Fire Management in Mount Kenya: A Case Study of Gathiuru Forest Station

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Abstract: This paper proposes an Integrated Fire Management (IFM) framework that can be used to support communities and resource managers in finding effective and efficient approaches to prevent damaging fires, as well as to maintain desirable fire regimes in Kenya. Designing and implementing an IFM approach in Kenya calls for a systematic understanding of the various uses of fire and the underlying perceptions and traditional ecological knowledge of the local people. The proposed IFM framework allows different stakeholders to evaluate the risks posed by fires and balance them with their beneficial ecological and economic effects making it easier for them to develop effective fire management approaches. A case study of the proposed IFM framework was conducted in Gathiuru Forest, which that is part of the larger Mt. Kenya Forest Ecosystem. Focus group discussions were held with key resource persons, primary and secondary data on socio-economic activities was studied, fire and weather records were analysed and the current fire management plans were consulted. Questionnaires were used to assess how the IFM is implemented in the Gathiuru Forest Station. The results show that the proposed IFM framework is scalable and can be applied in places with fire-dependent ecosystems as well as in places with fire-sensitive ecosystems in Kenya. The effectiveness of the proposed IFM framework depends on the active participation, formulation and implementation of the IFM activities by the main stakeholder groups (Kenya Forest Service (KFS), Kenya Wildlife Service (KWS), and the Community Forest Associations (CFA). The proposed IFM framework helps in implementing cost-effective approaches to prevent damaging fires and maintain desirable fire regimes in Kenya.

Keywords: human activities; participation; firewood; charcoal; grazing; water; honey; farming; community forest association

1. Introduction

Anthropogenic fires have been common throughout the world since the discovery of fire [1] and almost every landscape has a complex history of human land use and natural disturbances [2]. The distinction between 'natural' and 'cultural' landscapes is not always obvious [3] because different communities around the world have been using fire as a tool in land management for many centuries to manipulate vegetation composition, structure, and fuel loads on farmlands, rangelands and other wildland ecosystems [4].

Many communities in Kenya use fire as a tool in land management. Perennial grassland fires are common in many parts of the country because each year during the dry season, communities set grasslands on fire to keep them open and to facilitate the growth of new grass for livestock, especially before the rain begins. Farmers in Kenya use fire to prepare farmlands, break impenetrable bushlands; control weeds, pests and parasites and try to keep wildlife away from homes. Bushland and forest fires are common in Kenya because some community members use fire to burn charcoal, harvest wild honey, and hunt and roast game meat in forests and national parks [5].

Several studies have been done on traditional ecological knowledge based fires and the uncertainty of success of fire exclusion policies [6–8]. Even though the Kenya Grass Fire Act, Cap 327, provides a regulation for planned burnings of bushes, shrubs, grass, crops, and stubble within protected areas, the KFS and KWS have however continued to practice fire suppression campaigns instead of using prescribed burning activities to manage fuel accumulation in forests and national parks of Kenya. This is mainly based on the belief that any disturbance, such as fire, disrupts the progress towards an equilibrium state. Total fire suppression, in combination with other human-caused environmental changes have resulted in huge and catastrophic wildfires in forests and national parks of Kenya [4].

Kenya's fast growing population is increasing the pressure on the available forest resources [9]. Human activities in forests to obtain firewood, charcoal, timber, poles, and grass for livestock have increased tremendously over the past three decades. Additional pressures arise from the demand for good quality water, land for the cultivation of crops, income from ecotourism, herbal medicine, game meat, and honey, among others [9]. As a result, all five key forested water towers (Mt. Kenya, Mt. Elgon, the Cherangani Hills, the Mau Forest Complex, and The Aberdares) have experienced human encroachment, land use change, wildfires, and degradation. The same applies to lowland and coastal forests [10].

The changing climate, vegetation dynamics, human activities, and forest management influence the occurrence of fires [11]. Despite compelling evidence on the role of climate change in influencing fire regimes through changes to temperature, rainfall, humidity, wind, and the amount of carbon dioxide in the atmosphere, humans are most often the leading cause of fire ignition [4]. Human caused fire ignitions in forests and national parks of Kenya are more likely to increase in the future because climate change may affect fire season length and severity [12]. On the other hand, most of the natural fires in forests and national parks of Kenya are generally started by lightning [4]. However, most of the fires caused by lightning are recorded under unknown causes, making it difficult to estimate their social, economic, cultural and ecological effects [4]. According to the KFS, the number of forest fire incidences has increased causing more damage to the forests, socio-economy, and environment. Ground fires, surface fires and crown fires have occurred in Kenyan grasslands, farmlands, bushlands, and forests [12]. As a response, the government of Kenya has initiated a participatory forest fire management program that involves collaboration between the KFS, Kenya Wildlife Service (KWS), the Kenya Defense Forces (KDF), the British Army, Community Forest Associations (CFAs), and other stakeholder groups to work together in forest fire prevention and suppression efforts. However, the termination of donor funding, limited governmental funds to tackle forest fire issues, the retrenchment of human resources within the KFS and KWS, and the lack of adequate equipment and well-trained firefighters have seriously affected the capacity to effectively suppress and combat wildfires [13].

In the year 2014, the parliament of Kenya passed the county governments' fire and disaster management bill that prepared the ground for the country to establish and implement IFM approaches in the future. Currently, there is no IFM policy in place that aims to address both damaging and beneficial fires by evaluating and balancing the associated risks. Existing fire management guidelines do not consider the development of concepts for planning and operational systems that combine prevention and suppression techniques while integrating the use of prescribed fires and traditional burning practices. There is a need to consider social, economic, cultural and ecological aspects in minimizing the damage of catastrophic fires and maximizing the benefits of prescribed fires [13].

Establishing and implementing Integrated Fire Management (IFM) approaches in Kenya would call for understanding the various uses of fire, along with the underlying perception and traditional ecological knowledge of the local people [14–16]. However, at the local level, resource managers have largely been addressing fire as a hazard rather than a tool for land management. The traditional use of fire in Kenya for supporting the livelihoods of the local people needs to be considered when developing and implementing IFM guidelines and policies [17]. There is also a need to give special consideration to social and community values and engage the community in IFM planning and implementation. This will help communities and resource managers in Kenya to find cost-effective approaches to prevent damaging fires, as well as to maintain desirable fire regimes.

