A LITERATURE SURVEY: THE EFFECTS OF FOREST FIRE ON ECOLOGY AND REGENERATION

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A CAUTION TO THE READER

ABSTRACT

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The extreme natural disturbance could destroy the structure and the composition of the forest (Chen 2009). The damage caused by forest fire can be divided into three parts: natural resources, ecological factors and the cost of rescuing the burned areas (Zhou 2007). The average burned area in Canada in the past 25 years was 2.3 million ha per year. But the forest fire has two-sided effects. On the one hand, the light or periodic forest fire can facilitate the flow of nutrients and energy, improving the stability and maintain the biodiversity in the forest ecosystem, which also can increase the productivity of the stand. On the other hand, severe forest fire not only cause damage to resources and the environment but also bring economic losses and even casualties to people. However, planned fires are also part of forest sustainable management (Bigelow 2012). The purpose to classify the effects of forest fire is to improve the process of management during regeneration and make prescription to prevent damage to forest resources.

The first part of this thesis is a literature review of information on the effects of forest fire on ecology. The second part is to illustrate the impact of the forest fire in the stand on ecology and regeneration. It can provide the diagnostic keys to determine what kind of forest management plan should be implemented. The final part is to discuss the effects of different intensity of forest fire on ecology and regeneration.

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INTRODUCTION

To improve sustainable forest management, integrated comprehension of natural disturbance processes and effects is important (Hunter 1999). Over the past few years, there are more fire disturbances around the world, and the primary reason is climate change and human activity (Chen 2009). The forest fire is the major disturbance in many natural stands, and it can not only shape the structure and function of ecosystems but can cause much timber loss and area burned as well (Greene and Johnson 1999). What's more, a forest fire has an influence on the ecological factors, for instance, below or above the ground physical, chemical and microbial processes, potentially altering successional and mineralization rates. These changes have the indirect effects on degradation process, such as soil erosion, rainfall and water runoff by influencing the dynamics at spatial and temporal scales of land cover (Bowman et al. 2011). Moreover, the greenhouse gas CO_2 effect will lead to extreme climate change, and it is expected to increase the susceptibility to forest fire and the frequency of fire disturbances (Ackerly 2004). According to Dickmann and Leefers's opinion in 2003, the forest fire can affect the regeneration of the stands and the suppression and exclusion of fire dominated forest management throughout the 20^{th} century.

Traditionally, the boreal forest can regenerate successfully after fire by natural (CCFM 2005). The ecosystem response to fire disturbance is the basis of fire ecology, particularly for post-fire regeneration. Early phases of post-fire regeneration can be influenced by various factors. For instance, forest fire damage microclimate, substrate, and propagule availability that are significant for natural regeneration (Chen 2009). It also can provide important information for comprehending forest responses to fire disturbances and predicting subsequent forest dynamics (Wang 2003). For example, the forest fire disturbance can remove the canopy of the stand, which can cause the failure of regeneration. However, the forest fire not only can destroy the canopy, but roots and trunk as well. All of the damages have important effects on regeneration.

According to Nyland's regeneration triangle in 1996 (Figure 1.), the regeneration in the certain physiographic site can be influenced by the three ecological factors: seed-supply, environment and seedbed. The environment factor includes insolation, moisture, frost, temperature and wind, etc. Seedbed mainly incorporates the soil type, microclimate, depth of organic matter, ground vegetation, soil texture and erosion deposition, etc. Finally, the seed-supply contains the seed-source, species, production, quality and damage, etc. The three ecological factors will affect the regeneration together.

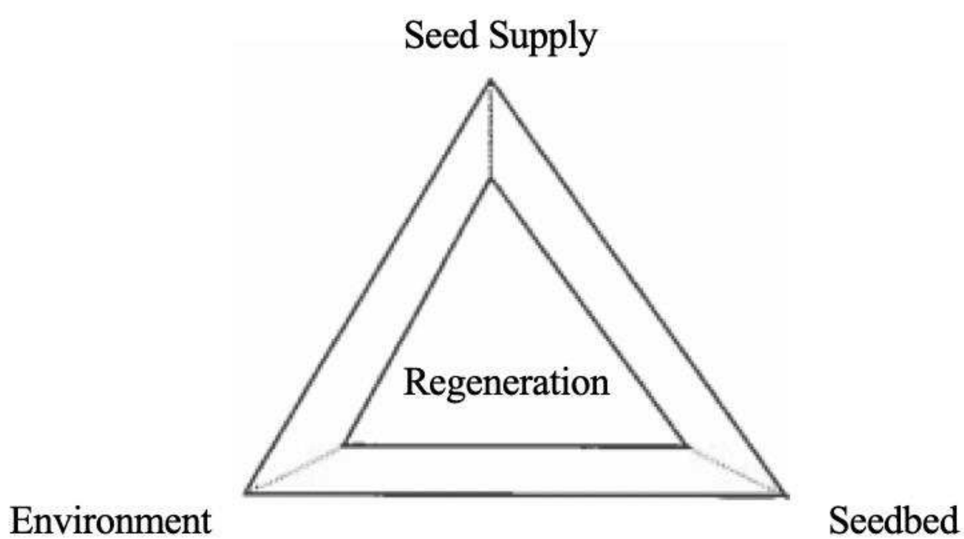

Figure 1. Regeneration Triangle (Nyland 1996)

Therefore, in this paper, the objectives are to examine the different effects of forest fire on site ecological factors and to investigate the role of forest fire on three aspects of the regeneration: seed sources, seedbed and environment. The question will be answered: How does the forest fire influence the regeneration triangle? Two hypotheses are: (i) forest fire influence the regeneration by changing the conditions of seedbed and environment (ii) the natural regeneration differs from different fire severity groups.

LITERATURE REVIEW

MICROCLIMATE, FOREST FIRE AND REGENERATION

Fire in nature are determined by the moisture content in the burning material (Stanimir 2015). Forest fire behavior has the potential to influence many aspects of microclimate changes in the stand (Bratislava 2015). It is possible that the forest fire can increase the temperature and reduce the moisture, which is expected to increase the risk of fire. And the impact of fire might become more severe in the coming years due to the frequency of extreme disturbances and the climate change of the whole world (Bratislava 2015). The trend of air temperature and precipitation can influence the condition of the burning material so the high temperature may result in the fire-prone ecosystem. (Stanimir 2015). What's more, forest fire not only can change the microclimate affecting the moisture and temperature of the environment but can increase the drought vulnerability by altering forest microclimate as well, which has a negative influence on regeneration by reducing the absorption of the water and changing the nutrient cycling for the juvenile (Refsland 2018). Moreover, the cyclic effect may deteriorate gradually with the high temperature and low moisture because the drought is projected to intensify the influence on regeneration by leading to increase the fire intensity.

In a nutshell, the forest fire can influence the environmental factors (temperature, moisture and, etc.). And higher temperature and lower moisture content will contribute to the drought and higher fire severity. The results suggest that forest fire can change the basic impact factors for the regeneration. However, according to my limited review, the exact process of influencing the regeneration by ecological factors are unclear.

