Article

The effect of wildfire on *Erica arborea L.* (Ericaceae) in Simien Mountains National Park, Northwest Ethiopia

Endalkachew Teshome[1], **Gerhard Glatzel**[2]
[1]Department of Tourism Management, University of Gondar, Ethiopia
[2]University of Natural Resources and Life Sciences, BOKU Institute of Forest Ecology, Peter Jordan Strasse 82 1190, Vienna, Austria
E-mail: endalkay@gmail.com, glatzel-home@chello.at

Received 15 March 2018; Accepted 10 April 2018; Published 1 September 2018

Abstract
Fire plays a crucial role in the Ericaceous forest ecology within the World Heritage Site of Simien Mountains National Park. Objectives of our study were to evaluate the potential of *E. arborea* epicormic shoot formation in different tree diameters and heights after forest fire occurred, and investigate establishment of woody species in the fire affected ericaceous forest. Two 40 m x 40 m sample plots were established, one at a fire affected site and another at an unaffected site. Within each plot, 1m x 1m subplots were placed at 2 m intervals along diagonal transects 51 in each site. Experimental treatments (soil scarification, mowing, fire and total enclosure) were assigned to subplots. A non-parametric t-test for two independent samples of unburned and burned plots was applied to test the degree of significance. From the crown-fire affected plots 56.3% of the trees were re-sprouted from the base in the first diameter class (0-4.9 cm). Out of 993.7 individual trees ha^{-1} in the second height class (1.5-3 m), 73 % were sprouted. *Erica arborea* is favoured by fire since re-sprouting of shoot from the remaining stumps is widespread. Prescribed burns for *E. arborea* regeneration should consider in future management plans.

Keywords *Erica arborea* ; fire ecology; Simien Mountains National Park.

Proceedings of the International Academy of Ecology and Environmental Sciences
ISSN 2220-8860
URL: http://www.iaees.org/publications/journals/piaees/online-version.asp
RSS: http://www.iaees.org/publications/journals/piaees/rss.xml
E-mail: piaees@iaees.org
Editor-in-Chief: WenJun Zhang
Publisher: International Academy of Ecology and Environmental Sciences

1 Introduction

Wildfire is the main factor responsible for the present heterogeneous structure of the lower Afroalpine and Ericaceous vegetation belt in the East African Mountains and elsewhere (Wesche et al., 2000, Kuma and Shibru, 2016). Fire is a determining ecological factor for most dry afroalpine ecosystems. Periodic fire can influence the survival of seedlings establishment (Caughlin et al., 2014). The role of heat-shock in stimulating regeneration from fire-following plant species is well known (Hanley et al., 2001). However, the effects of wildfire on landscapes vary depending on fire regime (type of fire, intensity, season, frequency, duration) and on the community burned (Vivian et al., 2008). The effects of spatial heterogeneity within a burn site, and in particular variable fuel loads caused by the distribution of pre-existing vegetation, may significantly affect patterns of post-fire seedling recruitment (Odion and Davies, 2000). Fire can kill nearly all hardwood regeneration and forcing the rootstocks to sprout (Brose and Lear, 1990). Moreover, frequent burning may reduce the capacity of resprouting species to regenerate (Pausas and Keeley, 2014) and if burnt within their primary juvenile age, species dependent on seedling regeneration are also eliminated (Salis et al., 2016). However, burned soils showed lower water holding capacity and soil carbon; however these changes did not affect topsoil water, and, contrary to expectation, there was a slight tendency toward higher seedling survival on more heavily burned soils (Kitzbergar et al., 2005). Heat shock may induce the production of chemicals that cause changes in the seed coat or other external layers to overcome water impermeability barriers and facilitate to seedling recruitment (van Breuge et al., 2016).

The topography of Simen Mountains is irregular and has large differences in slope; exposure and elevation give rise to strong gradients in temperature and precipitation pattern, shading effects and local microclimates, and these topographic variations may affect the plant recruitment and seed germination by prevailing dormancy. It is well recognized that appropriate light conditions, temperature, nitrate, microclimate, and hormonal treatments may favor germination in many species (Oliva et al., 2008). In addition fire may influence germination via the production of heat, ash, change in micro-sites, and heat damages the seed coat making it permeable and facilitates imbibitions of the embryo (Luna et al, 2007). Fire pro-ducts break the dormancy of species growing in fire prone habitats, and endorse seed survival (Ool et al., 2006).

Small height and size seedlings generally do not tolerate fire (Brand et al., 2012). Furthermore, most of the dry afromontane forest seeds, especially those in the top few centimetres of soil, can be killed by fire (Salis et al., 2016). *E. arborea* are often considered pyrophytes, although Kuma and Shibru (2015) report that seedling distributions following fire indicate that fire is unfavourable for their establishment. This is because of drought that fire dried the soil moisture. Accidental fires are common in the Simen, with peak frequency during the farming periods in April and May.

