UNIVERSITÀ DEGLI STUDI DI PADOVA
Department of Land, Environment Agriculture and Forestry

Second Cycle Degree (MSc)
in Forest Science

Characterization of forest fires in the Mount Kenya region (1980-2015)

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ACADEMIC YEAR
2015/2016

INDEX

FIGURE INDEX

TABLE INDEX

ABSTRACT

Mount Kenya is the second highest peak of Africa (5199 m.a.s.l.) and is one of the few site where "afro-alpine" ecosystem occurs. The area has a great ecological, touristic and livelihood importance within the country. Human-induced wildfires are the major threats of Mt. Kenya forest and the current fire management system does not have the capacities to control the spread of large-scale fires. Men and resources have to be organized and rearranged in relation to the probability of ignition and to the expected fire behaviour. This research analysed the wildfires behaviours during the years (1980 - 2015), highlighting prone areas, periods and conditions and describing the current fire fighting situation. Additionally, this research describes the effects of the fires on the vegetation, to have a better perception of changes and damages provoked by these events.

In the study information about the fires recorded in the Forest Stations of Mount Kenya forest were collected and analysed. The results were compared and verified with information from the NASA-online database MODIS (Moderate Resolution Imaging spectra-radiometer) and from the "Kenya's Forest Resource Assessment". Moreover, effects of fires on the vegetation are described comparing plots of natural forest and plantation in areas affected and not by fire, highlighting the differences in their structure, sizes and species composition.

January, February and March results to be the most prone months. A higher occurrence of big-size fires is detected in the northern side of the area, even though the most prone location varies during the year from west, in the first three months, to east in the rest of the year. Both, human and environment drive the occurrence of the fires. Weather conditions set the circumstances prone to fires (hottest and driest periods), while human being, topography and vegetation composition determine the place of fire ignition and spread. From the field analysis structure and biodiversity variations have both a big role, revealing fire influence on the species occurrence and on the (mainly vertical) dimensions of the trees. The areas rarely affected by fire registered the most evident variations. Fire intensity revealed a double role of the hazard, which enhances the heterogeneity of the forest if not excessively strong. At the same time, fires homogenizes structure and composition if very intense.

To our knowledge this is the first study regarding the wildfire behaviour in the region and this is the first step to protect significantly this rare ecosystem from fires.

RIASSUNTO

Il monte Kenya è la seconda cima più alta in Africa (5199 m.s.l.m.) ed è uno dei pochi luoghi in cui è presente il clima "afro-alpino". L'area ha una grade importanza ecologica, turistica ed una grande rilevanza nella capacità di sostentamento all'interno del Paese. Incendi causati dall'uomo sono le maggiori minacce che affliggono la foresta del Monte Kenya, l'attuale sistema di gestione degli incendi non ha la capacità di controllare la diffusione di incendi su vasta scala. Uomini e risorse devono essere organizzati e ridistribuititi in base alla probabilità di combustione ed al comportamento previsto dell'incendio. QUesta ricerca analizza i comportamenti degli incendi forestali durante gli anni (1980 - 2015), evidenziando aree, periodi e condizioni particolarmente a rischio e descrivendo l'attuale situazione dell'antincendio. Inoltre, questa ricerca descrive gli effetti di degli incendi sulla vegetazione, per avere una migliore percezione dei cambiamenti e dei danni provocati da questi eventi.

Nella ricerca sono stati raccolti ed analizzati i rapporti riguardanti gli incendi, registrati nelle stazioni forestali della foresta del Monte Kenya. I risultati ottenuti vengono paragonati e verificati con i dati provenienti dal database della NASA MODIS (uno spettroradiometro ad immagini di media risoluzione) e dalla "Valutazione delle risorse forestali in Kenya". Inoltre, gli effetti degli incendi sulla vegetazione sono descritti confrontando foreste e piantagioni affette da incendi e non, evidenziando differenze strutturali, dimensionali e di composizione di specie.

Gennaio, Febbraio e Marzo sono i mesi più inclini agli incendi. Nelle zone a nord della foresta è registrata una maggior presenza d'incendi di grandi dimensioni, sebbene l'area più incline agli incendi vari durante l'anno da Ovest, nei primi tre mesi dell'anno, ad Est, durante il resto dell'anno. Uomo e clima controllano entrambi il verificarsi degli incendi. Le condizioni metereologiche stabiliscono le circostanze a rischio (periodi più caldi e secchi), mentre uomo, topografia e composizione della vegetazione decidono il luogo d'innesco e di propagazione. Cambiamenti di struttura e biodiversità hanno entrambi un ruolo rilevante nello studio dei dati presi sul campo, rivelando l'influenza del fuoco sulla presenza delle specie e sulle dimensioni (prevalentemente verticali) degli alberi. Le aree raramente affette hanno rivelato le variazioni più evidenti. L'intensità dell'incendio ha svelato un doppio ruolo del fuoco, aumentando l'eterogeneità della foresta, se non eccessivamente forte. Allo stesso tempo, gli incendi stabilizzano struttura e composizione, se molto intensi.

A nostra conoscenza, questo è il primo studio sul comportamento degli incendi forestali nella regione e questo è il primo passo per proteggere in modo significativo questo raro ecosistema dagli incendi.

1. INTRODUCTION

Fire is an important disturbance in forest ecosystem, haltering their structure and in some cases could be a threatening factor to their biodiversity and ecology (Nyongesa K. W., 2015). Natural and non-natual disasters are increasing all around the world, especially in Africa and Asia, where hazards even more frequently become normality rather than exception (Huho J. M. et al., 2016). Fires occur naturally, but human influence can modify their frequency and intensity (Huho J. M. et al., 2016). In the forest fire human being has a big role, altering the ignition and the arrangement of the fuel (O'brien J. J. et al., 2009) in fact in Kenya the ignition at the majority of the wildfire is related to human being (KWS, 2010). The increasing of forest exploitation, the changes driven by climate and the even more demand of the human population, that is still growing, have improved and increased the number of forest-fires in Mount Kenya region (Nyongesa K. W., 2015).

Mt. Kenya is located in the middle part of Kenya, it is on the eastern side of the Great Rift Valley and its northern slopes reach the equator. The second highest peak of Africa is one of the five water towers in Kenya, whose water yield contributes almost half of the flow of the Tana River, a basin of great importance for national hydropower energy, irrigation, livestock, biodiversity and water supply. (IFAD, 2012). 3.46 million hectares of the Kenyan territory (5.9% of the country's surface) is covered by forest, of which 1.41 million hectares (2.4% of the total land area) is classified as indigenous closed canopy forest (Ngunjiri C. W., 2012). Mount Kenya Forest Reserve covers almost the 15% of Kenya's total indigenous forests and together with Mt. Kenya National Park, classified as a Natural World Heritage Site since 1997 (UNESCO, 2013), protect one of the most threatened forest of the country (Emerton L., 1999). The forest is an important source of food, water and heating for the Kenyans, and especially for the 200,000 people, who live within 1.5 km from the edge of the forest (Emerton L., 1999). These people depend for cultivation, grazing, fishing, food, fuel wood, honey, herbal medicine, water and other benefit on this forest, affecting heavily this particular ecosystem (Ngunjiri C. W., 2012).

Additionally to the direct exploitation, human-induced wildfires are a major cause of natural resources losses in Mount Kenya forest, defined by Peter Wass as "one of the largest, most ecologically significant and most commercially important natural forest in Kenya" (Wass P., 1995). The main cause of wildfire in the country is the human being, who for purposes (revenge) or lack of attention (honey collector who leaves the forest before to have mop up the fire) gives the ignition at the majority of the fire occurred in Kenya. The major causes of fires in Kenya (expressed as share of the total number of fire incidences) are arson (45%), honey collection (12%) and pasture management for livestock grazing (12%), while 11% of fire incidences recorded have unknown causes. Other additional causes recorded are: poachers and cigarette smoking (each 5%), charcoal burning (4%), land preparation (3%), cultural rites and ethnic clashes (2%), planned fires, child play and lighting (below 1%) (Nyongesa K. W., 2015). The risk of fire is driven by the weather conditions as moisture level, rain events (Kane V. R. et al., 2014; Marzano R. et al., 2013), but the intensified cultivation of exotic fire-prone tree species (*Pinus patula* S. & C., *Cupressus Lusitania* Mill. and *Eucalyptus* sp.) (KWS, 2010) and other human interaction (O'brien J. J. et al., 2009) can increase it.

Historically, in Mount Kenya region fire prevention and protection were led by the Kenya Forest Service and Kenya Wildlife Service and, in the early 1980s, a serious effort to combat wildfires in Kenyan forests was undertaken with the development and partial implementation of a Fire Management Plan (KFS, 2014). The termination of donor funding limited funds to tackle this issue, and seriously reduced the Kenya Forest Service's capacity to effectively suppress and combat wildfires (KFS, 2014). Almost everywhere within the territory is recorded a lack of equipment (Huho J. M. et al., 2016), moreover is commonly accepted the necessity to improve the actual wildfire organization and legislation (O'brien J. J. et al., 2009; K'Akumu O. A. et al., 2016). Homogeneity of the stand, concentration of fire-prone material (conifers' wood), lack of maintenance and attention are causing the most fire-damages in these areas. At the same time, fires occurred within the natural forest are difficult to fight because of the steep mountainous terrain and the lack of a road system (KWS, 2010). Is needed a good description of the problem to improve the fight fighting capacities and to establish a reactive and appropriate forest management (KFS, 2010). Fire management decisions will be much more effective if taken after had considered effect of the fire on the vegetation and its comportment within the territory and the time (Nyongesa K. W., 2015).

For these reasons, the objective of the research was to describe the main behaviour of fires and their effects in Mount Kenya forest. The first aim was to describe the changes that fires provoked within the forest, evaluating the modification of woodland structure and composition and highlighting the damages. Second objective was that to describe the past situation, analysing the forest fires recorded since 1980 in different Forest Stations and identifying areas and periods more prone to fires. After that we used geospatial techniques such as remote sensing (RS) and geographic information system (GIS) to compare and verify the historical data and as well the reliability of the new techniques. The additional goal of the research was to describe the effects of the fire on vegetation structure and biodiversity to provide a description of damages and changes.

2. MATERIALS AND METHODS

2.1 STUDY AREA

Mount Kenya is located in the central eastern side of African continent (Fig. 1), in the middle of Kenya, 0.15083° S and 37.3075° E, and is surrounded by approximately 200.000 hectares of forested area (UNESCO, 2013). Mt. Kenya National Park (715 km^2) and Mt. Kenya Forest Reserve (705 km^2) protect one of the most threatened forests of the country (KWS, 2010), classified as a Natural World Heritage Site since 1997 (UNESCO, 2013). Glacial erosion modified the original shape of this massif, an extinct volcano, which rises moderately from the surrounding foreland (1.800 m.a.s.l.) to about 5.200 (m.a.s.l.), giving the way to an alpine landscape where small valleys run up the sides of the mountain (JAMC, 2008). This rare ecosystem occurs only on few high-altitude areas in the continent (KWS, 2010), where the flora is defined as "afro-alpine" (UNESCO, 2013). The equatorial location of the study area influenced the research dissolving the differences between south and north aspects of the mountain slopes (Niemelä T. et al., 2004), enhancing the role of limit factor of the weather as rain and wind distribution.

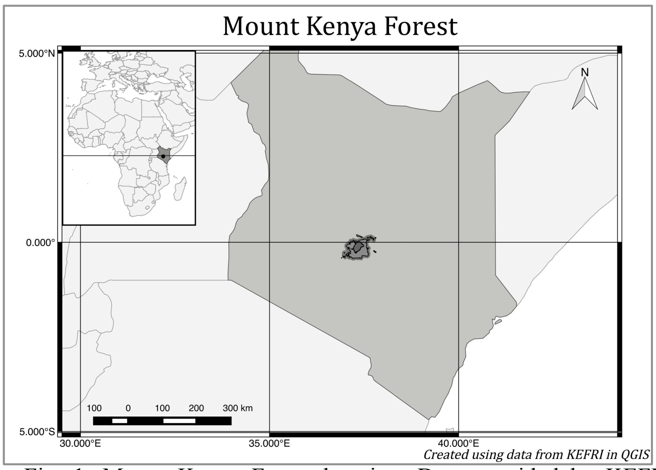


Fig. 1. Mount Kenya Forest location. Data provided by KEFRI; Maps created with QGIS.

Cassipourea malosana Bak. is the dominant species from the southwest and northeast wetter areas (over 2200 mm/year), then is replaced by *Juniperus procera* H. and *Podocarpus* spp. in the drier parts of the lower zone (below 2500 m.a.s.l.) (UNESCO, 2013). A dense evergreen forest covers the area between 2200 and 3500 m.a.s.l., with giant-size trees (*Ocotea* spp., *Olea capensis* L., *Podocarpus falcatus* T. and *Juniperus procera*). Above the montane rain forests *Arundinaria alpine* K. Schum. (mountain bamboo) creates an uniform layer in the southeastern area, leaving place to *Podocarpus* spp in the northern one and at higher elevations (Niemelä T. et al., 2004). Above 3000 m.a.s.l., grassy glades, moorlands and sedges follow each other (UNESCO, 2013). When cold climate becomes a limit factor *Hypericum* spp. results more common and the *Ericaceous* zone starts above 3500 m.a.s.l. (Niemelä T. et al., 2004). Tree line is fixed at 4500 m although isolated trees can grow also over 5000 m.a.s.l. (UNESCO, 2013).

Heavy rains influence Kenya when the Inter Tropical Convergence Zone (the area near the equator where northeast and southeast trade winds come together) crosses the equator. There are a "long rains" period (middle of March – beginning of June) and a "short rain" period (middle of October –

December) (Henne S. et al., 2008). Eastern and southern areas receive more rainfall than the others (Niemelä T. et al., 2004) and the amount of rainfall ranges from 900 mm in the North to 2300 mm on the southeastern region.

The forest spreads over two Conservancies (Eastern and Central), four counties (Embu, Kinrinyaga, Meru and Nyeri) and several different districts (counties' subdivision). The inner part of the forest belong to the National Park and it is strictly protected, since any kind of human alteration related to forest exploitation is allowed. The territory of Forest Reserve surrounds the inner part, as a kind of buffer zone, where forest is still highly protected and divided in Station administrations (Fig. 2). Plantations and crops, strictly connected in a rare agro-forest organization, take place exclusively in the zone more distant from Mount Kenya peak but also inside the territories of Forest Station as well. Shamba is a rotational agroforestry system, where farmers are encouraged to crop primary produces, as maize and beans, in order to restore the ground after a plantation clear cut, with the duty to replant the trees until the new plantation have been regenerated (Kagombe, 2005).

Fire is the major hazard of Mount Kenya vegetation (IUCN, 2013) and the increasing number of people living around the periphery of the forest exacerbates the threat (UNESCO, 2013). Fire prone areas are focused from the lower western forests to the North eastern moorlands in Gathiuru, Nanyuki, Ontulili, Marania, Mucheene and Meru forest stations, where the risk is strongly increased by the lack of rain event during the long dry season (KWS, 2010) and the part of the region where the research was focused (Fig. 2). More precisely, in the Eastern Conservancy, Meru County, Buuri District, Ontulili (coordinates: 37.11° – 37.20° E and 0.09° S – 0.06° N) was the Forest Station selected as sample to be analysed (Fig.3). This area, on the north-eastern region, was chosen because of its location, as it is situated in the middle of fire prone areas, its large size, and the presence of an heterogeneous vegetation layer, shared between natural forest and plantations (*Cupressus lusitanica* Mill. *and Pinus patula* S. & C.) (Mbugua D. K., 2012).

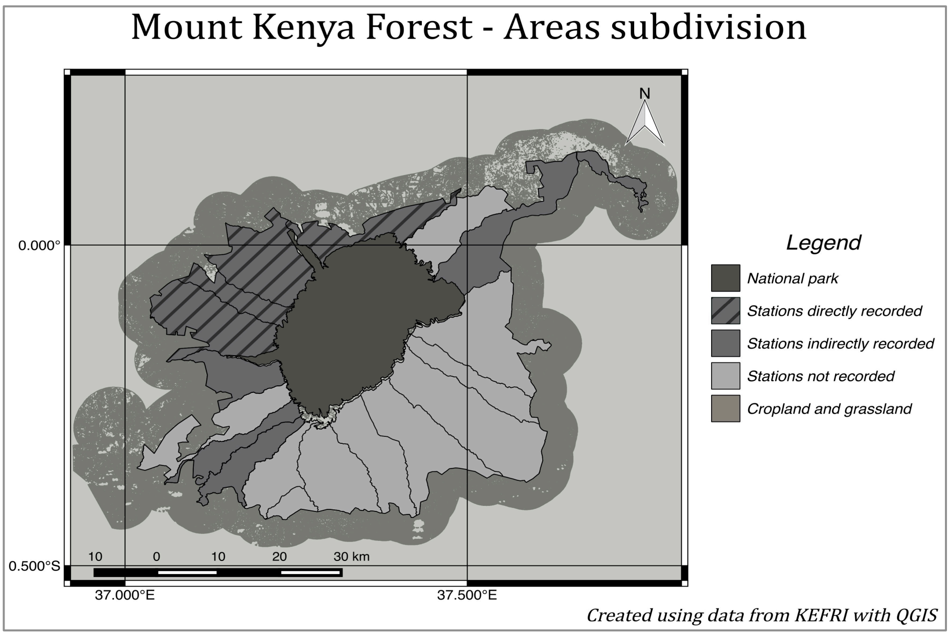


Fig. 2.
Mount Kenya forest, areas subdivision.
Data provided by KEFRI; Maps created with QGIS.

2.2 SAMPLING and MATERIALS

2.2.1 SAMPLING

28 plots were analysed in Mount Kenya forest. Lack of time, equipment and transports, bad weathers and danger for animal (elephant and buffalo) and human (poachers) attacks had severely influenced the number of samples. Within the territory of Ontulili Forest Station we selected 5 different areas (Fig.3):

- natural forest where fire occurs frequently, January 2015 last fire (6 A_F plots);
- natural forest not familiar to fire but affected in 2012 (9 An_F plots);
- natural forest never affected by fire (7 N_F plots);
- plantation affected in January 2015 (4 A_P plots);
- not affected plantation (2 N_P plots).

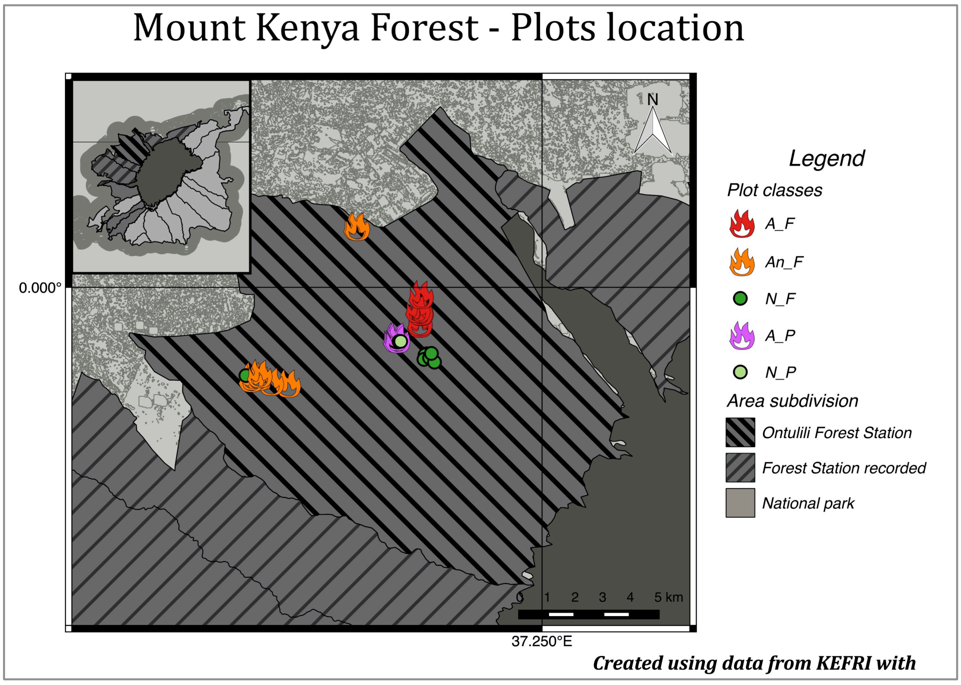


Fig. 3.
Ontulili Forest Station, location of field recorded. **Plot classes**: forest frequently affected by fire (A_F); forest rarely affected by fire (An_F); forest not affected by fire (N_F); plantation affected by fire (A_P); plantation not affected by fire (N_P).

The plots have been selected to be as homogeneous as possible with respect to the general physical, environmental and morphological characteristics (location, exposure, slope, geology, water resources and local climate). For the plots in areas damaged by fire the selection was based on accessibility of the surface, representative distribution of the sample and homogeneous distribution of the intensity of the fire. For the reference areas (zones where forest was not affected by fire) were chosen plots as similar as possible to the fire area regarding species composition and the physical, environmental and morphological characteristics. Previously estimated a mean diameter at breast height (DBH) > 20 cm, to ensure heterogeneity in biodiversity and structural composition of the samples, we analysed plots with circular shape and a radius of 10m (WALDBAU, 2014). For each plot, we recorded coordinates of the "central tree", altitude, mean slope and canopy structure (quantity and density of the layers).

“Central trees” were selected randomly, but at least at 30 meters from the edge of the fire perimeter and from another “central tree”, to avoid edge -effects and overlapping errors, in order to capture the variability. Within each plot all the stems and the snags (living and not living trees) with a DBH (diameter at breast height) ≥ 7 cm were numbered clockwise. Tree size can be described with a variety of information, such as diameter, height, crown height and ratio (Lexerød N. L. et al., 2006). For each stem we recorded tree species, DBH, total height of the tree, height of lowest living branch and height of the canopy. Additionally we recorded the percentages of crown healthy, damaged and consumed by fire, the percentages of charred back at DBH-height and on the surface level and the charred height on the trunk of affected trees. The choice of data collection was based on the instructions for mortality survey on forest fire areas developed by the Institute of silviculture in the University of Natural Science of Vienna (WALDBAU, 2014).

Sampling activities were carried out in the firsts weeks of March 2016. In the same period the digitalization of the historical knowledge related to the fires that have affected the area started. Each Forest Station recorded information about the fires occurred within its territory and those events which occupied its crew. We selected the forest stations more commonly affected (Gathiuru, Nanyuki, Ontulili and Marania) (Fig. 2) and scanned all the available documents related to fires registered from 1980 to 2015.

2.2.2 MATERIALS

Two armed rangers with the duty to ensure the safety of the team, a local man, who recognized the tree species and a student of the University of Natural Science of Vienna, delegated for data recording, performed the sampling activities in the field. Due to budget limits, it was not possible to use technological tools during the data recording. A tape was used to register the DBH values while all the other observations (heights and percentages) were carried by visual estimation by the team members. The whole team discussed on each of the uncertain data and the student enrolled for data sampling gave the final sentence.

Kenyan Forestry Research Institute (KEFRI) provided digitalized vegetation maps of Mt Kenya area, where the subdivision in different land use and vegetation type was already defined in a GIS file. These last data were essential for the research, providing locations and delimitations, the nature of the fuel burned and of the land use where fires occurred. Additionally the Kenyan institute provided times and locations details of the most relevant fires from 2003 to 2015, recorded by a remote sensing system (Moderate Resolution Imaging spectra-radiometer). The so-called MODIS archives the fires all around the world by detecting the brightness temperature of the area through temperature sensors, as explained by Sharma N. R. et al. (2015).

Regarding the analysis of the data, QGIS 2.8.4 software was utilized for the investigation and the development of the data, concerning vegetation distribution and fire location and occurrence, provided by KEFRI. We utilized R 3.2.2 software and R Studio for the statistical analysis of the records collected in field, whereas not statistical analyses were realized with Excel.

2.3 METHODS

2.3.1 FIELD SAMPLING

2.3.1.1 *Description of the forest structure*

Initially we analysed the data recorded on the field related to structure and damages dimensions, describing the general structure of the forest. In order to have a more clear perception of the reality in the different areas we initially described the type of species occurred and registered in the different zones. We estimated the mean values at plot class level for flame height and structure variables (DBH, basal area per hectare, tree height, height of first branch, crown height) recorded and estimated. After that the composition of the plot classes were studied evaluating the number of tree per hectares and the presence of species within the stands. Finally we analyzed the values of damages documented (% of bark blackness at surface and DBH level and % of crown damaged/burned). The trees were divided in 4 groups related to the level of blackness recorded: no (0%); low (5 – 35%); medium (40 – 70%); high (75 – 100%). Concerning the effects of the flames on the crown, the trees were grouped in relation to the percentage of crown burned and damaged in 4 categories: not burned/damaged (0%); low burned/damaged (5 – 35%); medium burned/damaged (40 – 65%); high burned/damaged (70 – 95%). In the analysis of the crown burned we evaluated an additional group related to that trees completely burned and classified as snag. In this first part of the analysis we focused our attention on the living trees, considering the snags (death trees, completely burned) only in the analysis of the burned crown.