THE EFFECTS OF FIRE ON ORGANIC MATTER IN SOIL

The forest fire can alter the chemical and physical properties, especially the organic matter and nutrients in soil will facilitate or inhibit the regeneration of trees in boreal forest (Bigelow 2012). There are different short-term effects of fire on composition and nutrients of soil (Heydari 2014), particularly the effect of a forest fire and post-fire mulching can produce some important consequences for the organic matter status of soils. Soil organic matter is an important component in ecosystem dynamics because it has the ability to exchange ions, interact with clay minerals, form soil aggregates, absorb and release plant nutrients and hold water (Huang 2018). Therefore, the indirect influence of forest fire on regeneration in the stand was determined by the quality of soil. However, there are some different results about the organic matter studies. According to the experiments by Shakesby et al. (2013), estimating the soil organic matter losses after a low-intensity experimental forest fire in central Portugal as a mere 3–5% of the original soil organic matter. The results from Heydari's study (2014) as well as other post-fire studies (Thomas et al., 1999) found larger decreases of organic matter around 8–68% of the original soil. These loss rates are similar to those reported from forest clearing or conversion to cultivation (Martínez-Mena et al. 2002). Finally, the study by Sun in 2011, the organic matter showed the light increased tendencies after the low-intensity fire because flame temperature varies with intensity, and the severe fire will cause more damage to the ecosystems, especially the site factors. Moreover, forest fire not only is a significant mineralizing agent in the nutrient cycles of moisture-limited ecosystems but contribute to decreased nutrient availability in the longer term by consuming soil organic matter and decreasing microbial processes responsible for nutrient turnover as well (Neary 2005). Severe fires may alter soil structure, wettability and porosity in ways that impact water holding capacity, potential for erosion and forest regeneration (Neary 2005) so severe fire may consume a large proportion of soil organic matter and reduce critical nutrient pools, and it even can sterilize the soil environment. Finally, fire had an overall negative effect (9%) on soil exoenzyme activities, although there are some arylsulfatase and proteolytic enzyme activities as well as positive responses, which have the indirect influence on nutrient transformations and organic matter cycling (Bowman 2011).

Based on the aforementioned review about the organic matter, the changes in content of soil organic matter post-fire vary with different intensity groups and research time after fire. Then, the burned soil organic matter induces the decrease of microbial decomposition which can cause the reduction of the nutrients in the soil and it has negative influence on regeneration.

FIRE SEVERITY AND REGENERATION

Post-fire regeneration functional groups (obligate seeders and re-sprouts) can be promoted under moderate and high burn severity, which can increase their abundance. Annual species (mainly herbs) colonized burned areas, persisting with higher presence under moderate burn severity (Crisitina 2017). Low-intensity forest fire just burns the herbs on the ground that have extremely strong regeneration capacity and it will not change the ecological factor (temperature, pH and organic matter, etc.) significantly. Therefore, after mild forest fire occur, herbaceous plants are the first to establish colonies, and these herbs directly affect the growth of some tree seedlings (Sun 2011). However, if these herbs have a strong ability to renew, then the ability of the trees to renew will become stronger after a mild fire because of the resource competitions. What's more, the low-intensity fire can increase the opportunities for seeds and ground contact that can benefit the further regeneration.

After the moderate fire has occurred, the environment in the forest has changed greatly. The herbaceous plants have all been burnt out, and there may be a small amount of seed residue on the ground. The canopy has also suffered a lot of damage, and the degree of canopy closure has been seriously reduced. The regeneration in this case is mainly depend on the herbaceous plants. Herbs occupy large canopy closure and last a long time during the process of regeneration. If in boreal forest, some pioneer species (jack pine, larches, poplar and trembling aspen) will start the succession in the stand and become the dominant species in the future. Finally, the dominant species will become some shade-tolerant species (Heather 2018).

After high-intensity fire, the change of soil organic matter is significant, the litter layer has been completely burned out, and the seeds in the soil are not much, which is very unfavorable for the regeneration of trees. What's more, the environmental factors of the ecosystem were destroyed. However, some grow-fast species (poplar, white birch and, etc.) will enrolled in the stand rapidly and become the dominant species in several decades. However, the regeneration of conifers will spend very long period because they can only rely on seeds to breed and grow slowly. Therefore, broad-leaved species will dominate the stand for a long time after high-intensity fire (Grau-Andrés 2018).

MATERIALS AND METHODS

In order to classify the effects of fire on ecology and regeneration, the study areas should be determined. The first step of the study is the literature collected. To achieve the objectives, the data was collected from some related kinds of literature which research areas are the boreal forest in North America and taiga forest in China because taiga forests are similar to the boreal forest, these occupy the extreme north of Manchuria in a permafrost region that covers of parts of China. The ecological factors in Taiga forests of China are similar to the factors in boreal forests in North America. Both of the forests are dominated by the needle leaf coniferous trees, including pine, larch, spruce, fir and Sabian forests. And a few kinds of literature's study areas are not the boreal and taiga forests.

The data which was associated with the ecological factors (temperature, moisture), seedbed (pH, organic matter and micronutrients in soil) and seed-supply (seeds, cones and seed spread) was collected. Also, most of the selected data was from the experiments which were conducted in summer because the experiments did with higher temperature can present more obvious changes. However, the topographic and geographic factors didn't take into consideration in the comparisons.

The temperature is not the only variance, and the different fire intensity groups also should be defined. Generally, the fire intensity is defined as the rate of heat energy released per unit time per unit length of fire front and the recommended SI unit is kilowatts per meter (kW/m) (Wang 2019). But most of the kinds of literature have not mentioned the fire intensity as heat release. Therefore, the fire intensity in this thesis is defined with the volume loss of the forest post-fire. For the low-intensity fire, its volume loss is less than 30%. The volume loss of moderate-intensity fire is more than 30% but less than 60%. Finally, the high-intensity fire's volume loss is more than 60%.

After acquiring the data from the related kinds of literature, the data was synthesized and analyzed by Microsoft Excel and the data will present by the column or bar diagram in this paper. What's more, there are some comparisons between some experiments have done by some scientists. The conclusion also obtained from the analysis of the experiments. The methods described below are an expansion of those presented in the analysis.

RESEARCH QUESTIONS

The research strategy was established to identify the studies answering the following primary research question:

What kind of effects of forest fire have on ecology and regeneration in the forest?

The research expected that the studies collectively would provide varying and apparently contradictory answers to the primary research question. To search for potential reasons underlying this heterogeneity, we considered the two research questions:

(i) How does the forest fire influence the three ecological factors in the forest?

(ii) How does the regeneration be influenced by seed sources, seed bed and environment?

Hence, the most significant step is to explore the influence of distinctions among the different fire intensity groups. Then, the data from various stands should also be collected and analyzed. Through my limited research, I hope to find out the influences of different intensity groups of fire on regeneration.

RESULTS

1. THE EFFECTS OF FOREST FIRE ON ENVIRONMENT

1.1 The effects of forest fire on temperature

The forest fire can burn most of the dead branches and leaves on the ground and reflectivity of the ground will decrease. Therefore, the forest fire could affect the balance of ground reflection and radiation, the stand or ground temperature are bound to fluctuate. According to the three studies have done by Bai in 2012, Davis in 2017 and Kasischke in 2005, the culmination of the temperature of burned area postfire is higher than unburned area. Therefore, the hypothesis is that the range of temperature will increase after forest fire, which can be illustrate by maximum temperature post-fire.

According to the Figure 1. and Figure 2., which was reintegrate from the experiment data from other kinds of literature. It shows the comparisons of temperature in the unburned forests and burned forests. In Bai's study in 2012, the area temperature of burned with high-intensity fire is 33.6 °C, which is higher about 8 °C than the unburned area. Then, the area temperature of burned with low-intensity fire is 28.6 °C, which is higher about 3 °C than the unburned area. In Davis' study in 2017, the area temperature of burned with high-intensity fire is 33 °C, which is higher about 5 °C than the unburned area. Then, the area temperature of burned with low-intensity fire is 32 °C, which is higher about 5 °C than the unburned area. Finally, in Kasischke's study in 2005, area temperature of burned with high-intensity fire is 6.3°C, which is higher about 4 °C than the unburned area. And area temperature of burned with low-intensity fire is 4.8°C, which is higher about 2.5 °C than the unburned area.