The government of Kenya needs to finance, educate, train, equip, and motivate resource managers, rangers, firefighters, CFA members, and forest scouts that are involved in fire prevention and suppression activities to achieve sustainable IFM strategies. Proper mechanisms for addressing inter-community conflicts over the use of forest resources can be incorporated in IFM strategies. IFM principles have to be established in accordance with relevant international laws, taking into account all technological, economic, relevant biological, social, cultural and environmental expert knowledge about Kenya's forests. There is a need to contribute to the implementation of county, sub-national, and national policies and planning mechanisms for establishing or improving the legal, regulatory, and institutional framework required for responsible IFM activities in Kenya's forests.

This paper highlights the importance of developing and using an IFM framework to support communities and resource managers in finding effective and efficient approaches to prevent damaging fires, as well as maintain desirable fire regimes, in Kenya. The objectives of this publication are (i) to propose a framework for an integrated fire management approach, (ii) to apply the framework in a case study, and (iii) to propose fire management guidelines considering the challenges faced by the KFS and local CFA. In the following sections, we will introduce the framework for IFM, present the Gathiuru Forest Station case study and methodological steps for analysis and draw some conclusions on fire management.

2. Integrated Fire Management Framework

There are several Integrated Fire Management approaches that have been suggested and adopted in various countries. The Implementation of the British Columbia Wildland Fire Management Strategy aims at achieving healthier forest and range ecosystems, communities that are less at risk from fire and smoke, and a more cost-effective fire suppression program [18].The Food and Agriculture Organization of the United Nations (FAO) Fire Management Voluntary Guidelines advise authorities and other stakeholder groups that fire-fighting should be an integral part of a coherent and balanced policy applied not only to forests but also across other land-uses in the landscape [17].

Mt. Kenya forest ecosystems are known to have a long fire history and fire has influenced the vegetation in the landscape. Some plant species found in the Mt. Kenya forest require fire to germinate, establish, or to reproduce, and total fire suppression not only eliminates these species, but also affects the animals that depend upon them [16]. The indigenous woody species mostly found in regularly burnt sites in Mt. Kenya include *Juniperus procera* (Hochst. ex Endl.) and *Hagenia abyssinica* (Bruce) J.F.Gmel., while the herbaceous species include *Ferula communis* (Linnaeus), *Gomphocarpus stenophyllus* (Oliv.) and *Cardius keniensis* (Linnaeus) among others [19].

More recent ecological research has shown, however, that fire is an integral component in the function and biodiversity of many natural habitats, and that the organisms within these communities have adapted to withstand, and even to exploit, natural and anthropogenic fires. It is true that in the fire management literature, traditional anthropogenic fires in the pre-industrial era are considered as a part of the historical fire regime and the distinction between anthropogenic and natural fires is difficult because of the uncertainty underlying the extent and scale of pre-industrial era anthropogenic burning [20]. More generally, fire is now regarded as a 'natural disturbance', similar to flooding, wind-storms, and landslides, that has driven the evolution of species and controls the characteristics of ecosystems [16]. Based on these findings from international scientific literature, an IFM framework shown in Figure 1 was designed to support the management of fire sensitive ecosystems, as well as of other ecosystems with more frequent historical fires in Kenya. It considers the fact that ecological benefits of prescribed fires often outweigh their negative effects. A regular occurrence of fires can reduce the amount of fuel build-up, thereby lowering the likelihood of a potentially large wildland fire [21]. Fire removes low-growing underbrush, clears dead or weaker trees, cleans the forest floor of debris, opens it up to sunlight, and reduces competition for nutrients and space, allowing established trees to grow stronger and healthier [22]. The ashes that remain after a fire add nutrients that are often locked in older vegetation to the soil for trees and other vegetation. Fires can also provide a way of controlling insect pests by killing off the older or diseased trees and leaving the younger, healthier trees [21]. Burned trees provide habitats for nesting birds, homes for mammals,

and a nutrient base for new plants. Overall, fire is a catalyst for promoting biological diversity and healthy ecosystems. Fire fosters new plant growth and wildlife populations often expand as a result [23].
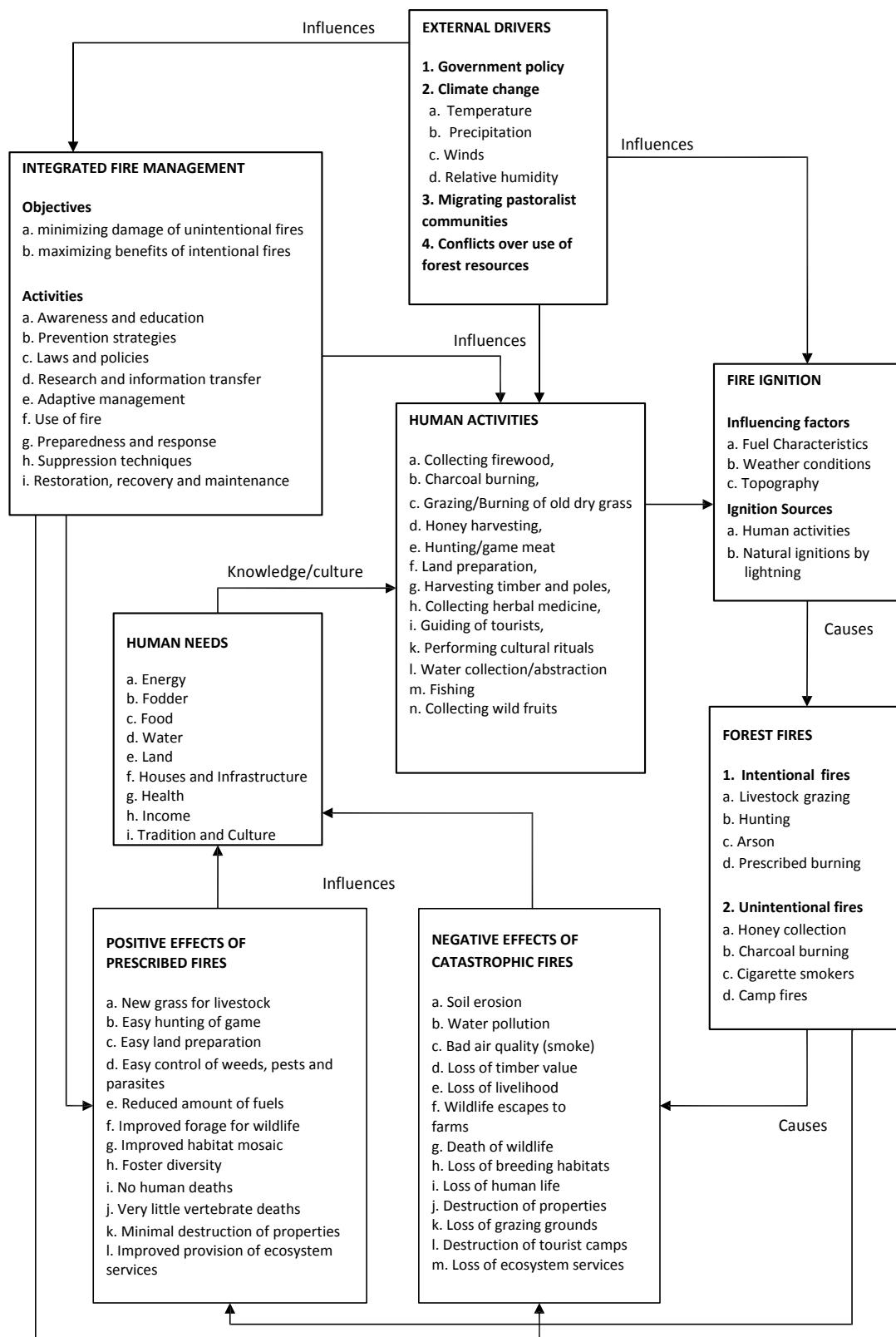
EXTERNAL DRIVERS

