Analysis of plant responses to the aftermath of fire outbreak in Muhabura Volcanoe, Rwanda.

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ABSTRACT

The structure of the community, composition of species and ecological processes at any given site are responses to various aspects of disturbance such as flooding, drought and fire (Alho & Silva, 2012). The majority of plant regeneration modes after fire, are based on resprouting, seed storage, dispersal, and germination. The objectives of this study were to assess plant regeneration in the burnt habitat, comparing the plant communities in unburned areas of the same altitude along the Muhabura volcano of the altitude slope in Volcanoes National Park (VNP), after one year. The study was conducted in the eastern part of the Muhabura volcano which was burned in 2009. Sixty plots in total, thirty in each habitat (burned and unburned), were surveyed using the Braun-Blanquet method. The stratified sampling technique was used in different vegetation types: herbaceous (2X2m), shrubs (5X5m) and forest (10X10m). Square plots were established every 25 m of altitude covering a total of 900m of elevation. The results showed a slight difference in plant diversity of burned area, in which 77 plant species were identified, against 74 plant species identified in unburned area. Five plant communities (two in the burned and three in the unburned habitats) were identified using the Detrended Correspondence Analysis. The coverage of annual plants, Therophytes (indicators of disturbed areas) was high in the burned habitats the unburned habitats were dominated by perennial plants, phanerophytes (indicators of undisturbed areas). The regeneration mechanism showed a great number of woody sprouters, which had an influence on the rapid recovery of the vegetation after fire, and played a positive role in preventing soil erosion and nutrient losses. *Erica arborea* woody plants did not show any signs of regeneration.

Key-words: *Plant community, Fire outbreak, Regeneration, Muhabura volcano*

1. INTRODUCTION

The necessity for efficient, economical and real time monitoring of earth resources is nowadays of global importance, particularly in environments which are highly sensitive to climatic fluctuations and which are critically dependent on meteorological conditions. The structure of the community, the composition of the species and ecological processes at any given site are responses to various aspects of disturbance such as flood, drought and fire. Many plant species have various adaptation mechanisms that allow them to survive, flourish, with some requiring disturbance events like fire (FAO, 2010).

In tropical forests, fire can cause a severe canopy of fast growing grasses or woody creepers which may dominate such severely burned areas (Chazdon, 2003). Some areas which are frequently burnt, plant communities adopt different functional groups depending on their response to fire (Keeling et al., 2006). The majority of post-fire regeneration modes are based on resprouting, seed storage, dispersal, and germination (Pausas et al, 2004). High temperatures, smoke and ash are characteristics of fire and the post-fire environment(Keith et al, 2009), thus, it has been suggested that heat, smoke, ash and the PH-value could have differential effects on seed germination depending on species' post –fire regeneration strategies (Keith et al., 2009).

Most resprouters produce few seedlings; the majority of individuals resprout vigorously after fire, which leads to a rapid regeneration (Bond & Midgley, 2001). While obligate seeders increase their density after seed germination, although seedlings suffer high mortality later (Keeley & Fotheringham, 2000). Not all plant species have efficient strategies to survive fire and, in fact, various species may disappear in the post-fire situation (Retana et al. 2002; Lloret & Vila 2003; Ordonez et al. 2004), and also, the different penetration depths of their root systems may determine regeneration process (Choczynska & Johnson, 2009).

Furthermore, other characteristics, such as growth rates and life cycle are also important in long-term dynamics of post-fire vegetation. Most obligate seeders have faster growth rates, greater allocation to reproduction, shorter life cycles and lower shade tolerance than resprouters (Bond & Midgley, 2001). A few years after fire, obligate seeders might be expected to be more abundant in post-fire plant communities than resprouters, consequently, in the long term this pattern could be reversed (Calvo et al. 2003).

Plant species also respond differently to stress conditions (Wang, 2003). Through morphological and physiological traits, particularly, in their root system, stomatal control, leaf water retention and carbon dynamics, obligate seeders show a higher drought tolerance than that found in resprouters (Calvo et al. 2003; Vivian & Cary, 2012). In addition, these differences could represent a better ability of seeders than resprouters to endure poor nutrient sites rather than drought tolerance (Leonard, 2015). Furthermore, the changes in the disturbance regime may be as important as climatic factors in determining the proportion of resprouters and obligate seeders in fire disposed areas (Calvo et al. 2003; Coca1 & Pausas, 2012).