In the same study, the temperature of unburned area is always lower than the burned area post-fire. Then, the temperature of burned area with the high-intensity fire is larger about 5 °C, 1 °C and 1.5 °C than the temperature of burned area with the low-intensity fire in Bai's, Davis' and Kasischke's study respectively. The increment differences are result of the various experiments' regions and average temperature. But it is obvious that the high-intensity fire can bring more significant influence to the forest.

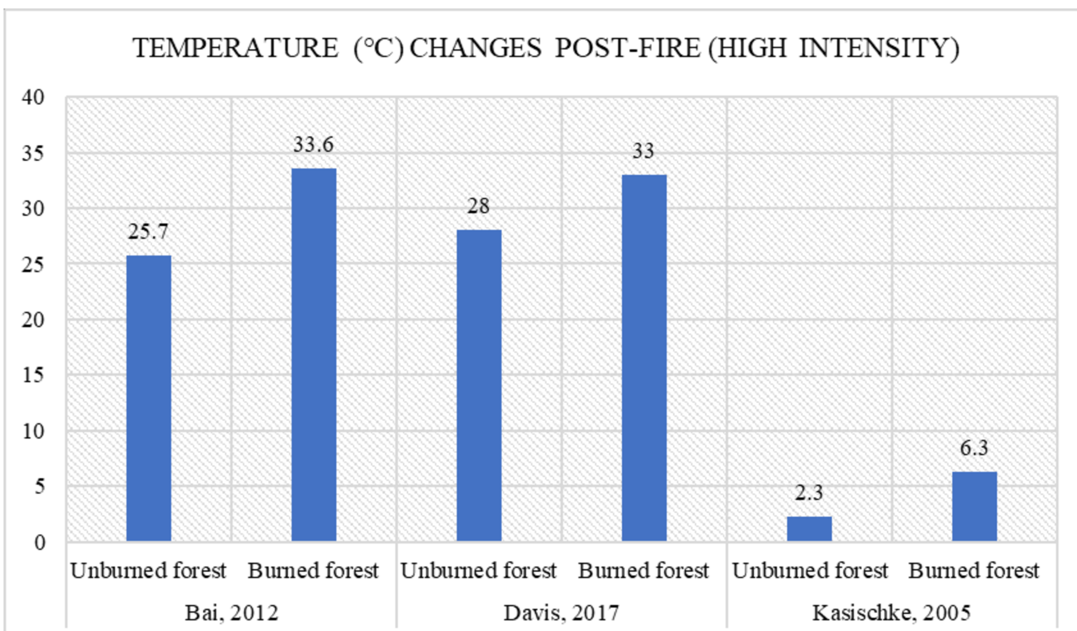

Figure 2. Temperature (°C) changes after high-intensity fire

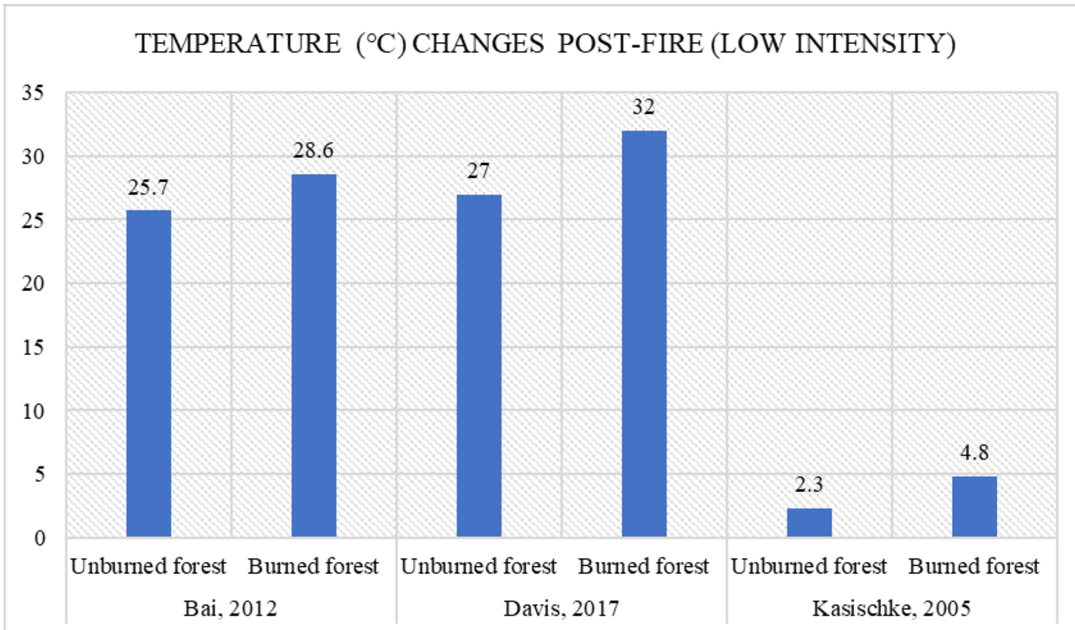

Figure 3. Temperature (°C) changes after low-intensity fire

The influence of temperature fluctuation on regeneration varies with the different fire intensity groups (Bai, 2012). First, the rising temperature caused by the low-intensity fire will promote the activity of microorganism (Sun 2011). Therefore, it will accelerate the decomposition of the litter, which will increase the organic matter content in the soil. Moreover, according Dr. Wang's lecture in 2019, the low-intensity fire will burn some of the grass and the herbs into ash on the soil surface, which could leach into the soil. The chain reaction can provide more nutrients for the plants in the area, which has the positive influence on improving the nutrient absorption (Hobley 2017). Therefore, the low-intensity fire can facilitate the regeneration in the stand. However, according to Reyes' study in 2004, the high-intensity fire will burn a lot of shrubs and trees in the stand. It can not only damage the temperature balance of the ecosystem, but have an influence on the ash layer and the nutrients in the soil as well, which are significant for the regeneration

(Reyes 2004). The resources will loss directly because of the severe fire burned (Wang 2019). Therefore, the high-intensity fire has negative effects on regeneration.

1.2 The effects of forest fire on moisture

The moisture in the environment of the stand can be divided into atmospheric humidity and soil moisture. Atmospheric relative humidity refers to the actual vapor pressure of air and the percentage of saturated vapor pressure at the same temperature (Refsland 2018). Moreover, changes in the moisture content of the atmosphere will affect the germination and growth of plants in the surface layer, and it may also exchange with the water in the soil, which is also one of the factors affecting the surface temperature. Soil moisture refers to the content of the water in the soil, which is an important factor in determining the potential yield. Soil water content is an important indicator of soil fertility and an important factor in forest development. Soil moisture content will directly affect the quantity and speed of soil heat transfer (Bai 2012). The higher the soil moisture content, the stronger the soil's ability to retain moisture, the more heat it absorbs, and the timely transfer of surface heat to the ground, thus preventing the soil from overheating. From last chapter mentioned before, the stand temperature post-fire will significantly increase. Therefore, the inference about the moisture is the water in the atmosphere or soil will decrease with the occurrence of the forest fire.

According to the Figure 4, it shows the moisture fluctuation in soil post-fire. The data reintegrated from the experiment data by Koster in 2017, Smith in 2005 and Kasischke in 2005. The soil moisture of the post-fire stand decreased obviously. It shows the comparisons of temperature in the unburned forests and burned forests. In Koster’s study in 2017, the moisture content of the area burned with high-intensity fire is 37.2%, which is lower about 18% than the unburned area. Then, the moisture content of the area burned with low-intensity and moderate fire is 49.1% and 40.3% respectively, which is lower about 5% and 15% than the unburned area. In Smith's study in 2005, the moisture content of the area burned with high-intensity fire is 17.6%, which is lower about 2% than the unburned area. Then, the moisture content of the area burned with low-intensity and moderate fire is 18.6% and 18.3% respectively, which is lower about 1% and 2% than the unburned area. In Kasischke's study in 2005, the moisture content of the area burned with high-intensity fire is 5.8%, which is lower about 28% than the unburned area. Then, the moisture content of the area burned with low-intensity and moderate fire is 22.7% and 14.5% respectively, which is lower about 11% and 19% than the unburned area.