1. Government policy
2. Climate change
 a. Temperature
 b. Precipitation
 c. Winds
 d. Relative humidity
3. Migrating pastoralist communities
4. Conflicts over use of forest resources

INTEGRATED FIRE MANAGEMENT

Objectives
a. minimizing damage of unintentional fires
b. maximizing benefits of intentional fires

Activities
a. Awareness and education
b. Prevention strategies
c. Laws and policies
d. Research and information transfer
e. Adaptive management
f. Use of fire
g. Preparedness and response
h. Suppression techniques
i. Restoration, recovery and maintenance

HUMAN ACTIVITIES

a. Collecting firewood,
b. Charcoal burning,
c. Grazing/Burning of old dry grass
d. Honey harvesting,
e. Hunting/game meat
f. Land preparation,
g. Harvesting timber and poles,
h. Collecting herbal medicine,
i. Guiding of tourists,
k. Performing cultural rituals
l. Water collection/abstraction
m. Fishing
n. Collecting wild fruits

FIRE IGNITION

Influencing factors
a. Fuel Characteristics
b. Weather conditions
c. Topography
Ignition Sources
a. Human activities
b. Natural ignitions by lightning

HUMAN NEEDS

a. Energy
b. Fodder
c. Food
d. Water
e. Land
f. Houses and Infrastructure
g. Health
h. Income
i. Tradition and Culture

FOREST FIRES

1. Intentional fires
a. Livestock grazing
b. Hunting
c. Arson
d. Prescribed burning

2. Unintentional fires
a. Honey collection
b. Charcoal burning
c. Cigarette smokers
d. Camp fires

POSITIVE EFFECTS OF PRESCRIBED FIRES

a. New grass for livestock
b. Easy hunting of game
c. Easy land preparation
d. Easy control of weeds, pests and parasites
e. Reduced amount of fuels
f. Improved forage for wildlife
g. Improved habitat mosaic
h. Foster diversity
i. No human deaths
j. Very little vertebrate deaths
k. Minimal destruction of properties
l. Improved provision of ecosystem services

NEGATIVE EFFECTS OF CATASTROPHIC FIRES

a. Soil erosion
b. Water pollution
c. Bad air quality (smoke)
d. Loss of timber value
e. Loss of livelihood
f. Wildlife escapes to farms
g. Death of wildlife
h. Loss of breeding habitats
i. Loss of human life
j. Destruction of properties
k. Loss of grazing grounds
l. Destruction of tourist camps
m. Loss of ecosystem services

Influences Knowledge/culture Influences Causes Causes

Figure 1. A proposed Integrated Fire Management (IFM) framework that helps communities and natural resource managers address both damaging and beneficial fires in Kenya.

According to the KFS records, catastrophic fires in Kenya have been causing soil erosion, water pollution, bad air quality (smoke), loss of timber value, loss of livelihood, wildlife to escape onto peoples farms, death of wildlife, loss of wildlife breeding habitats, loss of human life, destruction of properties, loss of grazing grounds, destruction of tourist camps sites, and loss of ecosystem services [4].

The proposed IFM framework helps communities and natural resource managers to address both damaging and beneficial fires within the context of the natural environments and socio-economic systems in which they occur, by evaluating and balancing the relative risks posed by fires with the beneficial ecological and economic effects they may cause in a given conservation area, landscape, or region. It helps to identify factors influencing fire ignition as it relates human needs and land use activities to factors influencing fire ignition. The roles of external drivers in influencing fire danger are estimated, and the positive and negative effects of fires are ascertained. It also helps in evaluating the benefits and risks of different management activities and developing fire management guidelines considering human needs and land use activities (Figure 1).

