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THE EFFECTS OF FIRE ON ECOSYSTEM FUNCTIONS: A STUDY WITH THE PURPOSE OF IMPROVING FIRE MANAGEMENT IN LESOTHO

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ABSTRACT

Rangeland burning is common in Lesotho during the dry season, though illegal. This practice has negative consequences as biodiversity is lost, and human well-being is negatively affected. The present study was primarily conducted as a desk study with focus on factors that affect fire behaviour; effects of fire on ecosystems and ecosystem functions; and fire management in Lesotho. The desk study was supported by a field study on the effects of fire on pine and birch ecosystems in Iceland. The field study focused on the effect of fire on vegetation composition; regrowth of burned areas; and cover of bare patches. Sixteen plots were established, eight for each ecosystem, equally divided between burned and unburned areas. The desk study showed that topography, weather, and fuel load influence the behaviour of fire. Fire severity, frequency, and duration influence the magnitude of the impact of fire on ecosystem components. It was also shown that the effects of fire on herbaceous vegetation, woody vegetation, soil nutrients, soil physical properties, animals and their habitats, differ according to the frequency, severity, and duration of fire experienced. The field study showed that the effect of fire is more severe on birch trees than pine trees as pine trees are taller and less flammable. Low shrubs and mosses were totally eradicated by the fire, while some herbaceous plants came back immediately afterwards. Certain species seemed to benefit from fire, while others take a long time to come back. Wildfires are a significant contributor to land degradation in Lesotho. For this reason, fires have not been used in rangeland management, but illegal rangeland burning is common.

Therefore, there is a need to limit unprescribed fire. Prescribed fires are recommended in the management of rangelands in Lesotho.

Key words: Forest fire, Iceland, Lesotho, rangeland, wildfires

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1. INTRODUCTION

Every year in the winter season, from May to July, rangelands are burned at an alarming rate in Lesotho (Department of Environment 2009). At least four sources of fire have been identified: herders, lightening, wildfires emanating from the neighbouring country, and cigarette stumps disposed of at the roadside by people passing by. It is common practice for herders in Lesotho to burn rangelands in pursuit of green forage for livestock.

The Department of Environment (2009) in Lesotho has shown in the Convention on Biological Diversity that vegetation in Lesotho has endured tremendous stress from key disturbances including uncontrolled fire, overgrazing, and encroachment by invasive plants, settlements, and cultivation. These have transformed the environment and the overall trend in the status of vegetation, mammals, reptiles, and birds has been observed to be declining. The national parks have lost a lot of valuable vegetation due to the burning of rangelands. Some species of vegetation are believed to have become extinct, and unprescribed fire, among other factors, is the probable cause of extinction. Many species of wild animals are no longer observed in the country, some are believed to have emigrated to South Africa, while some are believed to have died out due to fires. The IUCN (2021) compiled a list of species that are threatened in Lesotho and are on the verge of extinction. Many species have been declared endangered and some are kept in conservation areas for protection (IUCN 2021). The conservation efforts taken are only reducing the perceived rate of decline.

The decline has had a negative impact on human well-being as well. Replacement of naturally generated products by man-made materials has many costs which some people cannot afford. Many people in rural areas still depend on dry stocks of vegetation for firewood as the main source of energy. Unprescribed burning of these fuel loads renders the people susceptible to hunger and starvation. Weaving with grass and selling woven materials like baskets, mats, traditional hats, brooms, and some other ornaments is a means of income for many people in Lesotho. Many houses are built using thatching grass. To some people, it is not an option but a must to use thatching grass as it is the only cost-free and readily available material to roof houses. Vegetation is also of critical importance as many people use it for medicinal purposes, as forage for livestock, in recreation, and landscaping.

Despite the harmful effects that unprescribed fire can bring, there are also a lot of benefits that can be derived from proper use of fire. Heady (1975) stated that fire is a reasonably stable and consistent ecological disturbance and mentioned that over time, vegetation would have remained substantially stable if fire did not happen and cause restructuring. The ability of plants and animal species to develop adaptation mechanisms to certain environmental conditions was made possible by exposure to fire (Schwilk & Ackerly 2001). It stimulates renewed and increased activity by plants and animals. Heady (1975) considered fire as an important factor that reduces huge stores of organic carbon and makes nutrients available for plants.

This research attempts to establish how different kinds of fires affect ecosystem components, and hence ecosystem functioning. It will also investigate how the characteristics of the ecosystem itself affect the behaviour of fire. This report will be focussed on prescribed fire, i.e. fire that is initiated intentionally by trained personnel and is practised as a management tool; and on unprescribed fire, that is fire that starts naturally or is anthropogenic, i.e. is initiated by people who have other motives than management in their minds. The study will attempt to answer the following questions:

- How is the functionality of the ecosystem affected by the different intensities and durations of fire on the rangelands?
- How does fire affect different components of the ecosystem?
- What is the preferable combination of environmental and weather conditions to start a fire in Lesotho?

Many communities in Lesotho see fire as a destructive force that brings nothing but devastation into their lives. The Department of Range Resources Management Policy (DRRM [Department of Range Resources Management] 2014) regard rangeland fires as the major threat to the grassland ecosystem. This research, however, is about finding out if the real problem is fire itself or the management of fire. It intends to establish if fire could be useful in the management of rangelands in Lesotho, if and when it is managed properly. After completion of this project, a training manual will be developed in Lesotho for different stakeholders. This will be aimed at informing herders and the public at large on ecosystem fire management. Strategy 4.3.3 of the National Range Management Policy of the government of Lesotho states that research will be undertaken periodically and proposals on strategic rangeland ecosystem management, conservation, and rehabilitation be made (DRRM 2014). This research addresses that requirement.

1.1 Objectives

- To describe factors that affect the behaviour of fire.
- To find from the literature the effects of fire on ecosystems and ecosystem functions.
- To investigate the state of knowledge about fire management in Lesotho (and adjacent areas).
- To study the effects of fire on woodland in Iceland through a short field visit.

1.2 Goals

The knowledge gathered from this study will be applied in the management of rangeland fires to aid and the goals are:
- Improvement and maintenance of rangeland resource productivity and sustainability
- Restoration of rangeland quality
- Improvement of livestock and wildlife productivity
- Conservation of native plant species

2. METHODS

2.1 The desk study

This is primarily a desk study, and secondary data from previous studies was used. This information was gathered from trusted and credible internet platforms such as Google Scholar and Web of Knowledge. This information was supported by observations made in a field study that was conducted on the 17th of August 2021 in Heidmörk, just outside Reykjavík, Iceland.

The desk study focused on the following:
- To describe factors that affect the behaviour of fire
- To describe the effects of fire on ecosystems and ecosystem functions
- To explore the state of knowledge about fire management in Lesotho and adjacent areas

The information in this report is from all over the world, but the study focussed primarily on information gathered in African countries, particularly Southern Africa. This was done to accommodate the differences in important factors like climatic conditions, topography, soil types, vegetation types and biomass. The outcome of this study will be used in fire management in Lesotho.

2.2 Field study

A short study visit was undertaken to an area in Iceland that had recently experienced wildfire. It was necessary to have a picture of the differences in the ecosystem that has suffered and was recovering from fire and the ecosystem that had, at least not recently, suffered from fire. The observations made were compared to the information gathered from literature. In the study area, the following parameters were observed:

- Vegetation composition
- Regrowth on burned areas
- Availability of bare patches

2.2.1 Study site description

The study area is shown on Figure 1. It is located at Latitude: 64°03' and Longitude: 21°49'.