In the same study, the moisture of unburned area is always lower than the burned area post-fire. The differences of the moisture reduction mainly result of the diverse precipitation in the areas. It is certain that the high-intensity fire can cause more moisture loss in the soil.

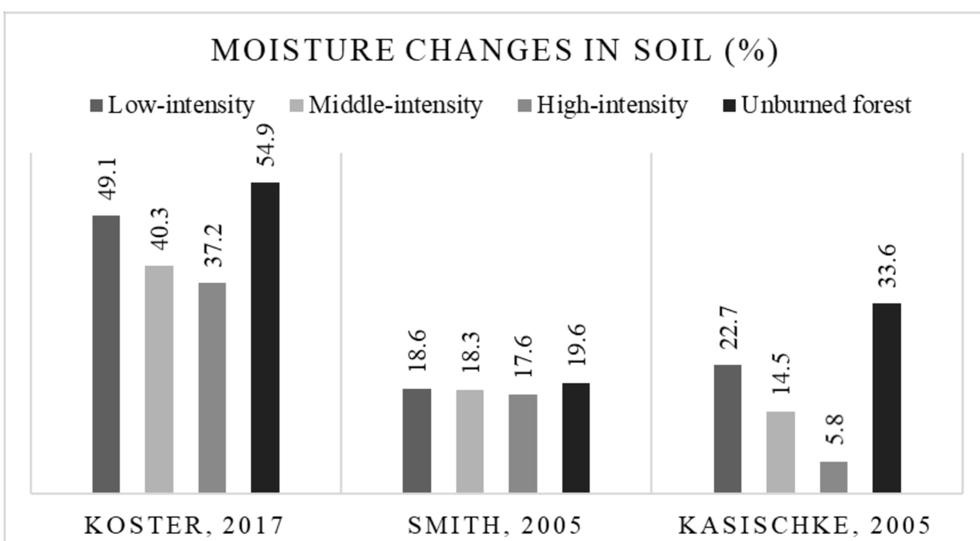

Figure 4. The moisture changes in soil post-fire

All in all, the effects of moisture reduction on regeneration is negative because water is the basis for the physiological action of trees (Heather 2018). And the plants should acquire water by stem-flow which is converging and transferring the precipitation and solutes in the plant stem (Holden 2015). The moisture reduction will lead the reduced water available to trees. Therefore, the effects of the forest fire on moisture in soil will inhibit the regeneration in the forest.

2. THE EFFECTS OF FOREST FIRE ON SEEDBED

Forest fire can alter the chemical and physical properties, even have significant influence on the microorganism (Sun 2015). And the organic matter and nutrients in soil will facilitate or inhibit the regeneration of trees in boreal forest (Bigelow 2012). The effects of the forest fire on the seedbed also can be divided into the physical impacts and chemical effects. The physical impact mainly includes the temperature, texture and the moisture content. During the process of forest fire burned, the soil temperature can arrive about 200℃ to 300℃ and the soil surface temperature is about 500℃ to 700℃ (Sun 2011). After the forest fire, the exposed patches in the forest are formed in different sizes. These exposed plots are directly exposed to sunlight, and due to the action of the vegetation ash, the soil color becomes black, which increases the surface heat and increases the soil temperature. As the ground temperature increases, the decomposition of organic matter by microorganisms in the soil is promoted, and the peat and litter layers in the soil are accelerated and decomposed into organic matter that can be absorbed by the forest (Neary 2005). Moreover, due to the increase of ground temperature, the absorption of root hairs of forest trees is enhanced, and the ability of root hair to absorb water and nutrients in the soil is improved, thereby promoting the growth of forest trees and creating favorable conditions for cultivating forest resources. However, the occurrence of the forest fire will burn the organic matter in the soil, and change the mineral composition of the soil (Moss 2009). Thus, it can change the structure of the soil, which is that the pores of the soil become smaller, the water flow capacity is reduced, and the water storage capacity of the soil is also followed decrease. Once there is heavy rain occurred, the fertility of the soil will decrease, which is very unfavorable to the growth of the root system (Parro 2015). In other words, the effects of forest fire on seedbed also can facilitate or inhibit the regeneration indirectly.

2.1. The effects of forest fire on pH

The pH of the soil directly affects the decomposition of soil organic matter, the existence of nutrients, and the release and transformation. The pH of the soil has a great influence on the growth and development of forest and soil microorganisms. Each tree species has the most suitable soil pH for growth. The appropriate pH is beneficial to microbial activity and accelerates the decomposition of litter, thus promoting forest growth. The ash of plants and their dead organisms contains a large amount of calcium, potassium and magnesium ions. The deposition of these substances does not increase the pH of alkaline soils because of the large number of powerful cations in alkaline soils. In the soil, the cations in the ash after forest fire tend to leaching and do not chemically react with the soil. Therefore, the increase in the pH value of the soil after the forest fire is primarily determined by the load of the combustibles pre-fire, the intensity of forest fire, and the original pH of the soil and the regional precipitation.

According to the research have been done by Sun in 2011, Smith in 2017, Merino in 2018 and Hosseini in 2016, the pH value of the soil is variance with the different areas and the intensity of the forest fire. According to the Figure 5. which is reintegrated from the collected data. It shows the pH fluctuation post-fire. From the Figure 5., the pH value of the forest soil which has been slightly burnt is increased after the forest fire, which means that the acidity of the soil is weakened. This is due to the potassium, calcium and magnesium in the ash after forest fire, which become the cation to neutralize the acidic material of the soil. Moreover, all the intensity groups' fire increased the pH in the different experimental regions. In the same study, the pH increment of area burned by high-intensity fire is always higher than the pH of burned area by low and moderate-intensity fire. Compared to the pH increment of area burned by low-intensity fire, the pH increment of area burned by high-intensity fire are larger about 0.3, 0.7, 0.4, 0.4 in Sun's, Smit's, Merino's and Hosseini's study respectively. The increment differences are mainly result of the various soil types and properties in different regions. But the increment is obvious that the high-intensity forest fire has the biggest impact on pH fluctuation.

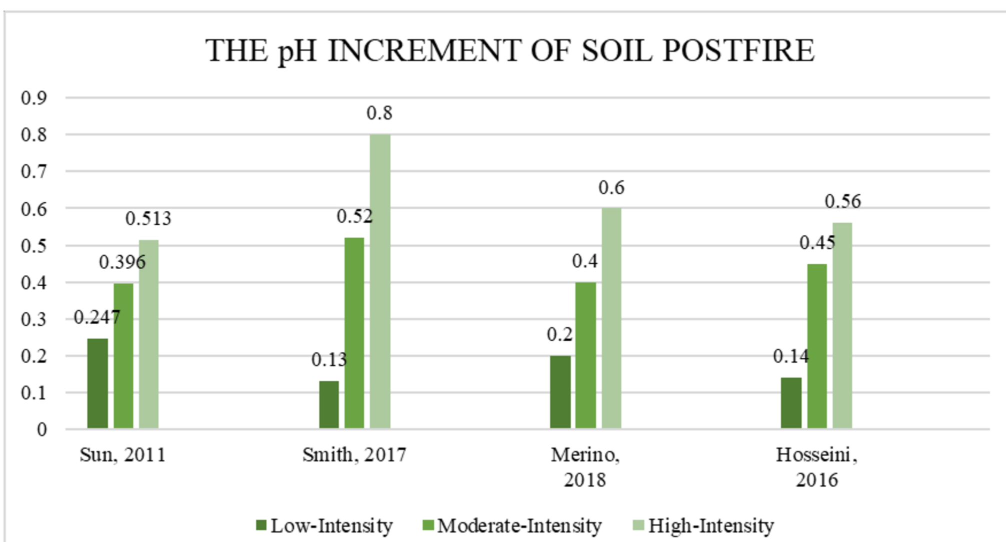

Figure 5. The pH increment of the soil post-fire

In conclusion, the forest fire has the ability to increase the pH in soil. And the influence of pH augment on regeneration is negative for the short-term development (Bai 2012). The first reason is the increase in pH will alkalize the soil, thereby altering the physical and chemical properties of the soil. And it is not conducive to the accumulation of soil nutrients as it also will break the environmental balance for the microorganism, which can affect the enzyme in the process of decomposing the organic matter (Hunter 1999). Therefore, it has the negative influence on regeneration by reducing the soil fertility.