2.3.1.2 *Diversities indices*

In forest research, species and structural diversity are important characteristics (Neumann M. et al., 2001), genotype and dimension measures are frequently used in forest analysis, highlighting changes in vertical and horizontal stand structure and in biodiversity configuration (Staudhammer C. L. et al., 2001). Due to the extremely similar organization and arrangement of the plantations we not considered these kinds of samples in this part of the study. To estimate the structural and species diversity in each forest plot we considered distance-independent measures as Brillouin index (HB) for height, diameter and species diversity, tree diameter diversity (TDD), tree height diversity (THD), following the method of Marzano R. et al. (2012). These indices are based on the Shannon index, one of the most commonly used in this kind of analysis, founded on the chance that a sample, randomly chosen from a big database will be part of a certain class (Staudhammer C. L. et al., 2001). Furthermore we estimated the Simpson's index of diversity for tree height, diameter and for the number of species present in the plot, in order to verify the results obtained with the first analysis. Simpson index (D) calculates the chance that two individuals randomly chosen from a large population, belongs to the same species or diametric/height class (Lexerød N. L. et al., 2006), so we considered the Simpson's index of diversity (1-D) which evidences the probability that two individuals belong to different classes. The indices chosen recurred on species and dimension (DBH and tree height) classes, ensuring equal importance to horizontal, vertical and species diversity (Staudhammer C. L. et al., 2001). Tree data were grouped in 5-cm DBH classes (from 2.5 to 102.5 cm, only one tree noted in class of 265 cm) and in 2.5-m height classes (from 2.5 m to 45 m). The indices chosen considered both class number and abundance of the single classes within the population together. Even though analyzing the same characteristics is not so important methods of calculation of the structural indices (Neumann M. et al., 2001), while Shannon is more influenced by the range of the classes analysed, Simpson is described as dominance measure (Lexerød N. L. et al., 2006). Simpson is more commonly used in situation with a large variety of classes, on the other hand, Shannon is not affected by the presence of little size class and it is considered more sensitive (Neumann M. et al., 2001).

2.3.1.3 *Correlation*

Highlighted structural and species diversity within the forest plot classes we estimated mean value at stand level for each single parameter described in the previous paragraph ("*Description of the forest structure*"), considering both the actual stand structure (living trees and snags) and only the trees alive. In this way was possible evaluate structure (tree number, tree height, DBH, crown height, ...), damages (crown damage and burned, blackness at the surface, …), species composition and part of their variation produced by fire, comparing actual situation (only the tree alive) and part of that one antecedent the event (all the stem). All the plot mean values evaluated were considered in an analysis to verify the existence of a relationship between these variables at a plot classes level. We choose Spearman correlation due to the non-parametric nature of some data and the little size of the samples to study. We included the Brillouin and Simpson diversity indices within the analysis as well, in order to verify their reliability. A low correlation between each other reveals an illogical value for at least one of them (Lexerød N. L. et al., 2006), on the other hand the presence of strong relationship of both with a third value ensure their association. The correlation coefficient was evaluated in four type of database: one containing the values for all the forested plots (Forest = A_F + An_F + N_F), the other three holding the data detected in one single plot class for each dataset (A_F; An_F; N_F). We decided to highlight that coefficient, which reveal a very strong correlation, with values > 0.9 and < -0.9 (the significant value for the sample with lowest size), moreover we evidenced that strong correlation present in the database of a single plot class and not in that containing all the living trees detected. Additionally we highlighted better the different situation of each case studied pointing out that strong correlation observed in one plot class and not in the others. ≤≥

2.3.1.4 *Comparison*

Described the general characteristics, evidenced the diversity indices and highlighted the more correlated variables in the forested areas, we estimated the significance differences of structure and damages between the different plot classes, continuing and ending the analysis of field records with a comparison. In this case we considered the records collected within the plantations as well. The non-parametric correspondent of a one-way ANOVA test is Kruskal-Wallis test (Dinno A., 2015) and, since its higher flexibility, it fit perfectly with our study. The Kruskal-Wallis test requires the same shape of distribution for the population utilized within the analysis and that the samples are random and independent, but does not make any assumptions about normal distribution and homogeneity of group variance (Ostertagová E. et al., 2014). When the Kruskal-Wallis rejects the null hypothesis, it indicates significant results and, more precisely, it evidences that at least one of the samples analyzed is significantly different from the others (Ostertagová E. et al., 2014). The test detects a difference but is not able to identify where it take place, for this reason a pair-wise comparisons is needed. Dunn's test, as non parametric analog to the t test, revealed to be the proper continuation of the Kruskal–Wallis test (Dinno A., 2015). To reduce the level of α (chance of wrongly reject the null hypothesis), requirement for this multiple comparison test, we decided to adopt the Bonferroni adjustment, which can reduce the p-values to reject any test, dividing α (fixed at 0.001) by the number of comparison realized (Dinno A., 2015). We adopted this analysis only for some of the variables detected from the living trees, selecting different variable and plot classes to compare (Tab. 1). The damages on the tree (% of charred bark at surface and DBH level, flame height and % of crown burned/scorch/green) were compared between that stand affected by fires. On the other hand, tree dimensions (DBH, tree height, crown height and crown ratio) were compared between all affected and not affected classes at the same time and within its vegetation reality (forest and plantation). Moreover we studied the variances of structure and damages of the species relevantly present in all the three forest plots: *Olea europea subsp. cuspidate* Wall. Ex G.Don.

DATABASE ANALYSED	CHARACTERISTICS ANALYSED	PLOT CLASSES ANALYSED				
		A_F	An_F	N_F	A_P	N_P
Complete	Structure	✓	✓	✓	✓	✓
	Damages	✓	✓		✓	
Forest	Structure	✓	✓	✓		
Plantation	Structure				✓	✓
Olea	Structure	✓	✓	✓		
	Damages	✓	✓			

Table. 1 (Structure of comparison analysis. **Database**: all living trees detected in the sampling (Complete); living trees detected in the of natural forest areas (Forest); living trees detected in the plantation areas (Plantation); live *Olea europea subsp. cuspidate* detected (Olea). **Plot classes**: forest frequently affected by fire (A_F); natural forest rarely affected by fire (An_F); natural forest not affected by fire (N_F); plantation affected by fire (A_P); plantation not affected by fire (N_P). **Characteristics**: DBH, tree height, crown height and crown ratio (structure); % of charred bark at surface and DBH level, flame height and % of crown scorch/burned/green (damages). ✓ when the plot class was included in the comparison analysis).

2.3.2 FIRE RECORDS

Fire data recorded on the Forest Stations were scanned, digitalized and analysed, describing the general behaviour of the fire occurred in the area. It was not possible to continue the investigation with a statistical analysis on these data because of their low reliability. Even tough size of samples could have been reasonably suitable for a statistical analysis, the trustworthiness of the data was not enough for a deeper investigation. Moreover the dataset created has some lack in information. Not all the scanned file contained all the data, so we were not able to create a complete database that had the same information and the same detail level for all the fires. The knowledge collected is the best and most detailed concerning the wildfires occurred in the area, nevertheless lack and reliability of some report not guaranteed at all the basis to continue with a statistical analysis. The scanned documents contained different type of information related to the events, which were explored with a not-statistical method. Thanks to this detection, it was possible to describe the common characteristics of fires (size, time and vegetation affected), and of fire fighting activities (time and location of fires detection, time to start the fighting, to extinguish it and equipment used) and related problems (causes, reason for delays and limits) in the Mount Kenya forests. When possible the information concerning location and period of the fire coming from the Forest Stations were compared with those available from MODIS to verify a common trend and assure the veracity of the data scanned for the period 2003 – 2015. To give a better perception of the size of the damages recorded, we compared the losses registered in the Forest Stations with that available within the “Kenya’s Forest Resource Assessment” (Wass P., 2000) estimating the amount of vegetation affected by fire in our study area to that of the whole Kenya. Unfortunately the national data were available only for some years: 1990, 1991, 1992, 1993, 1994, 1997, 1999.

3. RESULTS

3.1 FIELD RECORDS

In this first part of the research we decided to focus our attention on the information recorded in the field, analyzing the data registered in the five different areas: forest where fire occurred frequently (A_F); forest affected by fire but not familiar to it (An_F); forest never affected by fire (N_F); plantation affected by fire (A_P); plantation not affected by fire (N_P).

The regions frequently affected by fire (Fig. 4a) evidenced a lot of snags, but at the same time still a good presence of standing living trees, even though with big evidences of the fire transition. The regeneration was extremely rare and it revealed little size, on the other hand the trees still present had relevant vertical and horizontal dimensions (Fig. 4b).

Fig. 4. Mount Kenya forest, forest frequently affected by fire. Left (4.a) general view; right (4.b) detail.

The stands of forest burned evidenced similar appearance (Fig. 5a), even thought that, where the event occurred rarely, highlighted a more relevant presence of shrubs (Fig. 5b), so that the displacements in these zones were really difficult also by foot.

Fig. 5. Mount Kenya forest, forest areas rarely affected by fire. Left (5.a) general view; right (5.b) detail.

In these sites, the damages were not so easily detectable as in the previous one. Trees were easily noticeable thanks to the big gaps left by the flames but with inferior dimensions rather than the site previously described (Fig. 5b).

The only similarity detected in the forested stands not and rarely affected visited was the presence of death giant size trees. On the other hand, the differences were immediately visible if we compared the plots affected and that not damaged by the fires (Fig. 6a), where the vegetation looked unique and compact. The close aspect was slightly reduced if we observed the forest on a closer point of view, noting the presence of many big trees, that ensure multiple layer structure and undergrowth presence, even though not so dense and relevant as expected from outside (Fig. 6b).

Fig. 6. Mount Kenya forest, areas not affected by fire.
Left (6.a) general view; right (6.b) detail.

The plantations (Fig. 7.a and 7.b) revealed extremely analogous forms, with a dense structure and an overstory completely absent. The only exception and visible differences were the darkness observable on the trunk of the affected individuals and the canopy cover slightly less dense in the burned areas.

Fig. 7. Mount Kenya Forest plantation. Left (7.a) plantation affected by fire; right (7.b) plantation not damaged.

3.1.1 FOREST STRUCTURE

The analysis started focusing the attention on the general structure of the forest and of the plantation (Appendix 1 and Tab. 2). The trees revealed a higher density in the plantation, more precisely in the plantation affected by fire (637 trees/ha), rather than in the forest. The forest not burned showed a more concentrated organization (450 trees/ha) rather than A_F and An_F where were estimated a really similar tree density (330 trees/ha). Observing the characteristics of the forest at hectare level we estimated (Tab. 2) the highest basal area per hectare in natural forest not affected (78.8 m^2/ha) and the lowest, almost 10m^2/ha, in the forest rarely affected. Plantation revealed to have similar tree density values (around 36 m^2/ha) in both the areas considered, which are higher values than that evaluated in frequently affected (25.8 m^2/ha).

Plot classes	Tree species	Trees / ha	BA / ha (m^2/ha)	DBH (cm)	Tree height (m)	First branch height (m)	Crown height (m)	Plot affected by fire
A_F	9	329	25.8	27	10.2	3.4	5.9	✓
An_F	9	330	11.3	19	11.2	4.8	5.4	✓
N_F	8	450	78.7	36	14.6	6.2	8.5	
A_P	1	637	36.2	26	14.4	5.1	12.2	✓
N_P	1	557	37.2	28	15.3	4.6	11.4	

Table 2. Description of the structure of natural forest and plantation and of the trees dimensions (mean values of sizes) at plot class level. **Plot classes**: forest frequently affected by fire (A_F); forest rarely affected by fire (An_F); forest not affected by fire (N_F); plantation affected by fire (A_P); plantation not affected by fire (N_P). ✓ plot class affected by fire.

Observing the species richness (Appendix 2) we recorded similar values for areas of the same nature with respectively 1 species (*Cuperessus lusitanica* Mill.) present in plantation and 8 or 9 trees species within the natural forest (Tab. 3). *Juniperus procera* H., *Nuxia congesta* R. Br., *Olea africana* Mill. and *Afrocarpus falcatus* T. were registered within all the three forest zones but different tree species presence (Tab.11) revealed a different stand composition in the natural forest observed. *Pinus patula* S. & C., *Prunus Africana* H., *Tecoma capensis* S. and *Warburgia ugandensis* S. were detected only in the areas frequently affected by fire. In these areas we noticed an absence of *Olea capensis* L. and *Tarchonanthus camphoratus* L. . *Ekebergia capensis* S. and *Fraxinus pennsylvanica* M. lived only in the areas rarely affected, whereas just *Podocarpus latifolius* T. grown only in the areas not affected. In all the three natural zones we recorded some trees, never more than 4 for each plot class, which we were not able to classify, so the presence of other species is ensured.

TYPE OF TREE	TREE SPECIES	PLOT CLASSES				
		A_F	An_F	N_F	A_P	N_P
BROADLEAVES	Ekebergia capensis		✓			
	Fraxinus pennsylvanica		✓			
	Olea capensis		✓	✓		
	Olea europea	✓	✓	✓		
	Prunus africana	✓				
	Warburgia ugandensis	✓				
CONIFERS	Cupressus lusitanica				✓	✓
	Juniperus procera	✓	✓	✓		
	Pinus patula	✓				
	Afrocarpus falcatus	✓	✓	✓		
	Podocarpus latifolius			✓		
BRUSHES	Nuxia congesta	✓	✓	✓		
	Tarchonanthus camphoratus		✓	✓		
	Tecoma capensis	✓				
NA	NA	✓	✓	✓		

Table 3. Tree species recorded in different plot classes. **Plot classes**: forest frequently affected by fire (A_F); forest rarely affected by fire (An_F); forest not affected by fire (N_F); plantation affected by fire (A_P); plantation not affected by fire (N_P). ✓ presence of species within the plot class.

Within the stands frequently affected by fire, the composition (Fig. 8) is quite balanced between conifers and broadleaves, respectively 34% (mainly juniperus) and 40% (basically Olea europea and Warburgia) of the trees noted. Shrubs' presence reached 20% of the individuals collected in these areas, which mostly referred to *Tecoma capensis*. Fraxinus (48%) and african olive (22%) trees highlighted the dominance of broadleaves (68%) over the conifers (19%) and the shrubs (8%) in plots rarely affected by fire (Fig. 9). We observed a complete different structure in the areas not affected (Fig. 10) where conifers played the main role (60%) thanks to the Podocarpus latifolius (56%). Olea africana and capensis (235 and 7 %) were the only broadleaves detected in this type of stand, where shrubs covered simply the 8% of all trees registered.

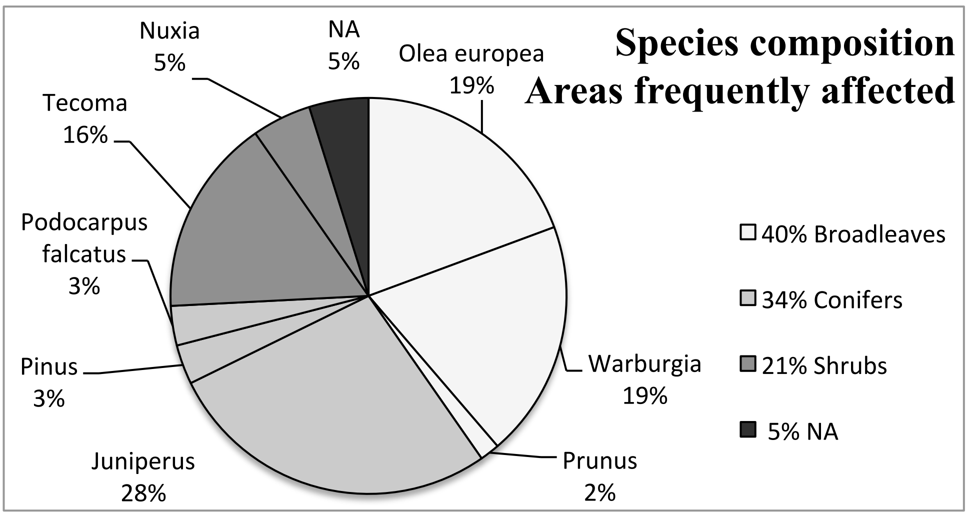


Figure 8. Tree species composition recorded in forest frequently affected by fire.

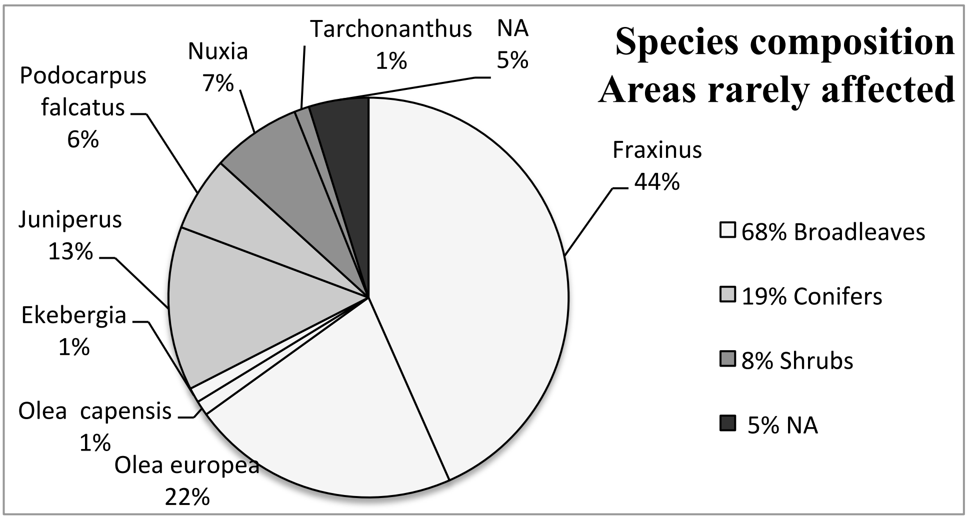


Figure 9. Tree species composition recorded in forest rarely affected by fire.

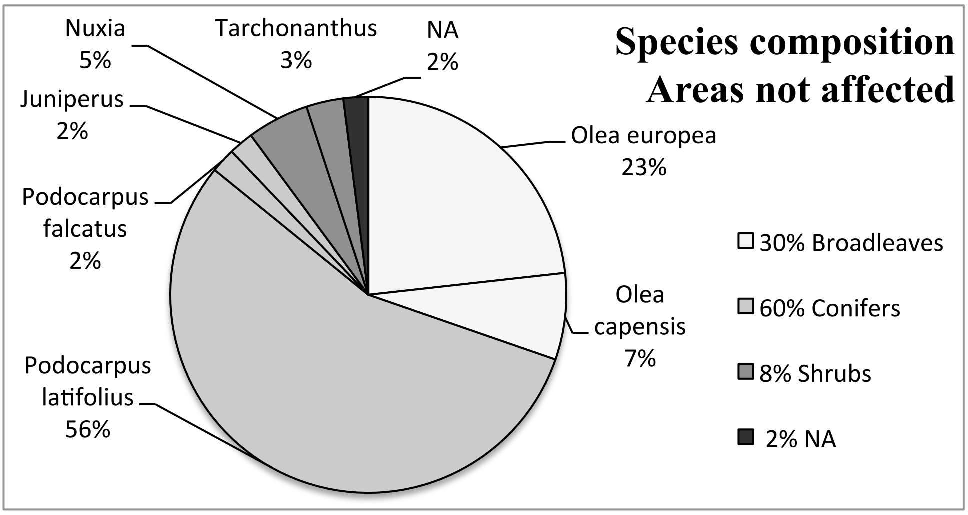


Figure 10. Tree species composition recorded in forest not affected by fire.

Analyzing the data recorded in the field we were able to estimate mean values related to the structure of the trees present in the different areas (Tab. 2). The diameter at breast height evidenced the highest mean value (36 cm) in the natural forest not affected. A_F, A_P and N_P revealed a similar mean DBH with a range of 26-28 cm, whereas the lowest mean DBH (19 cm) was estimated in that areas rarely affected (Tab. 2). Vertical dimensions (Fig. 11) revealed a common behavior in the forested areas between the height of the trees, of the first branch and, excepting for An_F, of the crown. In the tree parameters studied the mean values were low in areas frequently affected, medium in that rarely affected and higher in not damaged areas (only exception for the crown height, with lower mean value in An_F compared to A_F). The records showed means stature of the individuals similar (around 15m) for both the plantation areas and the forest areas not affected. The entities registered within A_P and N_P plots exposed higher crown height (12-13m) rather than that within the other plot classes. On contrary the elevation of the first branch is reasonably low (5m) and similar to the mean values estimated in forest areas rarely affected. The most relevant observations in vertical distribution could be summarized in: a continuous trend in forested plots with lower values in A_F; a similar structure of both the plantation classes; a minor crown ratio (roughly detectable with the distance between crown and total height of the tree) in A_P and N_P where there is a bigger gap between crown and first branch elevation.

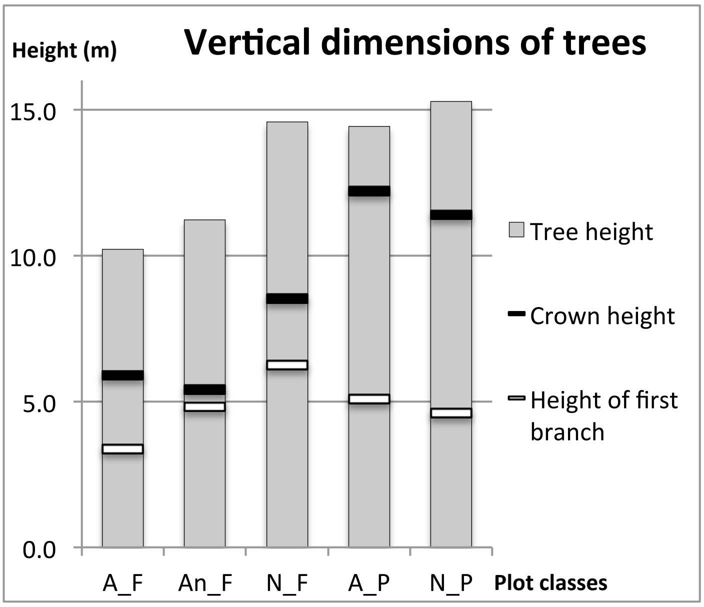


Fig. 11.

Vertical structures of plot classes analysed. Mean values of tree height, crown height and height of first living branch estimated at plot class level. **Plot classes**: forest frequently affected by fire (A_F); forest rarely affected by fire (An_F); forest never affected by fire (N_F); plantation affected by fire (A_P); plantation not affected by fire (N_P).

Regarding the effects of the fire, we focused on the three study areas that experienced the fires. The number of dead trees detected was meanly never higher than the 18.5% of the whole stems detected. The quantity of snags was more relevant in A_F (18.4%) and less in A_P (8%). In An_F the mean percentage of snags is very similar to that of trees not affected (respectively 15.5 and 14.4%). We never observed individuals not damaged in the plantation and their mean percentage in areas frequently burned is less than 4%. (Tab. 4).

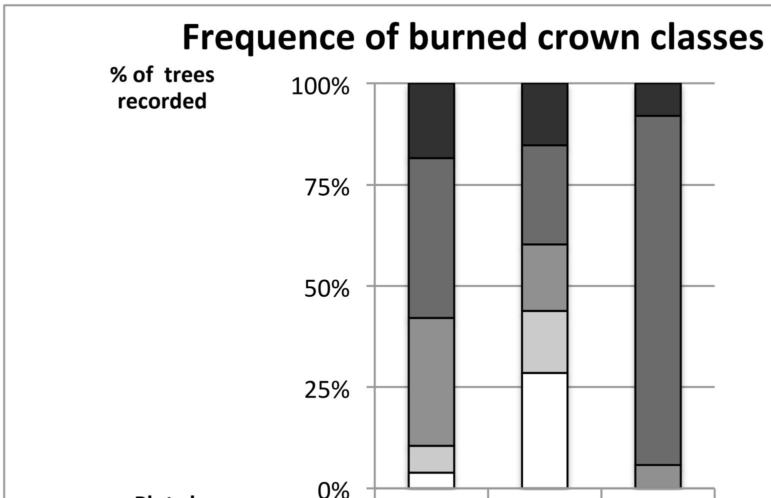
TYPE OF TREE PRESENT	**Plot classes**		
	A_F	**An_F**	**A_P**
Snags	18.4%	15.5%	8.0%
Tree affected	77.6%	70.1%	92.0%
Tree not affected	3.9%	14.4 %	0.0%

Table 4. Percentage of trees death, affected and not affected neither damaged recorded in the different plot classes. **Plot classes**: forest frequently affected by fire (A_F); forest rarely affected by fire (An_F); plantation affected by fire (A_P).

The information related to the percentage of crown burned (Appendix 3 and Fig. 12) evidenced high values in the plantation with the absence of low values at all, the presence (5.7%) of individuals with mediumly burned crown and the dominance (86.2%) of stem with a greatly burned crown. The samples recorded in areas rarely affected demostrated a good balance between classes of burned crown, with a relevant role for the not burned crown (28.6%). Within the same areas, only the 71% of the stems registered missing leafs, with a quite equal subdivision between low (15.3%), medium

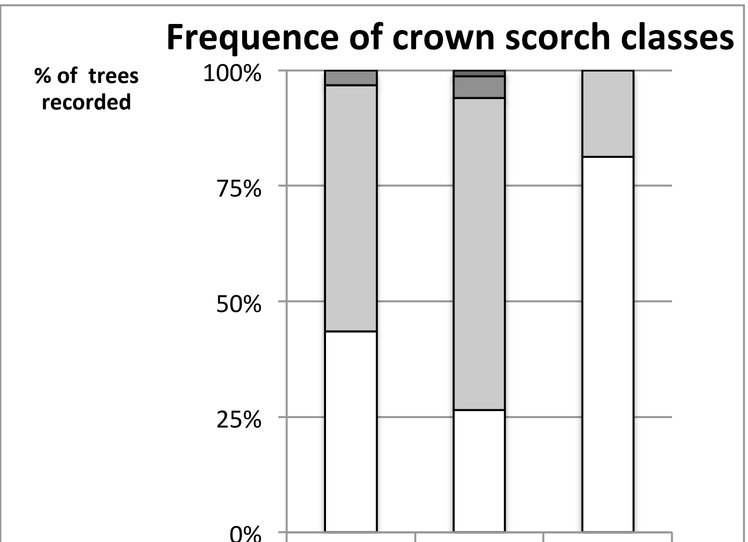
(16.3%), high (24.5%) and total (15.3%) burned crown groups. As observed in the plantation, the percentages of individuals with not/low burned crown is highly reduced in the areas frequently affected by fires (respectively 3.9 and 6.6%). On the other hand, we registered in these plots similar percentages of samples with medium (31.6%) and high (39.5%) burned crown.