Recent studies indicate that after fires, forests of resprouter and seeder species with efficient germination re-establish rapidly whereas forests of seeder species that produce only a few seedlings after fires and have limited long distance dispersal are replaced by other vegetation types (Clarke, 2013). Therefore, it is important to monitor the post-fire regeneration process of our forest for a wise management of natural resources.

In September 2009, the Eastern part of Muhabura slope in the Volcanoes National Park was burned from the lower altitude up to the top. Virunga massif contains a high number of animals adapted to high mountain habitat such as mammals, arthropods, insects, reptiles, amphibians and birds, some of which are Arbertine Rift Endemis and threatened with extinction such as mountain gorilla, (*Gorilla beringei beringei*), golden monkey and some bird's species (Owiunji et al., 2005).Therefore it is important to document the regeneration process of this key habitat. This study aims to assess the effects of fire on this habitat by comparing it to unburned habitat, along an altitudinal gradient.

The main objectives were (i) to assess plants regeneration in the burnt habitat along the Muhabura volcano slope after one year, by identifying plant species that have or not regenerated, and (ii) to evaluate plant communities with dominant species in the area, life-forms, in the burned area, comparing with the unburned habitat of the same altitudinal range.

2. METHODS

Study area

The study was conducted in August, 2010 on the eastern slope of Muhabura volcano, which lies partly in the Volcanoes National Park (VNP) in the northern province of Rwanda. Muhabura is an extinct volcano in the Virunga massif (1° 23′ 0″ S, 29° 40′ 0″E) with an altitude of 4,127m on the border between Rwanda and Uganda. In September 2009, part of the large forest along the entire Muhabura slope has been disturbed by fire outbreak. The forest is characterized by an open canopy with dry and rocky soil and frequent wind like in the savanna. The dense human population bordering on the bottom of the Muhabura volcano, depends on agriculture and beekeeping using the forest resources. This extended the 2009 fire attacks caused by honey collection from beekeeping along the edge of the forest.

