wildfires cause major disruptions to ecology, agriculture, housing, health, and tourism (Mancini *et al*., 2018). This article will only address a few wildfire predicaments among the many that the world is currently experiencing.

In a 2015 publication, National Institute of Standards and Technology (NIST) of the U.S. Department of Commerce estimated that the annual economic costs from wildfires could range anywhere between $71.1 billion to $347.8 billion USD (Thomas *et al*., 2015). The western U.S. has experienced a growing frequency of wildfires for decades. In 2018 alone, the state of California suffered an estimated $148.5 billion in total damage from wildfires, with $27.7 billion in capital loss, $32.2 billion in health care cost, and $88.6 billion in indirect costs (Wang *et al*., 2021).

Amazon rainforest fires directly threaten the economy and environment of South America and indirectly that of other continents. The resources such as timber and rubber from the Amazon rainforest contribute over $8 billion in the Brazilian economy, but the fires, suspected to be contributed to by massive deforestation, casts doubt on the sustainability of the resources. Additionally, this can also impact the rainfall and agriculture in the South and North Americas, (Czajk, 2019).

Australia is known for its enriched wild habitats. It is home to a variety of indigenous animals, including 200 kind of mammals, 200 kinds of reptiles, and 350 kinds of birds. Some of these amazing animals are dingoes, flying foxes, kangaroos, koalas, platypuses, possums, Tasmanian devils, and tree kangaroos. Australian bushfires hugely impact the Australian economy and its wild habitats. According to a United Nations Environment Program (UNEP) report, between 2019-2020, bushfires have burned over 18-million hectares (about 45-million acres) of

land, 5,900 buildings including 2,800 homes, caused human fatalities, and killed millions of animals. About 80% of all terrestrial plants and animals live in the forests. Wildfires are destroying the biodiversity at an alarming rate, and currently, over a million species are facing extinction globally (UNEP, 2021).

5.0 Points of Concerns

i. The frequency, duration and intensity of wildfires are growing all over the world, affecting more communities (UCS, 2020). Climate change models also forecast that the wildfire incidence and austerity will further increase and remain high in the near future (Murphy *et al*., 2018).

ii. It is disturbing fact that about 85% of the wildfires are caused by anthropogenic reasons (NPS, 2021a), producing substantial damages to natural resources, property, human health, ecology, and the environment.

iii. Heat and smoke from wildfire contain a large number of hazardous substances as previously described. All these substances have various deleterious health effects such as cancer, mutation, reproductive, endocrine, and respiratory dysfunctions, skin irritation and allergy (Kim *et al*., 2013; Kogevinas, 2001; Karol and Dean, 2008; Chu *et al*., 2019; Stevens *et al.*, 2010; Wakefield, 2012). However, the long-term health consequences from these fire toxicants are not completely understood.

iv. Wildfires produce a wide range of effects on soils, water, and the biota of ecosystems (Neary *et al*., 2005; Lesmeister, *et al*., 2019). By destroying the vegetation and organic matters that covers the soil, wildfires lead to soil erosion (Neary *et al*., 2005), alteration of soil texture, density, porosity, pH, and moisture content (Jhariya and Raj, 2014; Letey 2001). Such impacts on forest soil may lead to destruction of biodiversity and ecosystems.

v. Fires decrease soil carbon sequestration (Wang *et al*., 2012), nutrient cycling and soil fertility (Swallow *et al*., 2009; Sun *et al*., 2011), leading to loss of soil productivity thus affecting the distribution of forest flora and fauna.

vi. Fires impact wildlife by altering or destroying their habitats (Sheuyange *et al*., 2005; Bosso *et al*., 2018), causing them to miss reproduction opportunities (Stojanovic *et al*., 2016).

vii. High temperatures from wildfires help produce tropospheric O_3, a human health hazard at ground level (EPA, 2021b). Increased frequency of wildfires contributes to elevated levels of O_3 in the troposphere as recorded at monitoring sites (Jaffe and Wilder, 2012). Ozone is a major constituent in smog and may cause respiratory illnesses such as throat irritation, coughing, bronchitis, lung damage, and reduced lung functions, and since O_3 can be carried by wind, it affects distant areas (EPA, 2021b). Ozone affects photosynthesis, making plants weak and vulnerable to diseases, resulting in loss of plant diversity and subsequent loss of fauna (EPA, 2021c).