After that, we concentrated our attention on that parts of the crown not completely vanished but reddished by the flames (Appendix 3 and Fig. 13). The crown scorch revealed not a relevant presence in the trees detected within the stands. Individuals with medium values of crown scorch were noticed in both the forested areas (3.2% in A_F and 4.8% in An_F) and plants with high levels (1.2%) only in An_F. On contrary in the plantation the majority of individuals (81.3%) revealed not damaged crown, value reduced (43.5%) in the natural forest frequently affected and cut at 26.5% in the natural forest rarely affected. The class crown scorch prevalent in the natural forest was that related to low level of damages, detected in the 53.2% and 67.5% of the trees observed respectively in areas frequently and rarely affected. This level of registered effects was recorded only in the 18.8% of the trees present in the plantation that experienced the fire.



Plot classes	A_F	An_F	A_P
Completely burned	18.4%	15.3%	8.0%
High burned	39.5%	24.5%	86.2%
Medium burned	31.6%	16.3%	5.7%
Low burned	6.6%	15.3%	0.0%
Not burned	3.9%	28.6%	0.0%

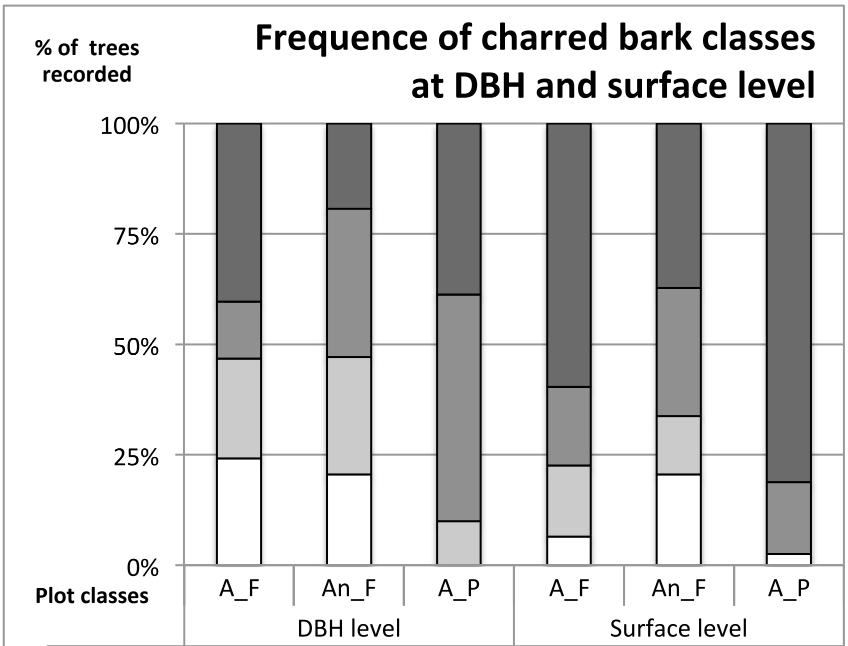
Fig. 12. Percentage of trees for burned crown classes in the different affected plot classes. **Plot classes**: forest frequently affected by fire (A_F); forest rarely affected by fire (An_F); plantation affected by fire (A_P).



Plot classes	A_F	An_F	A_P
High damaged	0.0%	1.2%	0.0%
Medium damaged	3.2%	4.8%	0.0%
Low damaged	53.2%	67.5%	18.8%
Not damaged	43.5%	26.5%	81.3%

Fig. 13. Percentage of trees fore crown scorch classes in the different affected plot classes. **Plot classes**: forest frequently affected by fire (A_F); forest rarely affected by fire (An_F); plantation affected by fire (A_P).

Regarding the effects of the fire detectable on the trunk (Appendix 4 and Fig. 14), we detected an high presence of them in the plantation plots. Here the trees revealed to have mainly high level of charred bark (81.3%) and medium level of charred bark at DBH level (51.3%). A_P demostrated to have not individuals with few detectable damages and rarely samples with not-effects of fires (2.5%) at surface level. The observation showed an opposite behaviour at DBH level with some trees with low level of blacnkess (10%) and no trees without damages. The areas rarely affected by fire revealed an homogeneous behaviour at DBH level recording similar percentages of trees with high, medium, low and no level charred bark, respectively 19.3%, 33.7%, 26.5% and 20.5%. The same trend was detected at surface level, where the presences of indivisuals with high and medium charred bark level (37.3% and 28.9%) were slightly higher than that with low and not damages at all (13.3% and 20.5%). The similarities between the two zones of the stem was present but not so evident in the plots frequently affected by fire. In these places, the trees with high charred bark level at DBH (40.3%) were estimated to be almost twice the individuals with low and not damages (respectively 22.6% and 24.2%) and definitely more than that with medium level of carred bark (12.9%). Also the analysis related to the surface level evaluated that the majority of the trees detected in this area had high level of charred bark (59.7%). At the same time, the percentages were undeniably reduced for the samples with medium or low charred bark (respectively 17.7% and 16.1%), whereas only the 6.5% of the trees registered no damages at the ground.



	DBH level A_F	DBH level An_F	DBH level A_P	Surface level A_F	Surface level An_F	Surface level A_P
High	40.3%	19.3%	38.8%	59.7%	37.3%	81.3%
Medium	12.9%	33.7%	51.3%	17.7%	28.9%	16.3%
Low	22.6%	26.5%	10.0%	16.1%	13.3%	0.0%
No	24.2%	20.5%	0.0%	6.5%	20.5%	2.5%

Fig. 14. Percentage of trees with charred bark at surface and DBH level. **Plot classes**: forest frequently affected by fire (A_F); forest rarely affected by fire (An_F); plantation affected by fire (A_P).

The elevation of detectable burned areas on the trunk was the last aspect studied related with fire effects on the vegetation. Evaluating the mean values of flame height in the three damaged plot classes (Fig. 15) we observed similar mean values (5.4 m) in both the forested areas but higher average in the plantation (7.7 m).

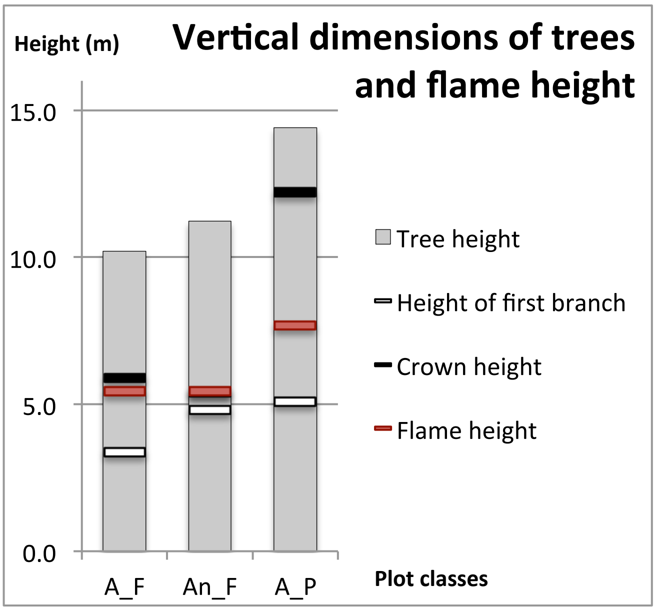


Fig. 15. Vertical structure and flame height in plot classes affected by fires. Mean values of tree height, crown height, height of first living branch and flame height valued at plot class level. **Plot classes**: forest frequently affected by fire (A_F); forest rarely affected by fire (An_F); plantation affected by fire (A_P).

3.1.2 DIVERSITY INDICES

We estimated the diversity indices (THD, TDD, Brillouin and Simpson) in different plot classes in order to evaluate the variability of dimensions of the samples (DBH and tree height) and species richness both between and within the areas (Appendix 5 and Tab. 5). All the indices evaluated higher values when diversity detected within a group was bigger and more relevant. The parameters that evaluated the variability revealed similar behaviours despite the use of different methods. We did not observe discordant results between two or more indices that analysed the same variables. The values recorded in the plantations showed a lower flexibility rather than that detected in the natural forest. The plantations evidenced a vertical structure more homogeneous and more heterogeneous DBH values where fire had affected the vegetation. Within the natural forest we noted higher indices for both height and species diversity in that plots frequently affected by the fire. The areas that had never experienced the fires exposed a higher heterogeneity of the dimensions of diameter at breast height. The natural forest rarely affected demonstrated to be more homogeneous in structural dimensions (DBH and tree height) but intermediate behaviour was observed in species occurrence.

Plot classes	DIVERSITY INDICES							
	DBH			HEIGHT			SPECIES	
	TDD	Brillouin	Simpson	THD	Brillouin	Simpson	Brillouin	Simpson
A_F	2.14	1.88	0.85	**2.00**	**1.80**	**0.87**	**1.67**	**0.83**
An_F	1.84	1.68	0.81	1.71	1.58	0.80	1.48	0.74
N_F	**2.53**	**2.28**	**0.91**	1.92	1.74	0.81	1.23	0.63
A_P	1.68	1.53	0.78	0.97	0.91	0.57	-	-
N_P	1.69	1.44	0.80	0.94	0.82	0.55	-	-

Table 5. Diversity of DBH, tree height and species composition within the plot classes. **Diversity indices**: tree diameter diversity (TDD); tree height diversity (THD); Brillouin diversity index (Brillouin); Simpson's index of diversity (Simpson). **Plot classes**: forest frequently affected by fire (A_F); forest rarely affected by fire (An_F); forest not affected by fire (N_F); plantation affected by fire (A_P); plantation not affected by fire (N_P).

3.1.3. CORRELATION

To ensure a better explanation of the correlation detected in our study we split the results in three groups, one for each plot classes analysed (A_F, An_F and N_F).

In areas frequently affected by fire (Tab. 6), Spearman coefficient evidenced a strong positive correlation between the presences of *Olea europea* and both the basal area of the plot and the absence of blackness at DBH level. On the other hand was detected a clear connection between the absence of damages at surface level and the number of *Olea africana* trees death. The height of the first living branch revealed to be higher when more medium damages at DBH level were detected and when the Brillouin index for species diversity were observed. The variation of the crown ratio followed the values of the basal area lost, increasing and decreasing at the same time. The research observed an absence of the damages on the crown in positive relation with the presence of *Nuxia congesta*. The crown highly burned revealed to have a strong negative correlation with both (Brillouin and Simpson) species diversity indices. On the other hand the charred bark level at DBH level showed to be strictly connected with the diversity indices of both DBH and height. Where the charred bark level at DBH level was low or medium the indices evidenced a high diversity, where it was high the diversity indices were low. A higher charred bark level at surface level evidenced a negative connection with low charred bark level at DBH as well. Medium level of charred bark at the ground were positive correlated with the Simpson height diversity index, but it had an opposite relation with the presence of *Olea europea*. Charred bark at DBH level showed a strong relationship with that at surface level, with low and high level positive correlated respectively in the two zones. Height Brilllouin diversity index revealed to have a negative relation with the high charred bark level at surface level, on the other hand Simpson diversity index of the species evidenced a positive connection with the presence of juniperus. Flame height highlighted a positive connection with the presence of broadleaves, same relationship evidenced between conifer and *Juniperus procera* species. In the areas frequently affected, Spearman correlation estimated strong negative values between the occurrence of death conifer and juniperus trees and the number of tree live. On the contrary the presence of conifers and juniperus trees completely burned revealed a positive relation with the total number of tree death, the basal area lost, the variation of crown ratio and the crown totally burned.

Parameters HIGHLY CORRELATED in A_F	POS. / NEG. CORR.	DATABASE WHERE CORRELATION WAS OBSERVED: Forest (A_F+An_F+N_F)	DATABASE WHERE CORRELATION WAS OBSERVED: An_F
Basal area and Olea africana presence	+	✓	
No blackness at DBH level and Olea africana	+		
No blackness at surface level and Olea africana death presence	+	✓	
First branch height and medium blackness at the DBH and surface level	+		
First branch height and Brillouin species diversity	+		✓
Crown ratio variation and basal area lost	+		
Crown not damaged and Nuxia presence	+		
Crown highly burned and species diversity indices (Brillouin and Simpson)	-		
Low/medium blackness at DBH level and height diversity indices (Brillouin and Simpson)	+		
High blackness at DBH level and height diversity indices (Brillouin and Simpson)	-		✓
Low blackness at DBH level and high blackness at surface level	-		
Medium blackness at surface level and Simpson height diversity index	+		
Medium and high blackness at surface level and Olea africana presence	-		✓
No blackness at DBH level and low blackness at surface level	+	✓	
High blackness at DBH level and high blackness at surface level	+	✓	
High blackness at surface level and Brillouin height diversity index	-		
Simpson species diversity index and Juniperus	+		
Flame height and broadleaves presence	+	✓	
Conifer presence and Juniperus presence	+	✓	
Conifer / Juniperus death presence and tree death – basal area lost – crown ratio variation – crown	+	✓	
Conifer / Juniperus death presence and tree live	-	✓	

Table 6. Strong correlations detected with Spearman coefficient in areas frequently affected by fire. **Correlation:** positive if coefficient > 0.9; negative if coefficient < -0,9. **Database**: all living trees detected in the forest plots, A_F+An_F+N_F (Forest); living trees detected in the forest rarely affected by fire (An_F).

In the plots rarely affected by fire (Tab. 7), the analysis evidenced that basal area was positively correlated with high level of charred bark at surface, but negatively with the Simpson diversity index of tree height. Crown height variation showed to be highly positively connected with basal area lost and negatively with flame height. The study revealed a positive relationship between the number of tree live and the Brillouin diversity indices for both height and DBH variables. The presence of *Fraxinus pennsylvaniica* was highly connected with the absence of damages at the crown and at the DBH level, which were in turn actively related. High level of charred bark at DBH level revealed to be negatively related to Simpson diversity indices for height and DBH, on the other hand the correlation between low charred bark level at the surface and Simpson diversity index for height revealed to be positive. Death trees of broadleaves and *Olea europea* were positively related each other and both with values of crown totally burned, basal area lost and number of tree death but negatively with the number of tree live and the crown height variation. Spearman correlation evidenced a strong positive correlation between the presence of *Olea capensis* L. and *Afrocarpus falcatus* T. and between the presence of *Nuxia congesta* R. Br. and brushes.

Parameters HIGHLY CORRELATED in An_F	**POS. / NEG. CORR.**	**DATABASE WHERE CORRELATION WAS OBSERVED**	
		Forest (A_F+An_F+N_F)	**A_F**
Basal area and high blackness at surface level	-		
Basal area and Simpson diversity index for height	+		
Basal area lost and crown height variation	-	✓	
Flame height and crown height variation	+		
Tree live and Brillioun diversity indices (height and	+		
Crown not damaged and Fraxinus presence	+		
No blackness at DBH level and Fraxinus presence	+		
No blackness at DBH level and crown not damaged	+		
High blackness at DBH level and Simpson diversity indices (height and DBH)	-		✓
Low blackness at surface level and Simpson height diversity index	+		
Broadleaves / Olea africana death presence and tree death – basal area lost – crown totally burned	+	✓	
Broadleaves / Olea africana death presence and tree live – crown height variation	-	✓	
Olea capensis presence and Podocarpus f. presence	+		✓
Broadleaves death and Olea africana death presence	+	✓	
Nuxia presence and bushes presence	+	✓	

Table 7. Strong correlations detected with Spearman coefficient in areas rarely affected by fire. **Correlation:** positive (+) if coefficient > 0.9; negative (-) if coefficient < -0,9. **Database**: all living trees detected in the forest plots, A_F+An_F+N_F (Forest); living trees detected in the forest frequently affected by fire (A_F).

Spearman coefficient highlighted in the areas not affected by fire (Tab. 8) a positive relation between basal area and crown ratio values. Crown height revealed to be negative correlated with the presence of *Olea africana*, same trend detected between conifer species occurrence and Simpson species diversity index. Furthermore *Podocarpus latifolius* T. presence revealed to be negatively related to both the species diversity indices (Brillouin and Simpson). The tree species evidenced a strong positive connection with the presence of conifers in the plots. At the same time, *Nuxia congesta* and *Tarchonactis camphoratus* trees revealed a positive relationship each other and both with brushes presence as well.

Parameters HIGHLY CORRELATED in N_F	POS. / NEG. CORR.	DATABASE WHERE CORRELATION WAS OBSERVED	
		A_F	An_F
Basal area and crown ratio	+		
Crown height and Olea africana presence	-		
Conifer presence and Simpson species diversity index	-		
Podocarpus l. presence and species diversity indices (Brillouin and Simpson)	-	✓	
Conifer presence and Podocarpus l. presence	+		✓
Tarchonanthus presence and Nuxia presence	+		✓
Brushes presence and Nuxia presence	+		✓
Brushes presence and Tarchonathus presence	+		✓

Table 8. Strong correlations detected with Spearman coefficient in areas not affected by fire. **Correlation:** positive (+) if coefficient > 0.9; negative (-) if coefficient < -0,9. **Database**: living trees detected in the forest frequently affected by fire (A_F); living trees detected in the forest rarely affected by fire (An_F).

3.1.4. COMPARISON

Comparing the plot classes all together was observed a general difference between forest and plantation structure and some variances between the plot classes as well (Appendix 6; Fig. 16). Regarding the DBH, A_F and N_F had higher median values. On the other hand, trees recorded in forest rarely affected (An_F) registered dimensions significantly lower than that registered in areas not affected by fire (N_F and N_P). The difference of the tree height was significant between both A_F and An_F and all the other areas (N_F, A_P and N_P). Plantation areas (A_P and N_P) evidenced the highest values for both the vertical dimension analysed, tree height and crown height. Concerning the crown height, the difference between the plot classes of the two realities (forest and plantation) revealed to be not significant within the same vegetation type and between N_P and both A_F and N_F. Crown ratio registered generally higher values in the forest rather than in the plantation. We observed a crown ratio significantly lower in A_P, compared with those of all the natural forest areas (A_F, An_F, N_F). Forest rarely affected (An_F) highlighted the highest value of crown ratio and a significant difference with the plantation not affected (N_P) as well.

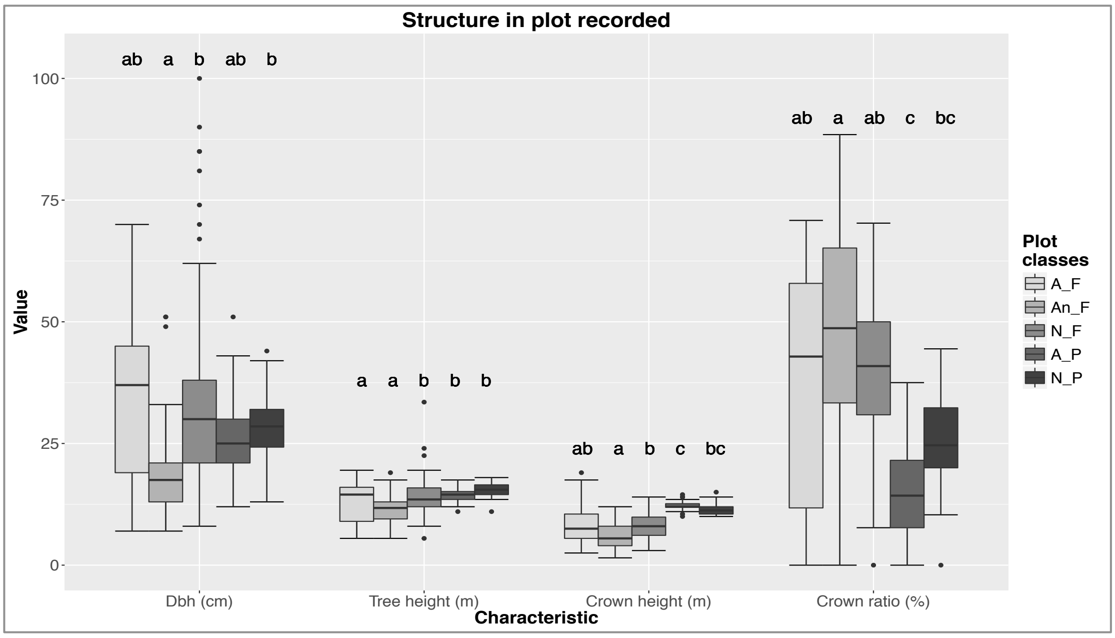


Fig. 16. Structure of all the plot classes. **Correlation:** boxplots with the same letter (a, b or c) revealed not significant difference from Dunn test. **Plot classes**: natural forest frequently affected by fire (A_F); natural forest rarely affected by fire (An_F); natural forest not affected by fire (N_F); plantation affected by fire (A_P); plantation not affected by fire (N_P).

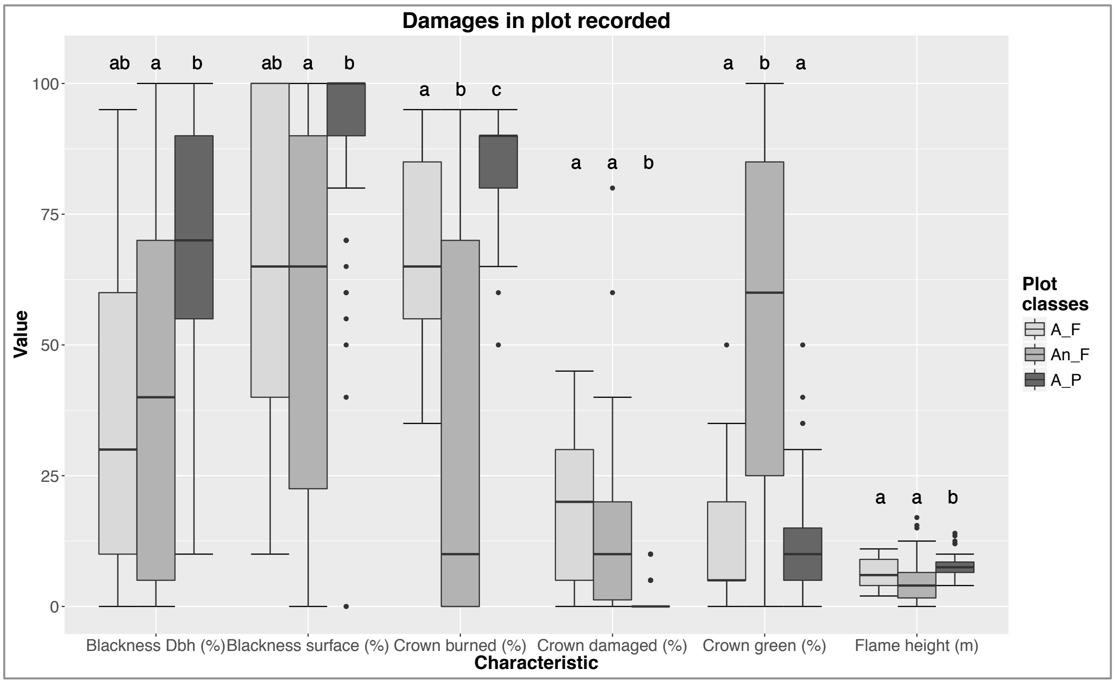


Fig. 17. Damages in all the plot classes affected by fire. **Correlation:** boxplots with the same letter (a, b or c) revealed not significant difference from Dunn test. **Plot classes**: natural forest frequently affected by fire (A_F); natural forest rarely affected by fire (An_F); plantation affected by fire (A_P).

The analysis of the damages on the trees recorded highlighted a big difference between plantation and forest areas (Appendix 6; Fig. 17). Crown scorch was not detected in plantation, on the other hand the area registered the highest values of damages for crown burned, flame height and charred bark at surface and DBH level. Forest rarely affected and plantation affected registered significant differences in all the characteristics evaluated, while a statistical diversity between forest frequently affected and plantation affected was observed only in crown burned, crown damaged and flame height values. Within the forest reality the two plot classes revealed similar values regarding the charred bark. The height of flames recorded values different in the two plots, but a significant difference was detected only in the crown burned, higher in forest frequently affected, and in the crown not damaged, higher in the areas rarely affected.

Observing only on the plots detected in natural forest (Appendix 6; Fig. 18), we were able to notice similar values for the trees detected in areas frequently burned and in that not affected. Plots rarely affected revealed the lowest values for DBH, tree height and crown height, but the highest crown ratio. Significant differences were identified between N_F and An_F in DBH, tree height and crown height variables. Significant difference between the two affected classes was noticed only for the DBH values.

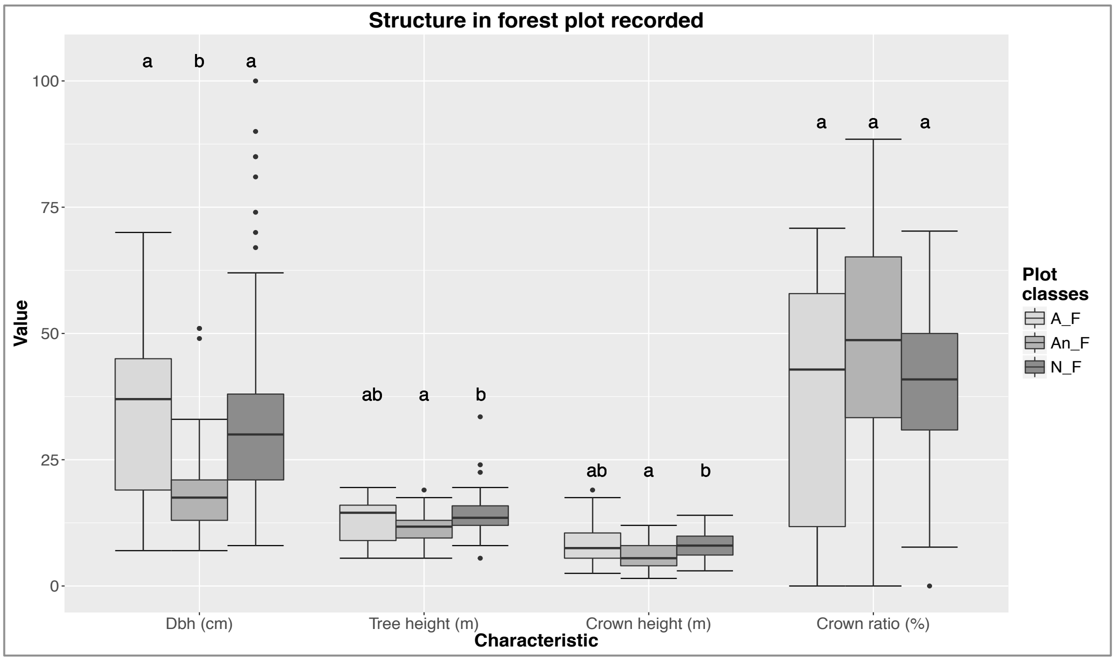


Fig. 18. Structure of natural forest plot classes. **Correlation:** boxplots with the same letter (a or b) revealed not significant difference from Dunn test. **Plot classes**: natural forest frequently affected by fire (A_F); natural forest rarely affected by fire (An_F); natural forest not affected by fire (N_F).