2.2. The effects of forest fire on organic matter

Another important factor in soil properties is soil organic matter, which is also one of the material foundations of soil formation. The organic matter content and composition of the soil will directly affect the soil fertility, because the organic matter of the soil is conducive to the formation of the soil aggregate structure, which can improve the status of soil moisture and nutritional status. The organic matter of soil is the source of soil nutrients. In the forest soils, the main sources of soil organic matter are litter, animal remains and microbial residues. These sources are also significant for soil to supplement organic matter. After the litter of the trees and the residues of the animals enter the soil, they are transformed into minerals by the action of microorganisms or converted into humus (Smith 2017). Both of these methods are decomposed from macromolecular organic compounds into simple inorganic materials, or intermediate products are used to form humus. Soil organic matter has an important influence on soil fertility and plays a huge role in the growth of forest trees. Therefore, it is necessary to study the changes of soil organic matter content.

According to Merino's study in 2018, Hobley's study in 2017, Sun's study in 2011, and Holden's study in 2015, the Figure 6 present the results about the organic matter of soil post-fire in the 4 researches. The content of organic matter in the area which burned with low-intensity fire shows the increase tendencies in these studies. Especially in Hobley's study in 2017, the low-intensity fire aggrandizes the content of organic matter about 5%. In other experimental regions, the increment of the organic matter is less than 2%. In contrast, the moderate-intensity and high-intensity fire reduce the content of organic matter. In Merino's and Hobley's study, the moderate-intensity fire and high-intensity fire decreases the content of organic matter about 6% and more than 10%. And in Sun's and Holden's study, the moderate-intensity and high-intensity fire decreases the content of organic matter just about 1% and 2%. The reduction differences are result of the various soil types and properties in experimental areas. But they suggest the same trends about the organic matter changes post-fire.

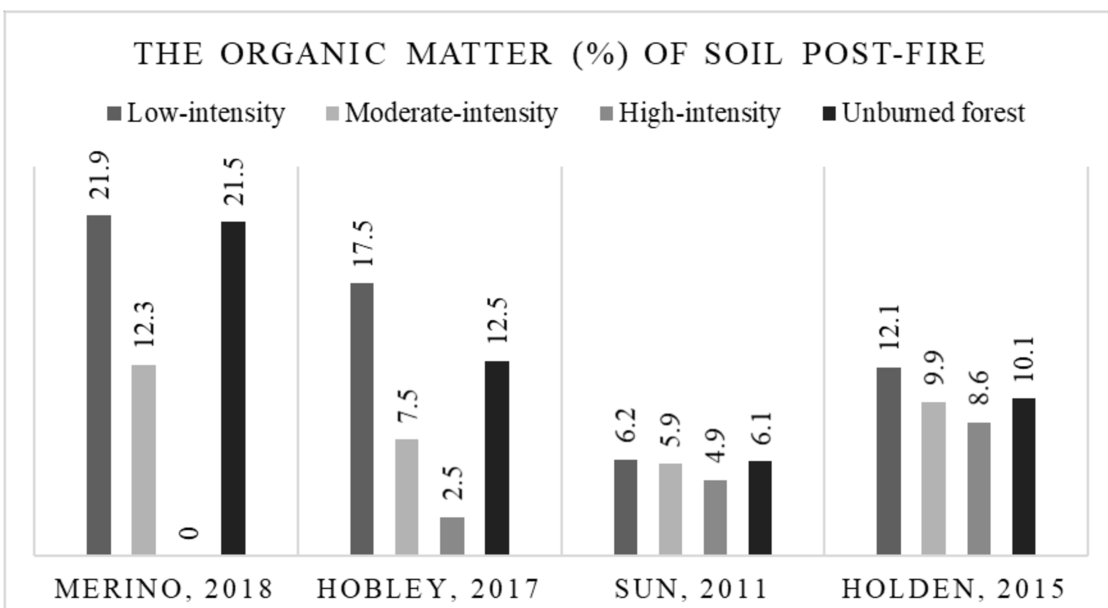

Figure 6. The organic matter changes of the soil post-fire

Then, according to Thomas et al.'s research in 1999, the content of organic matter in the soil will increase if the stand burned by the low-intensity forest fire because the cation in the ash of the soil can play an important role. However, if the stand burned by the high-intensity forest fire, it will cause the soil to be knotted, which can significantly decrease the content of the organic matter in the soil. From the study did by Faria et al. in 2014, the organic matter content of the soil that was not exposed to forest fire in the same stand was higher about 2.19% than that of the soil that received the forest fire. Furthermore, according to the Shakesby et al.'s study in 2013, the organic matter content of the soil reduced about 1.09% postfire. Finally, the Table 1. reintegrate the various opinions about the effects of the forest fire on organic matter in the soil. Under the same fire intensity, scientists have a more unified view of the impact of fire on organic matter content. From the table we can discover that the low-intensity fire not only can reduce the content of organic matter in the soil, but can improve the biodiversity in the ecosystem as well. The influence of moderate-intensity forest fire on organic matter is not clearly directed. Because the moderate-intensity forest fire will improve the exchange of some ions, which has a positive influence on improving the conditions of the seedbed. Finally, the destruction of the high-intensity fire on seedbed is irreparable.

Table 1. The effects of the different intensity of forest fire

Forest fire Intensity	Results about the Organic Matter	Reference
Low-Intensity	- Reduction of the content	Sun. 2011
	- Recoverable	
	- Benefit to the biodiversity	Heydari. 2014
	- Improve the ability to exchange ions	
Moderate-Intensity	- No more than one percent of the impact	Faria et al. 2014
	- Respond to the original state faster	
	- Uncertain influence direction	Shakesby 2013
High-Intensity	- Loss organic matter significantly	Thomas. 1999
	- Gradually deterioration	
	- Difficult to recover	Huang. 2018

Finally, the effects of the organic matter fluctuation on regeneration can be divided into two parts. First, the low-intensity fire will increase the content of organic matter because the low-intensity fire can burn the grass and the herbs into ash on the soil surface, which will leach into the soil and become the organic matter (Wang 2019). So it can provide more nutrients for the stand and improve the nutrient absorption process. Therefore, the low-intensity fire can improve the regeneration in the stand. However, the moderate and high-intensity fire will burn most of the shrubs and trees in the stand. Moreover, the organic matter will become the fuels which can be burned with the oxygen during the forest fire. Then, some of the vegetation nutrient stores will loss post-fire (Simansky 2015). The organic matter in the ash layer on the soil surface will fade away because of the wind, precipitation or other ecological factors (Wang 2019). Therefore, there are much nutrient losses when the moderate and high-intensity fire occurred, which has negative effects on regeneration.