viii. Slowly shifting Earth's weather patterns and global warming may lead to widespread drought in the next 30-90 years (Dai, 2013). This will potentially make the forests more vulnerable to fires (NG, 2020). Recent data from the NOAA indicate that the warming has not been ubiquitous across the United States, and the Southwest parts are drier than the rest of the country (NOAA, 2021), making these areas vulnerable to drought and fire.

ix. The economic impact of wildfires can obviously be associated with loss of private property, farmlands and various businesses destroyed by the fires. People have lost both their homes and livelihood due to widespread destruction by wildfires across the globe. (Diaz, 2012).

x. Kochi, *et al*. (2010) noted that potential damage to health also has direct and indirect economic impact including the cost of medical care, loss of labor and pain and suffering due to health damage.

6.0 Prevention and Management

According to NFPA (National Fire Protection Association), in the U.S., over 45 million homes and 72,000 communities which are intermingled with the wildlands and are exposed to threats from wildfires (NFPA, 2021). Wildfire management is costly as it requires significant preparedness and mitigation efforts. With the cooperation of federal, state, and local entities, the U.S. Forest Service (USFS), a federal agency under the U.S. Department of Agriculture (USDA) has been managing wildfires in national forests for over a century (USFS, 2021). The Bureau of Land Management (BLM), another important agency under the U.S. Department of Interior, is responsible for managing fires on 245-million acres of public land in the United States (BLM, 2021). For the past few decades, fire seasons have been prolonged, and wildfires became more intense and larger in size, causing increasingly challenging tasks for fire management. Wildfire prevention and management must involve both the fire management authorities and the residents around the wildland communities.

Fire management authorities use preventive methods such as, fuel treatments (pruning and removal of selective trees to create open spaces in the forests), prescribed burns (setting intentional fires to burn off excessive vegetation and dead plant materials) and construction of gutter trenches (digging deep and wide trenches on the downhill slopes around the fire perimeter to catch rolling firebrands to prevent fires below the fire-lines) to prevent large wildfires from spreading. Some basic fire safety tips for the residents around the fire-prone wildlands should include clearing dead vegetation, leaves and other debris within 10 feet of the house; clearing flammable materials such as, gas tanks, firewood within 30 feet of the house; pruning trees to keep the lowest branches 6-10 feet above the ground; keeping lawns hydrated; maintaining an emergency supply kit that must include medications, important documents and identification; and consulting the local fire department about the preparation and evacuation plans in the event of a wildfire (NFPA, 2021). Wildfires cannot always be prevented, but such mitigations will definitely be useful to reduce the fire damages.

7.0 Discussion and Conclusion

Like hurricanes, floods, and tornados, wildfires are considered a force of nature that is almost impossible to prevent and difficult to control. While smaller to moderate wildfires have some environmental benefits, such as aiding seed germination of some plant species, cleaning up debris on forest floors, removing dead trees and competing vegetations, removing unhealthy plants, and killing insects and pests that are harmful to plants, larger wildfires are capable of producing significant health, ecological, and economic damages. Some of these damages such as loss of lives, physical injuries, loss of infrastructure, property, and agriculture are direct, and relatively easy to measure. However, long-term human health consequences from asphyxiant gases, such as carbon monoxide, carbon dioxide, and hydrogen cyanide, and particulate matters produced during larger wildfires, and the broader ecological and environmental impacts, such as loss of habitat, and disruption of animal reproductive cycles are not easily comprehendible and will require long-term studies to fully understand. The Human Health Impacts, Environmental Impacts and Points of Concerns sections of this paper have addressed some of these key issues.

