Journal of Advanced Laboratory Research in Biology
E-ISSN: 0976-7614
Volume 11, Issue 4, October 2020
PP 58-65
https://e-journal.sospublication.co.in

Research Article

Fire Impacts on Forest Ecosystem: With a Focus on the Resilience of Tree Species and Dramatic Change in Insect Populations

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Abstract: The research data was collected from forests located at Haibat Sultan Mountain in Koya district for three years from 2014 to 2017. At the sampling location, fire outbreaks occur many times a year. This study aims to determine the environmental impacts of forest fire on vegetation and insects. This results in the identification of the most fire-resistant trees and the impact of burning on the environment. In the Haibat Sultan Mountain forest, four types of tree species are distinguished which are Pine, *Cupressus*, Pistachio and Oak, their contribution to cover the area is 63%, 19%, 15% and 3% respectively. Oak is the only native tree of the forest and one of the most resistant species, 93 percent of which can survive, but the other species *Cupressus*, Pine and Pistachio are introduced with different level of vulnerabilities, with 75%, 60% and 41% of combustion rates, respectively. Forest fire has a significant negative impact on the population of *Thaumetopoea solitaria* Freyer and *Schistocerca gregaria*, both of which are the main insects of the forest. The average of the number of egg masses of *Thaumetopoea solitaria* and nymph and adult of *Schistocerca gregaria* before the fire is (18.8 masses and 4.1 nymphs and adults), but the average declined dramatically to (3.3 masses and 0.9 nymphs and adults) during the fire season. In the post-fire season, the average is increased significantly (6.3 masses and 1.9 nymphs and adults).

Keywords: Haibat Sultan Mountain, Forest Fire, *Thaumetopoea solitaria* Freyer, *Schistocerca gregaria*, Pine, *Cupressus*, Pistachio and Oak.

1. Introduction

A forest fire may occur naturally or direct or indirect result of human activities. Sometimes it can be controlled with a minimum loss, but sometimes else it might be out of control and causes disaster. The vulnerability of the environment and tree species resistance against fire varies from place to place and depends on the type of vegetation and climate (Bahuguna & Upadhay, 2002). In the past, a forest fire was part of natural cycles, to add carbon dioxide (CO_2) into the air to keep the Earth's greenhouse phenomenon continuant, and to add aerosol to help in precipitation, but industrial activities have replaced that need. Thus, the forest fire increases greenhouse gases as a consequence, it contributes to accelerating global warming (De Groot *et al.*, 2007) because most of the carbon released is in the form of CO_2 by approximately 90%, carbon monoxide (CO) and methane (CH_4) are 9% and 1% respectively (Kasischke and Bruhwiler, 2002). In Canada, the level of carbon emitted from a forest fire is approximately similar to the proportion that comes from industrial emissions (Amiro *et al.*, 2001).

Wildfires may directly contribute to global warming by emitting large amounts of greenhouse gases, such as carbon monoxide, carbon dioxide and methane (Viswanathan *et al.*, 2006) and after the forest fire was extinguished, a large portion of the green space was disappeared. Green space was actively improving air circulation, providing a cooling effect, protects native plants and animal species and conserve plants, soil and water quality.

The frequency, intensity, duration, and timing of fire can vary with climate change (Dale *et al.*, 2001). The forest fire depends on climatic conditions, such as humidity, temperature, frequency of precipitation. In the area of this research, forest fire occurs only in the dry seasons. Dry season significantly increases the chances of drought, so the potential occurrence of forest fire may increase simultaneously. A sudden outbreak of fire is widespread and catastrophic and significantly impacts flora, fauna and biodiversity in certain environments

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Received on: 24 August 2020
Accepted on: 23 September 2020

(Loarie *et al.*, 2009; Myers, 2006; Nelson and Chomitz, 2009). Recovery of trees, vegetation and affected species, especially those that are distinct cannot go parallel with the changes.