2.3 The effects of forest fire on micronutrients

In addition to the forest fire affecting the forest by burning, the forest fire not only changes the ecological factors such as air, moisture, soil, light, temperature, water, but can influence the circulation of nutrients in the stand as well, which is determined by the type and site conditions of the combustibles and the severity of forest fire. The high-intensity forest fire will facilitate the loss of the phosphorus, potassium, calcium and other elements in the forest by transforming the formation of the elements in the soil, which are significant for the regeneration. And the nitrogen will complete obliteration under high temperature, which will interrupt the nutrient cycle of the ecosystem and reduce the fertility of the soil. However, the micronutrients especially the copper and zinc in the soil also are important for the growth (Stankov 2011). Copper is essential a micronutrient for plants because it is a major component of oxidase and is mainly found in chloroplasts which involved in the synthesis of chlorophyll and the metabolism of sugars (Sun 2011). Moreover, copper catalyzes the redox reaction in the metabolism of plants, which means the copper can promote the photosynthesis and respiration. Copper coexists in the soil in a substituted ion state and an organic bond state. Once the copper ions are adsorbed, they can move to the lattice position of the clay mineral. Zinc also plays an extremely important role in photosynthesis like copper. Moreover, zinc can also promote the synthesis of proteins for the growth of trees.

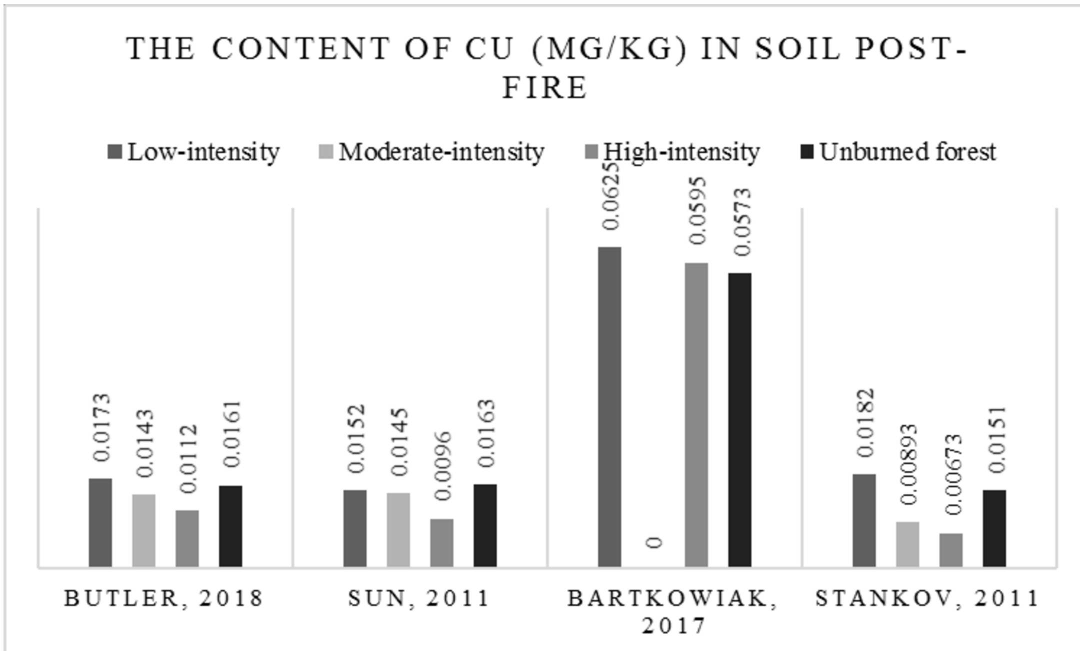

Figure 7. The content of Cu in the soil post-fire

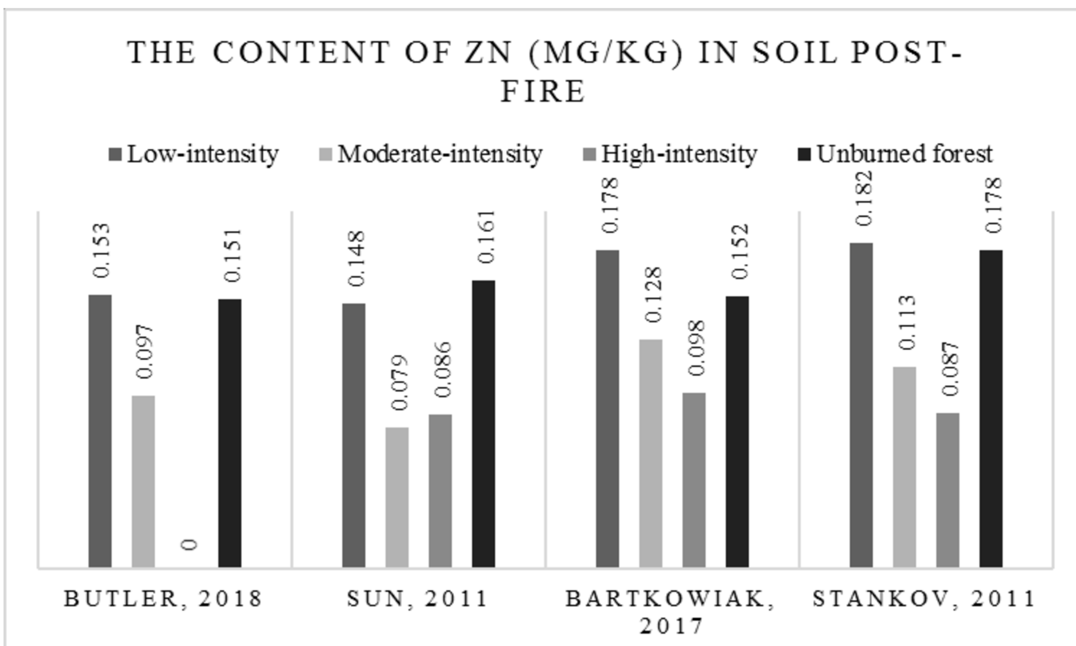

Figure 8. The content of Zn in the soil post-fire

According to the Figure 7 and Figure 8, which show the results about the content of copper and zinc in the soil post fire. From these four studies, the content of copper and zinc have the same trend post-fire basically. The low-intensity fire can increase the content of copper and zinc slightly except in Sun's study in 2011 which suggested that the content of copper and zinc decreased. Then, the content of copper and zinc in the soil after moderate and high-intensity fire shows the significantly declining trends in the four studies except the content of copper in soil of Bartkowiak study in 2017. It shows the totally contrast tendency to other three studies which are the content of copper increased after low and high-intensity fire. Finally, the reduction of the micronutrients is the largest of about 0.009 mg/kg (copper) and 0.09 mg/kg (zinc) after the high-intensity fire in Stankov's study.

The exact influence of copper and zinc content in soil on regeneration is not clear according to my restricted research. However, the phenomenon of copper deficiency in plants is that the young leaves become yellow because the loss of copper reduces the chlorophyll in the leaves which can cause chlorosis (Stankov 2011). Then, both photosynthesis and respiration are reduced during the process of growth, which has the negative influence on germination and sprout (Koster 2017). And the zinc is helpful for seed production because it is vital for the synthesis of proteins of seeds (Prats 2016). Therefore, the copper and zinc may affect regeneration by inhibiting the germination of seeds.

3. THE EFFECTS OF FOREST FIRE ON SEED-SUPPLY

The regeneration triangle by Nyland in 1996 outlines that the most significant factor of a successful natural regeneration is seed, which include the seed source, species, production, quality and damage. According to the studies have done by Zhou in 2007, it shows that most of the seeds can withstand higher temperatures, and the ability to germination of the seeds will be significantly enhanced after a certain temperature treatment. If the seed is buried in the surface soil, even after a severe fire, the seed will not lose its vitality, and even the germination rate of the high-temperature treated seed will increase (Zhou 2007). Some species can regeneration rapidly because of the exclusion of competitors from fire. The root reason for the regeneration is that forest fire eliminates the thick litter leaves on the seedbed and the seeds were easy to touch the soil, which was conducive to the growth and development of the seeds (Stanimir 2015). Also, the seeds will not be killed in large numbers because of their low-intensity of forest fire if the seeds of the trees are exposed to the ground and are burnt by light fire. On the other hand, according to Talita's research in 2016, the frequency of the forest fire will influence the amount of the seeds in the soil, which can germinate for the regeneration in the future. And Heather said in 2018, there is higher seed germination rate with more light burning in the stand. But the regeneration of these species depends on the seeds that are kept in the canopy during the after a devastating fire, which explain that the seed definitely is the basis of the regeneration.