Although the impact of human activity on increases in temperature is still a subject for debate, there is no question that humans have been responsible for most (85-90%) of the increase in wildfires, occurring via either accidental or deliberate mechanisms. The fact that temperatures have gone up in sections of the United States does implicate this as a contributing factor to the increased wildfires seen in recent years. Another factor that has not been addressed by anyone to our knowledge is the fact that the current COVID-19 pandemic has potentially led to an increase in outdoor activity particularly in those going outside of urban areas

for recreation. It is certainly possible that many of these individuals were not as experienced in outdoor protocols for campfires or were not as careful with other elements such as cigarettes, which may have led to an increase in accidental anthropogenic causes. Regardless, the increase in wildfires has unwanted and detrimental impacts on human health, economy, and the ecology of our planet.

References

AFF. 2021, "The good and Bad of Forest Fires", Am. Forest Found., URL: https://mylandplan.org/content/good-and-bad-forest-fires#:~:text=Forest%20fires%20help%20in%20the,so%20new%20plants%20can%20grow (Accessed: 10/29/2020).

Berner R.A. 2006, "GEOCARBSULF: A combined model for Phanerozoic atmospheric O_2 and CO_2", Geo. Cosmo. Acta, **70**, 5653-5664.

Black, C., Tesfaigzi, Y., Bassein, J.A., Miller, L.A. 2017, "Wildfire smoke exposure and human health: Significant gaps in research for a growing public health issue", Environ. Toxicol. Pharm. **55**, 186-195 (DOI: https://doi.org/10.1016/j.etap.2017.08.022).

BLM. 2021, "What we do", Bureau of Land Management, URL: https://www.blm.gov/programs/public-safety-and-fire/fire-and-aviation/about-fire-and-aviation/what-we-do#:~:text=The%20BLM%20is%20responsible%20for,the%20health%20of%20the%20land (Accessed: 6/2/2021).

Barkley, Y. 2019, "Wildfire and Wildlife Habitat", Surviving Wildfire, URL: https://surviving-wildfire.extension.org/wildfire-and-wildlife-habitat/ (Accessed: 4/25/2021).

Bond, W.J., Keane, R.E. 2017, "Fires, Ecological Effects of", Mod. Life Sci., (DOI: https://doi.org/10.1016/B978-0-12-809633-8.02098-7).

Borunda, A. 2020, "The Science Connecting Wildfires to Climate Change", Nat. Geo., URL: https://www.nationalgeographic.com/science/article/climate-change-increases-risk-fires-western-us (Accessed: 6/8/2021).

Bosso, L., Ancillotto, L., Smeraldo, S., D'Acro, S., Migliozzi, A., Conti, P., Russo, D. 2018, "Loss of Potential Bat Habitat Following a Severe Wildfire: A Model-Based Rapid Assessment", Int. J. Wildland Fire, **27** (11), 756-769 (DOI: https://doi.org/10.1071/WF18072).

Burns, J. 2020, "We know climate change set the conditions for Oregon fires. Did it stoke the flames, too?", Oregon Pub. Broadcast., URL: https://www.opb.org/article/2020/09/21/oregon-wildfires-climate-change-role/ (Accessed: 5/9/2021).

Cal Fire. 2021, "Cal Fire", URL: www.fire.ca.gov/incidents (Accessed: 10/27/2020).

Chu, H., Xin, J., Yuan, Q. 2019, "The effects of particulate matters on allergic rhinitis in Nanjing, China", Environ. Sci. Pollut. Res., **26,** 11452-11457 (DOI: https://doi.org/10.1007/s11356-019-04593-5).

Cubasch, U., Voss, R., Hegerl, G., Waszkewitz, J., Crowley, T. 1997, "Simulation of the influence of solar radiation variations on the global climate with an ocean-atmosphere circulation model", Climate Dynamics, **13** (11), 757-767 (DOI: https://doi.org/10.1007/s003820050196).

Czajk, B. 2019, "Will the Amazon Rainforest Fire Burn Down the Economy?", Global Edge, URL: https://globaledge.msu.edu/blog/post/56791/will-the-amazon-rainforest-fire-burn-down-the-economy— (Accessed: 6/7/2021)

Dai, A. 2013, "Increasing drought under global warming in observations and models", Nature Climate Change, **3** (171), 52-58.