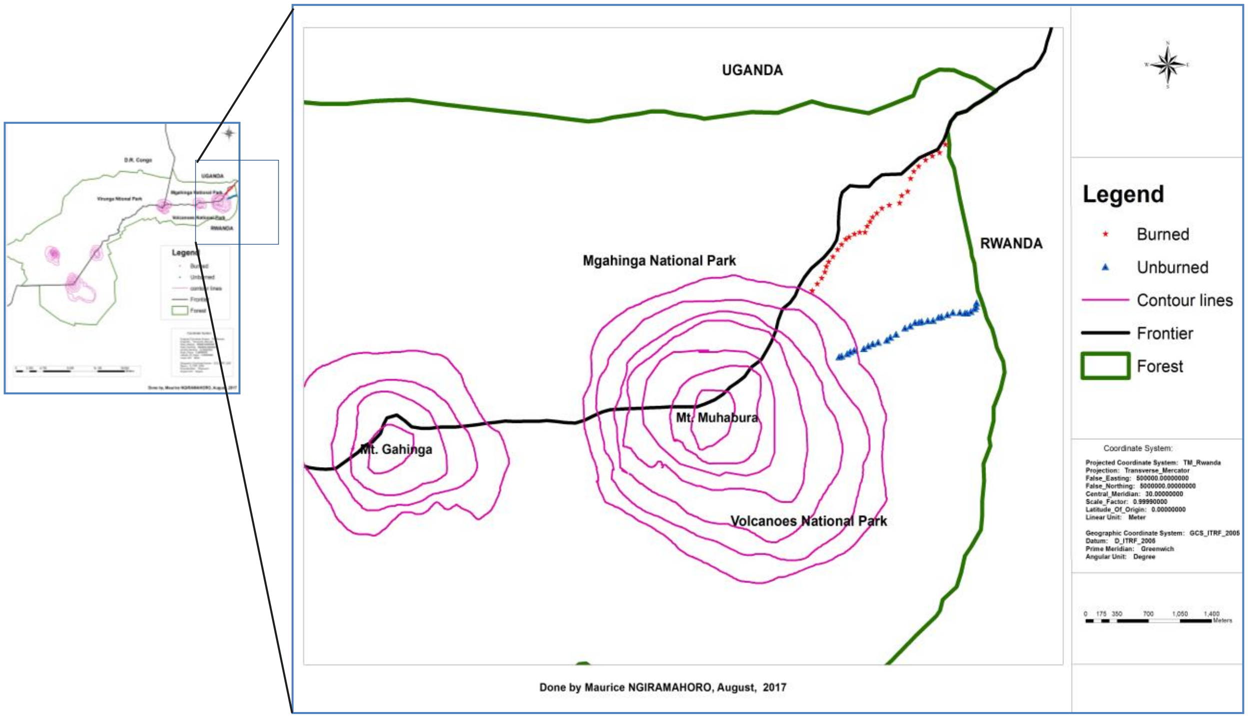


Figure1. Plots sampled map (Current orthophoto, 20060

Plot sampling techniques

Sixty plots were surveyed; thirty plots in burned and unburned areas respectively using stratified sampling methods. Their size were contingent on the vegetation types (2×2m in herbaceous and grassland, 5×5m for shrubs and 10×10m in forest habitats), and each plot was established at every 25m of altitude along 900m of elevation gradient. Other ecological parameters were recorded, such as the slope (steep, moderate and flat), altitude. To allow relocating the plots for long-term monitoring, GPS coordinates were recorded in each plot, which was also marked with a colored band. According to Braun-Blanquet (1972) method, the abundance was estimated by assessment of the coverage of each plant species.

Table 1. Plants abundance

Index	Coverage	Coverage mean
+	0.5%	0.5%
1	1 and 5%	3%
2	5 and 25%	15%
3	25 and 50%	37.5%
4	50 and 75%	62.5%
5	75 and 100%	87.5%

Plant identification

Through flore du Rwanda and East African flora, plant species were identified (Troupin, 1978, 1983, 1985, and 1988), and also, unknown plant species were collected, photographed, numbered and preserved for later identification using the herbarium of Karisoke Research Centre (KRC), and National Herbarium.

Through Raunkiaer’s system modified by Cornelissen et al. (2003), life-forms of all plant species were identified which are considered to be a good predictor of disturbance in ecosystem, and. Example of Therophytes: plants whose entire shoot and root system dies after seed production, so perennate only through their seeds; Geophytes:plants that have roots or shoots that are modified as storage organs; Phanerophytes: Normally woody perennials with resting buds more than 25cm above soil level (Trees and Shrubs or lianas); Chamephytes: woody perennials with the resting bud < 0.5 m above the ground; Hemicryptophytes: periodic shoot reductions to a remnant shoot system, such that the buds that produce new growth following the annual harsh season are located about at ground level; Hydrophytes: plants that grow in aquatic habitats, and whose perennating organs remain, during the harsh season, either in the water or (much more often) in the mud or soil at the bottom of that body of water.

Data analysis

Diversity indices were calculated to assess the diversity of plant communities identified in both burned and unburned areas. The Shannon's index was calculated: $\overline{H} = -\sum_{i=1}^{s} \frac{n_i}{N} \log_2 \frac{n_i}{N}$ Where ni/N is the proportion of species i in the community; n_i: abundance in i^{th}, species and N= total number of individuals. Plant communities have been identified using the Multivariate Statistical Package (MVSP) vers.3.1, MINITAB and Microsoft Office Excel were used for data entry and data analysis. Similarity indices for both, burned and unburned habitats were presented as dendrograms created using plant species abundance, and plant communities within plots (Owiunji et al., 2005).

3. RESULTS

3.1. Species diversity

In total, 151 plant species composed of 36 families, were found the this study. The number of plant species and families did not differ strongly between burned and unburned, and the number of plant species were decreasing with the increased altitude. The small difference was also determined, by calculating the Shannon's Index, which also varied slightly between the burned and unburned areas.