Considering only plantations (Appendix 6; Fig. 19), we observed higher DBH, tree height and crown ratio, but lower crown height in the areas not affected rather than in that affected. The differences are statistically significant for all the variables excepting for the DBH.

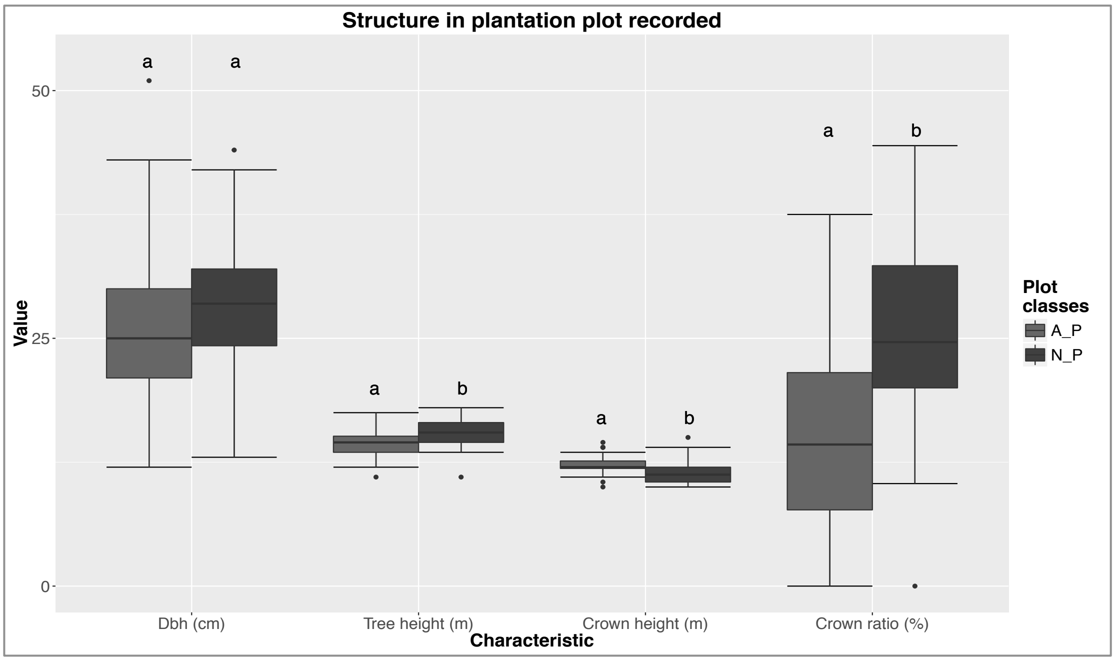


Fig. 19. Structure of plantations plot classes **Correlation:** boxplots with the same letter (a or b) revealed not significant difference from Dunn test. **Plot classes**: plantation affected by fire (A_P); plantation not affected by fire (N_P).

Considering only *Olea africana*, we observed a trend very different from that detected in the previous analysis of structure and damages (Appendix 6; Fig. 20 and 21). The species revealed the lowest DBH and tree height in the forest frequently affected. The areas rarely affected reported the lowest level of crown height but the highest values of crown ratio. Forest not affected highlighted the highest level of tree dimensions (DBH, tree height and height crown), but the lowest values of crown ration. Significant differences were revealed in the tree height and DBH values between A_F and N_F, whereas forest not affected evidenced a crown height singular and significantly different form the other areas.

Even though the trees present in areas frequently affected registered higher percentages of crown burned, the damages detected on this species showed generally higher values in the forest rarely affected. The differences between the two plot classes were present but not so relevant, in fact the comparison revealed significant values only for the charred bark at DBH level (Fig. 21).

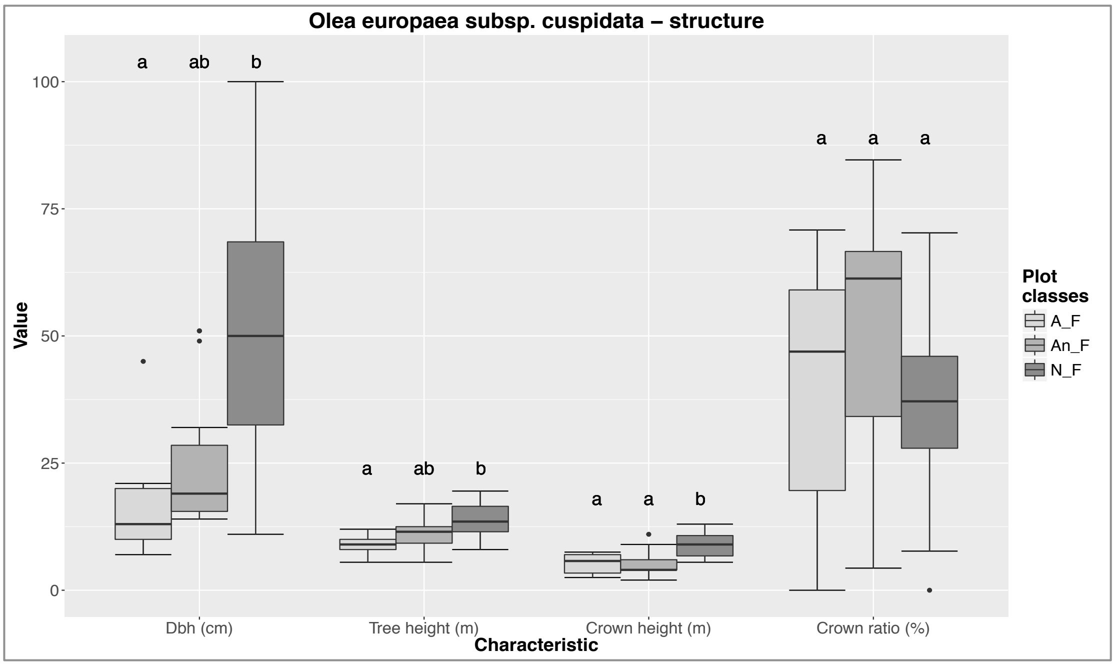


Fig. 20. Structure of *Olea europea* species in forest plot classes. **Correlation:** boxplots with the same letter (a or b) revealed not significant difference from Dunn test. **Plot classes**: natural forest frequently affected by fire (A_F); natural forest rarely affected by fire (An_F); natural forest not affected by fire (N_F).

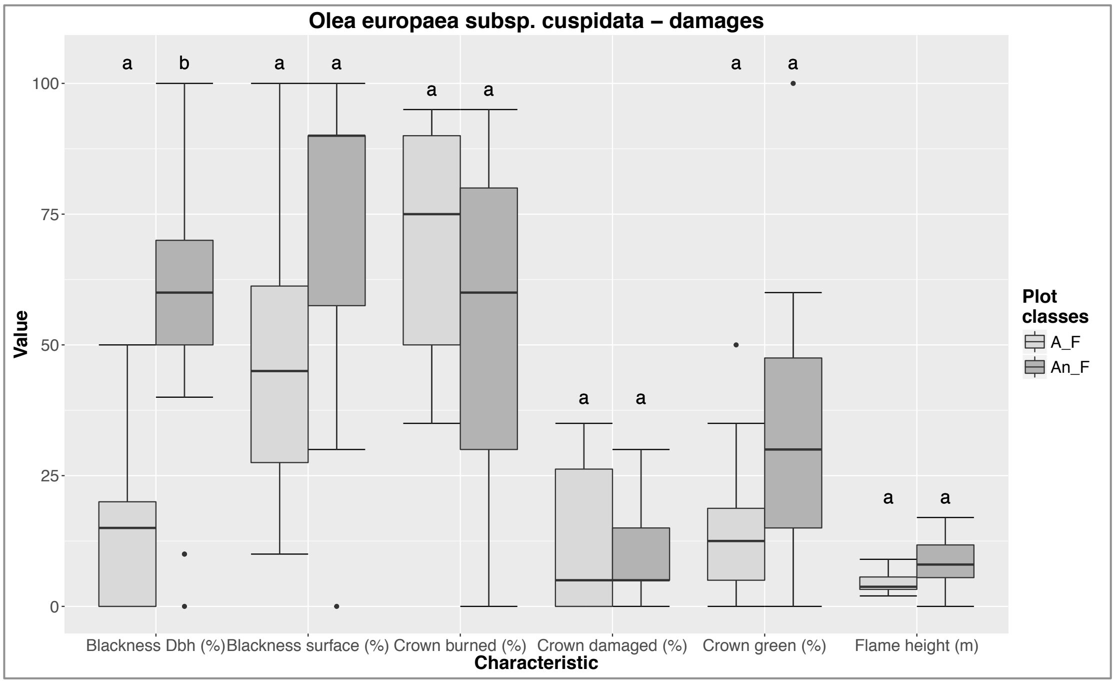


Fig. 21. Damages of *Olea europea* species in forest affected plot classes. **Correlation:** boxplots with the same letter (a or b) revealed not significant difference from Dunn test. **Plot classes**: natural forest frequently affected by fire (A_F); natural forest rarely affected by fire (An_F); natural forest not affected by fire (N_F).

3.2 FIRE RECORDS

Once analysed the structure of the forest in different stands and evaluated the damages caused by fires on the vegetation, we turned on a more general point of view. The attention moved on that files scanned in the Forest Stations commonly affected by fire: Gathiuru, Marania, Nanyuki, and Ontulili (KWS, 2010). The records contained information related to the fires occurred within the territory of the station and the events that occupied the crew of the station in the Mount Kenya area. For this reason we were able to have some data about Narumoru, Hombe, Lower Imenti and Ragati as well (Fig. 2). In these areas not directly explored, the fires revealed to have been relatively rare and to not have big dimensions.

3.2.1 OCCURRENCE WITHIN THE TERRITORY

We were able to collect information about 153 fires, occurred from 1980 to 2015, which revealed an average of more than 4 events each year. In this period of time 27271.30 ha of forest areas burned, with an estimated mean size of 178.24 ha for each single event. The most of these fires took place in Ontulili (44%) and Gathiuru (35%) Forest Stations, only few of them affected Marania (10%) and Nanyuki (6%) areas, whereas only the 5% of the whole records were related to that territory not directly recorded (Narumoru, Hombe, Ragati and Lower Imenti). In 35 years, the main part of the burned forest, more than 18000 ha, belonged to Ontulili (Tab. 9). Gathiuru and Marania had a relevant and almost equivalent role in terms of burned areas l (respectively 4500 and 3700 ha), whereas the sum of the areas burned in the other stations did not reached the 2% of the total amount of burned forest.

FOREST STATION	NUMBER OF FIRES	SIZE of AREA BURNED		
		Mean (ha)	Total (ha)	Percentage
Gathiuru	53	85.08	4509.10	16.53%
Hombe	1	2.00	2.00	0.01%
Lower Imenti	1	8.00	8.00	0.03%
Marania	9	418.06	3762.50	13.80%
Nanyuki	16	24.72	395.45	1.45%
Narumoru	5	8.60	43.00	0.16%
Ontulili	67	276.82	18547.25	68.01%
Ragati	1	4.00	4.00	0.01%
TOTAL	153	178.24	27271.3	

Table 9. Occurrence and extension of fires in Mount Kenya forest from 1980 to 2015 in different Forest Stations.

Despite the lower quantity of fires registered in Marania rather than in other stations visited, it revealed the biggest mean size (418 ha), that, together with Ontulili (277 ha), were the only territories with average values bigger than the total mean size. Gathiuru and Nanyuki revealed a mean size (respectively 85 ha and 25 ha) lower than the previous two, whereas the other records never overtook the dimension of 15 ha (Tab. 9).

The average size of the fires analysed within the research was estimated to be 178.24 ha. Nevertheless more than three fourth of the events recorded revealed dimensions lower than it. Half of the extensions observed were equal or lower than 25 ha, almost 75% of them were equal or smaller than 100 ha and only the 10% had size bigger than 500 ha (Tab. 10).

PERCENTAGE FIRE SIZE CLASS (ha)	
≤ 5	29%
5.1 - 25	24%
25.1 - 100	21%
100.1 - 500	16%
> 500	10%

Table 10. Percentage of fire size class in Mount Kenya forest from 1980 to 2015.

The dimensions of the burned areas varied in different ways within each single Forest Station (Fig. 22). Ontulili registered a homogeneous distribution of the size class with a role slightly minor for the fires that affected more than 5 but less than 25 hectares. Marania revealed a high percentage of big size events (more than 50% of the fire spread for more than 100 ha), on the other side Nanyuki and Gathiuru revealed smaller sizes with the absence or a small ratio (20% in Gathiuru) of fires bigger than 100 ha.

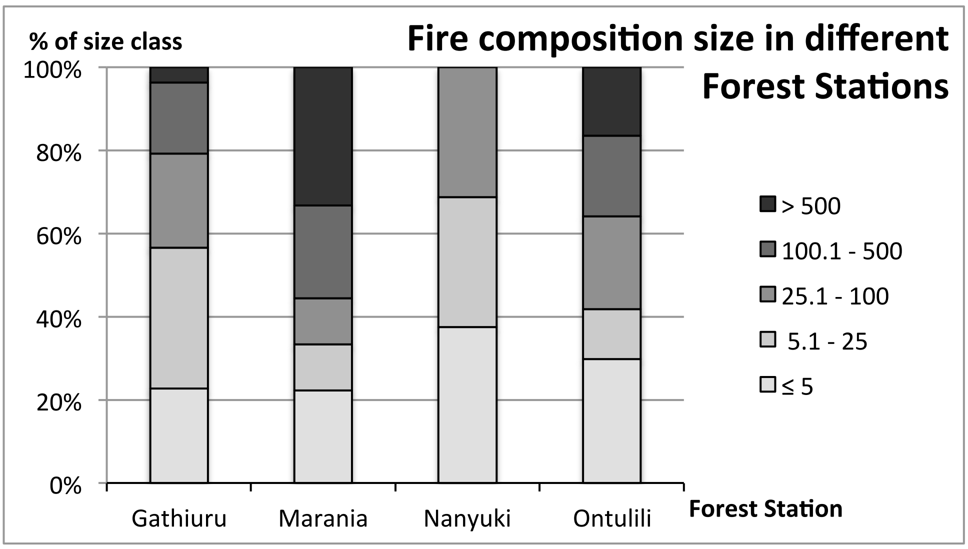


Fig. 22. Composition of size class in each visited Forest Station of Mount Kenya forest from 1980 to 2015.

3.2.2 OCCURRRENCE WITHIN THE TIME

Regarding the occurrence of the fire during the years we observed a constant increase of this event during the decades (Tab. 11). Even though it showed a bigger mean size in the last stage considered (2010 - 2015), it seemed getting lower till the previous period (2000 – 2009). The total amount of area burned revealed to have been stable since 1999, after that it decreased in the first ten years of the 21th century and finally increased again during the last period detected (2010 - 2015).

PERIOD (decade)	NUMBER OF FIRES	SIZE of AREA BURNED		
		Mean (ha)	Total (ha)	Percentage
1980 – 1989	37	236.51	8751.00	32.09%
1990 – 1999	41	209.18	8616.35	31.59%
2000 – 2009	53	96.98	5141.20	18.85%
2010 – 2015	22	216.49	4762.75	17.46%

Table 11. Occurrence and extension of fires in Mount Kenya forest from 1980 to 2015 in different decades. Consider that the last decade (2010 - 2015) has half-size of the other periods.

Observing the number of fires recorded during the years within the Forest Stations (Fig. 23), we noticed a major role of Ontulili at the beginning of the period analysed. It was slightly reduced, leaving to Gathiuru the leadership since 2000. Nanyuki revealed a not relevant role but a constant presence during the time, whereas Marania recorded fires only after 1990.

A similar trend was observed analysing the amount of the burned area in different decades and in varies Forest Stations (Appendix 7 and Fig. 24). We noted the high role of Ontulili in the first two decades analysed, whereas Gathiuru revealed a relevant role from 2000 to 2009. Nanyuki never evidenced a significant position in this kind of observation but Marania revealed to be the place where a big percentage of the total amount of areas burned in the last period (2010 - 2015).

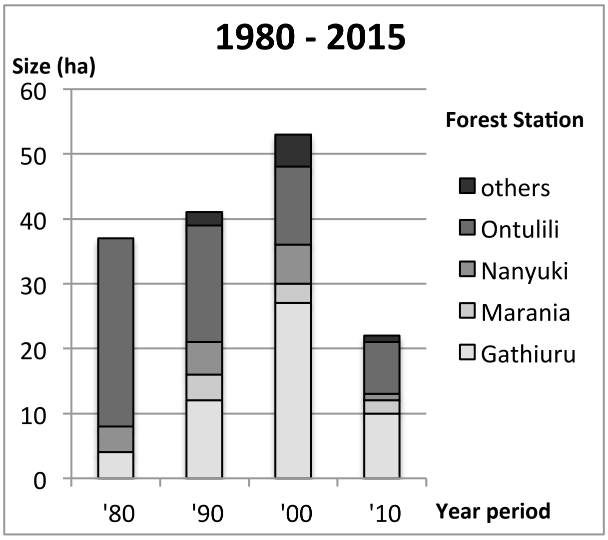


Fig. 23. Occurrence of fires in different Forest Station from 1980 to 2015 in various decades. Forest Stations with less than 10 fires where merged within the group "others".

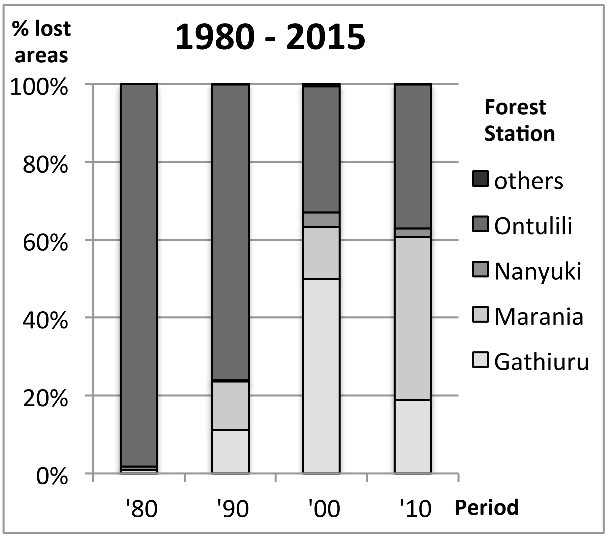


Fig. 24. Composition of burned areas in Mount Kenya forest. Distribution of the burned areas in each Station visited on the total amount of area burned for each decade. Forest Stations with less than 10 fires where merged within the group "others".

During the year the burning events were more concentrated within the first three months with a mean occurrence more than three times higher rather than the rest of the year. The records revealed a mean of more than 3 events for year from January to March and a mean occurrence of less than one for year from April to December. Also the size of the burned area is higher from January to March, reaching more than the 90% of the total amount territory lost (Tab. 12). We identified February as the month most prone to fire (in terms of both occurrence and extension of fires), followed by March and January. In the rest of the year August was the month most affected with an occurrence (13 fires in 35 years) slightly lower than January. On the other hand July, with only 5 events recorded, showed a total burned area higher than the following two months and a mean dimension higher than January as well. May, June, October and December recorded few events, all of them with a little size (max. 5 ha), while fires never occurred in November.

MONTH	NUMBER OF FIRES	SIZE of AREA BURNED (ha)		
		Mean (ha)	Total (ha)	Percentage
January	17	228.47	3884.05	14.24%
February	65	178.68	11614.15	42.60%
March	37	248.63	9199.40	33.74%
April	3	53.00	159.00	0.58%
May	1	2.00	2.00	0.01%
June	1	5.00	5.00	0.02%
July	5	228.60	1143.00	4.19%
August	7	16.36	114.50	0.42%
September	13	87.50	1137.50	4.17%
October	1	5.00	5.00	0.02%
November	0	-	-	0.00%
December	2	1.35	2.70	0.01%
Jan – March	119	207.54	24697.60	90.58%
Apr – Dec	33	77.84	2568.70	9.42%

Table 12. Occurrence and extension of fires in Mount Kenya forest from 1980 to 2015 in different months.

Observing the behaviour of the fire within the year in each Forest Station (Appendix 8) we noted a high fire activity in July only in Marania, with events that affected often big areas. Ontulili revealed an intense fire season that started in January and ended in March, with some less relevant events in December and April as well. Also in Gathiuru the fires occurred more frequently and intensively from January to March, but in September too. This area registered fires in all the months excepting April, November and December, even though they had dimensions generally lower than in Marania and Ontulili. Nanyuki registered an activity in January, February, March, August and September, but its fires never burned areas bigger than 100 ha.

3.2.3 DURATION

Almost all the file scanned had information related to the duration of the fire, only one of them lacked on this knowledge. The analysis evidenced a length that varied from 0 to 67 days. The majority of the events (59%) took less than 48 hours to be mopped up, one third of them a period between 3 and 10 days and only the 7% of the events revealed duration higher than 10 days. The dimensions of burned areas were homogenously little (except for few outliers) till the 6-day class, after that the size revealed an even exponential behaviour till the 10th day class. Finally, the connection between time and space extensions of the fire was not more clear with durations longer than 10 days.

MONTH	DURATION OF THE FIRES (days)																		
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**10**	**11**	**12**	**13**	**14**	**15**	**17**	**29**	**66**	**67**
January		3	2	2	3		1	1		2	1							1	1
February	13	20	11	5	1	3	1	3	2	1			1	1	1	1	1		
March	7	5	5	5	3	3			5	1		1	1		1				
April	2			1															
May		1																	
June		1																	
July		2	1					1		1									
August		4	1	1			1												
September	1	5	4		2				1										
October			1																
November																			
December		1		1															
TOTAL	**23**	**42**	**25**	**15**	**9**	**6**	**3**	**5**	**8**	**5**	**1**	**1**	**2**	**1**	**2**	**1**	**1**	**1**	**1**
	58.82 %			**33.33%**							**7.19%**								

Table 13. Number of fires with the same duration (in days) from 1980 to 2015 in different months. Only 1 fire of the total amount of records had not this kind of information.

We did not detected particularity on the duration variable at Station or years level with similar trend in each site and at each period. On the other hand the duration of the events and the month of occurrence highlighted an interesting relationship (Tab. 13), a higher duration of the fires narrower to January-March period. The reports that noted duration between 0 and 2 days evidenced a majority of happenings between January and March, but a lot of records (27%) in the rest of the year as well. The fires, which needed form 3 to 10 days to be mopped up, evidenced some occurrences from April to December, but a lower amount of it (18%). The fires took high amount of time to be mopped up (more than 10 days) only if occurred from January to March.

Compared with the size classes the duration revealed homogeneous behaviour in the first three of them (from 0 to 100 ha) with low values and some high outliers. Fires that affected areas between 100 and 500 hectares, needed more time to be mopped up, even though the most time spent to extinguish the fires was generally recorded in events bigger than 500 ha.

The fires that affected moorland were those that needed more time to be mopped up, followed by those which occurred in the natural forest and after those, with similar values, in grassland and plantations (Appendix 9).

3.2.4 VEGETATION BURNED

Within the records the burned areas were subdivided in vegetation types, more precisely in bamboo forest, bush- and grassland, indigenous forest, moorland and plantation. More than half of the territory lost belonged to the second class (Tab. 14). After that moorland played a relevant role (more than one fourth of the total amount of size burned), followed by the natural forest. Plantations did not recorded huge amount of burned areas, even tough the lowest values were taken by bamboo forest with only 155 ha lost in 35 years. In this period forest and plantation registered the majority of territory lost in the '90s, whereas more than the 75% of the moorland burned in the first decade analysed. The only type of vegetation with a continuous and not so different behaviour through the time was bush and grassland.

BURNED AREAS			**PERIOD**			
VEGETATION TYPE	**SIZE (ha)**	**PERCENTAGE**	**'80**	**'90**	**'00**	**'10**
Bamboo forest	155.00	0.57%	0%	0%	3%	97%
Bush- and grassland	14702.15	53.91%	19%	31%	28%	21%
Indigenous forest	4660.10	17.09%	4%	60%	14%	22%
Moorland	7208.00	26.43%	77%	13%	3%	6%
Plantation	544.85	2.00%	27%	58%	15%	1%

Table 14. Composition of burned vegetation in Mount Kenya forest from 1980 to 2015. Size of the areas burned from 1980 to 2015. Percentages of the burned vegetation during the decades.

In the different Forest Stations the bush- and grassland evidenced always a relevant role in total amount of burned areas, but the bigger areas of vegetation burned by a singular event belonged to moorland vegetation type, in particular in Marania and Ontulili (Appendix 9).

Generally grassland was the flora most affected, followed by the moorland and the indigenous forest but the type of vegetation preferably affected varied in 35 years (Fig. 25). During the period analysed plantation areas did not evidenced relevant role, even though some of these were affected during each decade. The fires burned bamboo forest, only in the last 15 years, whereas bush and grassland evidenced to be a relevant composition in all the periods. It had the major role in the whole period analysed excepting for the '80s, when moorland covered the biggest ratio. Moorland reduced its role in the following years, opposite behaviour of that detected in the indigenous forest.