Diaz, J.M. 2012, "Economic Impacts of Wildfire", Southern Fire Exchange, URL: https://fireadaptednetwork.org/wp-content/uploads/2014/03/economic_costs_of_wildfires.pdf (Accessed: 6/7/2021)

EPA. 2021a, "Health and Environmental Effects of Particulate Matter (PM)", Environ. Protect. Agency, URL: https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm (Accessed: 10/28/2020).

EPA. 2021b, "Ground Level Ozone Basics", Environ. Protect. Agency, URL: https://

www.epa.gov/ground-level-ozone-pollution/ground-level-ozone-basics (Accessed: 5/7/2021).

EPA. 2021c, "Ecosystem Effects of Ozone Pollution", Environ. Protect. Agency, URL: https://www.epa.gov/ground-level-ozone-pollution/ecosystem-effects-ozone-pollution (Accessed: 5/7/2021).

EPA. 2020d, "Climate Change Indicators: Wildfires", Environ. Protect. Agency, URL: https://www.epa.gov/climate-indicators/climate-change-indicators-wildfires (Accessed: 6/8/2021).

Falcon-Lang H.J. 2000, "Fire ecology in the Carboniferous tropical zone", Paleogeo. Palaeoclimatol. Paleoecol., **164**, 355-371.

Finlay, S.E., Moffat, A., Gazzard, R., Baker, D., Murray, V. 2012, "Health Impacts of Wildfires", PLOS Curr. Disasters, Ed 1 (DOI: https://doi.org/10.1371/4f959951cce2c).

Glasspool I.J., Edwards D., Axe L. 2004, "Charcoal in the Silurian as evidence for the earliest wildfire", Geol., **32**, 381-383.

Gray, E. 2019, "Satellite Data Record Shows Climate Change's Impact on Fires", NASA, URL: https://climate.nasa.gov/news/2912/satellite-data-record-shows-climate-changes-impact-on-fires/ (Accessed: 5/8/2021).

Hanninen, O.O., Salonen, R.O., Koistinen, K., Lanki, T., Barregard, L., Jantunen, M. 2008, "Population exposure to fine particles and estimated excess mortality in Finland from an East European wildfire episode", J. Expos. Sci. Environ. Epidemiol., **19** (4), 414-22.

IBFRA. 2021, "The Boreal Forest", Int. Boreal Forest Res. Assoc., URL: http://ibfra.org/about-boreal-forests/ (Accessed: 10/29/2020).

Jaffe, D.A., Wigder, N.L. 2012, "Ozone production from wildfires: A critical review", Atmos. Environ., **51**, 1-10.

Jafarov, E.E, Romanovsky, V.E., Genet, H., McGuire, A.D., Marchenko, S.S. 2013, "The effects of fire on the thermal stability of permafrost in lowland and upland black spruce forests of interior Alaska in a changing climate", Environ. Res. Lett. **8** (DOI: https://doi.org/10.1088/1748-9326/8/3/035030)

Jhariya, M.K., Raj, A. 2014, "Effects of wildfires on flora, fauna and physio-chemical properties of soil-An overview", J. Appl. Nat. Sci., **2**, 887-897.

Johnson, F., Hanighan, I., Henderson, S., Morgan, G., Bowman, D. 2011, "Extreme air pollution events from bushfires and dust storms and their association with mortality in Sydney, Australia 1994–2007", Environ. Res., **111** (6), 811-6 (DOI: https://doi.org/10.1016/j.envres.2011.05.007).

Karol, K.M., Dean, J.H. 2008, "Respiratory effects of inhaled isocyanates", CRC Critical Rev. Toxicol. **16** (4), 349-379 (DOI: https://doi.org/10.3109/10408448609037467).

Keeley, J.E. 2009, "A Burning Story: The Role of Fire in the History of Life", BioScience, **7**, 593-601 (DOI: https://doi.org/10.1525/bio.2009.59.7.10).

Kim, K., Jahan, S.A., Kabir, E., Brown, R.J.C. 2013, "A review of airborne polycyclic aromatic hydrocarbons (PAHs) and their human health effects", Environ. Int., **60**, 71-80.