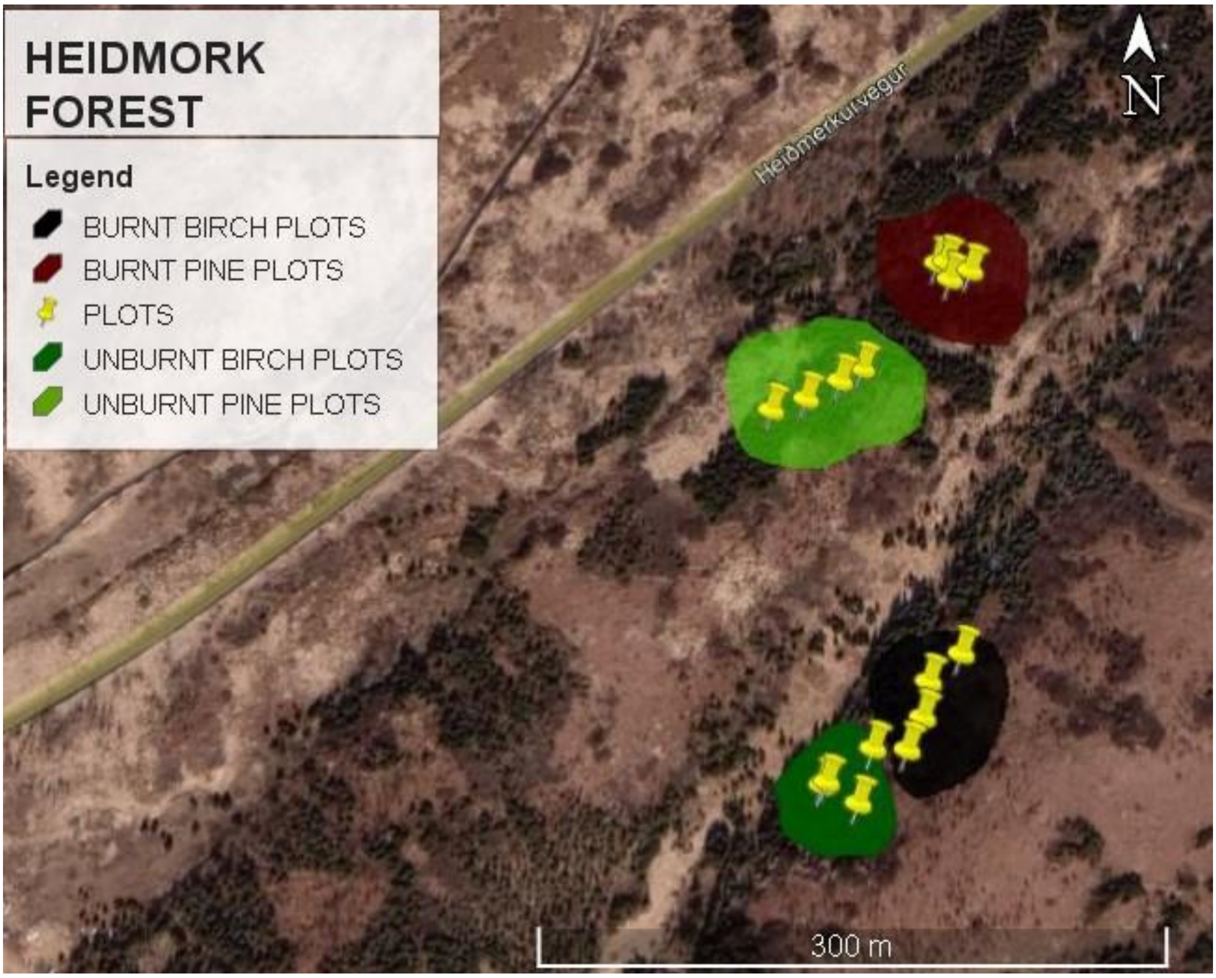

Figure 1. Distribution of plots in two distinct areas under pine (top) and two under birch forests (bottom). (Source: Google Earth).

At the time the study was conducted, this area was partly covered with native birch (*Betula pubescence*) woodland and partly with plantations of lodgepole pine (*Pineus contorta*), but other introduced tree species were also present. It consisted of a rough topography, with flat areas where most of the pine trees were planted, and a hill, with a high density of birch trees. This area was hit by fire during May 4-5 2021. The plots established on burnt and unburned areas were inspected. In the birch forest, four plots on a burnt area and four plots on an unburned area were studied. In a pine forest, four plots on a burnt area and four plots on an unburned area were studied. On each plot the coverage of trees and flora on the forest floor was visually assessed as well as the effect of burning in burnt plots. The plots were established by Dr. Brynja Hrafnkelsdóttir, forest entomologist at Mógilsá, Forest Research Station, to study the effects of burning of insects and fauna. As only one day could be allocated to this study the methods had to be adapted to this narrow time frame. Each plot used in the present study covered the centre part of the original plots roughly defined visually as a circular area around pitfall traps, established by Dr. Hrafnkelsdóttir and had ca. 8-10 meter diameter.

The cover of individual species and groups of plants, such as grasses and moss, were assessed visually using the Braun Blanquet cover classification scale, as shown in Table 1. Cover was assessed in three layers: (1) canopy cover of trees and shrubs, (2) cover of vegetative plants and (3) cover of bare ground, mosses and needles on the ground. Therefore, the upper cover limit always exceeds 100%.

Table 1. The Braun Blanquet vegetation cover classification scale. (Source: Adapted from Kent 2012).

Class	Cover
1	1 - 5%
2	6 - 25%
3	26 - 50%
4	51 - 75%
5	> 75%

All burned plots were checked for regrowth of woody plants. All non woody plants observed on the bottom of burned plots were supposed to have regrown. Cover of birch and pine in burned plots, before burning, was also assessed from the spread of branches and stems, although this is rather difficult. Fire damage on trees was also assessed.

3. FACTORS THAT AFFECT THE BEHAVIOUR OF FIRE

3.1 Weather

Lesotho has four seasons in a year: summer (November-January), autumn (February-April), winter (May-July) and spring (August-October). According to the Ministry of Energy, Meteorology and Water Affairs (LMS [Lesotho Meteorological Services] 2013), Lesotho experiences a temperate climate with maximum and minimum temperatures ranging from 10.9°C to 27°C in summer, and average minimum temperatures ranging from 0.1°C to 17.3°C in winter. The summer season in Lesotho experiences most of the rainfall, about 85% of the average range of 400-1,200 mm per year (LMS 2013).

The key meteorological variables which should be considered for prescribed burning of rangelands include precipitation, atmospheric air temperature, relative humidity, and wind speed (Heady 1975). The length of the dry season as well as its severity are determined by seasonal precipitation patterns. The dry season in Lesotho used to last around three months, which are the cold winter months, but with the prevailing climate change, it usually lasts up to six months. During this time, uncontrolled fires are common. Unprescribed fires are less likely in cold temperature areas where there are monthly rains and a short growing season. Prescribed burning conducted after rain, on the other hand, might be beneficial in removing undesirable standing material without harming growing plants or mineral soil. Heady (1975) advices that necessary factors should be considered when identifying the day of burning. The recommended time of burning is when the organic matter is still moist to avoid destroying it.

Heady (1975) states that the relationship between humidity and temperature shows an inverse proportionality: when air temperature increases, humidity decreases. This is of course the case considering all other conditions are kept equal or static. When the air is dry, fuel is dry, and this increases the probability of unprescribed fires spreading out of control. According to Heady (1975), there are no specific guidelines given as to when to start prescribed fires but it is suggested that prescribed fires in light fuel should not be conducted when the relative humidity is less than 25% and the atmospheric temperature is above 24°C. When the rangeland is full of dry and heavy fuel with loose twigs and leaves, relative humidity in the atmosphere required for prescribed burning should be over 35% and temperature less than 24°C (Heady 1975). These weather conditions usually fluctuate according to time of day and season of the year. Therefore, these conditions, along with wind speed and direction, are determining factors of the time of day for prescribed burning.

According to Heady (1975), wind catalyses burning as it drives the flame front forward to reach new unburned sites. Wind draws oxygen to flames and eliminates carbon dioxide. Oxygen then catalyses the flame and burning continues. Wind also pushes hot air masses forward and towards the earth, where radiant heat becomes dry and dries up fresh fuels as well, therefore facilitating ignition before the progressive flame front. Combustion is accelerated by strong winds, resulting in lengthy fingers of burned land. Benson et al. (2008) mentioned that the direction a fire takes is influenced by biomass or fuel supply, landscape terrain, and the direction wind is blowing. They further stated that in conditions where there are bare patches (i.e. uneven distribution of fuel), a fire may go out when it gets to a bare area and fail to spread, unless the velocity and direction of wind are high enough to allow the fire to jump bare patches.

Heady (1975) indicated that movement of wind is accelerated up-slope in the day and down-slope in the night. There is a great necessity to gather information on the prevailing conditions of wind before burning, as well as the wind prediction forecast to achieve a successful burning objective. Heady (1975) suggested that a fire should not be started if the velocity of the wind is greater than 10 km/h. Visual assessment can be made of the speed of wind. At velocities less than 10 km/h, loose papers do not move, tree leaves are stable, grasses do not show significant wave motions (Heady 1975).

3.2 Topography

The characteristics and behaviour of fire could be tremendously affected by variations in the land surface or topography, as these variations influence weather patterns (Heady 1975). The eastern and north-eastern aspects of Lesotho`s mountains and hills receive the most severe burning, perhaps because they are warmer and dryer most of the time. Trollope (1984) indicated that there is a considerable influence of slope on the spread of fire up-slope. When fire moves up-slope, unburned fuel in front of the fire is heated up before the flames get to it. This makes it easy for fire to spread rapidly (Trollope 1984). Heady (1975) also indicates that a fire that starts from the bottom of a slope moves faster to the hilltop than a fire that starts at the top of the hill and moves down (Fig. 2). Heady (1975) further suggests that fire which starts at the top of the hill may be facilitated by burnable material as it rolls down the slope and burns the dry fuel, spreading the fire across a bigger area in a shorter time. The rate of fire spread up-slope and down-slope could be utilised in decision making in the management of rangelands considering the amount and kind of fuel on that land.

Figure 2: A fire that started at the top of a mountain, moving slowly down the slope. Because it moves slowly, all dry combustible material is able to catch the flame and start burning. No dry matter is left unburned. (Photo: K. Ramatutu 12 July 2021).

3.3 Plant fuel

Plant fuel itself has several features such as dimensions, continuity, and compactness. Small surface-volume materials burn easily. For instance, grass leaves and needles burn rapidly and oxidise fully, whereas logs and big limbs may only burn on the exterior under the same intensity of fire (Heady 1975). Heady (1975) suggested that the largest flammable fuel is a combination of large and tiny components. Small materials easily ignite and fuel quickly, whereas bigger parts increase heat release and consumption.