E. arborea is favoured by fire since re-sprouting of shoot from the remaining stumps is widespread, but large herbivores browse the fresh shoots on every occasion (Kuma and Shibru, 2015), therefore re-growth is almost impossible in some heavily degraded sites. So far, fire provides the best opportunity for regeneration from seed (Ool et al., 2014).

Additionally, fire alters the cycling of nutrients, as well as the biotic, physical, moisture, and temperature characteristics of the soil (Cardil et al., 2014). Higher surface temperatures often enhance seed germination and plant growth (Chung, 2015). Fire plays a crucial role in the regeneration of *E. arborea* in both dry afromontane and Ericaceous vegetation (Wesche et al., 2000; Hendrickx et al., 2015; Kuma and Shibru, 2015). Studies from other tropical African Mountains monitoring post-fire successions provide insight into the regeneration capabilities of various Afroalpine vegetation types (Wesche, 2002; Robinson, 2014). Erica plants have survived fire, but it has been reported that the shoot development was slow and two years after the burning, the plants would recover their original structure (Kuma and Shibru, 2015; Juli et al., 2014). *E. arborea* forests have significant value for Simen residents and the surrounding lowland settlers as an essential source of harvestable products (e.g. wood, food, medicines, fodder), as an economic benefit from tourism by attracting visitors (Ejigu et al., 2015), and as a regulator of the climate and hydrology of the area (Kuma and Shibru, 2015). Conserving the remaining remnants is therefore extraordinarily important in order to provide a habitat and genetic reservoir for both animal and plant. The factors influencing regeneration by seeds have been studied in several fire-prone forest communities in Ethiopia (Miehe and Miehe, 1994; Wesche et al., 2000; Tesfaye, 2004; Teketay, 2005; Johansson et al., 2009). However, the relative importance of tree species recruitment by resprouting and the potential of epicormic shoot formation among different diameters and heights have not been studied. Objectives of our study were to (1) evaluate *E. arborea* epicormic shoot formation in different tree diameters**,** and heights after forest fire occurred, (2) investigate germination and establishment of woody species in the fire affected ericaceous forest. H_0: height class has no relation with epicormic shoots formation of *E. arborea* trees.

2 Study Area and Methodology

2.1 Study site

The World Heritage site, Simien Mountains National Park, and its *Erica arborea* L. *Ericaceae* forests are within the Tekeze River watershed area and are home to many conservation species of international note (i.e. endangered, rare and endemic). Simen Mountains National Park is located where the Adrk'y, Beyeda, Debark and Janamora and Telemet districts of the Amhara Regional State, North-west Ethiopia meet.

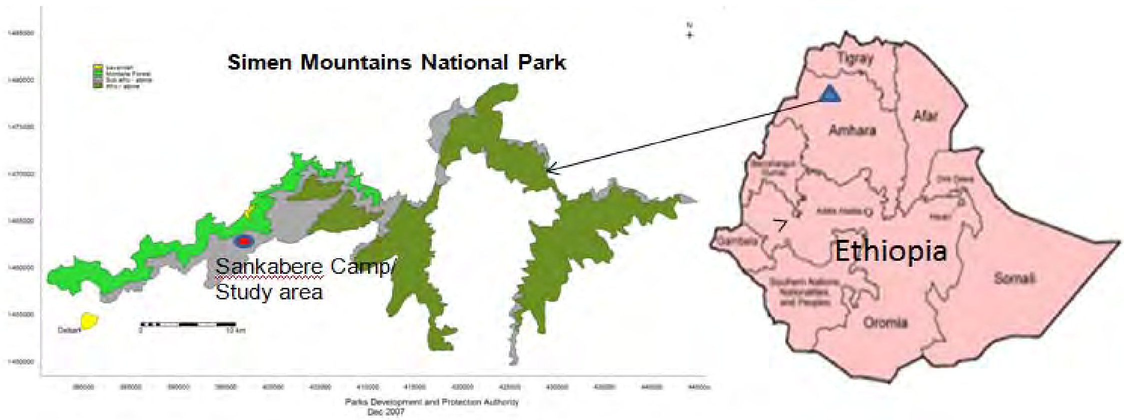


Fig. 1 Map of the study area.

The study area is at 13^0 11'N, 38^0 00'E. The nearest major city is Gondar, the capital of North Gondar Zone (Amhara Region), 138 km to the south. The park is one of only two legally gazetted national parks for the country and, at present, the only national park in Amhara Region. The gazetted area is 225 km^2 and after re-demarcate in 2004 the area increase to 412 km^2. Mean annual rainfall in the park is about 1515 mm (Hurni, 1986) and the monthly mean of minimum daily temperature is below 1.5^{O}C in November and December. An absolute minimum of -2^{O}C (November and December) has been recorded at Gich at (3600 m).