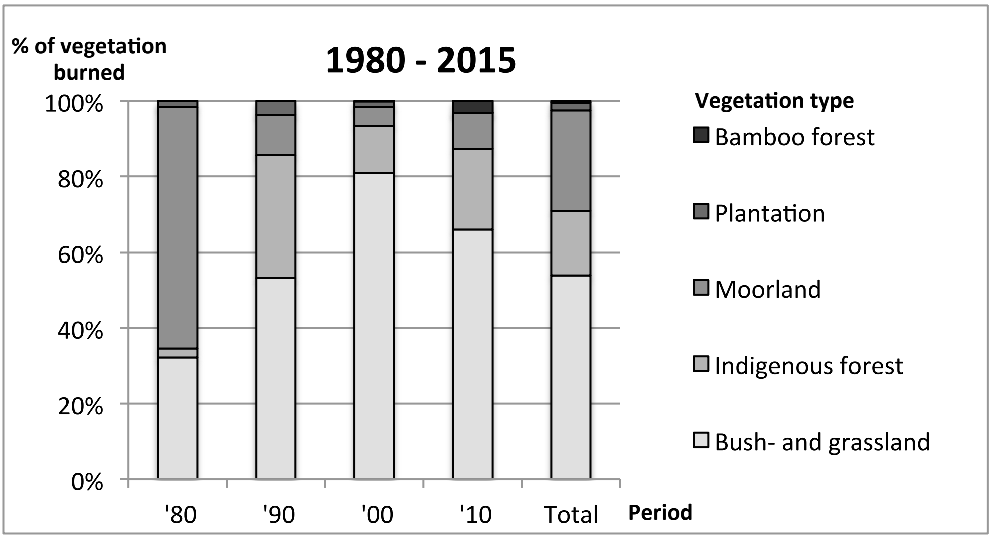


Fig. 25. Composition of burned vegetation in Mount Kenya forest. Distribution of the burned vegetation on the total amount of area burned for each decade ('80; '90; '00; '10) and for the whole research (TOTAL).

Regarding the size of the single events, it generally decreased with the time. The moorland followed this trend whereas bushland maintained constantly relevant - medium size. The natural forest registered constant presence but variable behaviour with some big-size outliers, whereas the burned plantations had little size during the whole period (Appendix 10).

Focusing the analysis within the time we observed a great part of the areas affected in the firsts three months of the year (Tab. 15). Only the moorland burned less than the 90% of its total burned area in this period, concentrating the losses between January and February (81%). Bamboo forest burned almost totally (97%) in January, whereas bush- and grassland was affected mainly (87%) in February and March. The burned plantations were recorded mainly (59%) in February, whereas half of the burned areas of indigenous forest were affected in March.

MONTH	BURNED VEGETATION TYPE				
	Plantation	Indigenous forest	Bush- and grassland	Bamboo forest	Moorland
January	2%	13%	2%	97%	38%
February	59%	33%	45%	3%	43%
March	33%	50%	42%	0%	7%
Jan - Mar	95%	97%	90%	100%	88%
Apr - Dec	5%	3%	10%	0%	12%

Table 15. Composition of burned vegetation in different months in Mount Kenya forest (1980 – 2015).

3.2.5 WHO DETECTED THE FIRE

Some of the file scanned, 76% of the total amount, reported the person who detected the fire, so we had not this kind of information for almost one fourth of the whole database. In addition, we were able to evaluate the time needed to start the fire fighting since its detection for 44% of the reports, while only 41% of them had both the information, who detected the fire and time to start its suppression, together.

Fires took meanly 2 hours and 19 minutes to be fought and forest guards most commonly detected them (35% of the total cases). Normally the time to start the suppression was quite low, overpassing rarely 1 hour and 15 minutes, with a maximum period recorded of 22 hours (Tab. 16). The "Workers", where forest workers and farmers were grouped, was the class that took meanly more time to respond. On a more general point of view the Kenya Forest Service, represented by forest guards, fire crew, foresters and their subordinates, detected more than half of the event registered, giving the alarm in less than 2 hours. The population (community, workers and others) noticed less frequently the fires (21%) and in this case more than 4 hours was meanly needed to start the suppression.

WHO DETECTED THE FIRE	% OF FIRE DETECTED	TIME FOR SUPPRESSION (h:min)		
		Mean	Min.	Max.
Forest guard	35%	2:14	00:00	15:00
Fire crew	8%	0:30	00:30	0:30
Forester	7%	1:14	00:30	2:00
Subordinate	4%	1:06	00:30	2:00
Community	10%	1:07	00:00	3:15
Workers	8%	7:47	00:15	22
Others	3%	0:30	00:30	0:30
Army	4%	0:52	00:34	1:00
TOTAL	76%	2:19	00:00	22:00
KFS	54%	1:55		
Population	21%	4:11		

Table 16. Who detected the fire and minimum, maximum and mean time to start the suppression. 76% of records with information about who detected the fire; 44% of records with information about the time for the suppression; 41% of records with both the information. **Who detected:** forest workers and farmers (Workers); Forest guard, Fire crew, Forester and Subordinate (KFS - Kenyan Forest Service); Community, Workers and others (Population).

We did not observe relevant behaviour of this characteristic, comparing it with size, time (years or month) and space (Forest Station and vegetation) classes.

3.2.6 WHERE FIRE WAS DETECTED

In some reports (40% of the total) was recorded where the fires were observed for the first time, adopting a differentiation similar to that used for the type of burned vegetation (bamboo forest was avoided due to the extremely low occurrence of fire in these areas). The four classes revealed similar percentages with a regular distribution between them and a range extended from 14%, in grassland, to 7%, in moorland (Tab. 17). Each Forest Station evidenced a singular behaviour in this case (Tab. 17).

In Ontlulili the fires were discovered in all the four vegetation types, while in Nanyuki the alarm was given only in the plantations. Gathiuru never observed events started in the moorland, whereas Marania detected the fires only within the moorland and the natural forest.

WHERE FIRE WAS DETECTED					
VEGETATION TYPE		**FOREST STATION**			
		Gathiuru	Marania	Nanyuki	Ontulili
Bush- grassland	14%	✓			✓
Indigenous forest	10%	✓	✓		✓
Moorland	7%		✓		✓
Plantation	12%	✓		✓	✓

Table 17. Where fires were detected. 42% of records with this information. ✓ where fires were detected at least two times.

We did not notice relevant or interesting trend connected to the period of the fire, excepting for the lack of knowledge related to the position of the fire ignition from 1980 to 1989.

We observed that the fires started in moorland took more time to be reached rather than the other vegetation types, even though the fires ignited in the bush- and grassland were that, which needed more time to be mopped up. Fires started within the indigenous forest revealed an intermediate behaviour in both the case, while plantations were the places of fire detection reached and mopped up in the lowest time (Appendix 11).

The relationship between the two variables with similar classes (where fire started and which size of vegetation was affected) were analysed, in order to understand where the fires that affected a type of vegetation came from and which amount of size the fires started in an area burned the others (Tab. 18; Fig. 26).

WHERE FIRE TOOK PLACE	**WHERE FIRES WERE DETECTED**			
	Bush - grassland	Indigenous forest	Moorland	Plantation
Bush - grassland	19	5	4	3
Indigenous forest	9	15	5	
Moorland		1	7	
Plantation	6	3		17

Table 18. Which vegetation fires affected and in which vegetation fires were detected. 42% of the records had this information.

In this comparison of information were observed the fires that started in an area, affected another one (Tab. 18). The fires originated within the forest spread at least once in all the other types of vegetation, on the other side, the fires ignited in plantations rarely affected a different area (only three times the grassland). If the event was detected within the moorland it affected frequently the indigenous forest and the grassland as well. On the other hand the fires originated in the bushes and grassland were able to affect the forest and the plantation but never the moorland.

Analysing the size of the area lost, was detected a strong relationship between grassland and indigenous forest with high dimension of burned zone started in one site and spread in the other one and conversely. Regarding the other vegetation types, the size of fires with a different origin were major to 100 ha only for the events started in the moorland or in the indigenous forest.

Ontulili (Fig. 27) were observed the most important size of events originated in one area and spread in another one, with a behaviour similar to that described before excepting for the absence of burned moorland for fires began in the forest.

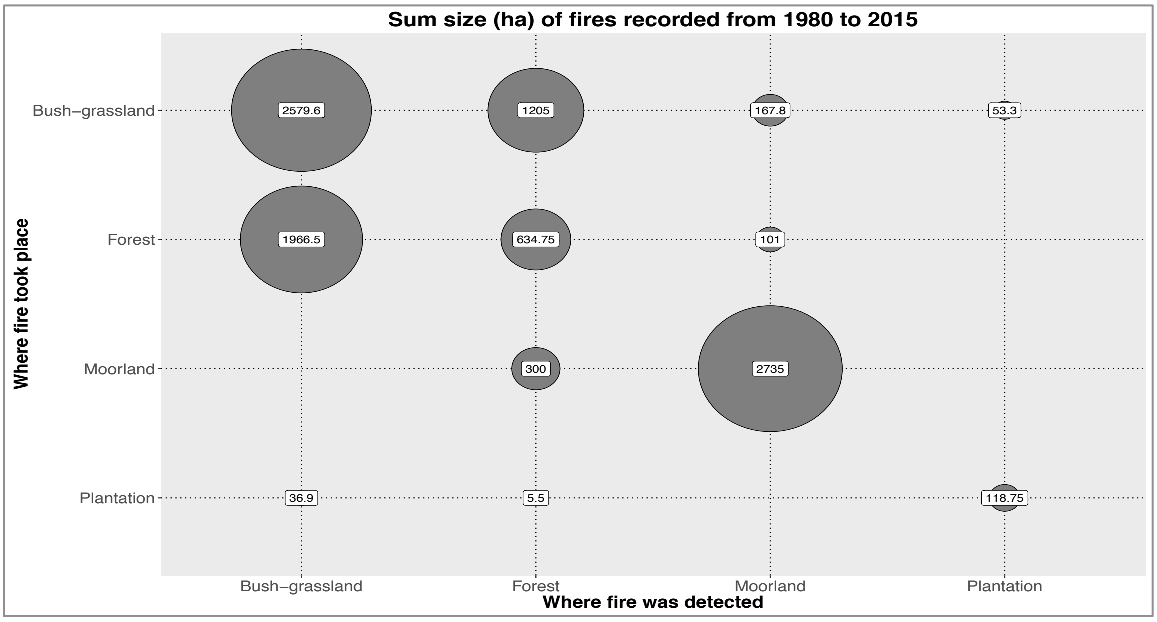


Fig. 26. Size (ha) of burned vegetation in Mount Kenya forest from 1980 to 2015. Which vegetation fires affected (vertical axis) and in which vegetation fires were detected (horizontal axis). 40% of records had these information.

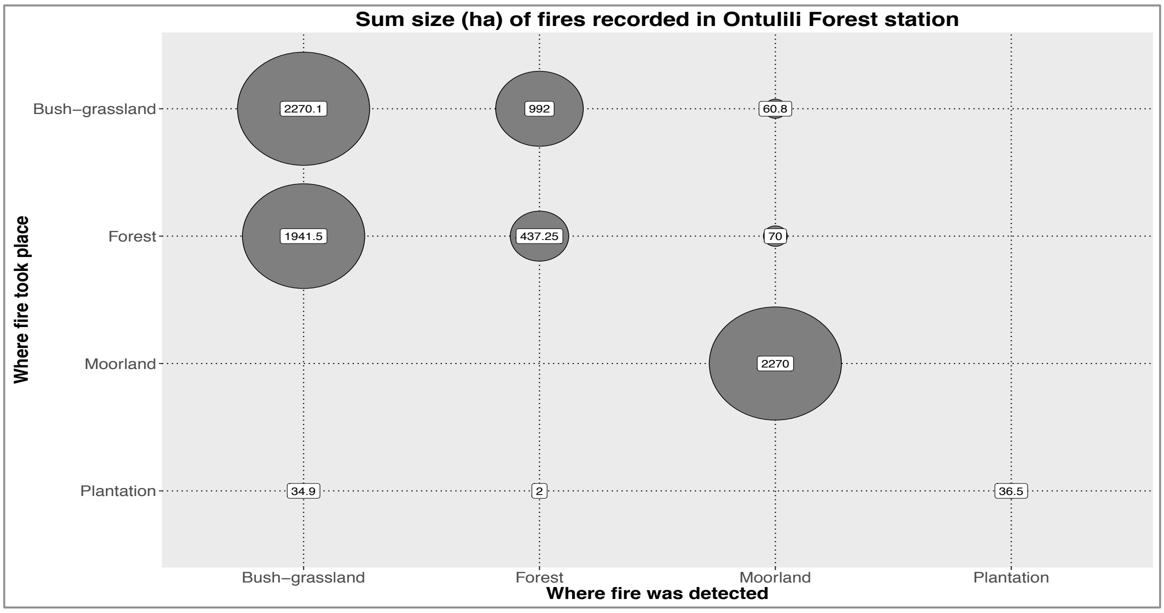


Fig. 27. Size (ha) of burned vegetation in Ontulili Forest Station from 1980 to 2015. Which vegetation fires affected (vertical axis) and in which vegetation fires were detected (horizontal axis).

Regarding the other Forest Stations only Marania showed relevant values in this kind of comparison (Fig. 28). In its territory the fires originated in the indigenous forest affected significantly moorland and grassland, whereas those ignited in the moorland burned more than 100 of grassland. Nanyuki and Gathiuru registered some mixing between starting and burned zones but sizes never higher than 50 ha.

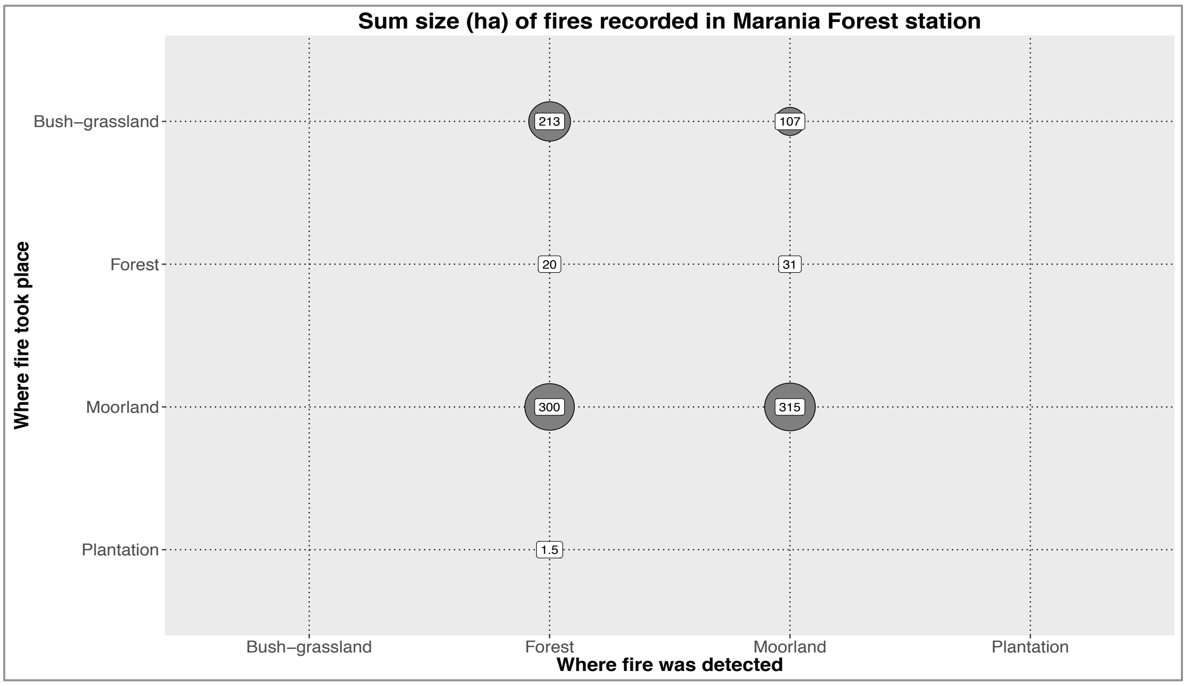


Fig. 28. Size (ha) of burned vegetation in Marania Forest Station from 1980 to 2015. Which vegetation fires affected (vertical axis) and in which vegetation fires were detected (horizontal axis).

3.2.7 FIRE DANGER RATE

Within the territory was present a fire danger rate system (Fig. 29), composed by evident signals, where was explained the level of site danger during the day, located at the entrance of the forests. The data regarding the rate evaluated at the time of the fires were available only for the 25% of the file analysed. Nevertheless the system seemed to be reliable evidencing bigger size of the fire in correspondence with a higher fire danger rate.

Fig. 29. Fire danger rate system in Mount Kenya forest.

3.2.8 EQUIPMENT

Half of the files scanned recorded the equipment utilised to fight the fire. Only pangas were used for more than half of the fires of which we had this information. The other most commonly used tools were (Tab. 19) fire beaters, back pumps and tree branches. Motorised pump and power saw were used in the 10% of the fires recorded that had this information, whereas water pumps, water tanks, fire rakes, spades, axes, bulldozers and other vehicles were recorded in less than 10% of the records with this information.

EQUIPMENT UTILISED	
Panga	37%
Fire beater	25%
Back pump	22%
Tree branch	17%
Motorised pump	10%
Power saw	10%
Water pump	8%
Water tank	5%
Bulldozer	5%
Veichle	4%
Fire rake	4%
Spade	3%
Axes	3%
Other	1%

Table 19. Occurrence of equipment utilised to fight the fires. 50% of records had this information.

We observed that any information related to this topic had not been recorded from 1995 to 1999, even though generally, during the time, the utilisation of pangas in fire fighting reduced, leaving place to tree branches.

The research did not evidenced relevant variations between the different Forest Stations but, comparing the equipment most used with the time needed to put the fire under control (information available together only for 40% of total fire recorded), power saws and motorised pumps revealed the highest values.

3.2.9 CAUSES

More than the 70% of the records registered a cause of the fire. The arsonist, followed by the honey collectors, in this case played the most relevant role (Appendix 12). Shamba system (an agro-forest practice), negligence, cigarette and cattle grazers caused each of them less than 10% of the fires recorded, whereas previous fires and poachers were the reasons for less than 5% of the reports (Tab. 20). Arsonists caused the burning of more than 5000 hectares, but shamba system and fires not completely mopped up were, each of them, the reason of the burned areas of more than 2000 hectares. Honey collectors and negligence were directly related to the burning of more than 1000 hectares, poachers caused the burning of 300 hectares, whereas each of the other causes burned 900 hectares in 35 years.

CAUSE OF FIRE		BURNED SIZE	
		Area (ha)	Percentage %
Arsonist	27%	5377.2	20%
Honey collector	12%	1335.5	5%
Charcoal burner	7%	922.8	3%
Shamba	6%	2540.0	9%
Negligence	5%	1809.4	7%
Cigarette	5%	852.5	3%
Cattle grazer	5%	929.0	3%
Previous fire	3%	2181.5	8%
Poacher	1%	322.0	1%

Table 20. Causes of fire in Mount Kenya forest from 1980 to 2015. 71% of records had this information. Area burned because of each cause and percentage on the total area burned.

From 1980 to 1999 previous fire, negligence and shamba system dominated the cause of fire occurrence. After 2000 they disappeared, leaving space to arsonists and charcoal burners. Honey collectors, cattle grazers and cigarette where detected with a similar ratio in the whole period analysed (Appendix 12).

Fire caused by poachers were the only with a very long duration (more than 30 days) and that, which needed more time to start the suppression. After this cause, previous fires and arsonists ignited fires that needed the most time to be mopped up, whereas honey collectors and charcoal burners were the causes of the fires that need more time to start the suppression (Appendix 13).

Regarding the type of vegetation affected, almost all the causes revealed similar behaviour and a preference for bush- and grassland. Natural forest covered the second role in almost all the causes of fire, with relevant sizes detected particularly in the previous fire class, when the fires were not extinguished at all and started a new fire (Appendix 14).

3.2.10 DELAY IN FIRE FIGHTING

Reasons of suppression and of reinforcement delays were recorded respectively in the 40% and 29% of the whole files. The main causes of delay in fire-suppression were “walking to reach the area” and “bad road system” (Tab. 21). The delay recorded was meanly higher than 2 hours, even though the occurrence of the fire in the evening and the necessity to look for men or equipment were the motivations that took more time (respectively 14 and 5 hours). The absence of suppression delay was recorded in 13% of the fires, percentages that decrease significantly to 4% if we focussed on the reinforcement delay. The reasons of reinforcement delay were driven by the long distance to cover on a bad road system and the necessity to look for men or equipment. Walking to reach the site revealed to had the smallest mean value (1 hour), whereas for the other causes the time varied from 5 and half to 12 hours.

Between the different Forest Stations an analysis was possible only for Gathiuru and Ontulili, due to the little quantities of information available in the other regions. From this comparison we observed, for delays of both suppression and reinforcement, high presence of necessity to walk to reach the area in records collected in Gathiuru and a relevant role of the rough road system in records collected in Ontuili. Additional peculiarity observed in Gathiuru was the absence of delay for almost the 40% of fires registered with this kind of information.

CAUSE OF DELAY	SUPPRESSION		REINFORCEMENT	
	Percentage	Mean time (h:min)	Percentage	Mean time (h:min)
Road system	13%	02:08	8%	09:17
Walking	13%	01:02	3%	01:02
Transport	4%	01:43	3%	06:55
Communication	1%	01:00	3%	06:15
Organisation	2%	00:45	2%	05:35
Looking	4%	05:08	8%	09:27
Other fire	2%	01:10	0%	-
Evening	3%	14:15	2%	11:50
NO delay	7%	01:37	3%	01:13
TOTAL	39%	2:36	29%	7:02

Table 21. Cause of delay for suppression and reinforcement in Mount Kenya forest from 1980 to 2015. 40% of the records had information related to the suppression; 29% regarding the reinforcement.

3.2.11 TIME OF ALARM

The exact time at which the fires were detected was registered in more than half of the scanned records. In 35 years the events were noted between 6:00 a.m. and 21:00 (Fig. 30), but more than the 88% of the alarms were given from 11:00 to 18:59 and the biggest hourly occurrence, almost 8% of the whole records, was observed at 13:00 (Fig. 30). The fires rarely occurred early in the morning (6:00 – 8:59) or in the evening (18:00 – 21:00), they were more concentrated in the afternoon (15:00 – 17:59) and especially just after midday (12:00 – 14:59). In the different Forest Stations an extremely analogous pattern was showed in Gathiuru and Ontulili, where the fires occurred mainly right after midday. Marania never registered a fire before midday, whereas Nanyuki reported an equal distribution of flame occurrence during the day (from 6:00 to 21:00).

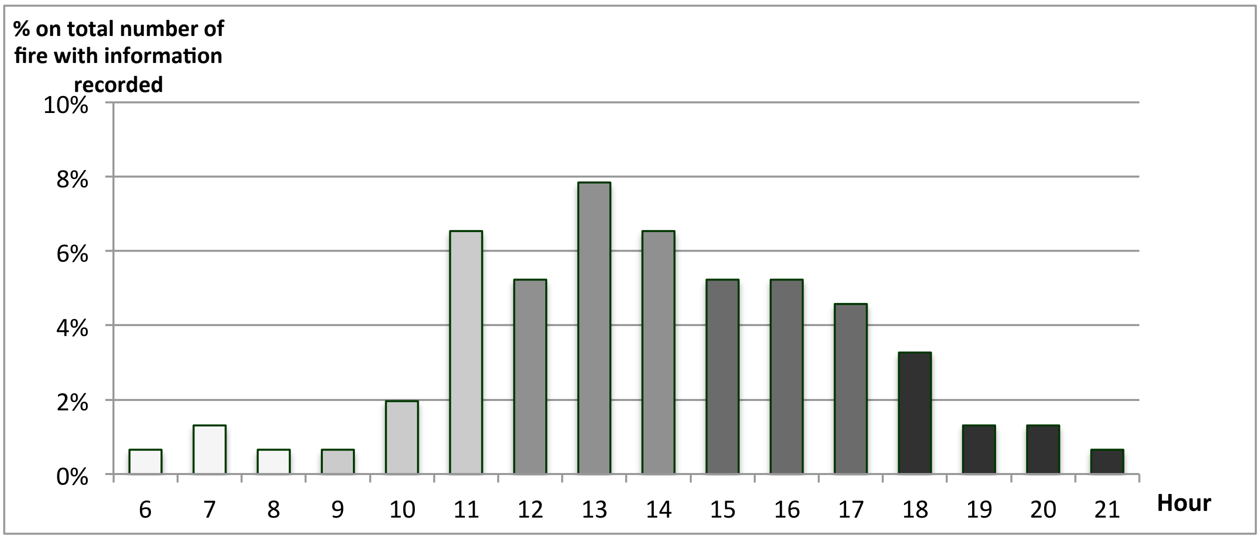


Fig. 30. Occurrence of fire during the day in Mount Kenya region from 1980 to 2015. 53% of the records had information related to the alarming time.

During the year, fires occurred early in the morning only from January to March, months when they were mainly occurred between 12:00 and 17:59. Similar behaviours were detected for the fires, which burned in the other months, except for September, when fires occurred mainly before midday (9:00 – 11:59).

If we compared the time and the type of vegetation where alarm was given (Fig. 31) (42% of the file contained both the information) we were able to observe that within indigenous forest and bush- and grassland the fires started mainly between 12:00 and 14:59. On the other hand, the fires detected in moorlands and plantations, revealed a prevalent occurrence in the afternoon (15:00 – 17:59). Fires never occurred early in the morning in the moorland, whereas bush- and grassland were always affected before 18:00.