3. Materials and Methods

3.1. Description of the Study Site: Gathiuru Forest Station

Gathiuru Forest is part of the larger Mount Kenya Ecosystem and is one of 18 forest stations. It covers an area of approximately 14,978 ha, which is comprised of 612.5 ha of grassland, 1187.9 ha of bush land, 1995.0 ha of bamboo, and 8625.3 ha indigenous and 2557.6 ha plantation forest areas as shown in Figure 2. Gathiuru Forest is highly prone to wildfire outbreaks and has a high number of recorded fire incidences [24]. The station experienced 63 fire incidences from 1980 to 2015. These fires have burned a total area of 4509.1 ha and the KFS has spent a total of $41,917 on fighting the fires. The total damage caused by forest fires from 1980 to 2015 is estimated to be $443,837.
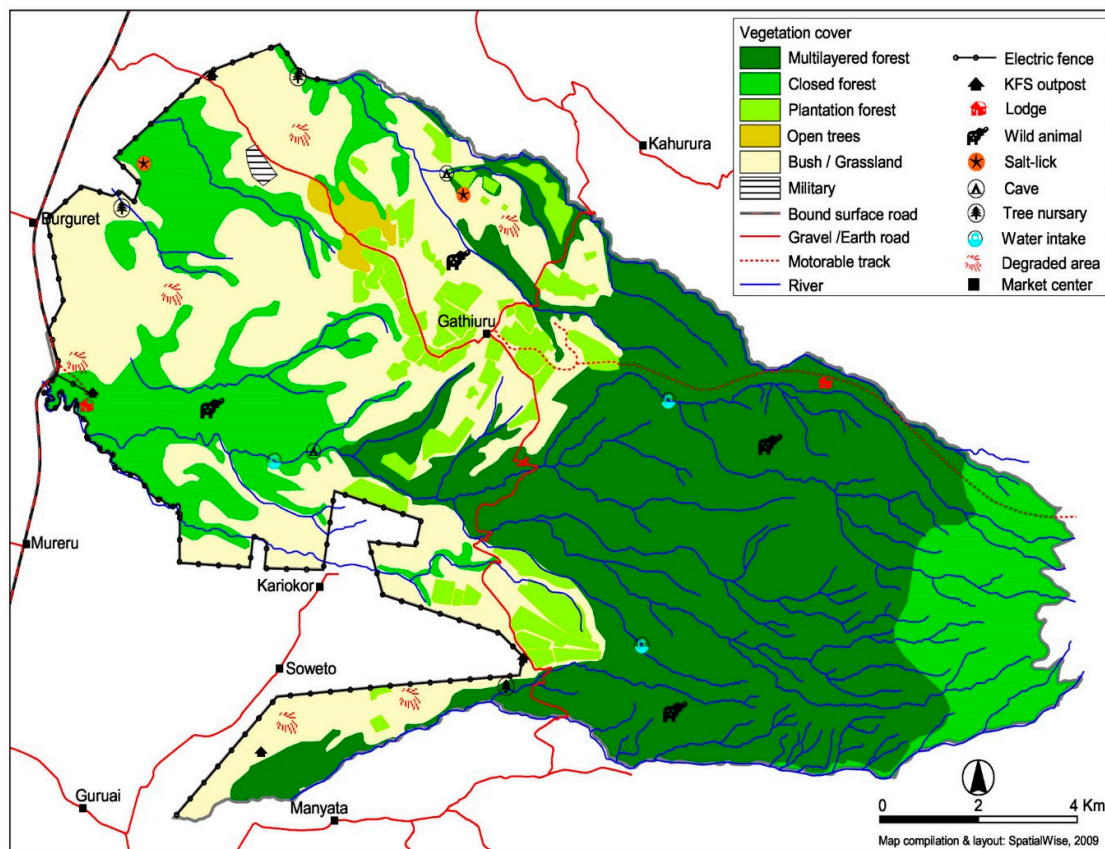

Figure 2. Gathiuru Forest Vegetation Types and Management Units, 2009.

3.2. Methods for Analysing the Conditions

3.2.1. Feasibility Study

A feasibility study was conducted from the 1 to 30 September 2015 in the 18 forest stations that form the Mt. Kenya Forest Ecosystem to establish forest stations that are prone to fires. Out of the 18 forest stations around the Mt. Kenya forest ecosystem, Gathiuru forest station was selected because it had the highest number of fire incidences recorded in the last 35 years compared to all the other forest stations and had fully developed a fire management plan that is under implementation from 2010–2019. It helps to guide fire management activities in high fire risk areas, identify objectives for fire management, outline strategies, and propose works to increase the level of fire preparedness. Formal and informal meetings were held with key resource persons from KFS, CFA members and other stakeholders that are involved in the management of the Gathiuru Forest. A study of primary and secondary data on socio-economic activities, fire records, weather records, and observation and documentation of the fire management plans in Gathiuru Forest Station was completed. An assessment of how well Gathiuru forest station was implementing the fire management plan was also performed.

3.2.2. Questionnaires

Questionnaires were designed and a pilot test was conducted to refine the questions. The questionnaire included: Yes or No responses, with some questions that allowed responses on a Likert type of scale ranging from a very great extent (5) to no extent at all (1) and no response (0); and others where participants were required to express their personal opinions verbally. The questionnaires were used to interview 16 respondents from Gathiuru Forest Station (one KFS manager, one ranger, two CFA leaders, and 12 CFA members) between October 2015 and December 2016. The level of education, gender, and socio-economic activities, motivation, potential, and constraints (problems) affecting forest managers, rangers, CFA members, and other stakeholders' participation in wildfire management in Gathiuru Forest and the surrounding villages were analysed. The awareness about the existence of the fire management plan; fire preparedness plans; damage caused by wildfire to communities and the environment; causes of wildfires; community participation in wildfire management; the channels of communication preferred by forest managers and CFA leaders to receive and give information on fires in Gathiuru Forest and the surrounding villages; and the training of CFA members, rangers, and forest scouts on fire fighting in Gathiuru Forest and the surrounding villages, were also surveyed using questionnaires.

3.2.3. Focus Group Discussions

A focus group discussion is a good way to gather people together with similar backgrounds or experiences to discuss a specific topic of interest. On the 10 November 2016, a focus group discussion was held with 24 participants that included the Chief Ecosystem Conservator, KFS forest managers, rangers, Kenya Forestry Research Institute (KEFRI) personnel, CFA members, and other stakeholders. The group was guided by a facilitator who introduced and moderated the topics for discussion on: how human activities at Gathiuru Forest influence the ignition of forest fires; the positive and negative effects of fires in Gathiuru Forest; and how the KFS, KWS, and CFAs were collaborating in the implementation of fire management plans, fire monitoring, fire prevention, fire-fighting, the reduction of hazardous fuels, and the maintenance of ecosystem health. The focus group discussions helped to gather information on how back firing has been used by firefighters in Gathiuru Forest to stop fire from spreading to other parts of the forest. The focus group discussions also helped in generating different ideas on IFM and how it is implemented in Gathiuru Forest Station.