2.2 Data collection

This study was done in a crown-fire affected area during the first growing season after the fire had occurred. The recently burnt area in the Simen National Park near the Sankaber site was studied. One 40 m by 40 m sample plot could be fitted in the burnt forest, a plot of the same size was laid out in an adjacent not fire affected part of the same forest. Fire un affected plots was 50 m far from the fire affected plots, and have similar vegetation characteristics, hydrology, topographic features, and exposure to the sun. Re-sprouts from lignotubers and epicormical buds were recorded on all *E. arborea* individuals (i.e. both dead and living plants) found within the sample plot. Individual plants were determined according to trees ≥ 3 m height and ≥ 10 cm diameter at breast height were recorded, identified by species, and grouped into three diameter and height classes; saplings (diameter < 10cm at breast height, tree height between 1.5 m and 3 m) and of sprouts or shoots of woody species (height < 1.5 m).

For germination and establishment of woody species in the wildfire affected forest, from 40 m by 40 m sample plots a total of 102 sample plots were investigated of which 51 were at sites where the understorey and topsoil was affected by fire and 51 in patches apparently not touched by fire. A 1 m by 1 m sub plots spaced at 2 m intervals along the transect line starting from the two corner point diagonally. From those sub plots germination and establishment of tree seedling at different micro-site in burn and unburned *E. arborea* stands were counted.

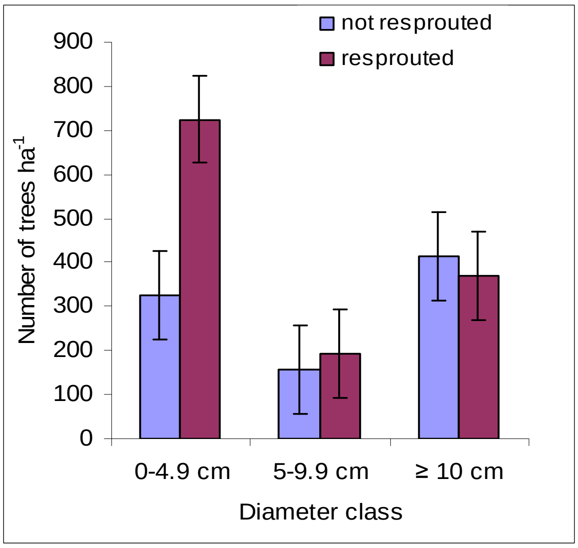
2.3 Analysis data

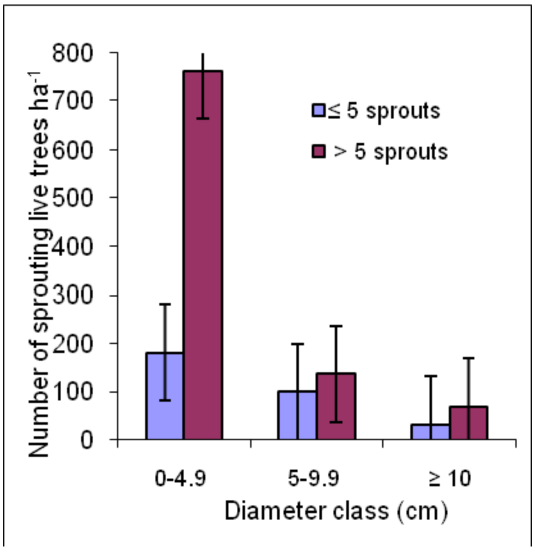
The quantitative information was analyzed using descriptive techniques of data analysis. In the data analysis process, the completed survey data were coded and analyzed by using the SPSS statistical software version 20 (IBM, 2011). In descriptive analysis; the frequency distribution, percentage and graphs (bar graph, histogram) were interpreted to show detailed picture of the existing situation on the study area. Data were also calculated using one-way analysis of variance and statistical analysis from the tabulated figures for each sampling plots burned and unburned *E. arborea* stand. To check either any epicormic shoots different in different height class were tested using Chi-square tests.

3 Results and Discussion

3.1 Regeneration by epicormic shoots formation at different tree diameter

From a total of 2.181 trees ha^{-2} (both alive and apparently dead with no indication of re-sprouting) in the crown-fire affected plots, 1.050 trees ha^{-2} were in the diameter class < 5 cm. Of these 325 trees ha^{-2} had not re-sprouted while 725 trees ha^{-2} showed re-sprouting. About 56.3% of the trees which showed re-sprouting from the base and/or epicormic shoots in the study area were in the first diameter class (0-4.9 cm).





(Vertical bars show standard errors of mean)

Fig. 2 Diameter to fire response. **Fig. 3** Number of sprouts after fire.

The results indicate that small size *E. arborea* can survive fires by resprouting from lignotubers (Fig. 2 & 3). The second diameter class also shows a relatively good-resprouting ability, compared to larger diameter classes. Generally, when the diameter classes increase, the number of sprouted and epicormic shoots decreases.