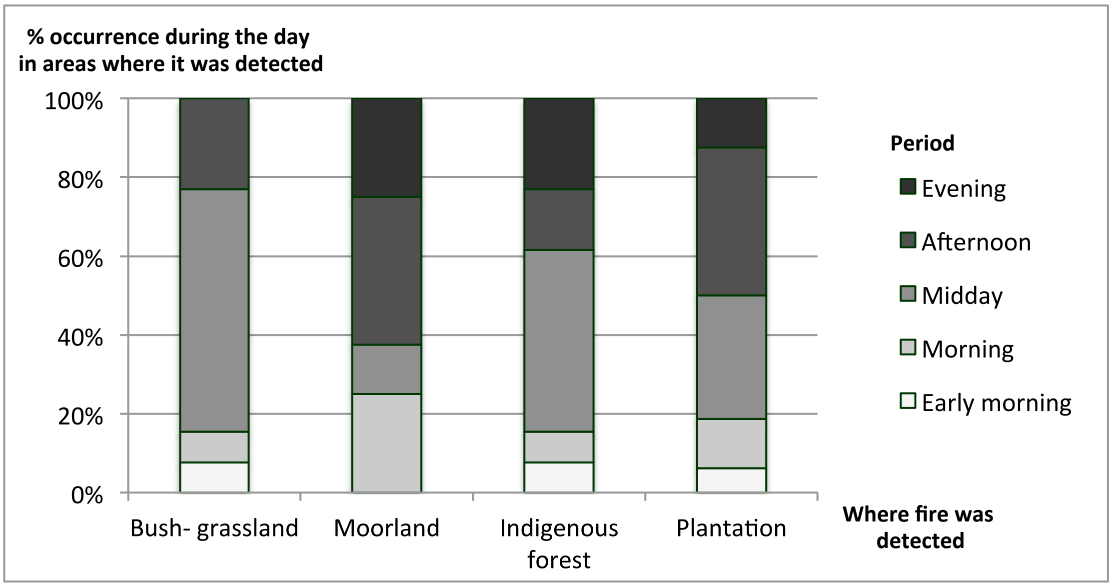


Fig. 31. Occurrence of fire during the day in areas where it was detected in Mount Kenya region from 1980 to 2015. 42% of the records had information related to place and time of fire ignition. **Period:** 6:00 – 8:59 (early morning); 9:00 – 11:59 (morning); 12:00– 14:59 (midday); 15:00 – 17:59 (afternoon); 18:00 – 21:00 (evening).

We were able to obtain information about both the time of fire detection and amount of suppression delay only in 39% of the whole database, but the analysis revealed a higher time to fight the fire for the events occurred in the evening. The fires ignited in the other periods of the day showed similar behaviour with a range of delay of 0 - 3 hours till 14: 59 and of 0 – 2 hours in the afternoon. The delay of reinforcement demonstrated a more homogeneous relationship with the time in which fires were discovered. Only the fires occurred in the early morning registered a delay never higher than 1 hour. In all the other periods of the day big outliers of 10 – 20 hours were recorded, nevertheless the reinforcement reached the fire meanly 9 hours after its detection (Appendix 15).

3.2.12 RATIO OF BURNED AREA

The research continued comparing data scanned in the different Forest Stations to that provided by KEFRI. We were not able to identify moorland and neither bamboo forest within the GIS database, so that, the evaluation trough the two data sources was restricted to plantation and cropland, strictly connected in the shamba agro-forestry system, natural forest and bush- and grassland.

First of all we evaluated the distribution of the different type of vegetation within the territory of each zone, not observing any relevant difference between the various administrations (Tab. 22). Nanyuki and Gathiuru highlighted the main divergence but all the areas were covered mainly by indigenous forest (64% – 86%). Secondly the grassland played an intermediate role (6% - 28%), whereas cropland and plantations had the lowest extension (4% - 12%).

After that we estimated the total amount of different burned vegetation classes recorded within the Forest Stations (Tab. 23). The analysis identified generally bush and grassland as the flora most affected (36% -75%), followed by the natural woodland (15% - 28%). Cropland and plantations burned for ratios much more little rather than the other vegetation classes (0% – 9%). The ratio of the burned vegetation calculated values slightly different in some stations. Nanyuki showed an amount of burned forest more pronounced rather than the other administrations, reducing the percentage of the bush- and grassland burned. Marania experienced extremely little burning areas in the plantations, whereas Gathiuru evidenced the highest ratio of burned grassland at station level.

Finally we merged the results of the two investigations relating the quantity of flora burned in 35 years with the ratio of vegetation present in the Forest Stations (Tab. 24). In this case each station revealed a particular composition but higher values always in grassland.

FOREST STATION	VEGETATION TYPE					
	PERCENTAGE			SIZE (ha)		
	Cropland Plantation	Indigenous forest	Bush- and grassland	Cropland Plantation	Indigenou s forest	Bush- and grassland
Gathiuru	8%	64%	28%	1222.25	9936.98	4373.84
Marania	4%	75%	22%	290.77	6150.14	1800.73
Nanyuki	7%	86%	6%	366.35	4439.56	327.80
Ontulili	12%	74%	15%	1432.57	9118.14	1828.28
TOTAL	**29%**	**48%**	**23%**	**128128.00**	**212889.00**	**104352.00**

Table 22. Composition of vegetation in the different Forest Stations (percentage and size) and in all the Forest Station analysed (TOTAL) from 1980 to 2015. Size of vegetation type provided by KEFRI (Kenya Forest Research Institute).

FOREST STATION	BURNED VEGETATION TYPE					
	PERCENTAGE			SIZE (ha)		
	Cropland Plantation	Indigenous forest	Bush- and grassland	Cropland Plantation	Indigenous forest	Bush- and grassland
Gathiuru	2%	19%	75%	85.80	836.50	3386.80
Marania	0%	15%	53%	1.50	568.00	1995.00
Nanyuki	9%	28%	36%	36.45	112.25	141.75
Ontulili	2%	17%	49%	421.10	3124.35	9140.60
TOTAL	**2%**	**17%**	**54%**	**544.85**	**4641.10**	**14664.15**

Table 23. Composition of vegetation burned in the different Forest Stations (percentage and size) and in all the Forest Station analysed (TOTAL) from 1980 to 2015.

FOREST STATION	AREA BURNED / AREA PRESENT VEGETATION			
	Cropland Plantation	Indigenous forest	Bush- and grassland	Whole Forest Station
Gathiuru	7%	8%	77%	27.55%
Marania	1%	9%	111%	38.17%
Nanyuki	10%	3%	43%	6.81%
Ontulili	29%	34%	500%	117.20%
TOTAL	**15%**	**13%**	**159%**	**56.87%**

Table 24. Percentage of vegetation burned from 1980 to 2015 in relation of the type of vegetation currently present in the different Forest Stations and in in all the Forest Station analysed (TOTAL).

Fire affected plantation and natural forest for less than 10% of their actual area in Gathiuru, whereas the percentage for the bush- and grassland reached the 77%. This last vegetation burned for more than the 110% of the present dimension within Marania, and the ratio touched the value of 500% in Ontulili, where in 35 years fires burned grassland for five times of its current dimension. Ontulili evidenced the highest percentages in all the type of flora analysed, with a decrease in plantation and natural forest areas that burned respectively for the 29% and the 34% of their actual extensions. On the other hand, Nanyuki experienced less important damages with a lost in grassland cover of 43% of its current dimension.

If we considered all the four territories together (Tab. 24) the analysis demonstrated that, in 35 years, plantations burned for 15 % of their current extension, indigenous forest for 13% of its actual extension and grassland for 159% of its current dimension. From 1980 to 2015, in the four Stations the fire burned an area bigger than half of the whole territory (Tab. 24). If we observed the subdivisions one by one the less affected was Nanyuki, which burned vegetation had an extension minor than 7% of the total region. Fire burned more than 27% its actual extension in Marania and more than 38% in Gathiuru, whereas in Ontulili the burned areas exceeded the entire size of the station, burning almost the 120% of its actual dimension.

To estimate the importance of Mount Kenya region in relation to the wildfires affecting the whole Kenyan territory, the burned area and the number of fires occurred within this area were compared to the statistics at the national level, proposed by Wass P. (2000). From this comparison we observed that the Mount Kenya region participated not so much in area burned in plantation (2% of the artificial woodland burned in the State), evidencing a more relevant value concerned to the bush- and grassland burned (10%). Not so many fires took place within the areas (6% of national fires), even though almost one third (28%) of the indigenous woodland affected by fire in Kenya belonged to Mount Kenya forests (Tab. 25).

	ROLE OF MOUNT KENYA REGION IN WILDFIRES OCCURRED IN KENYA			
	SIZE OF AREA BURNED			NUMBER OF FIRES OCCURRED
	Plantation	Indigenous forest	Bush- and grassland	
Kenya	16555.0 ha	9923.0 ha	45583.0 ha	548
Mount Kenya	296.0 ha	2736.5 ha	4448.2 ha	35
Ratio	2 %	28 %	10 %	6 %

Table 25. Burned vegetation size and number of fires recorded in 1990, 1991, 1992, 1993, 1994, 1997 and 1999 in Mount Kenya related to the total amount of burned vegetation and of fire occurred during the same period in Kenya.

3.2.13 FIRE OCCURRENCE IN THE MOUNT KENYA REGION

Once studied the amount of size burned we focussed our attention on the occurrence of the fires during the year, analysing the information detected by MODIS and provided by KEFRI. These information concerned only the years from 2001 to 2015. From this database we observed a higher fire occurrence from January to March, but working in GIS, the records evidenced a differentiation in the location during two different periods of time (Fig. 32). In the first three months of the year the fires affected the region homogeneously, without highlighting any prone area. During the rest of the year the fires were more concentrated on the north-east side of the region, with only few isolated exceptions in the other zones. Regarding this anomalies, only two fires revealed big sizes: one occurred between the 12th the and 13th of April 2011 in the north-west; the other around the 17th of December 2005 in the south-west.

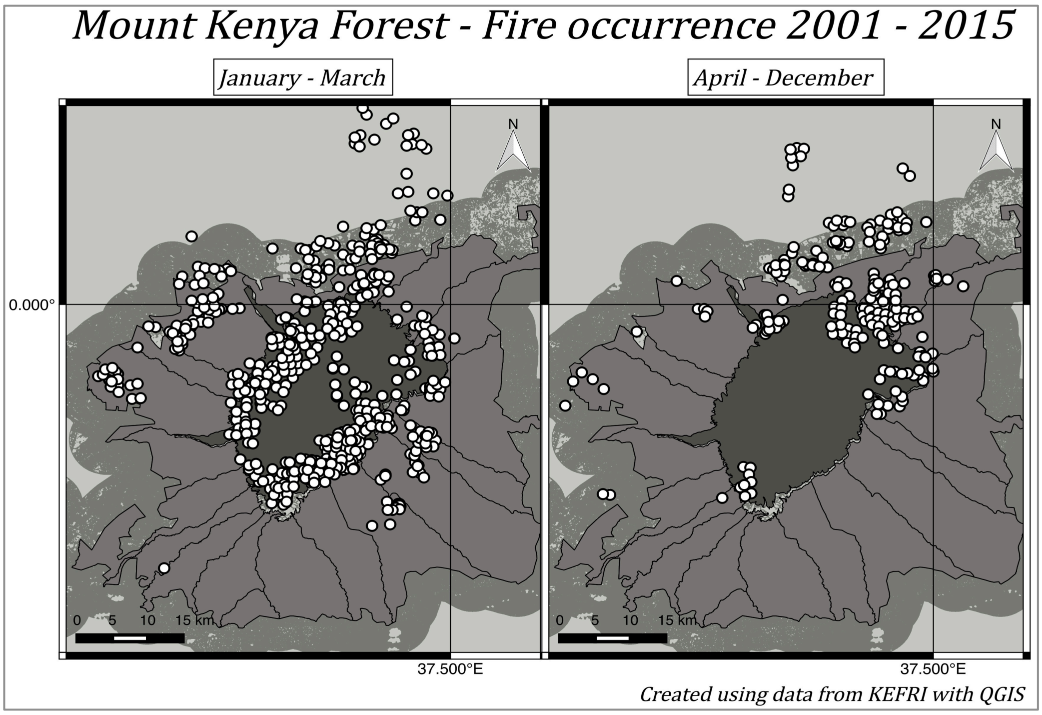


Fig. 32. Fire occurrence (**O**) in Mount Kenya forest from 2001 to 2015 in two different periods: January-March (on left) and April-December (on right). **Territory subdivision**: National Park (dark grey); Forest Station boundaries (grey); cropland and grassland (light grey). Data provided by KEFRI; Maps created with QGIS.

4. DISCUSSION

4.1 FIELD RECORDS

The most relevant differences between the plot classes were observed within the indigenous forest. The region rarely affected by the fires was burned three years before than that often damaged by fires. For this reason, the higher presence of regeneration in the areas affected by fires just once could be caused by the longer period since the last occurrence of the event. On the other hand, the absence of some species in area frequently burned but present in the zones not often burned, could prove a different type of reaction to the "natural" hazard. Additional dissimilarity detected on the field was related with the presence of big size trees (DBH $\geq$ 100 cm). The continuous occurrence of fires deleted completely the presence of this kind of individuals from the stand. If not so frequent fires killed them, leaving giant size snags after its occurrence. These trees, basis for micro-ecosystems and forest continuity, stored huge amounts of carbon for a long time as well (UNH, 2012). Background knowledge (UNH, 2012) proved that even after their death, the fallen individuals with huge dimensions retain a great amount of carbon, releasing it slowly for a long period of time. However, forest fire can deeply affect carbon cycle. Both, decomposition and wildfire, work in atmosphere inflow releasing carbon (UNH, 2012). Wood decay is a long and slow process so that ratio and velocity of this influx are sensibly increased during this kind of natural hazard (UNH, 2012). Standing death and lost giant size trees were the proves of the turning role of this individuals from a sink (Fig. 33.a) to a source (Fig. 33.b) of carbon stored in high quantities and, thanks to the fires, released as well.

Fig. 33. Example of how fire changed the role of giant trees. Left (33.a) in not affected areas a carbon sink; right (33.b) in rarely affected areas a carbon source.

The natural forest, which never experienced fires, revealed a low level of both, regeneration and canopy cover at the same time. This gaps and openings were strictly connected with the presence of wildlife (buffalos and elephants). Elephants density and their presence in a fenced area, as Mount Kenya Reserve is, proved to influence the woodland and, even if not strongly, the species composition as well. The mammals' presence has a strong connection with the vertical structure of the vegetation (Baxter P. et al., 2005) and with the density of the trees (Young T. P. et al., 2013).

Plantation revealed similar aspect evidencing the most relevant effects of the fire in an alteration of crown density and height. These results could have been driven by the medium intensity and the crown nature of the fire, as testified by the member of the team who were present during the event.

4.1.1 FOREST STRUCTURE

Forest revealed to have different structure in relation to the occurrence and frequency of fires. The research demonstrated that woodland had a dense structure (450 trees/ha) of living trees with relevant diameter dimensions (up to 260 cm) if not disturbed. Fires changed the tree density similarly in the two samples considered, but the areas frequently affected were settled by bigger individuals, creating a population with a basal area double of that grown in areas rarely affected. Frequent fires select strong and big individuals, the only which can persist, demonstrating enough resistance to bear these hazards. If the stand had never experienced high temperature and burnings, it proved to have more relevant losses not in terms of number of tree lost but in terms of their dimension, selecting characters with sizes not extremely big but vigorous and more resistant to damages. Due to the time passed since the last fire occurrence, the data could be influenced by the presence of a fast grown regeneration that had reduce the mean values of diameter estimated and increased the number of trees present as well. Leaving the time flow, tree density and basal area will increase, even though they will not reach the level of a not affected area (Verma S. et al., 2014). If we assumed this hypothesis, right after the fire, more similar values regarding forest structure would be observed in the two affected areas (A_F and An_F), with a much more consistent lost of living stem in An_F rather in A_F. After occasional events regeneration and growth of seedlings and woody species can be enhanced by the appearance of suitable conditions (Kumar R. et al., 2008). Fires influence regeneration both directly (stem tissues and seeds burned) and indirectly (reproductive trees killed) (Verma S. et al., 2014), and their effects are more relevant in the areas rarely affected rather than in that frequently affected (Balch J. K. et al., 2013).

Fires influence both forest structure and composition (Balch J. K. et al., 2013) modifying at the same time the dimensions of the trees and the presence of the species as well. Intensity and frequency of the fires varied the nature and the quantity of the damages that they provoked (Marzano R. et al. 2012). Fires drive various changes in forest composition, from the alteration of the successional patterns to the variation of many vegetative resources (Bakhtar A. J. et al. 2013). Fire mortality varied in relation to the species and to its characteristics, for example, large reproductive trees have more chances to survive (Balch J. K. et al., 2013). The features of the species that play the bigger role in fire-selection species are the propagation system (Marzano R. et al. 2012) and the necessity of light/shadow in the young stages (Beghin R. et al. 2010). After this kind of natural hazard the most prone individuals to survive are those with a pronounced resprouting ability (Marzano R. et al., 2012; Balch J. K. et al., 2013) and a pioneer nature, with a preference for open and not limited by the light (Beghin R. et al. 2010). In the study site, the fires were extremely selective in species composition, leaving only three species present in all the three plot classes analysed. All of them (*Juniperus procera, Afrocarpus falcatus* and *Olea Africana*) revealed an intermediate comportment between shade-tolerance and light demanding and a good resprouting system (Hines D. et al., 1993; Mbuya L. et al. 1994). This is the general behaviour observed in our study but the frequency of the events and their intensity can alter the behaviour described and the species selection (Marzano R. et al., 2012; Balch J. K., et al., 2013) detecting a reduction of regeneration when the force of the flame were high or more frequent. The frequency of the events leaded stand composition. Strong light demanding species, like *Pinus patula* (PFAF, 2012), and not strictly light demanding trees characterised by a slow seedling regeneration system, like *Warbugia ugandensis* and *Prunus Africana* (Mbuya L. et al., 1994), colonized/survived in those areas, that burned frequently (Marzano R. et al., 2012). On the other hand the zones rarely affected were composed by individuals, which don't disdain the light and have a good sprouting system, as *Ekebergia capensis* and *Fraxinus pennsylvanica* (Mbuya L. et al., 1994; Mullah C. et al., 2014). The trees more fire intolerant, *Olea capensis* (Hines D. et al., 1993), and that extremely shadow-demanding, *Podocarpus latifolius* (Mbuya L. et al., 1994), were detected almost exclusively in the areas not affected, revealing to prefer the unburned areas (Bakhtar A. J. et al., 2013). Similar behaviour was observed in the shrubs composition of the areas visited, where strictly light-demanding species, as *Tecoma capensis* (PLANT, 2014), grown only in the areas frequently burned. On the other hand, lower selective effects of the fires were detected for more shade tolerant genus, as *Nuxia congesta* and *Tarchonantus camphoratus* (PLANT, 2014), which grown within both affected and not affected stands.

In areas often burned, the fire itself favoured a higher presence of Juniperus, helping its necessity of light and opening in regeneration and propagation phases (Bussman R., 2004). Its seed dormancy played a relevant role in its distribution on the ground, exploiting the openings created by the fires to spread and grow in the affected areas, especially in that frequently affected, where the competition in regeneration is hardly reduced (Bussman R, 2004; Aynekulu E. et al., 2009). Once established the species grow higher than Olea and Podocarpus trees but it require human or natural manipulation of the ecosystem to reach a mature stage and ensure propagation (Bussman R, 2004; Aynekulu E. et al., 2009).

Olea africana was the only species with a similar ratio of presence in all the stands visited. The data evidenced a little decreasing in the species presence in areas affected by fire even though the fires had not reduced heavily its number. The shadow tolerance of the species usually encourages its proliferation within protected areas (Aynekulu E. et al., 2009). On the other hand the openings may help the renovation in dry disturbed regions thanks to its light tolerance (Aynekulu E. et al., 2009) and its transitory seed bank (Brussman R., 2004; Turner M. et al., 1994).

Podocarpaceae and Oleaceae families showed similar behaviour with a differentiation at species level. Both of the groups registered trees (*Olea africana* and *Afrocarpus falcatus*) that prefer shadow and close canopy but, once established, can resist to stresses as well, adapting to environments more open and bright. At the same time we observed species of the two families (*Olea capensis* and *Podocarpus latifolius*), which were heavily influenced by fire, disappearing in the affected areas, due to their low strength in light competition and their high shade-demanding nature. The effect of the disturbance was more evident for *Podocarpus latifolius*, the main species within this afromontane ecosystem (Wass P., 1995), but, its high light intolerance (Adie H. et al., 2011), reduced its presence till the extinction in areas that experienced fire.

Fraxinus established well and only in that habitat, rarely affected by the fire and, immediately after the event, its shade intolerant behaviour had no more limitations (Yeboah D. et al., 2016). Originally cropped for economical and fire protection purposes (Mullah C. J. A. et al., 2014 and KFS, 2010), this alien species can be observed also faraway from the plantations nowadays (Mullah C. J. A. et al., 2014). Fraxinus and its fast growth nature could be helpful for the restoration of the habitat after the disturbance but its aggressive reaction is ensured only by specific habitat features that safeguard the invasion (Mullah C. J. A. et al., 2014). Frequency of fire demonstrated to delete its role not evidencing any individual of the species in the areas frequently affected, even though the absence could have been driven by the lack of individuals artificially planted near these regions as well.

Especially in the vertical dimensions, the burning effects depend on fire regime and landscape structure (Godinho-Ferreira P. et al., 2006). Fires reduced the crown volume, particularly where they occurred frequently, decreasing the space where branches and leaves can survive closely. The time since last fire occurrence was different in the two regions so that the behaviours described could be opposite, even because the first living branches were much lower in the frequently affected areas, suggesting higher quantity of damages in the other stands. The rarely affected areas exposed higher trees, with individuals less often stressed and so that, exhibited bigger dimensions and lower canopy, thanks to a faster and less strained regeneration system. The quick reaction to the disturbance was detectable observing the crown height, equal to flame height only in this kind of stands.

The number of plots observed in the plantations was not enough to describe the stand in a proper way, but we were able to discuss about the data recorded, taking these as the most reliable and probable information. Plantations demonstrated similar behaviours in the two conditions analysed, where structure and organization were driven by the huge influence of human being. The effects of the fires were concentrated in the vertical structure, with a reduction of the crown ratio driven by the enhancing of crown height, burned at the lowest levels, and the decrease of tree height, due to the stress of a crown convalescence. The low intense fires could allow a fast crown recovery (Green S. R., 2005), reducing the losses provoked in vertical structure, even though in our case crown and flames height were the same, not evidencing a crown regeneration. Regarding the horizontal composition of the stand and the trees, the diversity detected could be lead by a slightly variation in plantation management. A larger amount of trees implied lower value of DBH in areas affected by the fire. DBH reduce the gap driven by population density with opposite values. Furthermore, the small ratio of dead trees could be the reason of the little variation of basal area per hectare, values that were similar in the two stands. Even though all the individuals stored damages and stress, fires did not modified tree dimensions in the plantations but more properly the tree density, reducing it. In this kind of events big mature trees revealed to be less affected and the reduction of the BA was more related to the understory and the bushes (Green S. R., 2005).

The damages that were observed on the individuals were directly related to the intensity of the fire only in the areas affected for the first time (Fig. 34.a) and in the plantation, whereas the frequently affected areas could have stored information and signs of previous events (Fig. 34.b).

Fig. 34. Example of damages provoked by fires on the trunk in the forest. Left (34.a) in rarely affected areas the damages were related to the last fire; right (34.b) in frequently affected areas the damages were related to the last event but to the previous as well.

The regeneration proved to have a big role in rarely affected areas, where higher ratio of individuals had crown, which were not burned. At the same time the intensity of the fire within these areas was relevant, proved by the amount of snags and by the presence of many damages visible at trunk and canopy still four years after the event. Regeneration evidenced different systems in the forest affected by fire, in fact where fire appeared rarely new individuals occupied easily the free spaces left. On the other hand the reaction of those regularly affected areas consisted in regenerating tissues of that individuals not completely burned with an even lower ratio of damages moving from the surface, through the DBH and reaching the crown level.

Plantation recorded high level of burnings at both canopy and trunk level, suggesting a relevant intensity of the flames, thanks to its dense structure and fire prone material (KWS, 2010), even though not strong enough to kill a lot of trees.

4.1.2 DIVERSITY INDICES

Simpson index is more sensitive to the variance of the dominant species/class, whereas Shannon index can evidence easily changes in the presence of rare species/classes. Analysing the diversities that occur within a population is useful to evaluate more indices in order to have more sure information and avoid incorrect estimation (CANFOR, 2003).

Fire brings heterogeneity in structure and species composition (Marzano R. et al, 2012), but in our research similar results were not observed for all the characteristics analysed.

Within the natural forest the range of DBH values was bigger in the areas not affected, whereas fires reduced horizontal dimension variability regarding both dominant and rare classes. Observing the indices evaluated, the variance was reduced more evidently in the Shannon indices, revealing a lower presence of occasional sizes. Furthermore mean DBH value decreased in these stands, especially if they were frequently affected, suggesting a reduction of big trees, in discordance with other studies (Verma S. et al. 2014; Green S., 2005). In the vertical dimension diversity the fire had ambivalent effects on the forest. The variability increased right after the event, whereas after 4 years the stand was more homogeneous than that not affected, thanks to a fast growing regeneration and to its rare exposure to fires as well. Despite other realities (Kumar R. et al., 2008), in Mount Kenya forest, species diversity was higher in the affected areas and the fires help to diversify forest composition even more if its occurrence was frequent and more recent.

The range of diametric and height classes detectable within plantation was much smaller than within the forest stands. Plantations recorded an extremely similar variance in both the realities and the differences in diversities registered could have been driven by human and not fires, also because of the larger variance in horizontal rather than in vertical dimensions.