Trollope (1984) indicated that the proximity of pieces of fuel to one another relates to the probability of fire spreading from burning to unburned pieces of fuel. When fuel is loose yet close enough to other pieces, there is sufficient oxygen in between the fuel to facilitate burning and keep the fire continuous. On the other hand, when there are many bare spaces in between fuel items, some fuel will be burned but some will be left unburned because patchy fuel distribution causes discontinuity of fire (Heady 1975).

3.4 Characteristics of fire

3.4.1 Fire severity

Fire severity is the concept that describes the physical effects of a type of fire upon ecosystems, industry, infrastructure, or any establishment. In this study, the focus is on ecological effects. It indicates the magnitude of change or modification that comes after fire in ecosystem components (Neary & Leonard 2019). Fire influences ecosystem components above the soil surface, in the soil surface, and even under the soil surface, but usually the effects are observed above the soil surface (Neary & Leonard 2019). Grassland fires experience this particular scenario as shown in Figure 3. Usually, a fire does not last long in grassland ecosystems as compared to forested and bush infested ecosystems because in grasslands there is a lower amount of fuel and biomass that burns quickly and the fire dies out (Neary & Leonard 2019). In bushlands and forestlands, fire takes a longer time to go out because of large amounts of compressed fuels.

Neary and Leonard (2019) divided fire severity into three classes: light burn; moderate burn; and deep burn.

Light burn is usually recognised in grasslands but can also occur in woodlands and forests. The above ground mass of plants is lightly burned but is still identifiable. Plant bases are not burned. Mineral soil is not affected. Short duration fires usually result in light burn.

Moderate burn is usually recognised in forests but can be applicable in woodlands and grasslands as well. When it occurs in grasslands, herbaceous vegetation is burned and plant bases are affected and unidentifiable. In woodlands, the damage of fire extends to the mineral soil to a depth of 3 cm.

Deep burns are characteristic of forests but usually not grasslands because very high fuel loads are required to support them. However, when it does occur in grasslands, vegetation is completely burned, leaving white ash on the surface. Even the roots are burned as fire runs deep into the soil. The soil structure is slightly changed.

Trollope and Potgieter (1985) classified fire into six groups based on its intensity measured in energy (kilo joules; KJ) per unit time (seconds; s) per unit length (meters; m). The six groups are: very cool fire is less than 500 KJ/s/m; cool fire is between 501 KJ/s/m and 1,000 KJ/s/m; moderately hot fire is between 1,001 KJ/s/m and 2,000KJ/s/m; hot fire is between 2001 KJ/s/m and 3000 KJ/s/m; and extremely hot fire is greater than 3000 KJ/s/m.

Figure 3**:** Intensive fires in a grassland ecosystem. (Source: From Neary & Leonard 2019).

3.4.2 Fire frequency

The effect on vegetation of the frequency of burn is contingent upon the number of times the treatment has been applied and the management intervention applied during the time interval between the burns (Booysen & Tainton 1984). Booysen and Tainton (1984) also mention that the treatment that is practised during the time interval between the burns could distort the results expected at the end of the rest period, hence creating confusion in the analysis of the results. In a study conducted in the Eastern Cape in South Africa, Robinson et al. (1979) discovered that when grazing was eliminated, annual burning resulted in an increased number of grasses but a decreased number of forbs. Contrary to that, burning after every four years resulted in a decline in grasses and a significant increase in forbs. In a five-year period of rest, a decline in the occurrence of grasses and an increase in the occurrence of forbs was observed. Therefore, burning once every four years could be confused with the impact of rest; the grasses could be decreasing because they are dying due to lack of defoliation and not because they are burnt every 4 years.

In a study conducted by Kennan (1971) in Zimbabwe, it was discovered that initially, burning in tree and shrub plantations had very harmful effects on trees and shrubs. When the plant litter was completely removed in later burnings, the burning became less harmful to the trees and shrubs. Therefore, the effect of burning varied with the frequency of burning.

4. EFFECTS OF FIRE ON ECOSYSTEMS AND ECOSYSTEM FUNCTIONS

4.1 Fire effects on vegetation

4.1.1 Fire effects on herbaceous vegetation (grasses, forbs, mosses, lichens)

Higgins et al. (1989) stated that fire has the potential to influence change in herbaceous vegetation, but whether it suppresses or promotes a certain plant species is largely determined by the time of the fire in connection to the phenology of the specific species, phenology being the study of the timing of life events in plants. Several studies show that the stage of growth is a crucial determinant of plant-fire damage. According to Anderson et al. (1970), fire can demonstrate varying effects on dormant and actively growing plants. The case in point could be when the area is set on fire; actively growing plant species could be affected more due to their susceptibility and vulnerability to injury and death than inactively growing plant species. Based on this understanding, Higgins et al. (1989) concluded that the appropriate time for prescribed burning could be based upon physiological and morphological stages of the plant such as the growth stage of roots and leaves. Heady (1975) concurs with this as he points out that a grassland fire occurring when some species are green, and others are dry will damage the green species more than the dry ones.

Heady (1975) outlined that for each plant, the degree of fire damage is determined by its physiological condition and the temperatures attained in its live tissue. Heady (1975) added that the growth stage, the growth form, and the size of the plant influence the susceptibility of live tissue to heat damage. Daubenmire (1968) also mentions that harmful temperatures for meristematic tissue appear to be above 60°C but, many seeds have a much higher heat threshold and withstand temperatures over 100°C.

Fire intensity (which is influenced by topography of the rangeland; the amount, distribution, and dryness of fuel; the weather condition; soil moisture) is also a contributing factor to the damage of plants by fire (Wright & Bailey 1982). Trollope and Potgieter (1985) suggested that if the objective of burning the rangeland is to get rid of moribund material, then the required intensity of the fire is less than 1000KJ/s/m. This kind of fire can be experienced when the temperature of the air in the local atmosphere is less than 20°C, wind speed is between 5 and 15 km/h and atmospheric relative humidity is greater than 50%. The effects of temperatures below 300°C rarely reach depths of 2 cm into the soil.

The biotic and abiotic factors that affect the response of vegetation to fire include among others the type of biome, historical exposure to fire, season of year, amount of vegetation, velocity and direction of wind, and air temperature (Heady 1975). A healthy rangeland ecosystem requires that there should be moderate defoliation of vegetation from time to time. As much as burning rangelands could be dangerous to ecosystem functions, withdrawal of fire from rangelands can also have bad effects on vegetation production because excessive litter accumulation causing lack of light could sabotage growth of new shoots of vegetation, hence minimise vegetation yield (Tomanek 1948). Competition for sunlight could be enhanced by moribund material. Moreover, Vogl (1974) noted that some plants are usually enhanced by fire as it triggers the process of natural selection in which plants modify their genetic make-up to adapt to changes in the environment. More plants are produced that are more resistant to disturbances. Vogl (1974) also noted that if a fire occurs at the right time, annuals and perennials with short life spans are usually enhanced as they grow up in less competition for sunlight after larger plants have burned.

When assessing the achievements of long term studies on savanna vegetation, Furley et al. (2008) made some observations on the effects of prolonged exposure of vegetation to fire:

- Fire intensity, behaviour and frequency influence the response of plants to fire in terms of sensitivity and tolerance.
- There is alteration of plant communities from dominance of perennial plants to annual plants.

While investigating the effects of fire frequency on mycorrhizal associations of key grass species of southern African savanna, Hartnett et al. (2004) discovered that recovery of vegetation from exposure to high intensity fires is contingent upon conducive temperatures, ability to resprout, and the intervention of mycorrhizae. Furley et al. (2009) reported that high frequency fires also result in alterations in plant composition. Species of vegetation that have adapted fire-tolerant mechanisms flourish and dominate the ecosystem. DiTomaso and Johnson (2006) reported that growth forms of plants have a bearing on the effects that fire has on them. Some annual grasses and forbs germinate right after the winter season bear seeds and disperse them in the late spring. They mature and disperse seeds before a sufficient fuel load has accumulated for burning. When a fire comes, the seeds are already in the soil awaiting germination. DiTomaso and Johnson (2006) go on to tell that on the other hand, some plants have a longer life cycle in which the fuel load is accumulated before they mature for seed dispersal. Fire catches these plants before they can disperse the seeds. The ecosystem of which they are part suffers the consequences of the fire as those species may not come back for over a long time, and their role in the ecosystem is not fulfilled. If a fire burns the plants before they disperse seeds, the ecosystem is badly affected, and so is its functionality (DiTomaso et al. 1999). Annual plants are controlled by burning once in a while but according to Keeley et al. (2003), a different approach to that of annuals is required to control biennial species. Multiple year burns should be practised to control biennial species, otherwise intervention with other control methods is necessary (Keeley et al. 2003).

According to Daubenmire (1968), the location of perennation organs on the plant species could determine the susceptibility of the species to fire. Plants species that possess these organs on the exposed plant body could suffer fire damage more than those with perennation organs located in the soil. High temperatures from high fire intensity kill plants perennation organs exposed to fire. However, Vogl (1974) adds that species diversity in a grassland ecosystem is not reduced by repeated burning of the grassland, instead, it may be increased by the introduction of species of grasses, legumes, forbs, and annual plants stimulated by fire. The condition of wetland sedges and grasses can be improved by prescribed burning. In contrast, a slow-moving fire that could penetrate through wetland peat would be harmful to all hydrophytes (Yancey 1964).