Fig. 3 shows relatively higher proportion of individual survived tree > 5 sprouts in all diameter classes. The number of sprouting shoots > 5 from one tree base is relatively higher than the sprouting shoots having ≤ 5 shouts from one tree.

Fig. 4 Sprouting shoots from lignotuber (Photos Glatzel, 2010).

However, the frequency in the first diameter class is significantly higher than in the other diameter classes and generally, the frequency of survived stems having > 5 sprouts decreased significantly from the first diameter class to the second diameter class. We observed a similar trend for surviving stems that had ≤5 sprouts, where an increase in the diameter class goes along with a decrease in the number of stems having ≤5 sprouts. The result shows that severely burned trees in the higher diameter class had fewer epicormic shoots.

Our results show that re-sprouting frequency is significantly higher in the smallest diameter class than in the larger classes (Fig. 2). The high frequency in the small diameter class may be due to high rates of re-sprouting from lignotubers. It has been reported that lignotuber is more important during the early stages of plant development (Kuma and Shibru, 2015). Sprouting ability is related to carbohydrate reserves, as plants with larger reserves in the lignotubers and roots support greater production of sprouts and consequently, greater total biomass than plants with smaller reserves (Walters et al., 2005; Catry et al., 2013).

In the larger tree diameter classes there were a limited number of re-sprouted individuals, which was perhaps the cause of higher litter accumulations around the stem base, which in turn causes the high fire intensity. A high intensity of fire has been reported as the main cause of the high mortality of both medium and large-sized trees (Brand et al., 2012). These results suggest that the re-sprouting mechanism provided by lignotubers is very important for seedling and sapling survival after fire, may be in areas of lower rainfall such as the Simen Mountains.

3.2 Epicormic shoot formation at different tree height

Sprouted shoots were found on plants within all three height classes. From a total stems 2.181 ha^{-2} all live and dead trees, 431 trees ha^{-1}were counted within the first height class (0 -1.4 m). Out of these, 45.4% were non-sprouted individuals and 53.6% were sprouted individuals. Out of 993.7 individual trees ha^{-1} in the second height class (1.5-3 m), 27% were non-sprouted individuals and 73 % were sprouted individuals, whereas out of 747.7 individual trees ha^{-1} in the third height class (> 3 m), 56.2 % were non-sprouted and 43.8% were sprouted. These results show that following this fire *E. arborea* was able to re-sprout from trees within all three size classes. However, compared to the other larger height classes, the second height class has a relatively higher sprouting. From a total of 1.287 individual trees ha^{-1} that survived fire, 231.3 sprouted individuals (18%) were in the first height class (0-1.4 cm), and 725 sprouted individuals (56.3%) in the second height class, and 331.2 sprouted individuals (25.7%) in the third height class (Fig. 5).

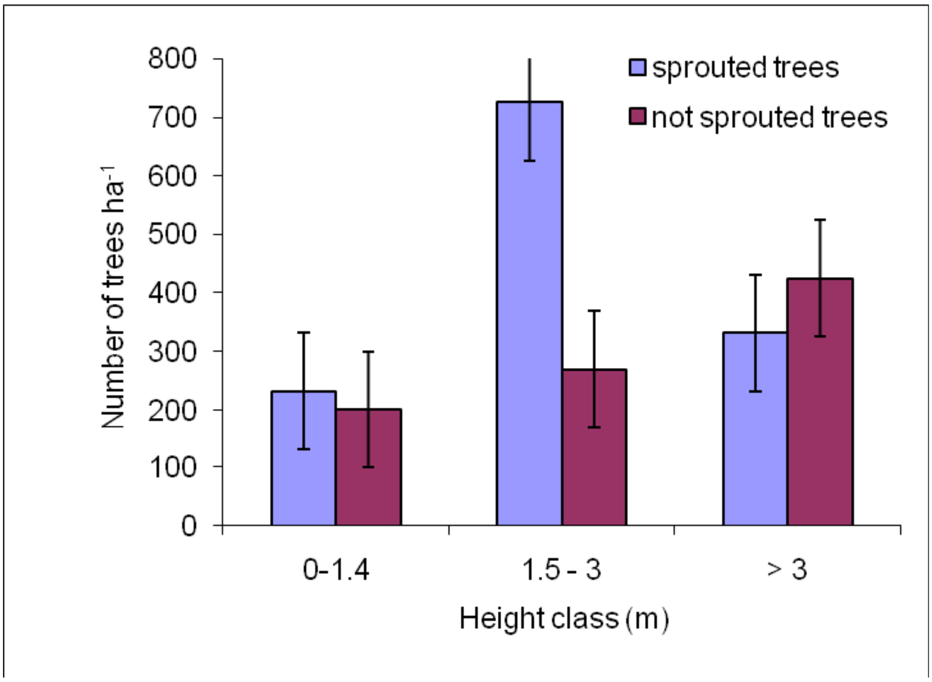


Fig. 5 Height to fire response (Vertical bars show standard errors of mean).