4.1.3. CORRELATION

Within the plots that frequently affected, *Olea africana* was the less damaged species. Once established, it can tolerate stresses (Aide H. et al., 2010) and had a fast regeneration system, evidencing a relevant role in basal areas calculations and in the absence of damages at DBH level and a strong negative correlation with medium/high damages observable at the surface as well. Nuxia revealed even lower direct connection with the fires and an extremely fast reaction to them, not registering damages at the crown. If African olive trees evidenced the bigger role in restoration and wounds reparation, Juniperus, the main conifer species present in the area, highlighted the main part related to the variation in structure and composition. Its loss was the only directly related to the deviation of basal area, crown ratio and number/species of living tree, proposing this genus as the most prone to fire and the most influenced by it. On the other hand, the high presence of broadleaves enhanced the flame height, even though this relationship could have been driven by the structure of the forest before the fire occurrence (Kane V. R. et al., 2014), evidencing higher individuals where they survive in groups. Continuous disturbances could have isolated the stronger and bigger individuals in green islands where they protect themselves, increasing their dimensions and consequently those of the flames as well.

The intensity of the fire influenced the effects that it produced at crown height (Godinho-Ferreira P. et al., 2006) and consequently the species composition. In frequently affected areas, if the fires were intense but not too much (medium damages), the height of the first living branch increased, enhancing the chances to grow for new specie and the index of diversity for species. On the contrary, the fire which was strong enough to burn high amount of canopy reduced the variability of species occurred within the stands. Similar observations were detected in the vertical diversity that was encouraged by fire if it was intense enough to create medium damages on the trunk but not so much to provoke relevant hurts. The injuries registered on the trunk revealed similar behaviour at the two levels observed with high or low quantity recorded at the same time at surface and DBH level. Furthermore few damages at DBH were more evident where the amounts of fires' effects at the surface were less common. The data suggested that the trees were commonly affected by surface fires, which damaged the trunk at least till 1.30m from the surface, and extremely rarely by ground fires. The hazards revealed to have been homogeneous, not focusing only on one level but affecting both, crown ratio and basal area at the same time. The fire affected both canopy and surface, influenced vertical and horizontal dimensions, but it is not verifiable if these variations were driven by the last event or by those occurred before.

In areas rarely affected, fires never affected *Fraxinus pennsylvanica* trees, probably growth after the hazard, thanks to its invasive behaviour (Mullah C. J. A. et al., 2014). The species did not revealed burnings on the crown and neither on the trunk. *Olea africana*, on the other side, was the main broadleaf and the main genus affected, evidencing a leading role in crown and basal areas losses and in death individuals. *Nuxia congesta* was the principal bush recorded, while *Olea capiensis* and *Podocarpus latifolius* growth often together, most probably in the areas less intensively affected due to their not pioneer characteristics (Bussman R., 2004). Within the plots disturbed for the first time, the fires enhanced the vertical heterogeneity of the forest structure when the event was not too intense. As described in other studies (Marzano R. et al., 2012), if the fire was particularly strong it burned and damaged the trees enough to increase the structure homogeneity. This behaviour was detected directly, comparing the quantity of damages on the trunk and the indices of structure diversity, but also indirectly. Flames height was strictly related to the variation of the crown height, but it, reduced the BA estimated, if strong enough to kill a tree, loss negatively related with the crown height variation. Furthermore, areas with more living individuals registered an organisation more heterogeneous, connection that corroborated the thesis according to which the events not so intense to kill many trees increase the heterogeneity. A higher horizontal dimension within the rarely affected areas reduced the quantity of damages detected on the surface, resulting to be a safer area, with a lot of big trees inside.

In not affected areas the bushes were mainly formed by *Nuxia congesta* and *Tarchonanthus camphoratus*, which were used to live together. The principal conifer in these stands was *Podocarpus latifolius*, which reduce the species differentiation within the plots with its extremely light intolerant behaviour (Aide H. et al., 2010). *Olea africana* demonstrated to have lower crowns, reducing the crown height with its presence within the zone. Regarding the structure, the forest suggested to grow horizontally and vertically together, highlighting bigger volume of foliage where the basal area registered higher values, relation altered in the affected areas, where was not so strong as in the not affected one.

4.1.4. COMPARISON

The trees within the forest that was rarely affected evidenced the most singular structure in both vertical and horizontal dimensions. They had smaller diameters, lower heights and bigger crown ratios, but their dimensions proved to be significantly different only with the individuals of plantations (both, affected and not affected) and of the not affected areas. Plantations highlighted a lower range of all the dimensions analysed, but significant diversities with the forest areas, especially with those affected, were recorded only in the height values (tree height and crown height). Plantations registered higher vertical sizes but lower canopy volume, characteristic driven by human being settling the trees close to each other, in order to enhance self-pruning and reduce the crown volume.

The damages registered generally higher values in the plantation, lower in the forest rarely affected and intermediate injuries in the frequently affected natural forest. This trend was observable in all the areas detected on the trees, even though the differences between the three environment were more evident at crown level. The effects of the fires on the trunk were more evident in the higher parts, whereas those more close to the surface were more various and similar between the forest areas. The presence of a fast regeneration growth within the rarely affected forest was proved one more time, evidenced by the renovation of the crown. Restoration system was not so efficient on the trunk where the effects of the fire were still evident. Within the natural forest the areas rarely burned highlighted the most particular composition with trees smaller and littler. Regeneration could had had a strong influence in these observations, in fact where the fires frequeently occurred the structure of the vegetation was much more similar to that fire free. The main difference was observed in the horizontal dimensions that estimated significant variance with the other two areas affected by fire. Vertical sizes revealed to have lower variance but still significant with the areas not affected, whereas crown ratio was the only similar parameter for all the three realities. The hypothesis of a regeneration influence was corroborated by these relationships, evidencing a structure similar to a fast grow reaction with individuals little but vertically developed and a crown competitive and well established.

Within the plantation the fires revealed to influence much more the vertical dimensions rather than the horizontal one. Trees stressed by the fire showed a bigger range of diametric sizes but generally smaller and littler individuals with a higher crown height. Managers of the plantation who organise the stands in different ways could have driven the structure of the vegetation, but observing the high ratio of damages recorded in these areas the hazard play surely a role, even though not evidently significant.

Olea europea, the only present relevantly species in all the three areas of the natural forest was the example considered to have a better perception of the amount of effect bring by fires, excluding the influence of the regeneration. It evidenced the effects of fire and its frequency in both horizontal and vertical dimensions. Fires reduced diametric and height sizes of the individuals and their occurrence increased the diminution. Time since the last event could have influenced and increased the differences between the two damaged areas (Verma S. et al., 2014), even though they were never evaluated as statistically significant. After the hazard the crown volume increased, and much more in the rarely affected areas, but also this observation could have been driven by the bigger period passed after the fire occurrence in these regions. Even not always significantly, the damages evidenced a double behaviour with more relevant effects on the crown in the frequently affected areas and higher damages on the trunk in the rarely affected areas. Regeneration and time could have masked quickly the effects on the crown restabilising it, but they did not cover the signs on the stem with the same rapidity.

4.2 FIRE RECORDS

The data collected revealed results similar to those of the previous studies (KWS, 2010; Huho J. M. et al., 2016; O'brien J. J. et al., 2009; K'Akumu O. A. et al, 2016). The location of fire prone areas took place in a semicircle that, from the middle-western side of the mountain, surrounded the peak till its northern slopes (KFS, 2010), whereas the fire prone period perfectly matched the dry seasons (January – March and August – September) (NAREDA, 2009). The research investigated more in detailing the phenomena, even though it considered only the most prone Forest Stations.

4.2.1 OCCURRENCE WITHIN THE TERRITORY

Mountain landscape has an extremely various organization that influences fuel accumulation, weather variables and species composition, modifying the fire regime at the same time (Kane V. R. et al., 2014). The analysis detected the most affected regions in the north-west side of the mountain but the fire registered singular behaviours in each one of the territories analysed:

- Ontulili, the most endangered area in the study, played the main role in fire affection, recording a lot of events, regularly with relevant extensions;
- Gathiuru experienced al lot of fires of little dimension, evidencing characteristics prone to the ignition but not to the propagation of the fires (only four events > 200 ha). This behaviour could have been driven by a more fragmented vegetation that did not allowed the fire to increase its size easily (Kane V. R. et al., 2014);
- Marania, the northerner region, had few report but almost always with a high extension (only three < 400ha). It is the third within the rank of total area lost but the records described it as an extremely risky area, where fires settled rarely but spread without difficulties;
- Nanyuki and Naromoru, located in the western side of the mountain, evidenced not so many occurrences and always of little size, describing an area not exactly prone to the ignition of fires and neither to their propagation;
- Hombe, Lower Imenti and Ragati noted only one small fire for each Station. We had not visited them directly, even because the fire records registered in these territories were extremely few if not absent.

4.2.2 OCCURRRENCE WITHIN THE TIME

From 1980 to 2015 the number of events followed the continental warming, 0.2 – 0.5 °C/decade (Hulme M. et al., 2001), and increased during the decades, even though their size reduced till 2000.

The trend could be connected with the environmental warming, but it had surely a relation with the place where the fires occurred. Ontulili and its frequent and intense fire activity had a relevant role in the firsts decades analysed, after that Gathiuru replaced its position in the last years. For this reason the hazards reduced in frequency and dimension, in the last decades, even though Marania influence increased the mean extension of the fires in the last years (2010 – 2015). Ignition and occurrence were driven by both, natural and human induced factors, which cooperate in modify and establish fire regimes and behaviour (O'brien J. J. et al., 2009 and Huho J. M. et al., 2016). Human being is the main responsible of this kind of events in Kenya (Wass P., 2000) and it could strongly influence the location where fires were ignited. On the other side the time when they started more easily could have been decided by nature. In our research the period of the year that was more prone to fire was defined mainly by the weather condition. Size and quantity of events concentrated the higher values from January to March and from August to September, the driest months of the year (Mbugua D. K., 2012). The occurrence of fires in the other months could be established in the more prone to ignition areas, which did not need extremely dry situations to burn, particularly Gathiuru for fire occurrence and Marania for fire propagation.

4.2.3 DURATION

The rain often mopped up the fires and the much more frequent rainy events from April to June and from October to December (Mbugua D. K., 2012) reduced significantly the duration of the event in these months, grouping the longer disturbances in the driest periods (KWS, 2010). These observations suggested that the weather influenced the duration of the hazard as well. The events that were more difficult to turn off were that of big size, which affected the moorland. The reason could have been the lack of attention and importance for this vegetation (high elevated grassland with rare trees) that had not significant economic value (Nyongesa K. W., 2015). The forest guards and the forester of Ontulili Forest Station explained that usually these areas, located at a the higher elevation, far away from the human settlements and not easily reachable, were left under the fires affection until they reached the edge of the forest.

4.2.4 VEGETATION BURNED

As previously described moorland evidenced big damages, even though bush- and grassland recorded the main amount of burned area. This last vegetation composed by herbs and shrubs was the more prone to fire in all the Stations recorded, whereas burnings in the moorland were strictly connected only with Ontulili and Marania. The relevant role of burned area in the first (as Ontulili) and last (as Marania) years analysed, evidenced the same trend described in the previous paragraph related to the fire regime present within the two territories (4.2.2 "occurrence within the time"). If grassland was the vegetation most prone to fire occurrence, moorland grassland was the vegetation most prone to fire propagation. Forest was frequently affected, suggesting intermediate part in both fire ignition and propagation. Fires occurred frequently in the plantations but always with little dimensions. Their composition based on conifers (*Pinus patula* or *Cupressus lusitanica*), species prone to fire occurrence (KFS, 2010), suggested a high ability to avoid and fight the fires in these areas. Bamboo forest evidenced rare events but with relatively big extension, highlighting the difficulties to fight the fires in these places. All the types of the vegetation evidenced a time occurrence related to the weather conditions, concentrating the events particularly in the driest period.

4.2.5 WHO DETECTED THE FIRE

To fight the fire and prevent them both government and communities worked together, creating groups responsible to fire detection and structures as fire tower where events were more easily detectable (Wass P., 2000 and KFS, 2010). Kenyan Forest Service and Kenya Wildlife Service work together in fire fighting, whereas the communities were involved in the most intense events (NAREDA, 2009). The personal of Forest Stations noticed the great majority of the events, even though communities played a relevant role in fire detection as well. The population usually discovered the fires when KFS failed, most probably in isolated areas, far away from the Station, for this reason they took more time to give the alarm. At the same time, the records could evidence the differences between people well qualified to fight natural hazards and those not trained, underlining the necessity of more skilled men inside the territory (KWS, 2010).

4.2.6 WHERE FIRE WAS DETECTED

The causes of fires in Kenya are almost totally related to the human being (Wass. P., 2000), so that the fire ignition place were detected mainly where people turned it on, acting in each Forest Station in different ways.

Marania evidenced the moorland as the site preferred to set the fire. Due to its long distance from human settlements, its low economic value and the high difficulties in fire fighting, these areas were often left under the fire effect since it reached other vegetation (Nyongesa K. W., 2015). This could be the reason of its fire regime that preferred spread the fires ignited there to forest and bush- grassland, rather than introduce burnings coming from other vegetation. Moorland required more time to be reached because of its long distance from the Forest Station and the road system. On the other hand fires that were detected in the bush- and grassland evidenced the longer time to be mopped up, probably due to its fire-prone fuel and its common propagation in the indigenous forest. The afrotemperate landscape is characterized by forest and grassland, which are strictly connected (Aide H. et al., 2010). This association could have influenced the fire regime and, at the same time, could have varied the places where fire started (Kane V. R. et al., 2014). Our data, particularly those recorded in Ontulili, underlined the strong relationship between natural forest and grassland, in fact fires ignited in one area affect frequently big sizes of the other one and vice versa. Events started in the forest (neither close to the Station, nor extremely far from it) revealed an easy propagation of the fire to other vegetation (especially to bush- and grassland), with an intermediate behaviour, regarding fire suppression and extinction, in the middle between plantation and grasslands environments. If fires were detected within the plantation the reaction was often fast and efficient (Mbugua D. K., 2012), avoiding their proliferation to other vegetations.

4.2.7 FIRE DANGER RATE

Even considering the little amount of available information, the actually adopted fire danger rate system seemed to be reliable. On the other side it was not so clear if its utilisation was commonly accepted and understood by the population.

4.2.8 EQUIPMENT

The lack of a well organized and structured road system did not allow to use vehicles (NAREDA, 2009) and those that were pretty designed for the fire fighting (water tank and helicopters) had too high costs for the wildfire management of the region. Probably, the most common tool that was utilised was tree branch, likely not recorded in many fire records because not considered properly a tool. The equipment were usually manual (pangas, fire beaters, back pumps, tree branches), whereas motorised tools were reserved only for the most prolonged events. The equipment turned out to be obsolete and surpassed and the situation was exasperated by the shortage of this poor equipment. The managers of these territories (NAREDA, 2009) and all around the country (Huho J. M. et al., 2016) requested for an amelioration or at least an increment of equipment availability to fight and control natural hazards.

4.2.9 CAUSES

Almost the totally of the fire occurred in Kenya were generated by human being (Wass P., 2000), in fact the ingnition of grass due to a lightning (KFS, 2010) or the strong wind that scrubbed very dry leaves between each other, were extremely rare. The main fire risk, considering both fire occurrence and fire extension, were related to arsonist, honey collectors (who entered in the forest to collect honey from wild bees, settled a fire to send them to sleep and left the woodland without turning it properly off), shamba system (prescribed not contained fire or lack of attention in preparing the meal) and previous fires (fieres not properly mopped up, which replaced after the fire fighting was declared ended). Assuming that the causes of the recorded fires did not mutate their meanings during the years, the fire causes were related to voluntary purposes ("Arsonist" and "Charcoal burners") in the last years, whereas lack of attention ("Negligence", "Shamba" and "Previous fire") was more frequent in the past rather than nowadays. During the time the informative system was improved, developing a national program to sensitize the population (Wass P., 2000). Nevertheless the weak improvement in fire-related laws and sanctions (KFS, 2010; KWS, 2010) did not decrease the occurrence of fires for economic reasons ("Honey collectors" and "Cattle grazers"), rather, improved them ("Arsonist" and "Charcoal burners").

Fires ignited in the middle of the forest, by honey collectors, charcoal burners and poachers, took more time to be reached due to their isolated location. On the other side, places double affected by the fires because of previously fire were not mopped up properly and areas extremely isolated visited by poachers were the most difficult to be mopped up, requiring more time for the fire extinction.

4.2.10 DELAY IN FIRE FIGHTING

The results of the analysis related to causes and times of delays gave confused and contradictory results, not ensuring the reliability of this kind of information. The reaction to a fire detection revealed to be relatively fast, even if the fire occurred not late in the evening, because the people were rarely allowed to spend the night within the forest also in this particular situation. The records evidenced that the delays of the first reaction were caused mainly by the occurrence of the fires in remote places and consequently by the absence of a well structured road system (NAREDA, 2009). Delay of reinforcement had the same ratio for this (road system) and other reasons that were less relevant in the delay of the fire suppression. The other causes of reinforcement delay were related to the lack of cooperation and organization in fire reaction, driven by the absence of a clear and efficient connection system within the country, present neither in the capital (K'Akumu O. A. et al., 2016).

The fast reaction detected in Gathiuru could be the reason of the relatively smaller sizes burned areas registered in this Forest Station, but the little amount of this kind of information did not ensure the veracity of the reasoning.

4.2.11 TIME OF ALARM

Fire occurrence is much more easily detectable in correspondence of extreme fire weather as high temperature and wind (Kane V. R. et al., 2014), so it was regulated by the weather. Within the day the ignition was concentrated in the hottest hours, around midday. Moreover, the trend is modified during the year highlighting alarms in the morning mainly in the driest months: January, February, March and September (KWS, 2010).

Both, environment and human being, influence the behaviour of the hazard (O'brien J. J. et al., 2009; Huho J. M. et al., 2016). Within the territory, the time of fire ignition defined fire prone and not prone areas evidencing Marania as the less prone for ignition, which happened exclusively after midday. The relation between vegetation and ignition could have been driven by the location of the flora, in fact the places that were most difficultly reachable (moorland) showed postponed ignition. Probably the inner sides of the mountain were less accessible and it was not sure to spend the night there, so arsonists reached these areas later rather than other more easily reachable and closer territories. Plantations were the most easily reachable places and here the fire ignitions were more equally distributed within the day. This could be the reason of the variance of suppression and reinforcement delay. Smaller delays in fire suppression and their reinforcement were present in the areas more accessible affected in the morning and bigger delays were registered in the evening, in more isolated and hardly reachable sites.

4.2.12 RATIO OF AREA BURNED

The distribution of the different vegetation (forest, grassland and plantation) was similar within the Forest Stations analysed, but the fire affected each territory differently. The fires affected more bush- and grassland rather than the other vegetation, thanks to its elevated inclination to fire spreading. Natural forest evidenced lower ability to fire propagation, whereas plantation were strictly controlled and well protected in all the studied Forest Stations excepting for Nanyuki. Ontulili demonstrated to be the most affected region, where fires burned an area bigger than its actual extension in 35 years (its bush- and grassland burned for more than 5 times its actual extension). Marania experienced lower amounts of burned area, even though the northern bush- and grassland detected an amount of burned area bigger than its current dimension.

Comparing our data with that detected by Wass P. (2000), Mount Kenya had a relevant role in the fire occurrence within the national territory. Even though, the bush – and grassland was the vegetation most affected, the region played a relevant role in the national contest for the lost size of indigenous forest. This was an useful information to highlight the importance of the problem in this protected areas and the relevance of the disturbance and of its effects at national scale.

4.2.13 FIRE OCCURRENCE IN THE MOUNT KENYA REGION

The data provided by KEFRI and recorded by MODIS covered only a part of the period previously analysed but corroborated the hypothesis developed by the records scanned in the Forest Stations. They evidenced the first three months of the year as the most prone fire period. In these months the fire occurred homogeneously within the territory, not evidencing any zone more prone to the fire. In the rest of the year the hazards focused mainly in the north-eastern side of the mountain (Marania Forest Station) labelling it as the most risky region, when fire occurred in the not-driest season. To remark that also the outliers, that not followed this trend, were detected right before or after this dry period, that could have been anticipated/extended in that particular year.

5. CONCLUSION

In Mount Kenya's forest the fires affect mainly the natural forest, which have been strongly influenced in both species composition and dimensional structure, especially if fires occurred in areas not used to it. On the other side and on a more general point of view, fire behaviour in this region can be summed up with the warnings "most dangerous areas in northern region" and "most hazardous period from January to March".

The analysis of the vegetation underlined the relevant effects of the fires on both forest composition and structure. The most evident change of the tree dimensions from the not-affected areas was detected in the areas rarely affected by fire, where the regeneration revealed to be fast and influent. The species composition varied differently in the two affected areas enhancing the invasion of alien-pioneer species (Mullah C. J. A. et al., 2014) where fires were rare enough to keep them away. In both the forest stand affected by fire, the vegetation maintained the less demanding species (Bussman R., 2004; Aynekulu et al., 2009), lost the more light-intolerant trees, leaving places to those light-demanding (Beghin R. et al., 2010; Bakthar A. J. et al., 2013). The fires demonstrated that could be helpful in some cases (Verma S. et al., 2014), maintaining the situation stable if occurred frequently (Kumar R. et al., 2008), minimizing the invasion of new species (Symstad A. J. et al., 2014) and ensuring the regeneration of species that required openings to reach a mature stage (Bussman R., 2004; Aynekulu et al., 2009). The fires increased the species diversity and, if frequently occurred, the height diversity as well. Regeneration homogenized the structure after the disease (Verma S. et al., 2014) even though the fire reduced the dimensions range driving mainly the loss of big size trees. The fires affected the stand homogeneously, without evidencing crown or ground behaviour but its intensity suggested different reactions. The fires encouraged species and vertical diversity if they were intense enough to create medium damages while they homogenized the structure when too intense provoking relevant damages and death (Marzano R. et al., 2012). The damages were more visible in the plantation and less in the natural forest rarely affected. Their differences were more evident moving on the stem from the surface to the crown. *Olea europea* was the considered example to describe the effects of the fire on the individuals. Fires decreased the diametric and height sizes of the trees and their frequency enhanced the decline. At the same time they enlarged the crown ratio, creating smaller trees that were much more photosynthetically active.

The fire revealed a behaviour influenced by both human beings and the environment (Huho J. M. et al., 2016). If the human being is almost the only cause of fire ignition, the events occurred more likely in fire prone environment and weather. The most prone areas were focused in the northern part of the region, moving from west to east during the year. Ontulili (north-western Station) revealed to be the most fire prone site during the driest months (from January to March), outside of which

Marania (north-eastern Station) replaced its role. Gathiuru evidenced to be prone to fire ignition and less weather related detecting events commonly smaller all around the year, whereas Marania was the most prone to fire propagation, where the fire had regularly huge extensions. The selection of vegetation that got burned was strictly connected to the human being, whereas the proliferation of the fires was influenced by the economic weight of the areas, its reachability and the interconnection between it and other flora. While the place where fire occurred and its propagation were more related to human, topography and vegetation interaction, the time of its manifestation was driven mainly by the weather conditions. Alternation of rainy and dry seasons regulated the duration of the fires and their monthly and hourly occurrence, evidencing the most prone period in correspondence to less rainy events and higher temperatures. Fire fighting and fire policy reduced the occurrence of events caused by negligence and encouraged the involvement of the communities through training, and sensitization and information systems. Nevertheless it was commonly detected the necessity: to enhance sanctions in fire existing laws; to establish well developed road and communication systems; to improve availability and adequacy of fire fighting equipment (KFS, 2010; KWS, 2010, NAREDA, 2009; Nyongesa K. W., 2015; Wass P., 2000; Huho J. M. et al., 2016; K'Akumu O. A. et al., 2016). In both the type of analysed records, plantations revealed to be well protected and managed against the fire, evidencing relevant lost neither in terms of burned size nor in terms of forest structure altered.

Forest fire can be an extremely destructive natural hazard, haltering quality and quantity of natural resources in a relatively short time. For this reason is extremely important to gain a detailed knowledge on the areas prone to wildfires, in order to take prevention and control measures (Sharma N. R. et al., 2015). To our knowledge this is the first study regarding fires in Mount Kenya forest and this could be the starting point for a more detailed and complete investigation. The main lacks in this research regarded the quantity of samples recorded and analysed, moreover the information registered were restricted only in determinate areas. They were the most numerous and detailed available for our budget and time limitations, even though they could be surely improved in number, accuracy and reliability. The analysis related to the data detected within the woodland should increase in number, recording plots in other territories within Ontulili and in other Forest Stations. In this way it would be possible to verify the homogeneity of fire effects and post-fire structures or discover new type of alterations and reactions within Mount Kenya forest. The data scanned should be integrated with those of the other forest Stations, even if less affected by the fire. Moreover, detailed information related to topography and weather conditions of the whole territory would help to explain better the hypothesis realized in this research and to build a more efficient fire prediction system (Kane V. R. et al., 2015). The fires proved to affect, on both little and large scale, this afroalpine environment that plays a relevant role not only in forest protection but unfortunately also in losses driven by wildfires. The information about the structure and species variations and about the most risky contexts, which varied during the year, can be really helpful for the forest and the fire management of this rare ecosystem.

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7. APPENDICES

Appendix 1 - Structure of the forest within the plots.