Lutz (1956) stated that mosses generally reproduce by means of spores, but after burning, they develop vegetative regeneration. As defined by Klimesova and Klimes (2007), vegetative regeneration is “[g]rowth of plant which follows after loss of biomass due to disturbance and results in at least partial restoration of plant functions (vegetative growth)” (p.125). Lutz (1956) stated that some moss species like *Ceratodon purpureus* regenerate readily after fire, and that lichens, on the other hand, are generally destroyed by fire. Lichens re-establish after a very long time after an event of fire on an area.

4.1.2 Fire effects on woody vegetation and trees

Fire has effects on woody plant species as well. These include trees and shrubs. As a general rule, all forest trees are killed by fires of very high intensity and severity (Lutz 1956). If a fire reaches the vascular tissue and the root system and destroys them, the tree has no chance of surviving, either from seeds, roots, or resprouting. Lutz (1956) mentioned that Balsam poplar, unlike other trees, possess a uniquely thick bark that protects the inner tissues form fire. These species usually survive high intensity fires, which other species would not survive. One tree species that has a unique response to fire is the Jack pine. According to Ahlgren (1974), this pine species retains the cones for many years without opening them for seed dispersal. The seeds accumulate and wait for fire to strike, after which the cones are opened and seeds dispersed and germinated. Ahlgren (1974) reported that a tough layer enclosing the cone is cut open by fire, releasing seeds which will germinate in the soil. The seedlings of the pine species survive where there has been some alterations in the structure and chemistry of humus layer that is caused by fire. Otherwise the pine seedlings establish where mineral soil has been exposed by some other means.

Schwilk and Ackerly (2001) talked about traits of plants that relate to fire, which are adaptation modifications of plants to resist destruction of aboveground biomass by fire, promote seedling and resprouting after fire. These traits in species of pines include the development of thick protective bark, elongation in height, removal of dead and dry branches, and the establishment of serotinous cones. Van Wilgen (2005) also pointed out that plants in areas of frequent burning have developed adaptation mechanisms which aid in surviving fires. Van Wilgen (2005) further added to the list of examples of such adaptation mechanisms: sprouting, smoke-stimulated germination, and flammability.

Betula papyrifera (paper birch) is one of the tree species often found in association with post-fire vegetation (Ahlgren 1974). Ahlgren (1974) reported that a large number of new shoots of birch appears after a fire, and they develop more quickly than seed-germinating conifers during the first years. According to Lutz (1956), young birch, like many other tree species, is killed by fire due to its thin developing bark. When it matures, the bark grows thicker and more flammable. Lutz (1956) also added that sprouting of birch is common in young stands from dormant buds on the previously burned stand.

Shrubs are also affected by fire, as Ahlgren (1974) reported. According to Ahlgren (1974), shrubs that emerge in burned areas were usually already present in those areas before the fire. Fire does not totally eradicate any species of shrubby vegetation and those that produce seeds at a high rate may emerge immediately after a fire, but they take longer to grow and colonise the ecosystem (Ahlgren 1974). However, Bond and Midgley (2001) reported that the characteristic potential of woody species to recover from burn is compromised by the increasing magnitude of a disturbance, and fire is one such disturbance that can cause deadly damage to woody vegetation. According to Bond and Midgley (2001), sprouting in shrubs is contingent upon life history stages and the magnitude of disturbance that hit the species. Bond and Midgley (2001) stated that in order to survive an injury, shrubs need resilient meristematic tissues and convenient food storages to support regrowth.

When assessing the achievements of long term experimentation on savannah vegetation, Furley et al. (2008) made some observations on the prolonged exposure of trees and shrubs to fire:
- As the frequency of fire increases, the above ground tree biomass decreases, especially the height of the trees.
- Tall trees, from heights of three meters up, are barely affected by fire as it only burns the lower parts of the tree.
- Even though the individual trees and shrubby vegetation may be damaged by fire, they are replaced by the resprouts. Therefore, their average density is not really affected by burning.
- Fire has a small effect on the composition of plants in an ecosystem.
- More severe effects of fire are observed on woody vegetation that grows in higher rainfall areas.
- The structural set-up of trees, shrubs and herbaceous plants is greatly affected, in which the proportion of trees to shrubs and to herbaceous vegetation is decreased, creating larger bare spaces on the ground.

4.2 Fire effects on soil nutrients

Plant residue or ashes left on the ground after rangeland burning comprise potassium, calcium, magnesium, and phosphorus (Heady 1975). Heady (1975) stated that there is an insignificant loss of these nutrients from the burning of rangelands, unless and until they are released through water and wind when they are bonded to other organic materials. As for nitrogen and sulphur, they are lost through volatilisation when the fire heat is high enough to leave white ash. Black ash symbolises light burning, and this results in little loss of minerals from the system. According to White and Gartner (1975), phosphorus in the soil increases when fire temperatures remain less than 200°C. Christensen (1976) reported an increase in the concentrations of magnesium, potassium, and calcium after fire while Ohr and Bragg (1985) reported an increase in the availability of zinc, copper, and iron after consecutive years of fires. A major influence in soil nutrients is when minerals are released rapidly, and pH is increased at a slow rate or there is just a small increase. Heady (1975) revealed that even though nitrogen is lost from the ecosystem through the smoke, loss of nitrogen from grassland ecosystems caused by burning does not always appear in the reports. The reason could be associated with the rapid replacement of that lost nitrogen through fixation by pioneer plants which are often composed of annual legumes.

Viro (1974) discovered that following a fire, herbaceous plants that make up pioneer plant species on a burned land serve to reduce the acidity of the soil and stimulate the land's biological activity. Viro (1974) added that carbonates and oxidants are produced after burning organic matter, causing an alkaline response. Thick humus layers contain huge amounts of nutrients but are inaccessible because of high acid levels in the soil. The decomposition of this humus is very slow, but fire accelerates this process and renders the nutrients available for consumption (Viro 1974).

White et al. (1973) affirmed that heat can lead to volatilisation of some nutrients or elements by showing that alteration of the physical properties of the soil by warming and cooling affects minerals in the soil. According to Dunn and DeBano (1977), nitrogen is lost during fire through different pathways. However, there is a quick replacement of such nitrogen through fixation by leguminous plants, which happen to dominate sites almost immediately after fire.

4.3 Fire effects on soil organic matter and microbial activities

Fire may not result in high temperatures of the soil, but it certainly has an impact on above-ground and below-ground organic substances (Heady 1975). Heady (1975) explained that fire changes the quantity of organic matter accessible for decomposition by lowering above-ground parts and frequently increases soil organic matter by destroying plants. There are many different aspects to the decline in the organic matter in the ecosystem (Ratsele 2013). Ratsele (2013) further suggested that fire is associated in many cases with the loss of organic matter in the soil, even though this is not always true. Removal of vegetation cover reduces organic matter content and the activity of micro-organisms in the soil because materials that constitute and decompose organic matter are eliminated from the system, which also affects the stability and infiltration characteristics of the soil (Mills & Fey 2003). Czimczik et al. (2005) indicated that high fire intensities may cause a decline in organic matter content within the organic soil as high intensity fires destroy the whole top soil. Conversely, weaker flames burn sections of the soil profile which are converted to black carbon by certain organic materials. Neff et al. (2005) reported that a much-reduced soil biotechnological material and a litter horizon no longer include identifiable unburned plant material during and soon after the fire.

In Southeast America, grasslands with a pine over-story often have organic matter enhanced after fire. Fires on grasslands typically show comparable impacts before the growth season. Moore (1960) working in Nigeria has shown a decline of 30 years of yearly, early dry season burning, compared to full protection, in soil organic matter, but late dry season burning. The reasons for increasing organic matter are high soil temperatures that boost development, a brief abundance of annual pioneering plants, and the decline of roots from fire-killed plants (Daubenmire 1968).

4.4 Fire effects on stability and properties of the land

Site stability describes the potential of an area to remain unaltered or the potential to return to its previous condition after disturbance (Griffiths et al. 2001). Fire and other disturbances of an ecological nature can change the functionality of the ecosystem if they hit intensively and create a different environment altogether (Folke et al. 2004). The capability of a soil to restrict loss of soil resources through erosion, and the soil's capability to fulfil its tasks, may be influenced by the intensity and frequency of fire (Archer & Pyke 1999).

Fire could affect soil properties as well. DeBano et al. (1977) reported that several soil properties such as soil texture, soil structure, soil porosity, soil infiltration capacity, and water holding capacity could be affected by the introduction of fire into the ecosystem. DeBano et al. (1977) also added that the impact, however, is contingent upon fire frequency, intensity, and severity. The effects of fire are not only evident on the soil`s physical properties, but can extend to plant metabolic functioning and growth. Plant uptake of nutrients and water can be altered if the soil structure is tempered with and moisture retention, as well as the porosity, are reduced (Nye & Tinker 1977). At the same time, growth of roots is retarded when bulk density is increased due to the introduction of fire (Gerard et al. 1982). Certini (2005) indicated that the severity of a fire, which could be defined by temperatures reached and the length of time a fire persists, can change the physical, chemical and biological properties of the soil. Certini (2005) also added that severe fires cause elimination of organic matter, destruction of the soil structure, and alteration of soil porosity. Significant amounts of soil nutrients are lost. Most of the factors that contribute to soil stability and structure are negatively affected by severe fires. The ability of the land to recover from the burn will be determined by the prevailing climatic condition, vegetation, and topography of the area (Certini 2005). However, Hungerford et al. (1990) argued that it is in rare cases that fires attain such temperatures high enough to impact the soil`s physical properties.