The habit of the river watercourse and quality of the water may change when the green space disappears in certain catchments, particularly after a catastrophic forest fire (Dahm *et al.*, 2015). Forests can manage floods, as they can reduce peak runoff (Dale *et al.*, 2001; Calder and Aylward, 2006; Tan-Soo *et al.*, 2016). Forest fire increases water repellency, which leads to infiltration and soil erosion. Water repellency is a soil property that is most affected by combustion during a forest fire (Doerr, *et al.*, 2000). Fire significantly affects soil physical properties including increased bulk density, reduced soil porosity, and decreased water storage capacity (Xue *et al.*, 2014). The changes in soil organic matter, affect chemical, physical, and microbiological properties of the soil (DeBano, 1991). High surface temperatures 'burn' off organic materials and create vapours that move downward in response to a temperature gradient and then condense on soil particles causing them to become water repellent (Letey, 2001). Soil water repellency is a reduction in the rate of wetting and retention of water in soil caused by the presence of hydrophobic coatings on soil particles (Hallett, 2009). Water repellency may influence seedling survival and subsequent stand establishment (Reeder and Jurgensen, 1979). Fire may also affect physicochemical properties of soil, including texture, colour, bulk density, pH, porosity, organic matter, nutrients availability and soil biota (Jhariya & Raj, 2014).

Also, the effect of forest fire on animals and insects has been extensively studied globally. Fires play an important role in regulating ecosystem productivity and diversity by promoting mineralization of nutrients stored in organic matter and allowing the invasion of rapid growing early successional species (Busse *et al.*, 1996; DeBano *et al.*, 1998; Boerner *et al.*, 2009). Fire has influenced the composition, structure and landscape patterns of animal habitat. Wildlife may be affected by fire both through direct mortality or habitat alteration (Lyon *et al.*, 2000b). Immediately after the fire, many insect groups decline markedly, reduction is related to the degree of exposure to flames and the mobility of the insect (Swengel, 2001).

Fire affects both overhead and underground ecosystem components (Neary & Leonard, 2020). Various moth families, in the Lepidoptera order, such as Saturniidae, Noctuidae and Sphingidae, usually pupate underground (Triplehorn & Johnson, 2005). Pupation of Pistachio Processionary Moth *Thaumetopoea solitaria* Freyer occurs in litter and upper soil, the depth of which varies from one place to another. In Israel, it is usually not more than 10cm below the surface, but in Iran, pupation was reported to occur at 15-25cm deep (Davatchi, 1958). This difference is related to the environment and climate conditions.

In some grassland ecosystems, fire can influence grasshopper population dynamics and community composition (Bock and Bock, 1991). This study shows that Desert Locust (*Schistocerca gregaria*) was influenced by fire in the Haibat Sultan Mountains, where planted and native trees are mixed with grass. Most grasshopper species in temperate regions overwinter as eggs in the soil (Guo *et al.*, 2009). Fire occurs more frequently and more extensively during the late spring and early summer and this period grasshopper eggs hatch into the nymphs (Padmaja, 2016). Adults and nymphs are more influenced than eggs as females lay eggs in an egg pod in sandy soils at a depth of 10-15cm below the surface (Symmons & Cressman, 2001). Whereas during fire events, heat penetration can change results due to higher soil temperatures (Hulbert, 1988), it can lead to an increase in egg mortality or accelerate hatching phenology.

This study has been observed for three years. It aims to understand the impacts of fire on trees and insects in the study area. The present study attempts to find which type of tree species is the most resistant and vulnerable to fire exposure. It also reveals the factors behind the decline in insect population; either it is their exposure to fire or lack of food and shelter after a fire event.

2. Methodology

The research data has been collected over three years from 2014 to 2017. During this time, several procedures were followed to survey both selected insects and trees in the study area.