Plot classes	Plot code	DBH (cm)	BA/ha	Tree height (m)	First branch height (m)	Crown height (m)	Flame height (m)	Tree number	Tree species	Plot affected
A_F	**C3**	29	39.7	12.1	4.0	9.0	5.7	13	3	✓
	C4	33	41.9	13.1	3.3	6.2	6.4	12	4	✓
	C5	18	4.5	6.9	1.8	4.4	3.6	5	2	✓
	C6	19	24.9	7.3	2.5	3.8	2.9	15	5	✓
	C7	26	19.1	7.8	2.4	4.1	7.7	9	1	✓
	C8	32	24.5	13.0	6.1	7.3	6.9	8	5	✓
An_F	**G1**	17	14.6	12.4	6.2	6.9	3.4	18	2	✓
	G2	15	18.2	11.8	5.5	5.6	2.7	29	4	✓
	K15	21	2.1	11.8	4.5	7.3	10.8	2	2	✓
	K16	23	9.4	9.5	2.6	4.4	6.4	7	1	✓
	K17	24	18.7	9.9	4.9	4.6	7.8	9	4	✓
	K18	31	10.0	13.0	3.1	5.9	12.4	4	4	✓
	K19	19	13.4	9.4	3.3	3.3	8.6	12	4	✓
	K22	29	4.3	11.8	3.0	6.5	11.0	2	1	✓
N_F	**E9**	42	129.5	12.9	5.2	7.2	0.0	23	4	
	E10	37	73.3	16.0	5.7	7.9	0.0	16	3	
	E11	22	26.8	15.3	9.0	10.9	0.0	14	4	
	E12	31	32.7	15.0	6.3	9.6	0.0	12	2	
	E13	87	212.9	27.1	8.8	12.3	0.0	6	4	
	E14	39	60.3	15.3	7.7	9.0	0.0	13	2	
	K20	19	15.5	8.9	3.6	6.2	0.0	15	4	
A_P	**F23**	27	42.5	14.4	4.7	11.9	6.8	22	1	✓
	F24	26	28.7	14.2	3.8	12.0	8.2	16	1	✓
	F25	28	39.5	14.8	5.1	12.9	8.9	19	1	✓
	F26	23	34.1	14.3	6.3	12.0	7.1	23	1	✓
N_P	**F27**	27	31.8	15.1	4.5	11.4	0.0	17	1	
	F28	30	42.7	15.4	4.7	11.4	0.0	18	1	

Appendix 2 - Number of individuals present for each species.

PLOT		TREE SPECIES														
Plot classes	**Plot code**	**Afr.**	**Cup.**	**Ekeb.**	**Frax.**	**Junip.**	**Nux.**	**Olea c.**	**Olea e.**	**Pin.**	**Podo l.**	**Prun.**	**Tar.**	**Tec.**	**War.**	**NA**
A_F	**C3**					7			4	2						
	C4					6			3			1		2		
	C5					1								4		
	C6					2	3		4					3		3
	C7														9	
	C8	2				1			1					1	3	
An_F	**G1**				17	1										
	G2				19	3			6							1
	K15	1						1								
	K16					7										
	K17						2		4				1			2
	K18	1		1			1		1							
	K19	3					3		5							1
	K22								2							
N_F	**E9**	1						1	8		13					
	E10							2	2		12					
	E11					1		3	1		9					
	E12								2		10					
	E13					1		1			2					2
	E14								4		9					
	K20	1					5		6				3			
A_P	**F23**		22													
	F24		16													
	F25		19													
	F26		23													
N_P	**F27**		17													
	F28		18													

Appendix 3 - Number of individuals related to each class of burned and crown scorch.

PLOT		% OF CROWN SCORCH				
Plot classes	**Plot code**	**No damaged (0%)**	**Low damaged (5 – 35%)**	**Medium damaged (40 – 65%)**	**High damaged (70 – 95%)**	**Tree number**
A_F	**C3**	1	10	2		13
	C4	3	9			12
	C5	3	2			5
	C6	11	4			15
	C7	5	4			9
	C8	4	4			8
An_F	**G1**	3	11	4		18
	G2	14	14			29
	K15	1	1			2
	K16		7			7
	K17	3	6			9
	K18		4			4
	K19	1	11			12
	K22		2			2
A_P	**F23**	22				22
	F24	14	2			16
	F25	8	11			19
	F26	21	2			23

PLOT		% OF BURNED CROWN					
Plot classes	**Plot code**	**No burned (0%)**	**Low burned (5 – 35%)**	**Medium burned (40 – 70%)**	**High burned (75 – 100%)**	**Dead (100%)**	**Stem number**
A_F	**C3**			6	7	2	15
	C4		2	8	2	3	15
	C5			1	4		5
	C6	3	3	3	6	8	23
	C7				9	1	10
	C8			6	2		8
An_F	**G1**	11	6	1	0		18
	G2	17	6	1	5		29
	K15			1	1	4	6
	K16		1	1	5		7
	K17		1	3	5		9
	K18			3	1	5	9
	K19		1	4	7	1	13
	K21					4	4
	K22			2		1	3
A_P	**F23**				22	1	23
	F24			2	14	1	17
	F25				19	4	23
	F26			3	20	1	24

Appendix 4 - Number of individuals related to each class of charred bark at surface and at DBH level.

PLOT		% OF CHARRED BARK AT SURFACE LEVEL				
Plot classes	Plot code	No burned (0%)	Low burned (5 – 35%)	Medium burned (40 – 70%)	High burned (75 – 100%)	Tree number
A_F	C3	2	4	4	3	13
	C4		1	3	8	12
	C5				5	5
	C6	2	5	2	6	15
	C7				9	9
	C8			2	6	8
An_F	G1		2	8	8	18
	G2	16	3	5	5	29
	K15				2	2
	K16			2	5	7
	K17	1	3	2	3	9
	K18		1	3		4
	K19		2	4	6	12
	K22				2	2
A_P	F23	2		1	19	22
	F24			7	9	16
	F25				19	19
	F26			5	18	23

PLOT		% OF CHARRED BARK AT DBH LEVEL				
Plot classes	Plot code	No burned (0%)	Low burned (5 – 35%)	Medium burned (40 – 70%)	High burned (75 – 100%)	Tree number
A_F	C3	5	5	2	1	13
	C4	1	3	1	7	12
	C5				5	5
	C6	9	4	2		15
	C7				9	9
	C8		2	3	3	8
An_F	G1	2	8	2	6	18
	G2	15	6	3	5	29
	K15			1	1	2
	K16		2	2	3	7
	K17		3	6		9
	K18		3	1		4
	K19			11	1	12
	K22			2		2
A_P	F23		2	16	4	22
	F24		5	9	2	16
	F25			2	17	19
	F26		1	14	8	23

Appendix 5 – Diversity indices of DBH, tree height and species composition within the plot classes.

PLOT		DIVERSITY INDICES							
		DBH			HEIGHT			SPECIES	
Plot classes	**Plot code**	**TDD**	**Brillouin**	**Simpson**	**THD**	**Brillouin**	**Simpson**	**Brillouin**	**Simpson**
A_F	**C3**	1.59	1.18	0.76	1.88	1.38	0.84	0.78	0.59
	C4	2.02	1.43	0.86	1.63	1.19	0.78	0.91	0.65
	C5	1.33	0.82	0.72	0.95	0.60	0.56	0.32	0.32
	C6	1.02	0.79	0.56	1.78	1.34	0.81	1.24	0.79
	C7	1.31	0.95	0.72	1.43	0.99	0.72	0.00	0.00
	C8	1.49	1.01	0.75	1.73	1.24	0.81	1.01	0.75
An_F	**G1**	1.38	1.11	0.72	1.56	1.20	0.70	0.16	0.10
	G2	1.44	1.24	0.74	1.51	1.29	0.76	0.81	0.52
	K15	0.00	0.00	0.00	0.00	0.00	0.00	0.35	0.50
	K16	1.28	0.86	0.69	0.96	0.66	0.57	0.00	0.00
	K17	1.52	1.07	0.77	1.68	1.15	0.79	0.92	0.69
	K18	1.39	0.79	0.75	1.04	0.62	0.63	0.79	0.75
	K19	1.47	1.09	0.74	1.55	1.16	0.78	0.97	0.69
	K22	0.69	0.35	0.50	0.69	0.35	0.50	0.00	0.00
N_F	**E9**	2.34	1.81	0.89	1.37	1.11	0.66	0.80	0.56
	E10	2.05	1.52	0.85	1.51	1.16	0.73	0.58	0.41
	E11	1.67	1.23	0.76	1.63	1.23	0.78	0.76	0.53
	E12	1.75	1.29	0.82	1.54	1.12	0.74	0.35	0.28
	E13	1.33	0.87	0.72	1.33	0.87	0.72	0.87	0.72
	E14	1.99	1.44	0.85	1.38	1.04	0.70	0.51	0.43
	K20	1.62	1.24	0.77	0.97	0.79	0.59	0.98	0.68
A_P	**F23**	1.46	1.21	0.75	0.82	0.69	0.48	0.00	0.00
	F24	1.56	1.21	0.76	0.86	0.71	0.54	0.00	0.00
	F25	1.51	1.20	0.74	0.91	0.76	0.53	0.00	0.00
	F26	1.50	1.23	0.73	1.07	0.90	0.61	0.00	0.00
N_P	**F27**	1.46	1.16	0.73	0.75	0.61	0.44	0.00	0.00
	F28	1.72	1.34	0.79	1.04	0.84	0.59	0.00	0.00

Appendix 6 - Comparison developed with Kruskal Wallis, the Dunn tests and Bonferroni correction.

DATABASE	CHARACTERISTICS - SIGNIFICANT DIFFERENCE DETECTED		PLOT CLASS - SIGNIFICANT DIFFERENCE DETECTED				
			A_F	An_F	N_F	A_P	N_P
Complete	Structure	DBH		✓-	✓+		
				✓-			✓+
		Tree height	✓+		✓-		
			✓-			✓+	
			✓-				✓+
				✓-	✓+		
				✓-		✓+	
				✓-			✓+
		Crown height	✓-			✓+	
			✓-				✓+
				✓-	✓+		
				✓-		✓+	
				✓-			✓+
					✓-	✓+	
		Crown ratio	✓+			✓-	
				✓+		✓-	
					✓+	✓-	
				✓+			✓-
	Damages	Black DBH		✓-		✓+	
		Black surface		✓-		✓+	
		Crown burned	✓+	✓-			
				✓-		✓+	
			✓-			✓+	
		Crown damaged	✓+			✓-	
				✓+		✓-	
		Crown green	✓-	✓+			
				✓+		✓-	
		Flame height	✓-			✓+	
				✓-		✓+	
Forest	Structure	DBH	✓+	✓-			
				✓-	✓+		
		Tree height		✓-	✓+		
		Crown height		✓-	✓+		
Plantation	Structure	Tree height				✓-	✓+
		Crown height				✓+	✓-
		Crown ratio				✓-	✓+
Olea	Structure	DBH	✓-		✓+		
		Tree height	✓-		✓+		
		Crown height	✓-		✓+		
				✓-	✓+		
	Damages	Black DBH	✓-	✓+			

Appendix 7 - Number and extensions of fires in the Forest Stations during the years.

FIRES OCCURRED	YEARS				FOREST STATION
	'80	'90	'00	'10	
Total (ha)	82.0	964.4	2565.7	897.0	GATHIURU
Mean (ha)	20.5	80.4	95.0	89.7	
Minimum (ha)	15.0	1.5	1.5	4.0	
Median (ha)	22.0	24.5	20.0	19.0	
Maximum (ha)	40.0	150.0	125.0	200.0	
Number	4	12	27	10	
Total (ha)	-	1077.5	685.0	2000.0	MARANIA
Mean (ha)	-	269.4	228.3	1000.0	
Minimum (ha)	-	3.0	5.0	500.0	
Median (ha)	-	238.3	8.0	1000.0	
Maximum (ha)	-	598.0	672.0	1500.0	
Number	-	4	3	2	
Total (ha)	77.0	26.5	192.0	100.0	NANYUKI
Mean (ha)	19.3	5.3	32.0	100.0	
Minimum (ha)	1.0	0.2	4.0	100.0	
Median (ha)	8.0	1.0	21.5	100.0	
Maximum (ha)	60.0	17.0	80.0	100.0	
Number	4	5	6	1	
Total (ha)	8592.0	6533.0	1664.5	1757.8	ONTULILI
Mean (ha)	296.3	362.9	138.7	219.7	
Minimum (ha)	1.5	1.2	1.0	0.3	
Median (ha)	53.0	40.0	25.5	2.8	
Maximum (ha)	800.0	1400.0	400.0	400.0	
Number	29	18	12	8	

Appendix 8 - Number and extensions of fires in the Forest Stations during the months.

FIRES OCCURRED	MONTH											FOREST STATION
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Dec	
Total (ha)	346	1352	2212	-	2	5	16	109	433	4	-	GATHIURU
Mean (ha)	69	84	158	-	2	5	8	18	72	4	-	
Minimum (ha)	1.5	4	1.5	-	2	5	4	1.5	8	4	-	
Median (ha)	18	25	39	-	2	5	8	19	30	4	-	
Maximum (ha)	200	510	800	-	2	5	12	30	200	4	-	
Number	5	16	14	-	1	1	2	6	6	1	-	
Total (ha)	-	1500	500	-	-	-	1127	-	636	-	-	MARANIA
Mean (ha)	-	1500	500	-	-	-	376	-	159	-	-	
Minimum (ha)	-	1500	500	-	-	-	5	-	3	-	-	
Median (ha)	-	1500	500	-	-	-	450	-	17	-	-	
Maximum (ha)	-	1500	500	-	-	-	672	-	598	-	-	
Number	-	1	1	-	-	-	3	-	4	-	-	
Total (ha)	100	206	19	-	-	-	-	6	64	-	-	NANYUKI
Mean (ha)	100	23	6	-	-	-	-	6	32	-	-	
Minimum (ha)	100	0.2	1	-	-	-	-	6	4	-	-	
Median (ha)	100	13	8	-	-	-	-	6	32	-	-	
Maximum (ha)	100	80	10	-	-	-	-	6	60	-	-	
Number	1	9	3	-	-	-	-	1	2	-	-	
Total (ha)	3439	8496	6436	159	-	-	-	-	-	-	2.7	ONTULILI
Mean (ha)	313	250	379	53	-	-	-	-	-	-	1.4	
Minimum (ha)	0.25	1	5	20	-	-	-	-	-	-	1.2	
Median (ha)	20	40	150	60	-	-	-	-	-	-	1.4	
Maximum (ha)	2000	2255	2100	79	-	-	-	-	-	-	1.5	
Number	11	34	17	3	-	-	-	-	-	-	2	

Appendix 9 - Number and extensions of fires in Forest Stations for each type of affected vegetation.

FIRES OCCURRED	VEGETATION TYPE					FOREST STATION
	Bamboo forest	Bush- and grassland	Indigenous forest	Moorland	Plantation	
Total (ha)	100.0	2986.8	831.5	100.0	85.8	GATHIURU
Mean (ha)	100.0	80.7	36.2	100.0	6.1	
Minimum (ha)	100.0	1.5	1.0	100.0	1.0	
Median (ha)	100.0	20.0	10.0	100.0	3.0	
Maximum (ha)	100.0	750.0	250.0	100.0	20.0	
Number	1	37	23	1	14	
Total (ha)	-	1995.0	568.0	1198.0	1.5	MARANIA
Mean (ha)	-	285.0	71.0	399.3	1.5	
Minimum (ha)	-	2.0	1.0	300.0	1.5	
Median (ha)	-	105.0	9.0	315.0	1.5	
Maximum (ha)	-	1000.0	500.0	583.0	1.5	
Number	-	7	8	3	1	
Total (ha)	55.0	141.8	112.3	50.0	36.5	NANYUKI
Mean (ha)	27.5	28.4	18.7	50.0	4.1	
Minimum (ha)	5.0	0.75	0.25	50.0	0.2	
Median (ha)	27.5	7.0	12.5	50.0	36.45	
Maximum (ha)	50.0	70.0	60.0	50.0	10.0	
Number	2	5	6	1	9	
Total (ha)	-	9140.6	3124.4	5860.0	421.1	ONTULILI
Mean (ha)	-	212.6	89.3	586.0	16.2	
Minimum (ha)	-	0.5	0.3	30.0	0.3	
Median (ha)	-	50.0	10.0	287.5	3.8	
Maximum (ha)	-	1000.0	1100.0	2225.0	200.0	
Number	-	43	35	10	26	

Appendix 10 - Number and extensions of fires in the vegetation types during the years.

FIRES OCCURRED	YEARS				VEGETATION TYPE
	'80	'90	'00	'10	
Total size (ha)	-	-	5.0	150.0	**BAMBOO FOREST**
Mean size (ha)	-	-	5.0	75.0	
Minimum size (ha)	-	-	5.0	50.0	
Median size (ha)	-	-	5.0	75.0	
Maximum size (ha)	-	-	5.0	100.0	
Number	-	-	1	2	
Total size (ha)	2819.8	4576.2	3759.7	3146.5	**BUSH- and GRASSLAND**
Mean size (ha)	122.6	183.0	113.9	185.1	
Minimum size (ha)	0.5	1.9	1.2	0.5	
Median size (ha)	20.0	50.0	20.0	20.0	
Maximum size (ha)	778.5	1000.0	750.0	1000.0	
Number	23	25	33	17	
Total size (ha)	201.9	2767.5	643.5	1012.3	**INDIGENOUS FOREST**
Mean size (ha)	15.5	147.2	23.0	67.5	
Minimum size (ha)	0.3	1.0	1.0	0.3	
Median size (ha)	5.0	20.0	9.0	5.0	
Maximum size (ha)	60.0	1100.0	250.0	500.0	
Number	13	19	28	15	
Total size (ha)	5580.0	928.0	250.0	450.0	**MOORLAND**
Mean size (ha)	797.1	309.3	125.0	150.0	
Minimum size (ha)	40.0	30.0	50.0	50.0	
Median size (ha)	400.0	315.0	125.0	100.0	
Maximum size (ha)	2225.0	583.0	200.0	300.0	
Number	7	3	2	3	
Total size (ha)	144.4	313.5	83.0	4.0	**PLANTATION**
Mean size (ha)	11.1	14.9	5.5	4.0	
Minimum size (ha)	0.5	0.2	0.3	4.0	
Median size (ha)	2.0	4.0	3.0	4.0	
Maximum size (ha)	68.4	200.0	26.0	4.0	
Number	13	21	15	1	

Appendix 11 - Time of reaction to fires detected in/affected different vegetation.

TIME OF REACTION - WHERE FIRES WERE DETECTED					
TIME SPENT	VEGETATION TYPE				REACTION
	Bush- and grassland	Indigenous forest	Moorland	Plantation	
Minimum (h:min)	0:00	0:00	0:00	0:00	Time to reach the fire
Mean (h:min)	0:47	2:03	138:30	1:20	
Median (h:min)	1:00	1:00	2:00	0:30	
Maximum (h:min)	2:00	12:00	1464:00	15:00	
Minimum (d)	1	1	1	1	Time to extinguish the fire
Mean (d)	5	5	16	3	
Median (d)	3	4	5	2	
Maximum (d)	17	10	67	13	

TIMEOF REACTION - WHICH VEGETATION FIRES AFFECTED					
TIME SPENT	VEGETATION TYPE				REACTION
	Bush- and grassland	Indigenous forest	Moorland	Plantation	
Minimum (h:min)	0:00	0:00	0:00	0:00	Time to reach the fire
Mean (h:min)	0:58	1:01	99:00	0:58	
Median (h:min)	0:00	0:00	0:00	0:23	
Maximum (h:min)	22:00	15:00	1464:00	15:00	
Minimum (d)	1	1	1	1	Time to extinguish the fire
Mean (d)	4	5	14	4	
Median (d)	2	4	8	2	
Maximum (d)	29	17	67	29	

Appendix 12 -Extension of the fires caused by different reasons for each deacade.

SIZE OF FIRE – CAUSES OF FRE IGNITION										
FIRES OCCURRED	**CAUSES**									**DECADE**
	Ars.	**Cat.**	**Char.**	**Cig.**	**Hon.**	**Neg.**	**Poac.**	**Prev.**	**Shamb.**	
Total size (ha)	60.0	150.0	-	17.5	160.0	853.0	-	1181.5	2440.0	**'80**
Mean size (ha)	60.0	150.0	-	8.8	80.0	213.3	-	393.8	488.0	
Number	1	1	-	2	2	4	-	3	5	
Total size (ha)	2229.0	660.0	-	815.0	589.5	926.4	122.0	1000.0	100.0	**'90**
Mean size (ha)	278.6	330.0	-	203.8	65.5	308.8	122.0	1000.0	25	
Number	8	2	-	4	9	3	1	1	4	
Total size (ha)	2525.2	119.0	802.0	-	185.0	30.0	-	-	-	**'00**
Mean size (ha)	101.8	29.8	133.7	-	30.8	30.0	-	-	-	
Number	25	4	6	-	6	1	-	-	-	
Total size (ha)	563.0	-	120.8	20.0	401.0	-	200.0	-	-	**'10**
Mean size (ha)	80.4	-	24.2	20.0	200.5	-	200.0	-	-	
Number	7	-	5	1	2	-	1	-	-	
Total size (ha)	5377.2	929.0	922.8	852.5	1335.5	1809.4	322.0	2181.5	2540.0	**TOTAL**
Mean size (ha)	131.2	132.7	83.9	121.8	70.3	226.2	161.0	545.4	282.2	
Number	41	7	11	7	19	8	2	4	9	

Appendix 13 - Time of suppression of fire caused by different reasons.

TIME REACTION – CAUSES OF FRE IGNITION										
TIME SPENT	**CAUSES**									**REACTION**
	Ars.	**Cat.**	**Char.**	**Cig.**	**Hon.**	**Neg.**	**Poac.**	**Prev.**	**Shamb.**	
Minimum (h:min)	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	**Time to reach the fire**
Mean (h:min)	0:35	0:09	0:58	0:26	4:29	0:17	6:05	0:45	2:27	
Median (h:min)	0:30	0:00	0:50	0:00	1:00	0:00	6:05	0:00	0:00	
Maximum (h:min)	2:00	0:35	3:15	1:00	22:00	1:30	12:20	3:00	15:00	
Minimum (d)	1	1	1	1	1	2	4	7	2	**Time to extinguish the fire**
Mean (d)	4	3	3	3	4	4	7	37	5	
Median (d)	2	3	2	1	2	4	7	37	4	
Maximum (d)	29	5	15	11	13	8	10	67	10	

Appendix 14 - Extension of the fires caused by different reasons for each vegetation affected and for each vegetation ignited.

SIZE VEGETATION DESTROYED – CAUSES OF FRE IGNITION										
WHICH AREAS FIRES AFFECTED										
FIRES OCCURRED	**CAUSES**									**VEGETATION AFFECTED**
	Ars.	**Cat.**	**Char.**	**Cig.**	**Hon.**	**Neg.**	**Poac.**	**Prev.**	**Shamb.**	
Total size (ha)	3644.7	675.0	842.5	244.5	728.8	1619.7	104.0	1311.0	125.0	**Bush- and grassland**
Mean size (ha)	130.2	168.8	105.3	40.8	66.3	231.4	104.0	437.0	41.7	
Number	28	4	8	6	11	7	1	3	3	
Total size (ha)	1374.0	252.5	75.25	600.0	237.0	175.3	17.0	401.6	176.5	**Forest**
Mean size (ha)	80.8	50.5	12.5	600.0	18.2	35.1	17.0	200.8	29.4	
Number	17	5	6	1	13	5	1	2	6	
Total size (ha)	200	-	-	-	345.0	-	100.0	400.0	2225.0	**Moorland**
Mean size (ha)	200	-	-	-	172.5	-	100.0	400.0	2225.0	
Number	1	-	-	-	2	-	1	1	1	
Total size (ha)	158.5	1.5	-	8.0	23.5	14.5	1.0	68.9	13.5	**Plantation**
Mean size (ha)	9.3	1.5	-	2.7	5.9	4.8	1.0	34.5	6.8	
Number	17	1	-	3	4	3	1	2	2	
WHERE FIRES WERE DETECTED										
FIRES OCCURRED	**CAUSES**									**WHERE FIRES WERE DETECTED**
	Ars.	**Cat.**	**Char.**	**Cig.**	**Hon.**	**Neg.**	**Poac.**	**Prev.**	**Shamb.**	
Total size (ha)	234.5	-	100.0	831.0	400.0	700.0	-	-	90.5	**Bush- and grassland**
Mean size (ha)	260.3	-	100.0	207.8	400.0	700.0	-	-	45.3	
Number	9	-	1	4	1	1	-	-	1	
Total size (ha)	435.0	157.5	4.3	-	35.5	-	-	1000.0	5.0	**Forest**
Mean size (ha)	108.8	78.8	2.1	-	11.8	-	-	1000.0	5.0	
Number	4	2	2	-	3	-	-	1	1	
Total size (ha)	250.0	-	-	-	553.8	-	200.0	-	-	**Moorland**
Mean size (ha)	250.0	-	-	-	92.3	-	200.0	-	-	
Number	1	-	-	-	6	-	1	-	-	
Total size (ha)	94.2	1.5	-	-	-	46.4	-	-	4.5	**Plantation**
Mean size (ha)	10.5	1.5	-	-	-	46.4	-	-	4.5	
Number	9	1	-	-	-	1	-	-	1	
Total size (ha)	5377.2	929.0	922.8	852.5	1335.5	1809.4	2181.5	322.0	2540.0	**TOTAL**
Mean size (ha)	131.2	132.7	83.9	121.8	70.3	226.2	545.4	161.0	282.2	
Number	41	7	11	7	19	8	4	2	9	

Appendix 15 - Time of reaction to fires ignited in different periods of the day

TIME OF REACTION - WHERE FIRES WERE DETECTED						
TIME SPENT	**VEGETATION TYPE**					**REACTION**
	Early morning	**Morning**	**Midday**	**Afternoon**	**Evening**	
Minimum (h:min)	1:00	0:00	0:15	0:00	0:30	**Delay of the suppression**
Mean (h:min)	1:15	3:53	1:16	2:11	8:21	
Median (h:min)	1:00	1:15	1:00	1:00	12:00	
Maximum (h:min)	3:15	3:00	3:00	2:00	15:00	
Minimum (h:min)	0:00	0:00	0:00	0:30	0:00	**Delay of the reinforcement**
Mean (h:min)	0:30	10:17	5:05	8:53	9:30	
Median (h:min)	0:30	9:53	1:00	9:08	8:15	
Maximum (h:min)	1:00	23:00	22:00	21:30	26:00	