3.2.4. Ranking of Benefits and Concerns in Gathiuru Forest

Focus group participants were actively involved in the importance ranking of their needs and benefits obtained from Gathiuru Forest. Participants were instructed by the moderators to come up with a list of the needs and benefits that they obtained from Gathiuru Forest and another list showing the concerns about fires in Gathiuru Forest. They voted by putting X or $\sqrt{}$ autonomously, without being influenced by members of their user groups. The same procedure that was used to vote for the needs and benefits was repeated for the concerns about fires in Gathiuru forest. A final tally was done to establish the total number of votes for each ranking. In the case where there was a tie in the first tally (TALLY I) of the ranking, a second round of voting was done (TALLY II) to determine the final rank of the benefits and concerns.

Data entry of respondents' views collected from the questionnaires, focus group discussions and processing by a ranking procedure was done. Analysis was conducted by using SPSS Statistics software (IBM Inc., Armonk, NY, USA).

4. Results

The human needs and the related land use activities are presented in relation to the major causes of fire ignition. The concerns related to fire and the assessment of the external drivers allow the design of fire management approaches.

4.1. Humans Needs and Benefits in Gathiuru Forest

Common human needs accessed by the local communities in Gathiuru Forest include water use, timber, firewood, livestock grazing, cultivation of crops, collection of herbs for medicinal purposes, and generally contributing to a good life style. Results from focus group discussions show that there are considerable environmental and economic values that support the livelihood of the communities living around Gathiuru Forest. The forests offer diverse resources for consumptive use, and local people are allowed to access these products through a permit and licensing system. Table 1 shows the voting and ranking of the benefits obtained by the CFA in Gathiuru Forest, where using the land as farmland (PELIS) is ranked as first and providing cultural/religious benefits is ranked last.

Table 1. The ranking of benefits obtained from Gathiuru Forest (N = 24).

Rank of Needs & Benefits	Benefit Class	Number of Votes for Benefits	Importance
		Tally I & Tally II	
1	Farmland (PELIS)	17	0.71
2	Water	13	0.54
3	Employment/income	12	0.50
4	Herbal medicine	10	0.42
5	Education & research	9	0.38
6	Timber	8 (11)	0.34
7	Grazing	8 (9)	0.33
8	Honey collection	3	0.13
9	Firewood	2	0.08
10	Cultural and religion	1	0.04

4.2. Human Activities and Their Influence on Fire Ignition in Gathiuru Forest

4.2.1. Perception about Factors Influencing Fire Ignition

Fuel characteristics, weather conditions, topographic factors, and the human activities influence fire ignition in Gathiuru Forest. The analysis of data collected using the questionnaires on the perceptions of the local people on the leading causes of fires in Gathiuru Forest is shown in Figure 3.
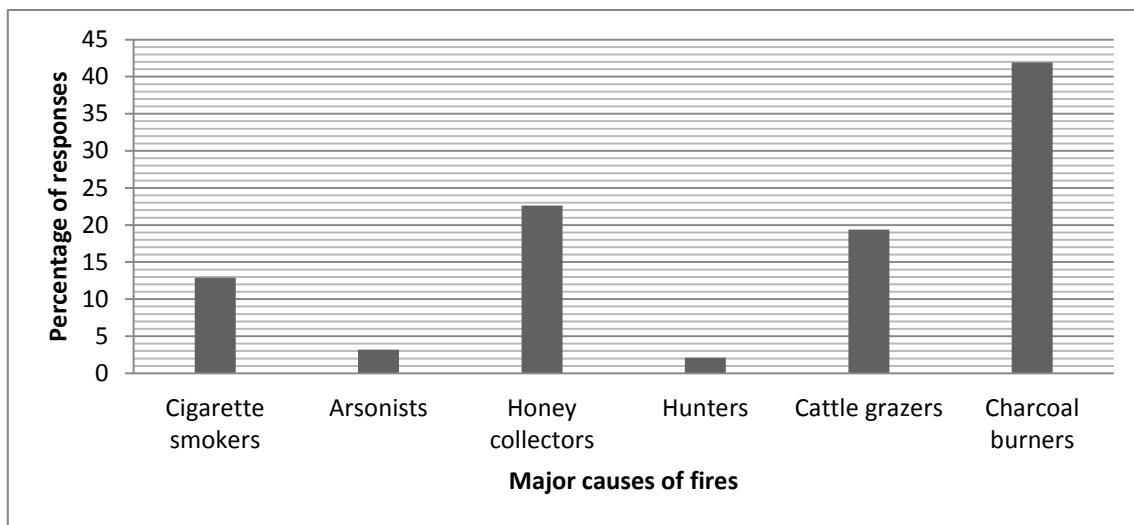
Figure 3. Major causes of fires in Gathiuru Forest indicated by questionnaire respondents (N = 16).

4.2.2. Legal Human Activities in Gathiuru Forest

According to the focus group discussions, farming (PELIS) is one of the activities practised by rangers and CFA members in Gathiuru Forests. The results from the voting and ranking of needs and benefits show that farmland (PELIS) got 17 votes and is ranked as the first benefit obtained by the communities from Gathiuru Forest. But, the use of fire to clear farm plots has been abolished and all CFA members declared that using fire to clear a farm plot would cause a loss of the farmers' user group rights and the plot would be given to a new member.

Communities obtain water from rivers that originate from Gathiuru Forest of the larger Mt. Kenya Water Tower for domestic use, the watering of livestock and, the irrigation of crops. Water abstraction has been licensed in Gathiuru Forest and a water user group has been formed. The results show that water use is ranked as the second most important benefit.

Rangers and CFA members conduct some casual jobs like the thinning and pruning of forest plantations. They get cash payments for these jobs. To reduce the fuel load, they are allowed to collect and sell some of the poles and firewood from thinning and pruning operations. The results show that employment/income is ranked as the third most important benefit.

The collection of herbs and spices for domestic use or commercial purposes by the local communities is currently not licensed and a user group has not been formed. The results show that herbal medicine and spice collection is ranked the fourth most important benefit in the Gathiuru Forest and their collection might cause a reduction of the available fuel.

Several national and international institutions have been doing research projects in Gathiuru Forest and some of their education programs have been considering and respecting traditional knowledge. The trainings allowed a mutual exchange of know-how and experiences between the trainers and the communities. The forests also provide a learning place for the traditional non-formal education that has been passed down for generations about plants and animals and their uses. The results show education and research is ranked as the fifth most important benefit, which shows the potential for KFS, KWS and Laikipia Wildlife Forum (LWF) to continue providing sound training on fire management to local stakeholders and CFA members in Gathiuru forest station.