This shows that *E. arborea* second height class survived fire better than the other two size classes by developing root lignotuber to sprouts after fire (Figs 4 & 5). This would suggest that medium height *E. arborea* can survive and continue to be common in an Ericaceous vegetation composition, even with a higher intensity of fire. A relatively high number of third height class and second height class survived the fire (Fig. 2), and regenerated from sprouts more than expected. Cal x^2 is equal to 153.3 which is larger than the critical value 5.991, therefore, we reject the null hypothesis and we can conclude that height class has a relation with epicormic sprouting shoots. Remarkably, trees showed less extensive epicormic sprouting, whereas the second height class (saplings) had epicormic sprouts of a greater percentage.

Both in the first height class (0-1.4 m) and the second height class (1.5 - 3 m) the number of trees surviving the fire is higher than that killed by fire. Survival was highest in the 2nd height class at the sapling stage (Fig. 5). This result suggests that not yet mature *E. arborea*, in particular trees in the sapling stage which have developed a healthy lignotuber to re-sprout after a fire (Fig. 5) are crucial for vegetative regeneration after wildfire. Closed stands of old trees with a high fuel load of litter are more likely to succumb to intense forest fire. Epicormic shoots are an important mechanism for a tree to regenerate its foliage and to remain photosynthetically active following crown damage by fire (Clarke et al., 2013). In our study epicormic re-sprouting was better in low diameter class than in large trees, most likely again due to the high intensity of fire under big canopy trees, related to fuel load. Our results are in line with those of former research in semi-humid mountain ranges and afroalpine vegetation. *E. arborea* is in general capable of surviving fire (Perry et al., 2015).

However, as the height of the trees and the fuel load around the stem base increase fire intensity may be severe killing the individual trees and the soil seed bank nearby, which leads to selective destruction of large and old trees (Fig. 2 & 5). Fires of moderate intensity can result in a loss of tree crowns in the middle height class (Juli et al., 2014), but these are frequently replaced by epicormic re-growth from the stems of the affected Erica trees. Regeneration from lignotubers or stem epicormic buds can enable the species to survive fire (Pausas et al., 2016). E. arborea seedlings and saplings of small height can survive fire better than those within the bigger height classes, by developing root lignotubers into sprouts after fire hazard (Fig. 4). Yirdaw et al. (2015) suggest that despite frequent fires in the Bale Mountains region, Erica species can survive in a bushy state and continue to constitute the common vegetation composition.

3.3 Seedling establishment of woody species in wildfire affected area

As Fig. 7 shows, more seedlings/ first height class (725 individual species) were found in burned plots than in plots not affected by fire, suggesting that fire is able to create conditions favourable to seedling establishment. In total we counted seedlings of three tree species, of which more than 99% in the burned and 94 % in the unburned plots were *E. arborea*. A non-parametric t-test for two independent samples of unburned and burned plots as group variables was applied to test the degree of significance and a two-sample Kolmogorov-Smirnov test showed a statistically asymptotical (2-tailed) significant difference of P < 0001.

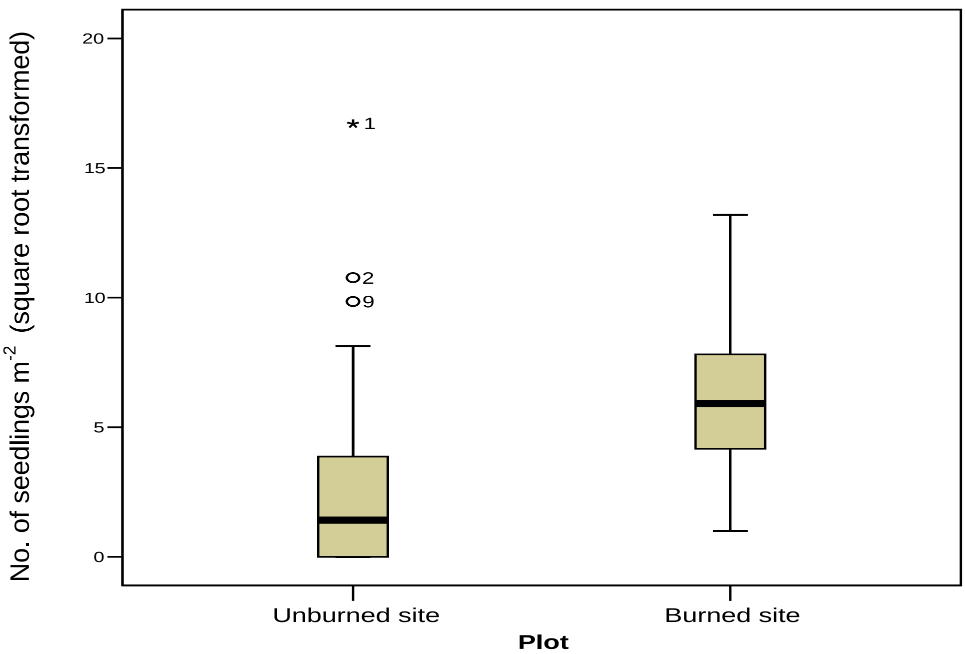


Fig. 6 Seedling density in 1m^2: comparison between burned and unburned sites.