Everson et al. (1989) stated that annual winter fires on rangelands do not result in accelerated soil loss. However, Bird (1996) claimed that burning rangelands during the winter season in the montane belt results in considerable sediment loss.

4.5 Fire effects on animals and their habitats

De Ronde et al. (2004) indicated that fire has a low effect on highly mobile animals as they can move away from the burning area or the burned area, but has a lethal effect on less mobile and flightless animals and organisms as they have difficulty moving out of the affected area. According to Heady (1975) the number of insects present in an area could rise or decline after fire. Many individuals are killed by fire, but some escape and come back after fires. The returning species find nourishment from certain plants that are abundant in different successional stages after a fire. Other insect species are abundant in relation to the amount of cover, which is influenced by fire.

Martin and Cushwa (1966) stated that ground-nesting birds are vulnerable to loss of nests, cover, and food. Because fire often affects both food and cover, bird populations respond to burning. For example, prescribed burning with hot fires in the south-eastern United States promotes herbaceous legumes and quail, but the absence of burning and light burning reduce legumes and bobwhite quail. De Ronde et al. (2004) also stated that changes in vegetation composition due to fire could have positive and negative effects on animals. Some animals take advantage of vegetation-cleared areas and reside in them to reduce the risks of being attacked by predators as visibility is improved. On the other hand, some animals prefer to hide behind tall grasses and bushes from predator attack (de Ronde et al. 2004). However, Heady (1975) indicated that grassland fires have little effect on larger animals, and most of these animals escape forest fires. Young sprout growth from surviving woody crowns generally is highly palatable and nutritious, so small burns or the edges of larger burns may be overgrazed. Shrubs that have grown beyond the reach of deer can be improved by burning the tops so that sprouts and seedlings develop. Large animal species run to escape fire, but they return to the new food soon after the fire is out. Animals respond more to a changed habitat than to the fire itself (Heady 1975).

In his study on burned areas, Gandar (1982) reported that the density of particular species of beetles did not go down immediately after a fire, which could mean that they survived. However, a few months later, the population decreased. Gandar (1982) attributed the decrease in population to the depleted food resources caused by fire. Gandar (1982) also observed that there were no dead termites in the upper layer of the soil which received some heating, and believed that termites escaped to the lower levels of the soil as they are quite mobile. Engstrom (2010) stated that the worst effect that fire can have on the ecosystem is when it causes mortality and extinction of rare species because the ecosystem could be permanently destabilised and lose functionality.

4.6 Fire effects on global warming

Carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the main greenhouse gases that contribute to global warming. Forests play a pivotal role in the global carbon cycle and are recognised as one of the major contributors to carbon sequestration from the atmosphere (Pan et al. 2011). However, Pan et al. (2011) revealed that there is a carbon sink in the global forests and this is caused by drivers including wild fires. Ribeiro-Kumara et al. (2020) indicated that wildfires are effective in the regulation of carbon cycling and conservation in forests and are accountable for about 10 percent of global carbon emissions.

While enormous quantities of carbon are emitted through burning, greenhouse gas fluxes after fire also contribute significantly to carbon budgets (Ribeiro-Kumara et al. 2020). Irrespective of the alterations made in the soil structure, the time period taken for plants to recover may influence the recovery of lost carbon. Ribeiro-Kumara et al. (2020) also stated that fires demonstrate little effect on the loss of methane but cause a fractional increase in the absorption of methane. Permafrost melting caused by heat, on the other hand, might transform upland soils into temporary sources of methane, which is determined by how quickly the shift from humid soils to drier ones takes place. According to Ribeiro-Kumara et al. (2020), there is only a slight decrease in the amount of nitrous oxide in the soil after a fire.

5. FIRE MANAGEMENT IN LESOTHO AND ADJACENT AREAS

The Lesotho Second National Communication to the Conference of Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) report states that one of the most pressing environmental concerns in Lesotho is the deterioration of land (LMS 2013). According to this report, wild fires are one of the contributors to this aggravation, along with deforestation, soil erosion, and overgrazing. For this reason, fires have not been used in the management of rangeland ecosystems.

Fire in Lesotho rangelands has been legally prohibited (GoL[Government of Lesotho] 2008). As a result no one is allowed to start fires. The exception is in selected protected areas such as Tsehlanyane National Park, Bokong Nature Reserve, and Sehlaba-thebe National Park where managed fire is used as a tool to reduce the accumulation of moribund material and to develop fire breaks around and inside these areas (Monaheng 2017). The Department of Range Resources Management has been using fire to establish fire belts as well, and it is still being used in some areas. There is, however, some reluctance in the continued use of this approach in the department. The department believes that the construction of fire breaks by using fire, sends the wrong message to the public, especially herders. Herders seem to have taken advantage of this approach and they use fire to burn the rangelands to satisfy their ulterior motives. The department has therefore resorted to other methods like clearing land strips or building stone-lines to establish fire breaks. According to strategy 4.2.3 of the Range Management Policy, a rangeland management fire policy is yet to be developed (DRRM 2014). Such a policy could introduce proper use of fire in rangeland management without contradicting the environmental act.

The Department of Environment is able to detect active fires daily, to make fire danger index-forecasts for the next three days, and to define the total area burned, all of which are produced once a month with the help of satellite technology obtained from the Monitoring for Environment and Security in Africa (MESA) project.

In the Western Cape in South Africa, fire is used in the eradication of alien woody species such as *Hakea sericea* and *Pinus pinaster* (Goldhammer & de Ronde 2004). In the Eastern Cape, fire is used to manage plant biomass in grasslands for use as livestock forage. It is used to remove excess growth from previous seasons that is not desired by livestock; to enhance development of palatable grasses; and to reduce selective grazing (Goldhammer & de Ronde 2004).

6. THE EFFECT OF FIRE ON WOODLAND IN ICELAND

An Icelandic study was undertaken to complement the information obtained from the literature review, as clarified in chapter 2. It was also meant to see how weather and environmental conditions in Iceland influence the behaviour of fire and the response of the ecosystem after a fire strike. Observations were made on plots in areas hit by fire (Fig. 4) and those not affected by fire.

Figure 4. Burnt area in Heidmörk, Iceland. Burnt pine trees in the background. Notice the burnt and dead stems and branches of willows and that the forest floor is fully vegetated only three and a half months after the fire.

6.1 Observations made on birch forest in an unburned area

The PLOTS B-c-1, B-c-2, B-c-3, and B-c-4 were established under birch forest in an unburned area (control).

PLOT B-c-1:
Birch tree canopy cover was estimated to be around 51-75% of the plot. Lupine was present in the plot, covering about 6-25%. Flowering plants, *Geranium sylvaticum* and *Rubus saxatilis* covered about 1-5%, each. Low shrubs were present, mostly *Vaccinium uliginosum* covering about 1-5%. Moss was present in abundance on the forest floor, covering about 6-25%. Some grasses were also observed, covering about 6-25%. See Figure 5 below.

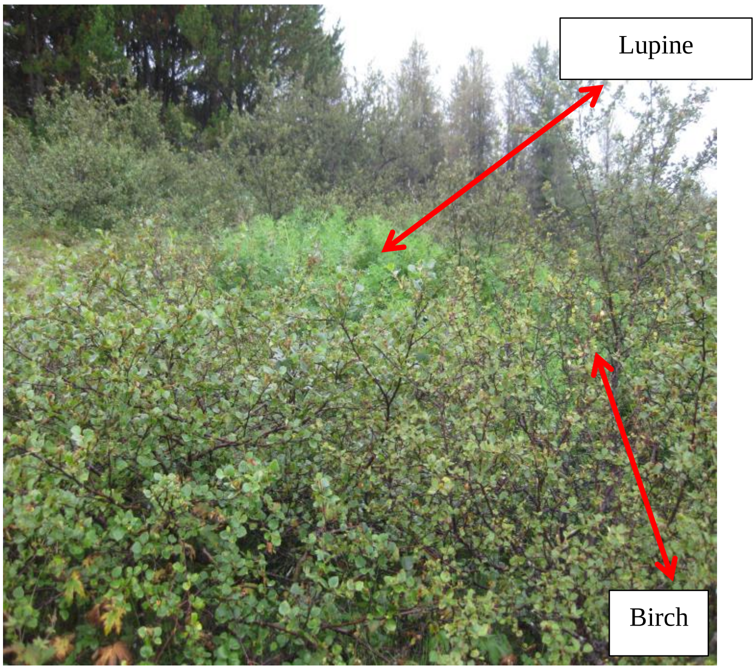

Figure 5. Plot B-c-1 was dominated by birch trees and lupine.