3. Tree Survey

The survey of the trees started after the fire in the study area occurred. Once the burnt and survived trees have been counted, the approximate number of trees before the fire event can be achieved. To have the most accurate data, this study relied on the practical survey instead of remote sensing data as the area is small because satellite images cannot provide data as accurate as it should be. Therefore a team of six people explored the study area for four days to count the complete burnt trees and the surviving ones. To obtain plant data, the burnt trees are marked and their species are determined. GPS was used to drag the exact map of the surveyed area. The authors attempted to collect emission data from local, regional and state authorities on fire characteristics, soil contamination and changes in flood habits, etc., but no data were available.

4. Insect Data Collection

In the study area, only two of the most common insect species have been selected as samples. Insect data were taken from a master's degree dissertation on Haibat Sultan Mountain entomology that was completed one

year before the fire occurred. Insect data were used to compare the years after the fire occurred. The second and third-year data were practically observed. During the daytime, insect egg masses and larvae were detected, calculated and measured, but their life stages have been watched at night, by using a camera, water traps under the trees and light traps around the selected trees.

5. Study Area

The area surveyed for this study covers approximately 355km^2 of Haibat Sultan Mountain. The geographic coordinates are 36.1002° N latitude and 44.6712° E longitude. It is located 3km North-East of Koya City and approximately 73km from Erbil, the capital city of the Kurdistan Province of Iraq. It is among the sub-mountainous area of Iraq that extends North West to South East, which has an elevation of about 1200m above sea level, but as shown on the map the study area elevation is up to 900m on sea level. The study area is within the Mediterranean Sea climatic pattern, with dry-warm summer and cool-wet winter (Saeed, 2008).

6. Results and Discussions

The result and discussion of this study have been divided into two sections: plants and insect data analysis.

6.1 Section one: Plants

In the study area, 2192 trees were observed over an area of approximately 355km^2. The forest includes both introduced and native trees. Four types of trees (Pine, *Cupressus*, Pistachio and Oak) occur in the study area with some other type of species such as Eucalyptus, these are very few in numbers which are not being included in the study (Table 1). Among them, only Oak is the native tree, the rest of them are introduced. The vast majority of forest trees are pines, which made up 63% of the total tree density in the surveyed area. Pine is an introduced tree species and it is a vulnerable tree type of the forest, as 60% of it is completely combusted, whereas only 40% did not burn or regenerated. Pine is a kind of conifer tree and in a dry climate, it has less fire resistance (Guiterman *et al.*, 2018).

Fig. 1: Map of Study Area Location.