Fire plays an important role in maintaining the diversity of the subalpine vegetation (Yirdaw et al., 2015). In our study on a recently burnt forest site, higher population of seedlings was counted at the burned site (59.3 individuals m^2) than at the unburned site (18.9 individuals m^{-2}). This is probably because fire can enhance the seedling establishment of *E. arborea* by providing specific requirements of light, nutrients, water and temperature (Bhadouria et al., 2017). Actuality, fire may have a basic role in stimulating the germination and establishment of *E. arborea*, whose germinates and establishment emerge even after being exposed to high temperatures (120°C) for 10 minutes (Baskin and Baskin, 2014). Crosti et al. (2005) and Pausas (2015) add that higher soil surface temperatures often enhance seed germination and plant growth in ericaceous vegetation.

Studies in the Bale Mountains have shown that *E. arborea* are presumably more successful re-seeders during early regeneration stages after fire (Yirdaw et al., 2015), which would explain the much higher abundance of seedlings at this burned site, compared with that at the unburned site, since fire can destroy humus and alter its soil chemistry due to an increase in soil temperature, thus altering the microbial inhabitation and reducing the moisture retention capacity of the soil in favour of germination (Bhadouria et al., 2017; Satyam and Jayakumar, 2012). According to former studies, during fire 95% of the nitrogen and 20-30% of the other principal plant nutrients and accumulated litter are lost from the system and the enhanced thermal characteristics of the charred wood material on the soil surface can trigger the germination of heather species (National Wildfire Coordinating Group, 2001; Nathalie, 2015).

As Fig. 6 shows, the number of seedlings at the burned site was higher than at the unburned plots, with a few exceptional plots, such as plots number one and forty eight, on which we counted a relatively high number of seedlings per plot as compared to both burned and unburned plots. This is because these plots are situated on fully sun exposed sites with recent soil erosion and almost no or little competition from grasses and herbs. This is in line with the finding that light is stimulating germination in several forest tree species (Khurana and Singh, 2001), thus being the most important factor for the regeneration of pioneer species and the major requirement to break the dormancy of deeply buried seeds (Pons, 2000; Jaganathan et al., 2017).

We counted three species, of which over 99% at burned site and 94 % at unburned site were *E. arborea*. It has been reported that fire plays a crucial role in the regeneration of *E. arborea* in both dry afromontane and Ericaceous vegetation (Wesche et al., 2000). Studies in the Mediterranean region suggest that under natural conditions smoke provides an important cue for triggering the seed germination of Erica species (Hall et al., 2017). However, if the plots are intensively burned, only few seedlings were recorded as evidence in few plots. This is because the strong heat in these two plots probably killed the viable seeds in the soil seed bank. This point has been further illustrated by the work of Probert (2000), who describes seeds being killed if temperatures are too high.

4 Conclusions

Fire is part of the natural dynamics of Erica forest. Fire plays a crucial role in the Simen Mountains National Park Ericaceous forests. Fire damaged stands in the study area were covered by sufficient *E. arborea* young trees, those young trees were re-sprouting from lignotubers and epicormic buds. *E. arborea* is favoured by fire since re-sprouting of seedlings from the remaining stumps is widespread. Ground fire also facilitates regeneration and seedling establishment form seed deposited after fire. To encourage the regeneration of the *E. arborea* prescribed fire should be considered in future management plans.

References

Baskin CC, Baskin MJ. 2014. Seeds: Ecology, Biogeography and Evolution of Dormancy and Germination. https://www.elsevier.com/books/seeds/baskin/978-0-12-416677-6. Retrieved on 20/02/2018.