PLOT: B-c-2:
The plot was dominated by birch trees, covering 51-75% of the plot. Lupine was present, covering about 6-25%. Flowering plants, *Geranium sylvaticum* covered about 1-5% and *Rubus saxatilis* covered about 1-5% each. Grasses were present, covering about 1-5%. Moss covered about 6-25%. Shrubs (dominance of *Salix phylicifolia*) were also present, with a cover of about 6-25%. See Figure 6 below.

Figure 6. Plot B-c-2. *Salix phylicifolia* and grasses in the plot. Some other plants were also identified but were less dominant.

PLOT B-c-3:
Birch trees were estimated to cover about 26-50% of the plot. *Salix phylicipholia* was present, constituting about 26-50% of the plot. Lupine was present, covering about 6-25%. Moss was also present with a cover of about 6-25%. A lot of *Geranium sylvaticum* was observed, covering about 26-50%. Grasses were also present with 1-5% cover. See Figure 7 below.

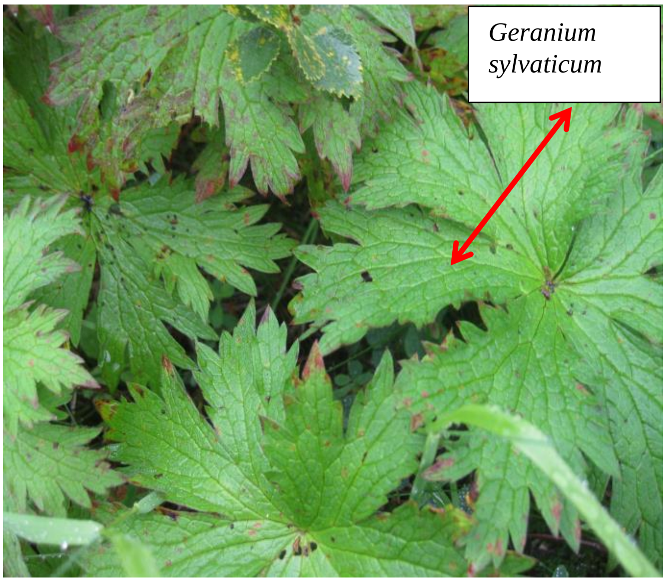

Figure 7. Plot B-c-3. *Geranium sylvaticum* was present in the plot in large numbers.

PLOT B-c-4:
Birch trees dominated the plot, with estimated canopy cover of about 51-75%. *Salix lanata* covered about 1-5%. *Rubus saxatilis* covered about 1-5%. A lot of *Geranium sylvaticum* was observed with 6-25% cover. *Larix sibirica* covered about 1-5% and *Picea sitchensis* covered about 1-5% of the plot. Moss was present on forest floor, covering about 26-50%. *Salix phylicifolia* was also present with a cover of about 1-5%. See Figure 8 below.

Figure 8. Plot B-c-4. *Picea sitchensis* was present at the edge of the plot, as well as Larix sibirica.

6.2 Observations made on birch forest in a burned area

The PLOTS B-b-1, B-b-2, B-b-3, and B-b-4 were established under birch forest in a burned area.

PLOT B-b-1:
Many birch trees were present, but with almost no leaves left. Surviving birch foliage was estimated to cover 1-5%. Grasses were present, covering about 1-5% of the plot. *Geranium sylvaticum* was abundant with about 26-50% cover. Some lupine plants were present with about 6-25% cover. Some bare patches covering about 6-25% of the plot were observed. See Figure 9 below.

Figure 9. Plot B-b-1. Birch trees were almost totally black with only a few tiny leaves at the tips of branches. The green herbaceous vegetation is *Geranium sylvaticum*, which was observed in abundance in this plot.

PLOT B-b-2:
The plot was dominated by birch trees which had been badly burnt but had some green leaves on the top branches. Surviving birch foliage was estimated to cover 6-25%. A few new shoots of birch covering about 1-5% were observed growing from the soil. Lupine covered about 51-75% of the plot. Grasses and *Rubus saxatilis* were present, covering about 6-25%, each. Burnt moss was observed on some areas, but it did not show any signs of recovery. No living moss was observed. Some bare patches were observed covering about 6-25% of the plot. See Figure 10 below.

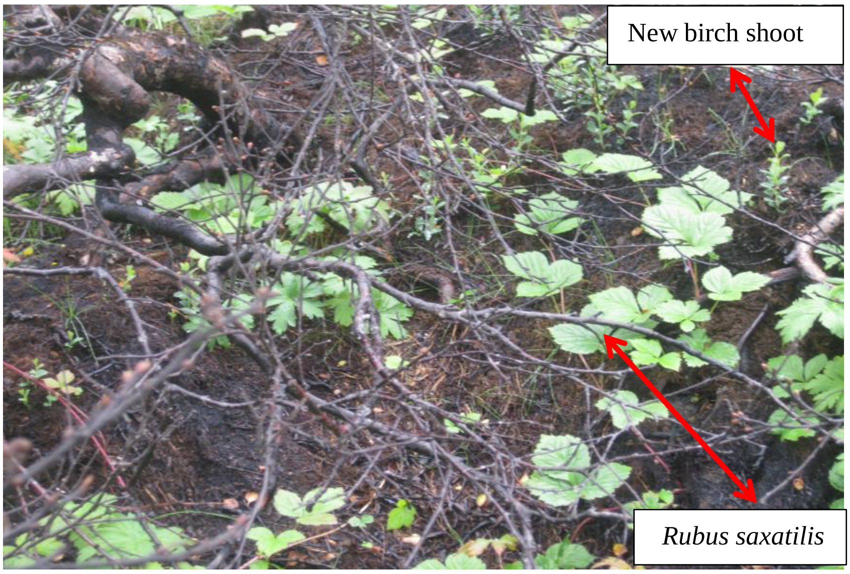

Figure 10. Plot B-b-2. New shoots of birch growing from the ground, and *Rubus saxatilis* was flourishing. Bare patches can be observed in the picture.

PLOT B-b-3:
All birch trees had been burnt and there was less green foliage than in the previous plot. Surviving birch foliage was estimated to cover 1-5%. Lupine covered 51-75%. *Geranium sylvaticum* was also present with a cover of about 26-50%. Burned moss was present on the forest floor and showed no signs of recovery. Grasses were present, covering about 6-25%. Bare patches covered about 6-25% of the plot.

PLOT B-b-4:
The plot was established on a hill. Burning in this plot was more intense than in the other plots. Green leaves were only observed on top of one birch tree. Surviving birch foliage was estimated to cover 1-5%. No new shoots of birch were observed on the ground. A lot of *Geranium sylvaticum* was present, covering about 26-50%. Some plants of lupine were present with a cover of about 6-25%. Grasses were present, covering about 6-25%. A few bare patches with a cover of about 6-25% were observed. See Figure 11 below.

Figure 11. Plot B-b-4: Birch trees experienced more fire than in the other plots. Geranium was showing fast regrowth.

6.3 Observations made on pine forest in an unburned area

The PLOTS P-c-1, P-c-2, B-c-3, and P-c-4 were established under pine forest in an unburned area.

PLOT P-c-1:
Canopy cover of pine trees was estimated to be over 75%. Most of the ground was covered by accumulated dead pine needles, covering about 51-75% and moss covered about 26-50% of the plot. A lot of *Equisetum pratense* covered about 6-25%. *Geranium sylvaticum* covered about 6-25%. *Equisetum hyemale* was also observed in the plot, covering about 1-5% of the plot. See Figure 12 below.

Figure 12. Plot P-c-1. *Equisetum hyemale* growing with *Geranium sylvaticum*, with no signs of bare ground.

PLOT P-c-2:
Canopy cover of pine trees was estimated to be over 75%. There was heavy accumulation of pine needles on the forest floor, covering about 51-75% of the ground. *Equisetum pratense* was present with a cover of about 6-25%. *Equisetum hyemale* was present, covering about 1-5%. *Rubus saxatilis* covered about 6-25% and *Geranium sylvaticum* covered about 6-25% of the plot. See Figure 13.

Figure 13. Plot P-c-2. Dead needles on the ground as well as *Equisetum hyemale* and *Geranium sylvaticum*.

PLOT P-c-3:
Pine trees canopy covered over 75% of the plot. There was accumulation of a lot of pine needles on the forest floor, covering about 51-75% of the plot. *Equisetum pratense* occupied about 6-25%. *Equisetum hyemale* covered about 6-25%. *Geranium sylvaticum* was observed in the plot, covering about 51-75%. Moss covered about 6-25%. See Figure 14 below.

Figure 18. Plot P-c-3. Many plants of *Geranium sylvaticum* in the plot, with a few individuals of *Equisetum pratense* and *Equisetum hyemale* around them.

PLOT P-c-4:
Cover of pine trees canopy was estimated to be over 75%. There was accumulation of a lot of pine needles on the forest floor, covering about 51-75% of the plot. *Equisetum pratense* covered about 6-25%. *Equisetum hyemale* covered about 6-25%. *Rubus saxatilis* was observed in the plot, covering about 26-50%. *Geranium sylvaticum* covered about 6-25%. Moss covered about 26-50% of the plot. See Figure 15 below.