3.1. The effects of forest fire on seeds

For most of the species in boreal forest, the seeds can tolerate up to 82 to 140 °C for 5 minutes. Therefore, the seeds will not be dead after low-intensity fire. And the seeds or cones in boreal forest will not fall to the ground immediately when they become mature, but last for several years or even longer on the crown. These seeding will occur in a long period after the cones mature. During the process, these seeds will be gradually consumed by some animals as food. The longer time, the less residual seeds. According to Melissa's study in 2009, the low-intensity forest fire can accelerate the release of the cones, which can reduce the losses of the seeds. What's more, according to Song's research in 2000, the mountain ash (*Eucalyptus regnans*)'s seeds will fall down to the ground in 2 years after mature. Under normal circumstances (without disturbances), only 10 percent of the free-falling seeds of this species can germinate. However, the forest fire can make the seeds of the species 100% release at one time. Although the fallen seeds will be preyed by the animals, remain seeds which can germinate are around 90%.

Some boreal forest species cones have characteristics of physical dormancy (late-opening), sometimes only forest fire occurred, can cones crack. For example, the cones from jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*) in North America. Both species have the characteristics of late cone open. Generally, the cones can not open and release the seeds directly after mature. For jack pine (*Pinus banksiana*), the cones usually hang on the crown for several decades. And the seeds still have vitality. And the low-intensity fire can stimulate the seeds release and cone open for them. Within the same forest stand, due to the different altitudes of the distribution, the cracking time of the cones also vary widely. For the jack pine (*Pinus banksiana*) and black spruce (*Picea mariana*), the cones are easier to crack when the trucks have thick barks. In addition, low frequency and low-intensity fire will reduce the ratio of late open cones (Wang, 2019). And high-intensity and severe forest fire will increase the genotype of the cone's early-open.

There are other types of seeds that cannot be released. For instance, the cones of some species are hard (such as the walnut (*Carya cathayensis*), etc.), the outer layer of the cones is oily and waxy (such as cashew (*Anacardium occidentalis*) and cypress (*Platycladus orientalis*), etc.). These features are not conducive to seed germination. What's more, for prolific wind-borne seeds, the low-intensity forest can help with spreading the seed as well. And for some seeds have the oil and wax on the cones (for example, Figure 9. *Sabina chinensis*), the low-intensity can volatilize it during the process of forest fire, and the seeds can be released easily for germination.

Figure 9. The cones of *Sabina chinensis*

In a nutshell, the low-intensity fire has a positive influence on regeneration by accelerating the release of the seeds and cone open (Zhou 2007). The moderate and high-intensity fire will damage the seed except the seeds which covered by soil because of the extreme temperature during the forest fire (Huang 2018).

3.2. The effects of forest fire on seed germination

The tree species in fire-prone ecosystem can regeneration by re-sprouting, recruiting from seeds, or utilize both of the strategies (Bond & Midgley 2001). Therefore, the species in forest fire-prone ecosystem present the various seed germination strategies to survive postfire. During the process, the germination can be resulted from different mechanisms. For instance, temperature fluctuation, smoke and head shocks (Williams et al. 2005). Also, according to Williams' study in 2003, the forest fire and high temperature may break the physical dormancy and improve the germination.

After fire, because of the increase of the temperature, the seeds will be exposed to the high temperature environment and experience wide temperature fluctuation. And according to Baeza's studies in 2008, the temperature fluctuations can influence and enable the germination in hard-seeded species and break the physical dormancy. Furthermore, the daily temperature can affect the rate of germination (Musso et al. 2015). According to Talita's research in 2016, there are four species seeds were used into the experiment to record the germination rate under different treatments. It indicated that the seeds burned by the low-intensity forest fire have the highest average germination ratio. Especially for the grey-leaved cistus (*Cistus albidus*), its seed germination ratio after low-intensity forest fire is more than 25 percent. However, the germination ratio of controlled treatment is less than 5 percent. Furthermore, according to the Heather's research in U.S. in 2018 and the experimental species was cajander larch (*larix cajanderi*). All the seedbeds were treated by the low-intensity, moderate-intensity and moderate-intensity fires. The amount of new germinant (indiv/m^2) of the seedbed treated by low-intensity and moderate-intensity fire was significantly less than the seedbed treated by high-intensity fire about 5 indiv/m^2. Moreover, the survival ratio of the seedbed treated by low-intensity and moderate-intensity fire was less than the seedbed treated by high-intensity fire about 10 percent. The survival ratio of seedbed treated by high-intensity fire is the highest about 35%, and the survival ratio of unburned area was only about 15%. Therefore, it can illustrate that the forest fire can improve the germination of the seeds and low-intensity fire has the positive influence on regeneration.

4. CONCLUSIONS

In conclusion, although there are many factors impact the regeneration, all of the factors can be summarized as environment, seedbed and seed source, which are the most significant for the regeneration. Furthermore, the influence of forest fire on regeneration is from the accumulation of environment, seedbed and seed source. The effects of the different intensity forest fire are various (Table 2.). The low-intensity fire doesn't have the significant influence on temperature, moisture, pH and other components. It has the positive influence on regeneration because it can not only stimulate the cone-open but improve the biodiversity and nutrient-cycle in the ecosystem as well. The moderate-intensity fire in the stand has the two-direction effects, which are larger than low-intensity fire because of the negative effects on ecological factors and it can break the balance of the original ecosystem. The moderate-intensity fire sometimes can facilitate the regeneration because of the ecosystem integrity and pioneer species post-fire. The high-intensity forest fire will destroy the original ecosystem and force the stand regeneration into succession process. Finally, the regeneration will vary with the different intensity of forest fire and forest species as there are many kinds of communities post-fire and different types of forests.

Table 2. The summarized influence for the different fire intensity groups

	Environment		Seedbed			Seedsource	
	Temperature	Moisture	pH	Organic Matter	Micronutrients	Seeds	Cone open
Low-intensity Fire	+	–	+	(+) –	(+) –	+	+
Moderate-intensity Fire	+	–	+	–	–	–	–
Hight-intenwsity Fire	+	–	+	–	–	–	–

LITERATURE CITED

Ackerly, D., 2004. Functional strategies of chaparral shrubs in relation to seasonal water deficit and disturbance. Ecol. Monogr. 74, 25–44.

Baeza MJ & Roy J. 2008. Germination of an oblígate seeder (Ulex parviflorus) and consequences for wildlife management. Forest Ecology and Management 256: 685-693.

Bai et al. 2012. The research on the change of temperature and humidity after the forest fire clear cutting area and not cutting area. Huhehaote. Inner Mongolia.

Bowman et al. 2011. The human dimension of fire regimes on Earth. J. Biogeogr. 38, 2223–2236.

Bond WJ & Midgley JJ. 2001. Ecology of sprouting in woody plants: the persistence niche. Trends in Ecology and Evolution 16: 45-51.

Bergeron Y, Charron D. 1994. Postfire stand dynamics in a southern boreal forest (Que´ bec): a dendroecological approach. Ecoscience 1:173–84.

Bigelow, S. W., & North, M. P. 2012. Microclimate effects of fuels-reduction and group-selection silviculture: Implications for fire behavior in Sierran mixed-conifer forests. FOREST ECOLOGY AND MANAGEMENT, 264, 51–59.