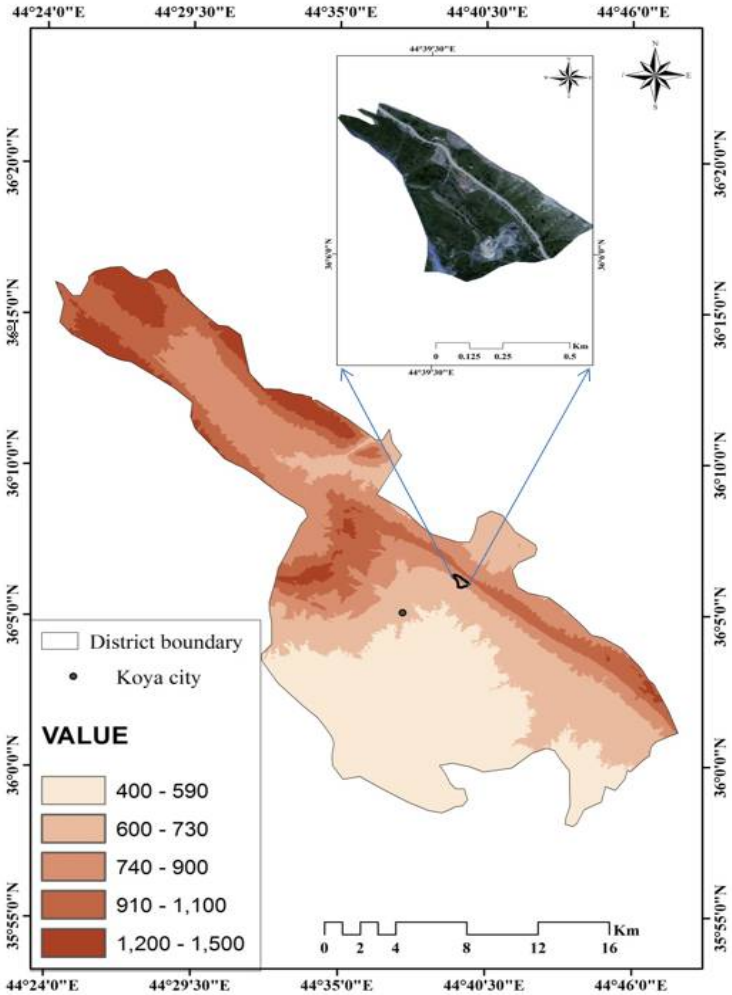

Table 1: Tree combustion and regenerated data of 2014 fire.

	Pine		*Cupressus*		Pistachio		Oak	
	No.	Percentage	No.	Percentage	No.	Percentage	No.	Percentage
Combusted*	823	60	318	75	134	41	5	7
Regenerated**	545	40	105	25	195	59	67	93
Total 2192	1368	63	423	19	329	15	72	3

*Includes the trees are totally burnt.

**Includes both non-burnt trees and those regenerated.

Cupressus is also an introduced tree species which contributes 19% of the forest in the surveyed area, which comes after pine. It is the most vulnerable type of tree species, combusted by 75%, with only 25% not burned or regenerated. Pistachio is native tree species in Kurdistan, but it is an introduced tree species in the study area, 41% of the trees die from forest fire, whereas 59% of Pistachio regenerated after the forest fire, most of which regenerated from the roots. As mentioned earlier, oak is a native plant species of the forest, which contributes only 3% to the surveyed area, but it is one of the most resilient tree species against fire, as also confirmed in North American forest studies (Guiterman *et al.*, 2018). After the fire incident, only 7% of the trees did not recover, but 93% were regenerated (Table 1).

The trunk diameter of the trees is one of the factors that increase the combustion percentage. The diameter is mainly related to the tree age, but the environmental condition, soil and tree types may also play a role. In this study, most of the young trees were completely burnt, because their trunk diameter was small and their height was short and that made them come into more contact with the fire because they were closer to the ground. While tall trees and those grown on the rocky surface had less fire impacts.

Grass and other types of seasonal vegetation were not surveyed specifically, but in general, the grass cover density was remarkably noted in the first spring after the fire event. Fire occurred during harvesting season, which is the period when most of the vegetation is at maturity. After forest fire grass and other short vegetation regenerate from their roots and some seeds that remain in the soil. Moreover, wind may help disperse vegetation seeds over greater distances. If vegetation is removed from an area, then rain erodes the topsoil which leads to sediment.

Global warming is one of the major threats to biodiversity and ecosystem. Globally, fire is a major source of emitted carbon, contributing to global warming, which could lead to biodiversity changes. As global warming increases, fires are likely to become more intense and extensive and may result in significant changes in the ecosystem that would affect biodiversity through species loss or changes in species composition (Nasi *et al.*, 2002; Sintayehu, 2018).

The main focus of this study has been on the fire resistance of tree species because there is no data on soil or flood and there is no monitoring system for the gas emissions in the area. A simple bottom-up approach with the following equation:

$$\text{Emission}_1 = A * B * \text{CE} * e_1 \quad (1)$$

Where A is the area burned, B is the fuel loading (mass of biomass per area), CE is the combustion efficiency or fraction of biomass fuel burned, and e_1 is an emission factor for species i (mass of species per mass of biomass burned) (Wiedinmyer *et al.*, 2006), is not applicable, because we only have the A which is the burned area. But the fact is that any forest fire emissions include greenhouse gasses as per its biomass and its burning ratio.