Saw millers and communities obtain poles and timber from Gathiuru Forest. Logging has been licensed and is one of the leading economic activities as the demand for timber is higher than the supply. The results show that timber harvesting is ranked as the sixth most important benefit.

Grazing and cutting of grass to feed livestock has been licensed and a grazers' user group has been formed in Gathiuru Forest. Additionally, migrant pastoralists do graze their cattle (*Bos-Taurus* Linnaeus.) in Gathiuru Forest illegally during years of extreme drought (2009 and 2017). The results

from the focus group discussions show that grazing and cutting of grass is ranked as the seventh most important benefit and the questionnaires indicate that grazing and burning of old grass contributes to 19.4% of the fires in Gathiuru Forest.

Honey collection is practised by communities living around Gathiuru Forest. Bee keeping has been licensed and the bee keepers' user group has been registered. The results show that honey collection is ranked as the eighth most important benefit. However, illegal honey collection is also practised in Gathiuru Forest and the results from the questionnaires show that honey collection contributes to 22.6% of the fires in Gathiuru Forest.

Firewood collection by CFA members is practised in Gathiuru Forest as part of fuel management. It has been licensed and the firewood collectors' user group has been registered. It helps to reduce fuel build up and contributes to lowering the risk of large fires occurring. The results show that firewood collection is ranked as the ninth most important benefit that local people gain from Gathiuru forest.

Gathiuru Forest contains caves that, over centuries, have been used by the Kikuyu, Embu, and Meru communities as sacred cultural and religious sites. Some trees have also been declared as sacred trees and no one is allowed to cut them for any use or set them on fire. The results show that cultural and religious sites is ranked as the tenth most important benefit from the Gathiuru Forest.

4.2.3. Illegal Activities in Gathiuru Forest

Illegal charcoal burning is practised in Gathiuru Forest by communities living around the forest. This has caused fire outbreaks and destroyed large parts of Gathiuru Forest in the past. Results from the questionnaires show that illegal charcoal burning contributes to 42.6% of the fire outbreaks in Gathiuru Forest. However, the practice of illegal charcoal burning is on the decline due to good collaboration between KFS and CFA members in Gathiuru Forest. The illegal charcoal burners have been arrested and prosecuted according to the law. The CFA has also trained community members on using solar energy, gas and other energy-saving stoves.

Results from the questionnaire show that poachers are perceived to contribute to 2.1% of fire ignitions in Gathiuru Forest. Illegal hunters use fire as a hunting tool and to roast game meat in Gathiuru Forest. It was reported from the focus group discussions that sometimes poachers cause fires so that the rangers have to concentrate on fighting the fire, while the poachers escape from being arrested. Interestingly both the illegal activities of charcoal burning and poaching were not mentioned as an important benefit for the local people in the Gathiuru Forest.

Conflicts have occurred between KFS, KWS, CFAs, and other stakeholders over the right to use forest resources. Focus group discussions revealed that conflicts do arise when some locals are not allocated land in Gathiuru Forest to practice farming (PELIS) because the need for farming is higher than land available. Conflicts also arise when the locals are arrested by KFS staff, forest scouts, or CFA members for conducting illegal logging, grazing, collecting firewood, collecting honey, herbal medicine, burning charcoal, or hunting in Gathiuru Forest. The culprits usually set the forest on fire as revenge (arson). Results from the analysis of data from the questionnaires show that arson contributes to 3.2% of the fire ignitions in Gathiuru Forest.

4.3. Concerns Related to Fires

Fires can have several effects on the social, economic, and cultural aspects of the livelihood of local people. Focus group discussions indicated that the participants support the idea that when fire is used and managed properly, it has some positive effects for the communities, but there are also concerns about the damages that can be caused by wanted and unwanted fires that are lit intentionally or unintentionally in Gathiuru Forest. Table 2 shows the voting and ranking of the concerns related to the negative effects of fires by the CFA in Gathiuru Forest, where the loss of grazing grounds (pasture) is ranked as first and the loss of livestock is ranked last.

Table 2. The votes and rank of concerns related to fire effects in Gathiuru Forest (N = 24).

Rank of Concerns	Concerns	Number of Votes for Concerns	Importance
		Tally I & Tally II	
1	Loss of grazing grounds (pasture)	9	0.38
2	Loss of wildlife habitat/escape to farms	6	0.25
3	Loss of wildlife	5	0.21
4	Water pollution	4	0.17
5	Bad air quality	3 (3)	0.13
6	Soil erosion	3 (2)	0.12
7	Loss of life	2	0.08
8	Loss of livestock	1	0.04

The respondents of the questionnaires also indicated two main fire seasons per year. The first fire season is from January to March and the second from August to October as shown in Figure 4. Their perceptions nicely correspond to the documented number of fire records per month during the year. This indicates the high awareness of the CFA members regarding the fire seasons in Gathiuru Forest. Most of the fires that occur between January, February, and March are as a result of land preparation during the planting season.
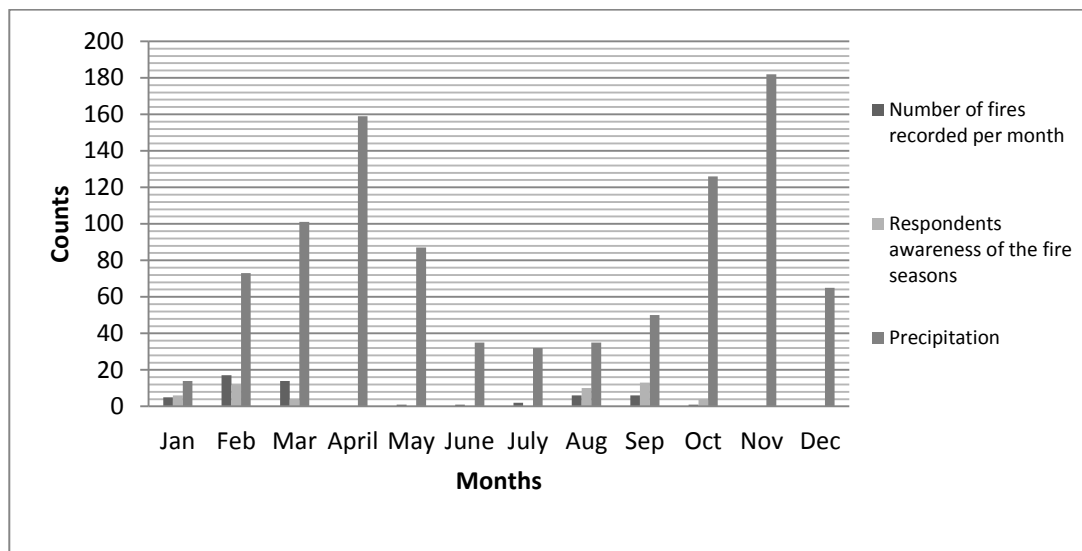
Figure 4. Precipitation, the number of fires recorded by KFS and the fire seasons in Gathiuru Forest based on the perceptions of the local people (N = 16).