Kochi, I., Loomis, J., Champ, P., Donovan, G.H. 2010, "Health and Economic Impact of Wildfires: Literature Review", Int. J. Wildland Fire, **19**, 803-817.

Kogevinas, M. 2001, "Human health effects of Dioxins: Cancer, Reproductive and Endocrine System Effects, Human Reproduction Update, **7 (3),** 331-339.

Lesmeister, D.B., Sovern, S.G., Davis, R.J., Bell, M.D., Gregory, M.J., Vogeler, J.C. 2019, "Mixed severity wildfire and habitat of an old forest obligate, Ecosphere, **10** (4), (DOI: https://doi.org/10.1002/ecs2.2696).

Letey, J. 2001, "Causes and consequences of fire-induced soil water repellency. Hydrological Processes", **15** (15), 2867-2875.

Mancini, L.D., Corona, P., Salvati, L. 2018, "Ranking the importance of Wildfires' human drivers through a multi-model regression approach", Environ. Imp. Assess. Rev., **72**, 117-186 (DOI: https://doi.org/10.1016/j.eiar.2018.06.003).

Murphy, S.M., Vidal, M.C., Smith, T.P., Hallagan, C.J., Broder, D., Rowland, D., Cepero, L.C. 2018, "Forest Fire Severity Affects

Host Plant Quality and Insect Herbivore Damage", Front. Ecol. Evol., 6 (DOI: https://doi.org/10.3389/fevo.2018.00135).

NG. 2019, "Wildfires", Nat. Geo., URL: https://www.nationalgeographic.org/encyclopedia/wildfires/ (Accessed: 10/27/2020).

NG. 2020, "The Ecological Benefits of Fires", Nat. Geo., URL: https://www.nationalgeographic.org/article/ecological-benefits-fire/ (Accessed: 10/29/2020).

Neary, D.G., Ryan, K.C., DeBano, L.F., eds. 2005 (revised 2008), "Wildland fire in ecosystems: effects of fire on soils and water", Gen. Tech. Rep. RMRS-GTR-42-vol.4. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 250 p. URL: https://www.fs.fed.us/rm/pubs/rmrs_gtr042_4.pdf (Accessed: 10/29/2020).

NASA, 2019, "What Is the Sun's Role in Climate Change?", NASA, URL: https://climate.nasa.gov/blog/2910/what-is-the-suns-role-in-climate-change/ (Accessed: 5/9/2021).

NOAA. 2021, "NOAA Delivers New U.S. Climate Normals", NOAA National Centers for Environmental Information, URL: https://www.ncei.noaa.gov/news/noaa-delivers-new-us-climate-normals (Accessed: 10/27/2020).

NFPA. 2021, "Wildfire preparedness tips", Nat. Fire Protect. Assoc., URL: https://www.nfpa.org/Public-Education/Fire-causes-and-risks/Wildfire/Wildfire-safety-tips (Accessed 6/2/2021).

NPS. 2021a, "Wildfire Causes and Evolutions", National Park Service, URL: https://www.nps.gov/articles/wildfire-causes-and-evaluation.htm#:~:text=Nearly%2085%20percent*%20of%20wildland,and%20intentional%20acts%20of%20arson (Accessed 10/27/2020).

NPS. 2021b, "Researching the Effects of Wildland Fire", Nat. Park Service, URL: https://www.nps.gov/articles/researching-the-effects-of-wildland-fire.htm (Accessed: 10/29/2020).

OCCRI. 2021, "Fifth Oregon Climate Assessment - January 2021Executive Summary", Oregon Climate Change Res. Institute, URL: https://oregonstate.app.box.com/s/3ce2qvmxy881vug4qu4wgb4ypijbv7m5 (Accessed: 5/9/2021).

Scott, A.C. 2000, "Pre-Quaternary history of fire", Paleogeo. Palaecol. Climatol. Paleoecol., **164**, 297-345.

Sheuyange, A., Oba, G., Weladji, R.B. 2005, "Effects of anthropogenic fire history on savanna vegetation in northeastern Namibia", J. Environ. Manage., **75**, 189-198.