6.2 Section Two: Insects

This section describes two types of insects to be found in the Haibat Sultan Mountain. The first insect is Pistachio Processionary Moth, *Thaumetopoea solitaria* (Freyer, 1838) (Lepidoptera: Thaumetopoeidae). *Thaumetopoea solitaria* Freyer is a leaf borer moth (Mehrnejad, 2020) and causes severe damage to Pistachio. It has one generation per year. The neonates only feed and survive on very young leaves, while older larval instars consume mature foliage, this causes the infested trees to defoliate (Gindin *et al.*, 2008). During the early season, the larvae of the pest first damage Pistachio buds and reducing the number of shoots emerging, and then voraciously consume leaves until pupation. High pest population, especially on young trees hampers the development of the trees. As a result, a significant reduction in yield occurs (Er *et al.*, 2007). A weakened, damaged and dying plant attracts other pests such as borer beetles.

The second insect was Desert Locust, *Schistocerca gregaria* (Forskål, 1775) (Orthoptera: Acrididae), is one of about a dozen species of short-horned grasshoppers. It is the most dangerous locust species because of the ability of swarms to fly rapidly across great distances. It has two to five generations per year (Mariod *et al.*, 2017). These insects are usually solitary, but under certain circumstances, they become gregarious, which is a type of polyphenism (Simpson *et al.*, 1999; Pener and Simpson, 2009). The two phases differ considerably in behaviour, morphology and physiology (Ott, 2018). In response to changes in population density, this is known to change their behavior and physiology by forming swarms of adults or wingless nymph bands called hoppers. Swarms may contain billions of individuals

behaving in unison; in their gregarious phase, they can migrate over hundreds or even thousands of kilometers. They feed any green vegetation voraciously that comes their way. Bands may contain thousands of non-flying nymphs which also act as a cohesive unit (Cressman, 2001).

6.2.1 Effects of Fire on *Thaumetopoea solitaria* Freyer

In 2014-2017, the effect of fire on *Thaumetopoea solitaria* was statistically significant (Table 2). In the pre-burning season (2014-2015) there were 13.6 egg masses/tree for the first plot, which was the lowest number compared to the second and third plots as they were (18.3 and 24.4) egg masses/tree, respectively. During the active season, from the middle of March to the end of May, a large proportion of the larvae can be seen on the Pistachio trees in Haibat Sultan. During outbreaks most of the trees were completely defoliated, especially during the last larval instar stage; larvae feed on the leaves from the late evening and continue over the night. The number of egg masses/tree decreased during the burn season (2015-2016), the third plot was the lowest number 0.3 egg masses/tree because fire burnt the grass and Pistachio trees completely, the highest number was 9.2 egg masses/tree for the first plot and it was not burnt completely. In the post-burn season (2016-2017) number of egg masses/tree increased gradually in all three plots. The highest was 15.6 egg masses/tree in the first plot and the lowest was 1.3 egg masses/tree in the third plot. Overall, the effect of fire on the third plot was very harsh, total number of egg masses/tree in the post-burn season on each Pistachio tree decreased by 24.1 egg masses/tree compared to the pre-burn season. However, in the first plot, the number of egg masses/tree increased from 13.6 egg masses/tree in the pre-burn season to 15.6 egg masses/tree in the post-burn season. It may be concluded that *Thaumetopoea solitaria* was significantly affected by fire and there was a dramatic change in the number of egg masses/tree during the pre, post and burn seasons.

6.2.2 Effects of Fire on *Schistocerca gregaria*

The Desert Locust was severely affected by the fire. It can be seen from (Table 3) that the first plot of the pre-burn season in the year (2014-2015) had the lowest 1.5 nymphs and adults/m^2, and the highest in the second plot of the same season was 7.4 nymphs and adults/m^2. *Schistocerca gregaria* nymph and adult number decreased during the burn season in the year (2015-2016), in the first plot, number of nymphs and adults per square meter was 1.7, which was the highest number recorded, because this plot wasn't completely burned and few nymphs and adults immigrated from the other two plots. The lowest number 0.4 nymphs and adults/m^2 was recorded in the second plot. In the post-burn season (2016-2017), the lowest and highest numbers were recorded in the first and second plots are 1.3 nymphs and adults/m^2 and 2.4 nymphs and adults/m^2 respectively.