4.4. Implementation of Integrated Fire Management

4.4.1. Stakeholder Involvement

The involvement of different stakeholders in the implementation of IFM guidelines varies. Results from the questionnaires show that the leading stakeholders involved in IFM in Gathiuru Forest are forest managers with 34%, CFA members with 33%, and rangers with 27%, while the other stakeholders have only exhibit a value 7%. Appendix A shows the detailed results of the main stakeholder groups involved in the establishment of guidelines for responsible Integrated Fire Management activities in Gathiuru Forest, including their interest, roles, and responsibilities.

4.4.2. Provision of Fire Training and Technical Support to Improve IFM

Results from the analysis of the questionnaires show that KFS and KWS have to some extent been providing fire educational programmes and firefighting training programmes to rangers, CFA

members and forest scouts with the aim of improving their knowledge and skills in fire prevention and suppression in Gathiuru Forest. It also indicates that the government of Kenya has only been providing firefighting equipment to the Gathiuru KFS and CFAs to a small extent, as shown in Figure 5. This has greatly affected their ability to fight the huge fires that have been occurring repeatedly in recent years.
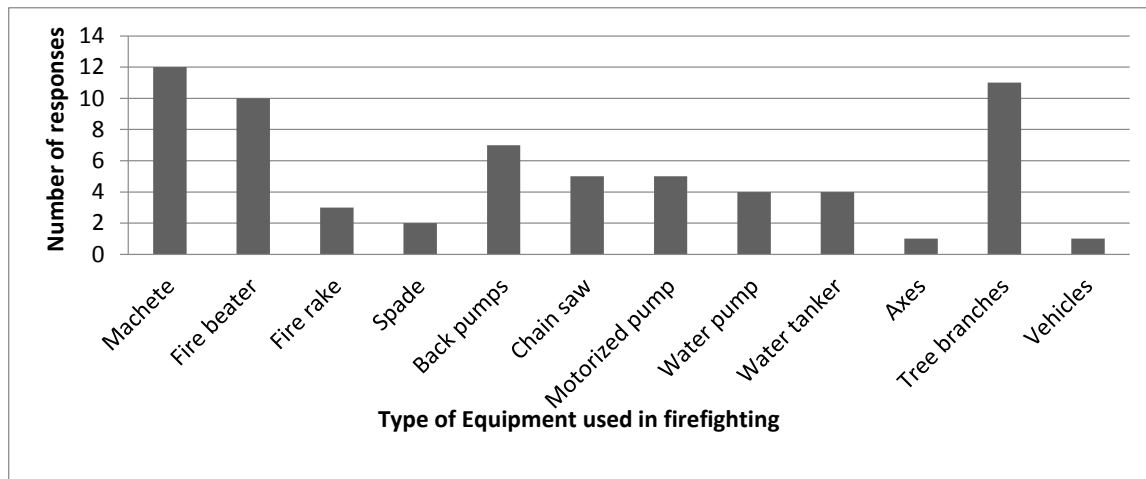

Figure 5. Type of equipment used to fight fires at Gathiuru Forest Station (N = 16).

4.4.3. Existence and Revision of IFM Plans

Results from the analysis on the existence of IFM plans and their revision based on the records of the number of fires that have occurred, the damage caused by those fires, and community participation in Gathiuru Forest show that 6% of the respondents said to a very great extent, 38% said to a great extent, 19% said to some extent, 19% said to a small extent, and 6% said to no extent, while 12% gave no information. This means that the KFS, KWS, and the CFAs have, to a great extent, given special consideration to social, economic, and environmental values of the local community in their IFM planning.

4.4.4. Land Use and Fire Danger Rating in Gathiuru Forest

Results from the analysis of data from questionnaires show that 50% of the respondents said that, to a great extent, there exists a fire risk analysis plan in Gathiuru Forest Station based on land cover, daily weather conditions, and socio-economic activities. Results show that 50% of the respondents said that, to some extent, there exists a regional early warning system about fire outbreaks in the Mt. Kenya Forest.

5. Discussion

5.1. Land Use Practices and Fire Ignition

Gathiuru Forest Station is one of the Mt. Kenya forest stations with a high number wildfire incidences recorded over the last three decades. According to the fire records and interviews conducted, it was found that the charcoal burners, honey collectors, cattle grazers, cigarette smokers, arsonists, and hunters are the main causes for fire ignition in Gathiuru Forest. However, other studies have shown that not all ignitions are directly linked to land use activities, for instance, fires due to arson and the careless disposal of smoked cigarettes are related to social behavior [25–27]. It is important to understand how, at the local level, communities utilize land resources with or without the use of fire and the social behavior that drives ignitions, and incorporate them into integrated fire management approaches as a basis for addressing the risk of fires [28,29].

In many studies, it was found that the growing human population and the increase in per capita food consumption are driving agriculture expansion and affecting natural ecosystems [30]. According to the 2009 Kenya Population and Housing Census, many of the communities living around Gathiuru Forest are poor and do not have enough land for farming [31]. Communities living around Gathiuru Forest also heavily depend on the land resources for preparing the farmland and managing the forests for many ecosystem services and non-timber forest products. The Gathiuru CFA was formed in 2009 to involve the community in Participatory Forestry Management and at the same time to help regulate human activities according to the agreed user rights in Gathiuru Forest. The user groups have the right to conduct their activities within Gathiuru Forest which includes timber production and running saw mills, grazing, firewood collection, beekeeping, collecting herbs, water abstraction, farming trout fish (*Oncorhynchus mykiss* Walbaum), providing hotel and cottage services as well as ecotourism and cultural exhibitions, conducting the PELIS system on farms, and acting as community scouts. The signing of the user group's agreement has enabled the CFA to source funding from other key sources, principally the Green Zones Development Support Project. Each of these user groups has been provided with an area for their business and in the case of a fire outbreak, the whole group will lose their user rights [24].