Figure 15. Plot P-c-4. Accumulation of pine needles. The needles that were lying underneath the surface were decomposing into organic matter.

6.4 Observations made on pine forest in a burned area

The PLOTS P-b-1, P-b-2, P-b-3, and P-b-4 were established under pine forest in a burned area.

PLOT P-b-1:
The effect of fire was confined to the lower part of the trees. Canopy cover of surviving pine foliage was about 26-50% of the plot. The ground was covered with dead moss and dead pine needles covering 26-50%. *Geranium sylvaticum* was present in large numbers, covering about 26-50%. *Equisetum pratense* covered about 1-5% and *Equisetum hyamale* was also observed with a cover of about 1-5%. See Figure 16 below.

Figure 16. Plot P-b-1. Burned pine trees with no needles left on branches. Burning has affected only the bark as can be noticed on the branches where the bark has peeled off. Fire did not reach the inner tissues.

PLOT P-b-2:
Pine trees were moderately burned, with living foliage cover of about 6-25% of the original cover. The plot was partly covered with burned moss. Dead pine needles covered about 26-50%. A few grasses were present covering about 6-25%. *Equisetum pratense* covered about 1-5% and *Geranium sylvaticum* covered about 26-50% of the plot. See Figure 17 below.

Figure 17. Plot P-b-2. Moderately burned pine trees and some plants species growing from the ground.

PLOT P-b-3:
Pine trees were present in large numbers. Living pine foliage covered about 26-50% of the plot. The ground was mostly bare patches which covered about 51-75%, dead moss and pine needles, which covered 6-25% *Geranium sylvaticum* was present, covering about 6-25%. *Equisetum pratense* was observed growing from the ground with a cover of about 6-25%. See Figure 18 below.

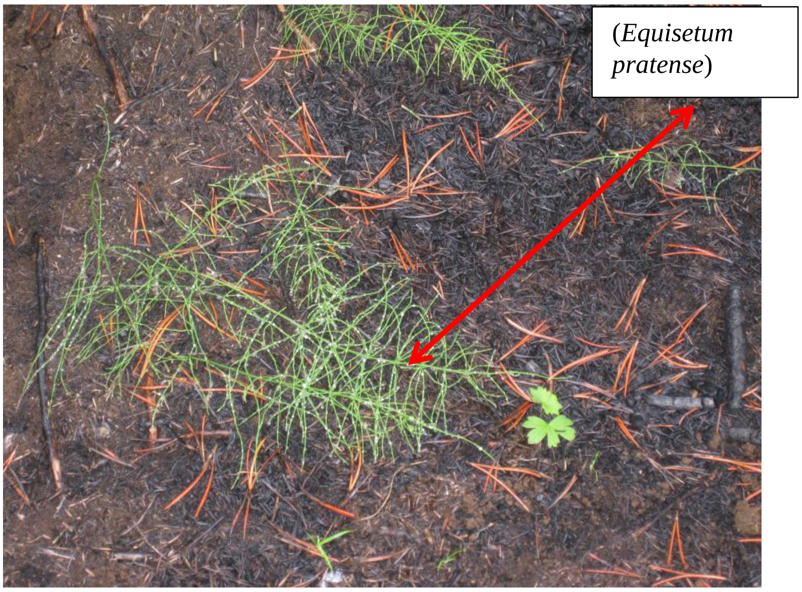

Figure 18. Plot P-b-3. An advanced growth of *Equisetum pratense* with a few dead pine needles and some burned moss around.

PLOT P-b-4:
Burning had affected the lower part of most pine trees but their upper part still had green needles. Living foliage on tall trees covered about 51-75% and 6-25% on short trees. Some shorter trees did not have remaining needles at all. New shoots of *Geranium sylvaticum* were

present, covering about 6-25%. The ground is mostly covered by dead pine needles, at 50-75%, and dead moss, black from burning. See Figures 19 and 20 below.

Figure 19. Plot P-b-4. The lower parts of pine trees with dry needles as a sign of burning and the upper part still having green needles as a sign that fire did not reach them.

Figure 20. Plot P-b-4. A lot of dead needles on the ground, and a few plants arising.

Vegetation cover of different plant species as well as the bare batches in every plot are summarised in tables 2 and 3 below.

Table 2. Summary of vegetation cover classes in burned and unburned plots found in birch plots. Cover classes are according to the Braun Blanquet scale: 1 = 1-5%, 2 = 6-25%, 3 = 26-50%, 4 = 51-75% and 5 > 75% cover (see Table 1)

	Unburned plots				**Burned plots**			
Species	**B-c-1**	**B-c-2**	**B-c-3**	**B-c-4**	**B-b-1**	**B-b-2**	**B-b-3**	**B-b-4**
Living birch foliage	5	5	3	4	1	2	1	1
Lupine	2	2	2	-	2	4	4	2
V. uliginosum	1	-	-	-	-	-	-	-
Grasses	2	1	1	-	1	2	2	2
Moss	2	2	2	3	-	-	-	-
G. sylvaticum	1	1	3	2	3	-	3	3
S. phylicifolia	-	2	3	1	-	-	-	-
S. lanata	-	-	-	1	-	-	-	-
R. saxatilis	1	1	-	1	-	2	-	-
L. sibirica	-	-	-	1	-	-	-	-
P. sitchensis	-	-	-	1	-	-	-	-
Bare patches	-	-	-	-	2	2	2	2
Birch regrowth	-	-	-	-	-	1	-	-

Table 3. Summary of vegetation cover classes in burned and unburned plots found in pine plots. Cover classes are according to the Braun Blanquet scale: 1 = 1-5%, 2 = 6-25%, 3 = 26-50% , 4 = 51-75%, and 5 > 75% cover (see Table 1)

	Unburned Plots				**Burned Plots**			
Species	**P-c-1**	**P-c-2**	**P-c-3**	**P-c-4**	**P-b-1**	**P-b-2**	**P-b-3**	**P-b-4**
Living pine foliage	5	5	5	5	3	2	3	2
Lupine	-	-	-	-	-	-	-	-
V. uliginosum	-	-	-	-	-	-	-	-
Grasses	-	-	-	-	-	2	-	-
Equisetum pratense	2	2	2	2	1	1	2	-
Equisetum hyemale	1	1	2	3	1	-	-	-
Moss	3	-	2	3	-	-	-	-
G. sylvaticum	2	2	4	2	3	3	2	2
S. phylicifolia	-	-	-	-	-	-	-	-
S. lanata	-	-	-	-	-	-	-	-
R. saxatilis	-	2	4	3	-	-	-	-
L. sibirica	-	-	-	-	-	-	-	-
P. sitchensis	-	-	-	-	-	-	-	
Dead pine needles	4	4	4	4	3	3	2	4
Bare patches	-	-	-	-	-	-	4	-
Pine regrowth	-	-	-	-	-	-	-	-

7. DISCUSSION

This chapter briefly discusses the factors that influence the behaviour of fire, the findings on the effects of fire on forest and woodland vegetation from the literature and compares them with observations made on the field study in Heidmörk, Iceland. It was learned in the earlier chapters that the high rate of fire-spread is facilitated by dry air and high temperatures, which decrease humidity and promote drying of fuel, as in accordance with Heady (1975). High fuel load and a less patchy land burn easily and rapidly. It was also learned that fires that move down the slope are slower and burn intensively, while fires that move up-slope are much quicker. Wind is also an important factor influencing the behaviour of fire.

7.1 Fire effects on vegetation

High intensity and prolonged fires kill vegetation of all kinds. The permanent damage done to vegetation is when the growth tissues, the root system, storage organs, and transportation tissues are destroyed by fire. Low intensity fires damage some plants temporarily, and they recover after some time when the conditions for recovery are set. Some plants take a longer time to recover, while others do not recover at all.

While some plant species are killed by frequent fires, some are stimulated to develop fire tolerant mechanisms (Vogl 1974; Van Wilgen 2005). This is particularly evident in tree species. They are able to regenerate through different pathways after a fire. Some plants thrive after a fire due to reduced competition for light and other resources and increased soil fertility. New plant species are often introduced into the ecosystem after a fire event.

On the study site in Iceland, the birch trees were heavily burnt and had lost almost all their leaves (Table 2). Only a few leaves were observed, mostly on the top branches, and usually less than 10% of the total foliage survived the fire. This indicates that the vascular tissues conducting water from the ground up were still functional, which indicates that the fire was not very intense. A few new shoots were observed growing from roots in the soil, which shows that the roots were still alive. This is a sign that fire did not reach the depths of the root system, or if it did, that it was of very low intensity. The effect of fire observed on the birch trees corresponds to the statement given by Lutz (1956) that birch assumes high flammability characteristics as it matures. New shoots were expected to develop in line with what as Ahlgren (1974) stated, that birch is mostly associated with early post-fire vegetation and has the ability to sprout abundantly after fire.

Fire that hit the pine trees only burned the lower part of the trees and did not reach the upper parts. The surviving needles on the top of the pine trees showed that the fire did not reach to the treetops. It also means that they have been getting water to support their fundamental processes after the fire, which occurred nearly three and a half months earlier. Furley et al. (2008) also made the same observation that tall trees, from heights of three meters up, are barely affected by fire as it only burns the lower parts of the tree. Schwilk & Ackerly (2001) mentioned elongation in height as an adaptation modification to pine trees when they discussed the traits of plants that resist destruction of aboveground biomass by fire.