7. Conclusion

Results in this article indicate that out of the four chosen tree species, Pine covers the majority of the studied area by 63%, *Cupressus* 19%, Pistachio 15% and Oak 3%. It also indicates that *Cupressus* an introduced tree species is the most vulnerable, as 75% of them have been combusted, followed by pine and pistachio which are combusted by 60% and 41%, respectively. Oak, which is the native tree species is the most resistant as 93% of them could survive.

The average of the number of egg masses of *Thaumetopoea solitaria* and nymphs and adults of *Schistocerca gregaria* before the burn season (2014-2015) is (18.8 masses and 4.1 nymphs and adults), but the average declined dramatically to (3.3 masses and 0.9 nymphs and adults) during the burn season (2015-2016), which meant that fire had a destructive effect on insect habitats. The number of insects in both species increased in the post-burn season (2016-2017), with an average of (6.3 masses and 1.9 nymphs and adults).

Table 2: Number of egg masses of Pistachio Processionary Bud Moth (*Thaumetopoea solitaria*) per tree from 2014-2017 in Haibat Sultan Mountains.

Thaumetopoea solitaria	Plot Number	2014-2015 Pre-burn Season	2015-2016 Burn Season	2016-2017 Post-burn Season
No. of egg masses/tree	1	13.6	9.2	15.6
	2	18.3	0.5	2
	3	24.4	0.3	1.3
	Average	18.8	3.3	6.3

Table 3: Number of nymphs and adults of Desert Locust (*Schistocerca gregaria*) per meter^2 from 2014 to 2017 in Haibat Sultan Mountains.

Schistocerca gregaria	Plot Number	2014-2015 Pre-burn Season	2015-2016 Burn Season	2016-2017 Post-burn Season
No. of nymphs and adults/m^2	1	1.5	1.7	1.3
	2	7.4	0.4	2.1
	3	3.3	0.6	2.4
	Average	4.1	0.9	1.9

The species of these insects were chosen because of their widespread presence in Haibat Sultan Mountain, and they were used as a sample for this study to reflect the effect of forest fire on other living species. They were not chosen because they are crucial for the foresee wellbeing they cause a lot of harm to the leaves of the tree, young shoots, flowers and fruits. Also, the forest aesthetic effect does not remain a center of attraction for visitors, when the insects defoliate the leaves. And sometimes the foresters are suffering from hives with itching, burning and stinging. However, they are also part of the ecosystem of the forest as a part of the food chain.

In concluding this section, this paper does not include any information on greenhouse gas emissions, soil properties or changes in flood habits after a fire occurrence, because there are no such data available.

8. Recommendations

Because of the variety of aspects of this study, the authors of this article recommend various authorities, such as regional government, local municipality, scientific committees and non-governmental organizations.

It recommends that the regional government take proper care of vegetation and restore native plant habitat not only in the study area but also in the entire highlands because native tree species are well adapted to the local climate over time and most resistant against fire, whereas the introduced tree species are vulnerable and may vanish due to such fire events. One of the economic benefits of the native trees is that they do not require regular maintenance while the non-native trees need irrigation system and this can cost the local municipality a lot of resources. However, the concerned authorities need to install and maintain adequate firebreaks in the forest to minimize the damage caused by a fire. Gravel or evergreen grass along the roadside reduces the risk of human-caused fires caused by transportation and/or passengers. Moreover, both regional and local authorities should start monitoring and archiving data on forests and their issues and then comprehensive research can be carried out based on reliable data. Non-governmental organizations, especially those concerned with environment, should be actively involved in enhancing the environmental awareness attitude among citizens. They need to familiarize local people with the value and significance of the environment for both current and future generations. People should understand the fact that the conservation of environment and forest are their responsibility.

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