Table 2. Shannon's index

Sample	Number of species	Index	Eveness
Burned	77	3.038	0.661
Unburned	74	2.888	0.636

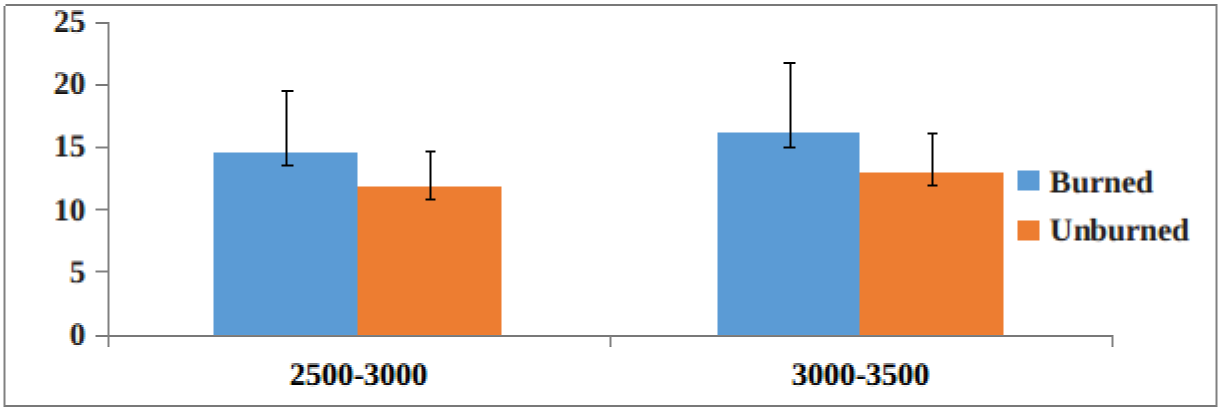
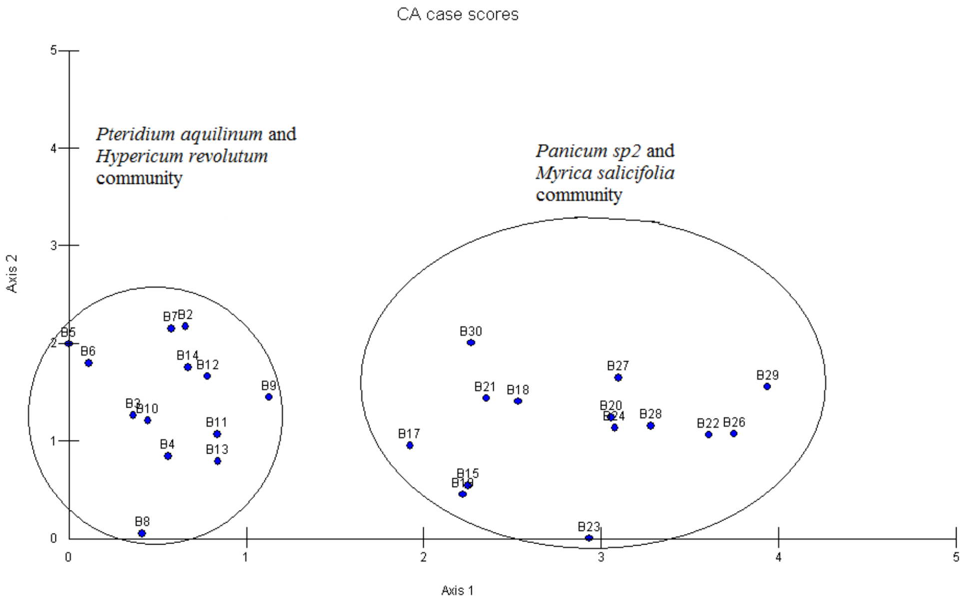


Fig.2. Species richness along altitudinal range

3.2. Plant communities in the burned and unburned habitat

Five plant communities were found; two of them were from burned habitat, including *Pteridium acquilinum* and *Hypericum revolutum* community (C3), with *Panicum species* and *Myrica salicifolia* community (C5), and also three communities were from unburned habitat, including *Erica arborea* and *Panicum species (C1)*, C2=*Hypericum revolutum* and *Periploca linearifolia(C2) and the dominance of Hypericum revolutum with Erica arborea* community(C4).

a)



b)