Bhadouria R, Srivastava P, Singh R, et al. 2017. Tree seedling establishment in dry tropics: an urgent need of interaction studies. Journal of Economic and Social Development, 37(1): 88-100

BM. 2011. Programming and Data Management for IBM SPSS Statistics 20: A Guide for IBM SPSS Statistics and SAS Users. USA

Brand PM, Nepstad DC, Balch JK. 2012. Fire induced tree mortality in a neotropical forest: the roles of back traits, tree size, wood density and fire behavior. Global Change Biology, 18: 630-641

Brose HP, Van Lear HD. 1998. Responses of hardwood advance regeneration to seasonal prescribed fires in oak-dominated shelter wood stands. Canadian Journal of Forest Research, 28(3): 331-339

Cardil A, Salis M, Spano D, Delogu G, Molina DM. 2014. Large wild land fires and extreme temperatures in Sardinia. i-Forest-Biogeosciences and Forestry, 7: 162–169

Catry XF, Moreira F, Tujeira R, Silva SJ. 2013. Post-fire survival and regeneration of *Eucalyptus globulus* in forest plantations in Portugal. Forest Ecology and Management, 310: 194-203

Caughlin TT, Ferguson MJ, Lichstein WJ. Bunyavejchewin S, Levey JD. 2014. The importance of long-distance seed dispersal for the demography and distribution of a canopy tree species. Ecosphere Journal, 95(4): 952-962

Chung W. 2015. Optimizing fuel treatments to reduce wild land fire risk. Current Forestry Reports, 1: 44-51

Clarke PJ, Lawes MJ, Midgley JJ, Lamont BB, Ojeda F, et al. 2013. Resprouting as a key functional trait: how buds, protection and resources drive persistence after fire. Journal of New Phytologist, 197(1):19-33

Corona P, Ascoli D, Barbati A, et al. 2015. Integrated forest management to prevent wildfires under Mediterranean environments. Ann. Silvicultural Research, 39: 1-22

Crosti R, Ladd PG, Dixon KW, Piotto B. 2005. Post-fire germination: The effect of smoke on seeds of selected species from the central Mediterranean basin Forest Ecology and Management, 221: 306-312

Ejigu D, Bekele A, Powell L, Lernould JM. 2015. Habitat preference of the endangered Ethiopian walia ibex (*Capra walie*) in the Simien Mountains National Park, Ethiopia. Journal of Animal Biodiversity and Conservation, 38: 85-100

Hall AS, Newton JR, Holmes MP, Gaertner M, Esler JK. 2017. Heat and smoke pre-treatment of seeds to improve restoration of an endangered Mediterranean climate vegetation type.Journal of Australian Ecology, 42 (3): 354-366

Hanley EM, Fenner M, Ne'eman G. 2001. Pre-germination heat shock and seedling growth of fire-following Fabaceae from four Mediterranean-climate regions. Acta Oecologica, 22(5-6): 315-320

Hendrickx H, Jacob M, Frankl A, Guyassa E, Nyssen J. 2015. Quaternary glacial and periglacial processes in the Ethiopian Highlands in relation to the current afro-alpine vegetation. Zeitschrift Fur Geomorphologie, 59(1): 37-57

Hurni H. 1986. Management Plan Simen Mountain National Park and Surrounding Rural Area. UNESO and World Heritage Committee and Wildlife Conservation Organization, Ethiopia

Jacob M, Frankl A, Beeckman H, Mesfin G, Guyassa E, Nyssen J. 2015. North Ethiopian Afro-Alpine Tree Line Dynamics and Forest-Cover Change Since the Early 20th Century. Land Degradation and Development, 26(7): 654-664

Jaganathan KG, Song D, Liu B. 2017. Diversity and distribution of physical dormant species in relation to ecosystem and life-forms. Journal of Plant Science Today, 4: 55-63

Johansson M, Rooke T, Fetene M, Granström A. 2009. Browser selectivity alters post-fire competition between *Erica arborea* and *E. trimera* in the sub-alpine heathlands of Ethiopia. Plant Ecology, 207(1): 149-160

Juli GP, Jon EK. 2014. Evolutionary ecology of resprouting and seeding in fire-prone ecosystems. New Pathologist Journal, 204(1): 55-65

Kaeppeli M. 1998. Regeneration and age structure of relictellct Ericaceous Forests/ A dendrochronological Study near the timberline in the Simen Mountains, Ethiopia; Diploma thesis at the Institute of Geography University of Berne, Ethiopia

Khurana E, Singh JS. 2005. Ecology of tree seed and seedlings: Implications for tropical forest conservation and restoration. Science, 80(6): 748-757

Kitzberger T, Raffaele E, Heinemann K, Mazzarino JM. 2005. Effects of Fire Severity in a North Patagonian Subalpine Forest. Journal of Vegetation Science, 16(1): 5-12

Kuma M, Shibru S. 2015. Floristic composition, vegetation structure, and regeneration status of woody plant species of Oda Forest of Humbo Carbon Project, Wolaita, Ethiopia. Journal of Botany, 1-9

Lanckriet S, Derudder B, Naudts J, Bauer H, Deckers J, Haile M, Nyssen J. 2014. A political ecology perspective of land degradation in the north Ethiopian highlands. Land Degradation & Development, 26(5): 521-530

Luna B, Moreno JM, Cruz A, Fernández-González F. 2007. Heat-shock and seed germination of a group of Mediterranean plant species growing in a burned area: an approach based on plant functional types. Environ Exp Bot, 60: 324–333