There was a very clear difference in vegetation at the floor of burnt and unburned birch plots. The woody species: *Salix phylicifolia, S. lanata* and *Vaccinium uliginosum*, were only observed in unburned plots and not in burnt plots. This could mean that fire had eradicated these woody species, although they might come back later by regrowth from roots, as Ahlgren (1974) indicated that fire does not totally eradicate any species of shrubby vegetation. Lutz (1956) also mentioned that shrubs have a vegetative regeneration tendency through sprouts that evolve from roots. With time, these species may come back. Moss was also totally eradicated by the fire. Lupine was observed with markedly higher coverage in burnt plots than in unburnt plots and grasses were also more common in burnt plots than in unburnt plots. The most likely explanation is reduced competition by trees and shrubs. All other identified species were present in the burnt and unburned plots.

The vegetation on the floor of burnt and unburned pine plots was less diverse than under birch. The woody species: *Salix phylicifolia*, *S. lanata* and *Vaccinium uliginosum*, were not observed under pine plots. *G. sylvaticum* was more common than under birch but did not show a distinct reaction to fire under either tree species. *Rubus saxatilis* was observed only in the unburned pine plots, as under birch. This means that *Rubus saxatilis* does not respond well to burning. *E. pratense* and *E. hyemale* were observed in the pine plots, but not under birch. Both species were less common in burnt plots than unburnt, especially the latter species.

In general, the fire seems to have reduced the diversity of plants on the forest floor of birch and pine. However, Vogl (1974) indicated that species diversity in an ecosystem is not reduced by repeated burning, but it could be enhanced by the establishment of newly evolving species of grasses, legumes, forbs, and annual plants stimulated by fire. The ground was almost all covered under all plots.

Bare patches were observed in all burnt birch plots, but only in one pine plot. None of the unburnt plots had bare patches. This difference may partly be due to the fact that some of the birch plots are a slope, and it is easier for water to remove burnt moss and detached vegetation, leaving bare patches. The pine plots, on the other hand, are on a flat area below the slope.

Burned moss was observed under both birch and pine and did not show signs of recovery. This may be associated with the fact that moss does not have a proper root system. Fire easily destroys the shoot and leaves no meristematic tissues alive. On the studies on burned sites, Viro (1974) reported that mosses were established three years after a fire hit the forest. This means mosses take a long time to re-establish on a burned site.

The burnt areas did not show any signs of soil erosion. Most of the ground is covered with living vegetation and dry, burned plant material that has mulched the area very well. Chances of wind erosion are very minimal because of tree cover. Chances of water erosion are also minimal because the soil is covered and where there are bare patches, the soil structure is loose enough to allow for high water infiltration. A lot of dead pine needles (under pine forest) covering the ground are decomposing into soil organic matter. This decreases the risk of soil erosion because the soil is covered.

7.2 Fire effects on soil nutrients

It was discovered by Heady (1975) that fire adds potassium, calcium, magnesium, and phosphorus to the soil in the form of ash and that fire has insignificant effect in their release from the soil. However, nitrogen and sulphur are lost through volatilisation under high heat combustion. Potassium, calcium, magnesium, copper, iron, and zinc contents are found to increase after fire (Christensen 1976; Raison 1979; Ohr & Bragg 1985). Heady (1975) also revealed that the loss of nitrogen from the soil does not have a significant impact in ecosystem functioning as nitrogen is quickly replaced through fixation. Mayland (1967) supports this by showing that nitrogen fixation is commonly active after fires. Therefore, fire helps accumulate minerals in the soil and facilitates ecosystem functioning. Nitrogen fixation cannot be a problem in Lesotho as there is rapid introduction of pioneer plants, consisting of leguminous plants, after burning to compensate for any lost nitrogen.

7.3 Fire effects on soil organic matter and microbial activities

As explained by Heady (1975), fire changes the quantity of organic matter accessible for decomposition by lowering above-ground parts and frequently increases soil organic matter by destroying plants. Removal of vegetation cover reduces organic matter and microbial activities in the soil because materials that constitute and decompose organic matter are eliminated from the system, which also affects the stability and infiltration characteristics of the soil (Mills & Fey 2003). Czimczik et al. (2005) explain that high fire intensities may cause a decline in the amounts of organic matter within the organic layer because high intensity fires destroy the entire organic soil layer. However, less powerful flames burn only sections of the organic layer which are converted to black carbon and certain other organic materials required by the ecosystem. Microbial activity will be negatively affected by high soil temperatures brought about by fire. As much as heat is required for microbial activity, soil micro-organisms are incapacitated by very high soil temperatures. Fire heat that penetrates a few centimetres into the topsoil is enough to heat the soil to required microbial temperatures.

7.4 Fire effects on stability and properties of the land

High intensity and long duration fires have the potential to change ecosystem characteristics and create a different environment, as stated by Folke et al. (2004). This is the situation prevailing in Lesotho, whereby unprescribed fires burn intensively, opening opportunities for invasive plant species to take over and infest the ecosystem. The infestation of such woody, invasive vegetation is often a sign of degradation. They have negative effects on rangeland ecosystem functioning, including biodiversity depletion, increased soil erosion, destabilised wetlands and riverbanks, nitrogen pollution and loss of grazing potentials (Lesoli et al. 2013).

DeBano et al. (1977) report that several soil properties such as soil texture, soil structure, soil porosity, soil infiltration capacity, and water holding capacity could be affected by high frequency, intensity, and severity of fire. This could potentially harm ecosystem functionality. Plant uptake of nutrients and water can be altered if the soil structure is tempered with and moisture retention as well as porosity are reduced (Nye & Tinker 1977). It is however, argued that it is in rare cases that fires attain temperatures high enough to impact soil physical properties (Hungerford et al. 1990).

7.5 Fire effects on animals and their habitats

Animals and organisms respond differently to the effects brought about by fire. Some animals, especially small animals and invertebrates which live in a confined space, easily burn in high intensity and long-lasting fires. Their food resources and habitats are also destroyed. Even those that can survive fire struggle to live because they are deprived of food. But as soon as plant cover is re-established, these animals spread quickly. Loss of these animals greatly affects ecosystem equilibrium and some ecosystem functions can be compromised.

Larger animals are able to escape fire, moving to secure places, when they have noticed it in time. They find ways to survive in their new locations, usually temporarily, until the fire is out.

Usually, they do not have permanent habitats, so they are less affected in this case. New fresh feed after fire is very palatable for animal grazing and browsing. In Lesotho, there are no large wild animals so the only large animals are domestic animals.

8. CONCLUSION

The objectives of this study were to describe factors that affect the behaviour of fire; to find from the literature the effects of fire on ecosystems and ecosystem functions; to investigate the state of knowledge about fire management in Lesotho (and adjacent areas); and to study the effect of fire on woodland in Iceland through a brief field visit.

High intensity, high frequency, and long duration fires are generally destructive and harmful to ecosystem components, which retards the functionality of the ecosystem. These kinds of fires usually occur naturally or are unprescribed. On the other hand, low intensity, low frequency, and low duration fires could have negative impacts to some components of the ecosystem but have positive impacts on many.

Fire is a very important tool to use in the manipulation of ecosystem equilibrium. Prescribed fire can be used as a management tool in the management of rangelands in Lesotho. However, there is a lot of awareness and education that should be conveyed to the public about fire before adopting it as a management intervention. The knowledge about fire is inadequate in Lesotho, especially regarding its benefits. Prescribed burning principles will be communicated with communities and other stakeholders to utilise it in the proper management of the ecosystems in Lesotho.

9. RECOMMENDATIONS

Fire can be used as a sustainable ecosystem management tool in Lesotho. It is recommended that it should be used to manipulate the balance in the rangeland ecosystem, as well as to improve other conditions such as:

- To reduce undesirable plants
- To favour certain plant species
- To produce more forage for livestock
- To increase quality of livestock feed
- To control distribution of animals
- To control undesirable animals
- To encourage certain animal species

Herders reside in the rangelands during the warm seasons of the year. They are part of the ecosystem, and they see everyday changes in the ecosystem. As much as they derive first-hand benefits from the ecosystem, they are the first people to suffer the consequences of losses of ecosystem functionality in the ecosystems of which they are part. In Lesotho, herders have been informed about the dangers of unprescribed burning to the sustainability of the ecosystem but that has not stopped them from burning the rangelands, and it is not working in favour of the ecosystem. The interests of herders can, however, be met without compromising the condition of the ecosystem. It is therefore recommended that a different approach be employed to this matter. Instead of telling herders to stop burning the rangelands, they should be taught about the management of rangelands using fire as a tool. In that case they would be able to assess the conditions conducive for burning and would be able to practice prescribed burning. They should be advised and encouraged to report on areas that require burning so that they get the necessary support. They nurture the ecosystem and should be able to play a pivotal role in its management without direct intervention of ecosystem specialists.

Herders´ associations should have fire management teams, which would intervene when there is a recommendation for burning a certain area in their jurisdiction. Prescribed burning should be made public knowledge so that public participation is fully engaged.

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