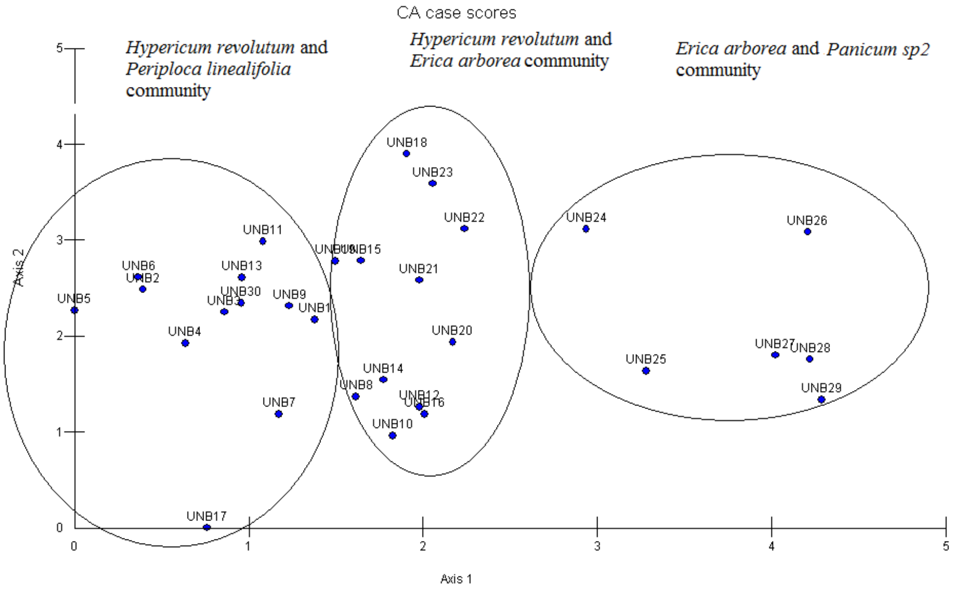


Figure 3. Plant communities; (a) burned and the (b) unburned habitats.

3.3. Life forms in burned and unburned areas

Four categories of life forms of Therophyte(T), Phanelophytes(P), Geophytes(G), and Chaemephytes(Ch) were identified in burned and unburned areas; in burned habitat the coverage of annual plants(Therophytes) was clearly higher in burned habitat, which on the other hand had a higher coverage of perennial plants (Phanerophytes) compared to the burned habitat. Geo; geophytes were also found as a stressed area indicators and (ch;chamephytes) as a sign of the absence of water. (Figure6). Annual plants (therophyte) increase with altitude (Figure7).

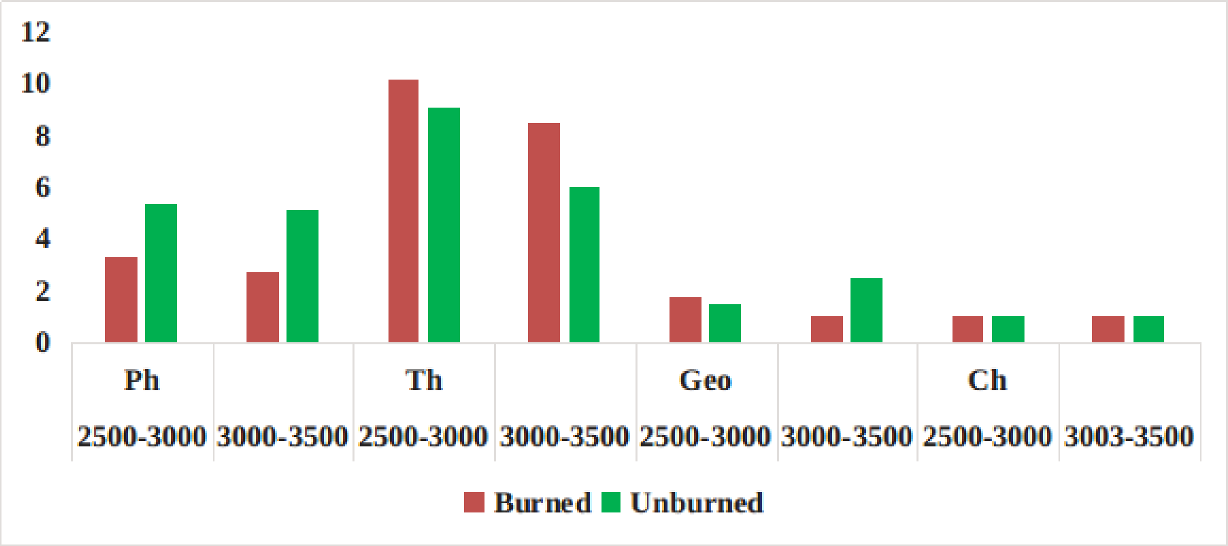


Figure 4. Plant life form abundances

3.4. Regeneration process in burned habitat

By observing plant regeneration process on burned habitat, there was sign of regeneration, through different part of plant. While, there was no regeneration of wood plant species of ericaceace, namely, *Erica arborea*