Markos K. 2016. Diversity of woody plant species of gamuwa and Oda Forests of Humbo Carbon Project, Wolaita, Ethiopia: For conservation and management of forests. International Journal of Biodiversity, 16: 8

Miehe G, Miehe S. 1994. Ericaceous forests and heathlands in the Bale Mountains of South Ethiopia: Ecology and man's impact. Stiftung Walderhaltung in Africa, Hamburg

Nathalie P. 2015. Functional role of fire-derived charcoal in boreal forest ecosystem processes. Doctoral Dissertation. Acta Universitatisagriculturae Sueciae, 24: 1652-6880

Odion DC, Davies FW. 2000. Fire, soil heating and the formation of vegetation patterns in Chaparral. Ecological Monographs, 70: 149-169

Oliva RS, Leidi OE, Valdes R. 2009. Germination responses of *Erica andevalensis* to different chemical and physical treatments Journal of Ecological Research, 24: 655

Ooi KJ, Andrew JM, Denham M, Victor MS, Tony S, Auld D. 2014. Temperature thresholds of physically dormant seeds and plant functional response to fire: Variation among species and relative impact of climate change. Ecology and Evolution, 4(5): 656–671

Ool MJ, Auld T, Whelan TB. 2006. Dormancy and the Fire-centric Focus: Germination of Three *Leucopogon* Species (Ericaceae) from South-eastern Australia. Annals of Botany, 98(2): 421-430

Pausas GJ, Keeley JE. 2014. Evolutionary ecology of resprouting and seeding in fire-prone ecosystems. New Phytologist, 204: 55-65

Pausas GJ. 2015. Evolutionary fire ecology: lessons learned from pines. Journal of Trend in Plant Science, 20(5): 318-324

Pausas GJ, Pratt BR, Keeley EJ, et al. 2016. Towards understanding resprouting at the global scale. Journal of New Phytologist, 209(3): 945-954

Perry LWG, Wilmshurst MJ, Ogden J, Enright JN. 2015. Exotic mammals and invasive plants alter fire-related thresholds in southern temperate forested landscapes**.** Journal of Ecosystems, 18(7): 1290-1305

Pons TL. 2000. Seed Responses to Light: In: Seeds; The Ecology of Regeneration in Plant Communities (2nd edition) (Fenner M, ed). CABI Publishing, UK

Probert RJ. 2000. The Role of Temperature in the Regulation of seed Dormancy and Germination. In: Seeds. The Ecology of Regeneration in Plant Communities (Fenner M, ed). 261-292, CAB International, Wallingford, UK

Robinson KL. 2014. Assessment of the effects of fire and associated grazing on the recovery of Merxmuellera drakensbergensis in the Sani Pass region, Lesotho. http://hdl.handle.net10539/14840

Salis M, Laconi M., Ager AA. Alcasena JF, et al. 2016. Evaluating alternative fuel treatment strategies to reduce wildfire losses in a Mediterranean area. Forest Ecology and Management, 368: 207-221

Satyam V, Jayakumar S. 2012. Impact of forest fire on physical, chemical and biological properties of soil: A review. Proceeding of International Academy of Ecology and Environmental Science, 2(3): 168-176

Teketay D. 2005. Seed and regeneration ecology in dry Afromontane forests of Ethiopia: I. Seed production - population structures. Tropical Ecology, 46(1): 29-44

Tesfaye G, Teketay D, Assefa Y, Fetene F. 2004. The Impact of fire on the soil seed bank and regeneration of Harenna Forest, Southeastern Ethiopia. Mountain Research and Development, 24(4): 354-361

Van Breuge P, Friis I, Demissew S, Peter J, Lillesø B, Kindt R. 2016. Current and Future Fire Regimes and Their Influence on Natural Vegetation in Ethiopia. Journal of Ecosystem, 19(2): 369-386

Vivian ML, Cary JG, Bradstock AR, Gill AM. 2008. Influence of fire severity on the regeneration, recruitment and distribution of eucalypts in the Cotter River Catchment, Australian Capital Territory. Austral Ecology, 33: 55-67

Wesche K, Miehe G, Kaeppeli M. 2000. The Significance of Fire for Afroalpine Ericaceous Vegetation.Mountain Research and Development, 20(4): 340-347

Wesche K. 2002. The high-altitude environment of Mt. Elgon (Uganda, Kenya): climate, vegetation, and the impact of fire. The German Society for Tropical Ecology, Germany

Wesche K, Miehe G, Kaeppeli M. 2000. The significance of fire for the ericaceous belt of the East African Mountains. Mountain Research and Development, 20(4): 340-334

Yirdaw E, Starr, M, Negash, M, Yimer F. 2015. Influence of topographic aspect on floristic diversity, structure and treeline of afromontane cloud forests in the Bale Mountains, Ethiopia. Journal of Forest Research, 26(4): 919-931