Stevens, J.J., Graham, B., 1, Walker, A.M., Tchounwou, P.B., Rogers, C. 2010, "The Effects of Arsenic Trioxide on DNA Synthesis and Genotoxicity in Human Colon Cancer Cells", Int. J. Environ. Res. Pub. Health, **7**, 2018-2032 (DOI: https://doi.org/10.3390/ijerph7052018).

Stojanovic, D., Voogdt, J.W., Webb, M., Cook, H., Heinsohn, R. 2016, "Loss of habitat for a secondary cavity nesting bird after wildfire", Forest Ecol. Manage., **360**, 235-241.

Sun, Y., Wu, J., Shao, Y., Zhou, L., Mai, B., Lin, Y., Fu, S. 2011, "Responses of soil microbial communities to prescribed burning in two paired vegetation sites in southern China", Ecol. Res., **26**, 669-677.

Swallow, M., Quideau, S.A., Mackenzie, M.D. Kishchuk, B.E. 2009, "Microbial community structure and function: the effect of silvicultural burning and topographic variability in northern Alberta", Soil Biol. Biochem., **41**, 770-777.

Taylor, L.H. 2020, "Flameable Plants to Avoid Having in Your Garden", The Spruce, URL: https://www.thespruce.com/firescaping-the-most-flammable-plants-4107522 (Accessed 10/27/2020).

Thomas, D., Butry, D., Gilbert, S., Webb, D., Fung, J. 2015, "The Costs and Losses of Wildfires: A Literature Review", NIST - US Dept. Comm. (DOI: https://doi.org/10.6028/NIST.SP.1215).

UCS. 2020, "The Connection Between Climate Change and Wildfire", Union of Concerned Scientists, URL: https://www.ucsusa.org/resources/climate-change-and-wildfires (Accessed: 5/9/2021).

UNEP. 2021, "Ten Impacts of the Australian Bushfires", UN Environ. Program, URL: https://www.unep.org/news-and-stories/story/ten-impacts-australian-bushfires (Accessed: 6/7/2021)

USFS. 2021, "Wildland Fires", US Forest Serv., URL: https://www.fs.usda.gov/managing-land/fire (Accessed: 6/2/2021).

Veraverbeke, S., Rogers, B.M., Goulden, M.L., Jandt, R. R., Miller, C.E., Wiggins, E.B., Randerson, J.T. 2017, "Lightning as a major driver of recent large fire years in North American boreal forests", Nat. Climate Change, **7**, 529-534.

Wakefield J.C. 2012, "A Toxicological Review of Products of Combustion", Health Protection Agency Chemical Hazards and Poisons Division Report HPA-CHaPD-004, URL: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/458052/HPA-CHaPD-004_for_website.pdf (Accessed: 10/28/2020).

Wang, D., Guan, D., Zhu, S., Kinnon, M.M., Geng, G., Zhang, Q., Zheng, H., Lei, T., Shao, S., Gong, P., Davis, S. J. 2021, "Economic footprint of California wildfires in 2018", Nature Sustain., 4, 252-260.

Wang, Q., Zhong, M. and Wang, S. 2012, "Meta-analysis on the response of microbial biomass dissolved organic matter, respiration, and N mineralization in mineral soil to fire in forest ecosystems", Forest Ecol. Manage., **271**, 91-97.

WHO. 1999, "Health guidelines for vegetation fire events", World Health Org.; World Meteor. Org.; Inst. Environ. Epidemiol.; Ministry of the Environment, Singapore, Schwela, D.H, Goldammer, J.G., Morawska , L.H., Simpson, O., eds., URL: https://www.who.int/docstore/peh/Vegetation_fires/Executive_Summary.pdf (Accessed: 10/28/2020).

Xiao, Z., Li, D., Zhou, L., Zhao, L., Huo, W. 2017, "Interdisciplinary studies of solar activity and climate change", Atmos. Oceanic Sci. Lett., **10** (4), 325-328 (DOI: https://doi.org/10.1080/16742834.2017.1321951).

Zaman, M.S. 2015, "Ecological Significances of Climate Change", Adv. Sci. Technol. **9**, 1-5.