Butler, O. M. et al. 2018. High-frequency fire alters soil and plant chemistry but does not lead to nitrogen-limited growth of Eucalyptus pilularis seedlings. PLANT AND SOIL, 432(1–2), 191–205.

Bartkowiak Agata, & Lemanowicz Joanna. 2017. Effect of forest fire on changes in the content of total and available forms of selected heavy metals and catalase activity in soil. Soil Science Annual, (3), 140.

Chen HYH. et al. 2009. Wildfire promotes broadleaves and species mixture in boreal forest. For Ecol Manage 257:343–50.

Chen HYH and Wang JR. 2006. Post-harvest regeneration of low- land black spruce forests in northeastern Ontario. New Forest. 31:115–129.

Canadian Council of Forest Ministers (CCFM). 2005. Criteria and indicators of sustainable forest management in Canada. National status 2005. Ottawa, ON. Natural Resources Canada, Canadian Forest Service.

Cristina Gouvêa Redin. et al. 2017. Grazing Changes the Soil-Plant Relationship in the Tree-Regeneration Stratum in Thepampa of Souhtern Brazil. Cerne, Vol 23, Iss 2, Pp 193-200 (2017), (2), 193.

David M. Hix et al. 2012. Fire Effects on Soils in Lake States Forests: A Compilation of Published Research to Facilitate Long-Term Investigations. Forests, Vol 3, Iss 4, Pp 1034-1070.

Davis, R. et al. 2017. The normal fire environment—Modeling environmental suitability for large forest wildfires using past, present, and future climate normals. Forest Ecology and Management, 390, 173–186.

Dickmann, D., Leefers, L.A., 2003. The Forests of Michigan. University of Michigan Press.

Greene DF, Johnson EA. 1999. Modelling recruitment of Populus tremuloides, Pinus banksiana, and Picea mariana following fire in the mixedwood boreal forest. Can J For Res 29:462–73.

Grau-Andrés, R. et al. 2018. Fire severity is more sensitive to low fuel moisture content on Calluna heathlands than on peat bogs. Science of the Total Environment, 616–617, 1261–1269.

Hunter ML. 1999. Maintaining biodiversity in forest ecosystems. Cambridge, UK: Cambridge University Press.

Hart SA, Chen HYH. 2008. Fire, logging, and overstory affect understory abundance, diversity, and composition in boreal forest. Ecol Monogr 78:123–40.

Heather D. et al. 2018. Impacts of increased soil burn severity on larch forest regeneration on permafrost soils of far northeastern Siberia. Forest Ecology and Management. 417: 144-153.

Hosseini, M. et al. 2017. Effects of fire occurrence and recurrence on nitrogen and phosphorus losses by overland flow in maritime pine plantations in north-central Portugal. Geoderma, 289, 97–106.

Holden, S. R. et al. 2015. Decreases in soil moisture and organic matter quality suppress microbial decomposition following a boreal forest fire. Soil Biology and Biochemistry, 87, 1–9.

Hobley, E. U. et al. 2017. Forest burning affects quality and quantity of soil organic matter. Science of the Total Environment, 575, 41–49.

Kasischke, E. S. et al. 2005. Variation in postfire organic layer thickness in a black spruce forest complex in interior Alaska and its effects on soil temperature and moisture. Canadian Journal of Forest Research, 35(9), 2164–2177.

Kostas Kalabokidis. et al. 2015. Effect of Climate Change Projections on Forest Fire Behavior and Values-at-Risk in Southwestern Greece. Forests, Vol 6, Iss 6, Pp 2214-2240 (2015), (6), 2214.

Köster, E. et al. 2017. Carbon dioxide, methane and nitrous oxide fluxes from a fire chronosequence in subarctic boreal forests of Canada. Science of the Total Environment, 601–602, 895–905.

Merino, A. et al. 2018. Inferring changes in soil organic matter in post-wildfire soil burn severity levels in a temperate climate. Science of the Total Environment, 627, 622–632.

Musso C. et al. 2015. Simulated post-fire temperature affects germination of native and invasive grasses in Cerrado (Brazilian savanna). Plant Ecology & Diversity 8: 219-227.

Moss, M., & Hermanutz, L. 2009. Postfire seedling recruitment at the southern limit of lichen woodland. Canadian Journal of Forest Research, 39(12), 2299–2306.

M. Heydari, & M. Faramarzi. 2014. The Short Term Effects of Fire Severity on Composition and Diversity of Soil Seed Bank in Zagros Forest Ecosystem, Servan County. Iranian Journal of Applied Ecology, Vol 3, Iss 9, Pp 57-69.

Prats, S. A. et al. 2016. Mid-term and scaling effects of forest residue mulching on post-fire runoff and soil erosion. Science of the Total Environment, 573, 1242–1254.

Parro, K. e tal. 2015. Impact of postfire management on forest regeneration in a managed hemiboreal forest, Estonia. Canadian Journal of Forest Research, 45(9), 1192–1197.

Raphael K. Didham, & John H. Lawton. 1999. Edge Structure Determines the Magnitude of Changes in Microclimate and Vegetation Structure in Tropical Forest Fragments. Biotropica, 1 - 17.

Refsland, T. et al. 2018. Fire increases drought vulnerability of Quercus alba juveniles by altering forest microclimate and nitrogen availability. Functional Ecology, (10), 2298.

Reyes O. and Casal M. 2004. Effects of forest fire ash on germination and early growth of four pinus species. Plant Ecology. 175: 81-89.

Refsland, T. et al. 2018. Fire increases drought vulnerability of Quercus alba juveniles by altering forest microclimate and nitrogen availability. Functional Ecology, (10), 2298.

Smith, J. E.et al. 2017. Does the presence of large down wood at the time of a forest fire impact soil recovery? Forest Ecology and Management, 391, 52–62.

Stankov Jovanovic et al. 2011. Wild fire impact on copper, zinc, lead and cadmium distribution in soil and relation with abundance in selected plants of Lamiaceae family from Vidlic Mountain (Serbia). Chemosphere, 84, 1584–1591.

Swanepoel, P. A., & Tshuma, F. 2017. Soil quality effects on regeneration of annual Medicago pastures in the Swartland of South Africa. AFRICAN JOURNAL OF RANGE & FORAGE SCIENCE, 34(4), 201–208.

Sun M.X. 2011. The impacts on soil properties and revegetation from forest fire in Tahe forest region. Beijing,China.

Šimanský Vladimír. 2015. Changes in Soil Structure and Soil Organic Matter Due to Different Severities of Fire. Ekológia (Bratislava), Vol 34, Iss 3, Pp 226-234.

Sannigrahi, S. et al. 2018. Effects of forest fire severity on terrestrial carbon emission and ecosystem production in the Himalayan region, India.

Talita Z. et al. 2016. The effect of simulated heat-shock and daily temperature fluctuations on seed germination of four species from fire-prone ecosystems. Acta Botanica Brasilica. 30(3): 514-519.

Huang W.T. et al. 2018. Effects of Fire Severity and Topography on Soil BlackCarbon Accumulation in Boreal Forest of Northeast China. Forests, Vol 9, Iss 7, p 408.

Williams P.R. et al. 2003. Fire-related cues break seed dormancy of six legumes of tropical eucalypt savannas in north-eastern Australia. Austral Ecology 28: 507-514.

Williams P.R. et al. 2005. Germinable soil seed banks in a tropical savanna: seasonal dynamics and effects of fire. Austral Ecology 30: 79-90.

Živanović Stanimir et al. 2015. The effect of air temperature on forest fire risk in the municipality of Negotin. Glasnik Srpskog Geografskog Društva, Vol 95, Iss 4, Pp 67-76 (2015), (4), 67.

Zhou L.B. & Xu XT. 2007. The effects of forest fire on forest. Inner Mongolia Forestry Investigation and Design. Vol 30.