Table 3. List of post-fire plant species and their regeneration process (B – Burned, Ph – phanerophytes, Th – therophytes, Geo – geophytes).

Plot nº	Family	Species	Regeneration process	Life form
B1	Proteaceae	*Faurea saligna*	Woody sprouter	Ph
B2	Clusiaceae	*Hypericum revolutum*	woody facultative sprouter	Ph
B3	Myiricaceae	*Myrica salicifolia*	Woody sprouter	Ph
B4	Proteaceae	*Faurea saligna*	Woody sprouter	Ph
B5	Clusiaceae	*Hypericum revolutum*	Woody facultative sprouter	Ph
	Rubiaceae	*Pavetta ternifolia*	Woody sprouter	Ph
	Myiricaceae	*Myrica salicifolia*	Woody sprouter	Ph
B6	Clusiaceae	*Hypericum revolutum*	woody facultative sprouter	Ph
	Rubiaceae	*Pavetta ternifolia*	Woody sprouter	Ph
B7	Clusiaceae	*Hypericum revolutum*	Woody seeder	Ph

B8	Poaceae	*Hyparrhenia sp1*	Herbal facultative sprouter	Geo
B9	Proteaceae	*Faurea saligna*	Woody sprouter	Ph
B10	Ericaceae	*Erica arborea*	Woody plant(no regeneration)	Ph
	Ericaceae	*Agauria salicifolia*	Woody sprouter	Ph
B11	Ericaceae	*Erica arborea*	Woody plant(no regeneration)	Ph
B12	Lamiaceae	*Pychnostachys goetzenii*	Woody seeder	Ph
B13	Asphoderaceae	*Kniphofia princiae*	Herbal facultative sprouter	Geo
	Asteraceae	*Conyza sumatrensis*	Herbal seeder	Th
B14	Clusiaceae	*Hypericum revolutum*	woody facultative sprouter	Ph
B15	Clusiaceae	*Hypericum revolutum*	Woody seeder	Ph
B16	Ericaceae	*Agauria salicifolia*	Woody sprouter	Ph
B17	Ericaceae	*Erica arborea*	Woody plant(no regeneration)	Ph
B18	Clusiaceae	*Hypericum revolutum*	Woody seeder	Ph
B19	Myiricaceae	*Myrica salicifolia*	woody facultative sprouter	Ph
B20	Clusiaceae	*Hypericum revolutum*	woody facultative sprouter	Ph
	Myiricaceae	*Myrica salicifolia*	Woody sprouter	Ph
B21	Clusiaceae	*Hypericum revolutum*	Woody sprouter	Ph
	Myiricaceae	*Myrica salicifolia*	Woody sprouter	Ph
B22	Myiricaceae	*Myrica salicifolia*	Woody sprouter	Ph
	Asteraceae	*Carduus leptacanthus*	Herbal seeder	Th
B23	Clusiaceae	*Hypericum revolutum*	woody facultative sprouter	Ph
	Lamiaceae	*Pychnostachy goetzenii*	Woody seeder	Ph
	Asteraceae	*Inura mannii*	Herbal seeder	Th
B24	Lamiaceae	*Pychnostachys goetzenii*	Woody seeder	Ph
	Poaceae	*Panicum sp2*	Herbal seeder	Th
B25	Asphoderaceae	*Kniphofia princiae*	Herbal facultative sprouter	Geo
B26	Poaceae	*Panicum sp2*	Herbal seeder	Th
	Asteraceae	*Carduus leptacanthus*	Herbal seeder	Th
	Cyperaceae	*Bulbostylis lanifera*	Herbal facultative sprouter	Geo
B27	Clusiaceae	*Hypericum revolutum*	woody facultative sprouter	Ph

	Poaceae	*Panicum sp2*	Herbal seeder	Th
	Asteraceae	*Carduus leptacanthus*	Herbal seeder	Th
B28	Myiricaceae	*Myrica salicifolia*	Woody sprouter	Ph
	Asteraceae	*Carduus leptacanthus*	Herbal seeder	Th
	Polygonaceae	*Rumex ussambarensis*	Herbal seeder	Th
B29	Asteraceae	*Carduus leptacanthus*	Herbal seeder	Th
	Myiricaceae	*Myrica salicifolia*	Woody sprouter	Ph
	Poaceae	*Panicum sp2*	Herbal seeder	Th
B30	Asteraceae	*Senecio tricopterigius*	Herbal seeder	Th
	Polygonaceae	*Rumex ussambarensis*	Herbal seeder	Th

4. DISCUSSION

Species richness varied slightly between the burned and unburned habitat along the Muhabura slope.The slightly higher number of plant species found in the burned habitat compared to the unburned habitat may be due to the greater number of annual plants regenerated in the burned plots. Many annual and short-lived seeder species benefit from an increased light and nutrient supply after the mineralization of high quantities of organic material (Buhk et al., 2005).

The decrease in the number of plant species with altitude in burned and unburned areas is consistent with previous findings, which showed that floristic composition of communities several years after fire does not differ markedly from more mature communities in the area (Arnan et al., 2007).

Community “C2” was the most diverse. Some species from other close communities are also well represented. We can signal the case of *Hypericum revolutum* which is normally found inside the *Hypericum revolutum* and *Erica arborea* community (C4) and in *Pteridium acquilinum* and *Hypericum revolutum* community (C3). The least divers is *Erica arborea* and *Panicum sp2* (C1) because *Erica arborea* is very competitive with the other plant species.

The abundance of therophyte increased with altitude in burned habitat, whereas their great abundance in unburned habitat is remarked at the lower altitude and decreasing in middle altitude then increase in the high altitudes as it is contrary to the abundance of phanerophytes. This could be due to the plants perturbation at the edge of the forest in previous years; in 1997 people used to cultivate that area at the lower altitudes. The altitude strongly influenced the plant species composition and community structure of the forest landscape. Furthermore, disturbances would be expected to alter such natural gradient that are mainly controlled by temperature (Nagaike, 2010).

The difference of plant species between burned and unburned areas might be linked to the abundance of therophytes. These therophytes may be partly replaced by phanerophytes (perennial plants) after fire, which were abundant in unburned areas. As trees (large woody perennial plants) have a key effect on the composition of the plant communities where they live, it could be expected that the composition and structure of plant communities after fire are directly related to the regeneration of the dominant tree species (Sousa, 1984).

Rapid recovery of vegetation through resprouting after fire plays a critical and positive role in preventing soil erosion, preventing nutrient losses and re-establishing suitable environmental conditions for the recovery of animal communities (Espelta et al., 2003), of which facultative resprouters are species that primarily regenerate through seed germination but they can also regenerate through resprouting, e.g. *Sarcopoterium spinosumand Erica spp*(Arianoutsou, 1999). However, ericaceous plants at Muhabura slope showed no sign of regeneration. This could be due to the less seed dispersal factors, and a higher intensity of fires which threatened the survival of sprouters.

5. CONCLUSION

The regeneration mechanism at Muhabura volcano showed a great number of woody sprouters, which had an influence on the rapid recovery of the vegetation after fires and may play a positive role in preventing soil erosion and nutrient losses.

The Muhabura volcano is mainly characterized by rocky and dry soil, between moderate and steep slope with strong wind, which may play an important role in seed dispersion. However, other studies in tropical dry forests found that many tree species produce abundant and well-dispersed seeds with high viability, though, seed predation, water stress, and other factors, successful recruitment from seed is often rare (Nathan & Muller, 2000).

Plant species, *Erica arborea* did not regenerate. Since this study was conducted one year after fire break out, it is uncertain to know its response afterward. Therefore, a study on its response to fire and monitoring should be done.

Further studies of vegetation patterns and mechanisms are needed to understand the complexity of factors influencing the specific mechanisms and to possibly forecast changes in vegetation due to fire and climate conditions.

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