According to the farming (PELIS) rules and guidelines, the growing of beans (*Phaseolus vulgaris* Linnaeus), potatoes (*Solanum tuberosum* Linnaeus) and onions (*Allium cepa* Linnaeus) has been practiced in Gathiuru forest from 2008 to 2017. PELIS has helped to reduce poverty and to increase food security amongst Gathiuru CFA members involved in the production of high-quality potatoes with an estimated production of 7500 tons per year. From 2008 to 2017 total sales of food crops (potatoes) amounted to KSh 756 million ($7.56 million) and this enabled CFA members to stop depending on the forest resources and start other income generating activities. The use of fire in Gathiuru Forest is forbidden by the forest station managers according to the PELIS guidelines. The CFA members involved in farming activities are not allowed to use fire for land preparation. This is not compatible with their traditional farming practices. However, farmers still use fire illegally in Gathiuru forest and when these fires get out of control, they usually cause larger unintentional fires.

Firewood is utilized in many parts of the world as a source of energy and is a major focus in the management of primary and secondary forests [32,33]. According to the studies done by CIFOR [34], the increased demand for fuelwood can lead to forest degradation, slow down regeneration, change tree species composition, cause a reduction of tree cover, increase fine fuel (grass) accumulation, and consequently change the rate of wildfire spread [35]. We found out that firewood collection also plays an important role for the CFA members as well. Firewood collection has been licensed and the fee for collecting firewood two or three times per week ranges from KSh 100 to 150. However, the Gathiuru CFA bought 1150 energy saving cooking stoves (jikos) and distributed them among CFA women. This has helped to reduce the fire wood consumption and hence women do not need to go to the forest daily to collect firewood [24]. There is also great potential for Gathiuru CFA members to use the pruned lower branches and thinned small diameter trees for charcoal or briquettes for domestic use or commercial purposes (income) as this may help prevent ladder fuel accumulation, thus partly mitigating fire risk.

Several studies have been done to assess the impacts of cattle grazing on forests fires, water quality, biodiversity, invasive species, soil fertility, regeneration, tree damages, and soil erosion [36–39]. Cattle grazing and cutting of grass to feed livestock is allowed and has been licensed in the Gathiuru Forest. Grazing and cutting grass helps to reduce the fuel load and at the same time minimizes the risk of rapid surface fires occurring. Cattle grazing reduces low ground fuels, which decreases wildfire intensity and the length of flames, thereby reducing the risk of higher fuels (such as branches) catching fire [40]. The CFA is responsible for collecting grazing fees of Ksh. 100 per head of cattle. The agriculture officers have been involved in designing a carrying capacity for cattle grazing in the forest to help reduce the problem of over grazing. When the grass in the grazing area is gone, the cattle grazers are reallocated to another grazing area according to the carrying capacity. The CFA cattle

grazers group is not allowed to use fire for managing grasslands in Gathiuru Forest, but is responsible for monitoring and reporting to the forest manager any illegal grazing activities and fire outbreaks so that the culprits are arrested and prosecuted. Nevertheless, there have been many cases of illegal grazing and fire outbreaks caused by illegal grazers (migrant pastoralists) who set grasslands on fire to keep them open and to facilitate the growth of new grass for livestock [24].

Studies of sacred forests and other sacred sites show that religious and spiritual beliefs can sometimes be the motivation for conservation and environmental protection. African indigenous religions view land and its resources as communal property that belongs not only to the living, but also to their ancestors and to future generations [41]. Mt. Kenya is a holy mountain for the Kikuyu community. The term Kikuyu originates from the Mukuyu tree (*Ficus sycomorus* Linnaeus). According to the Kikuyu culture, three sacred trees make the community believe that they should conserve the forest: Mukuyu tree (*Ficus sycomorus* Linnaeus), Mugumo tree (*Ficus thonningii* Blume), and Mukurwe tree (*Albizia gummifera* J.F. Gmel.). Nobody in the community is allowed to cut down or set fire to these trees. This is similar to other places in Africa [42] and contributes to the efforts of conservation.

Ecotourism can be an incentive for conservation activities, and may provide socio-cultural benefits [43] and income for local communities living around nature parks [44,45]. Fires burning camp grounds and other tourist resorts, destroying the national park, and causing evacuations of tourists from fire-threatened recreation sites are a great concern [46]. The CFA ecotourism group views fire in Gathiuru Forest as a serious threat to ecotourism, but studies have shown that there are wild herbivores that benefit from plant regrowth after fires. Using prescribed fires in the landscape can help to maintain native flora and fauna that might attract tourists [47]. The perception of risk and the knowledge about wildfire by tourists has to be considered, as some tourists are not aware of the potential danger of becoming trapped by wildfires or causing a fire due to the negligent handling of barbecue fires or cigarettes [46]. The Gathiuru CFA has established hiking trails that are being used by tourists and also act as fire breaks [24].

Controlled small-scale fires are traditionally used in the African savannah to flush out small mammals for hunting purposes. However, poachers in some areas have carelessly been deploying crude versions of this practice, causing unmanageable bush fires and large-scale destruction [48]. Hunting of game-meat used to be a traditional practice of many communities in Kenya. The communities used fire as a hunting tool and to roast game meat for centuries. With the introduction of a ban on hunting in Kenya in 1977, the hunting practice was rendered illegal. But poachers have continued to use fire as a hunting tool and to distract rangers from arresting them as the rangers try to put out an early fire outbreak, which allows the poachers to escape [49]. The KWS, KFS, and CFAs are working together to ensure there is no more hunting of wildlife in the Gathiuru forest and national Park. Nowadays, the CFA members are educated on how to keep rabbits (*Oryctolagus cuniculus* Linnaeus), chicken (*Gallus gallus domesticus* Linnaeus), sheep (*Ovis aries* Linnaeus), goats (*Capra hircus,* Linnaeus), and cattle (*Bos Taurus*) for producing food and hence the need for game-meat is declining. The legal fine for those involved in illegal hunting has also been increased tremendously to discourage this bad practise [24].

In Africa, the North Western Province of Zambia emerged as the "Honey Province" because of its historical tradition of trading beeswax, its remoteness, and its vast miombo woodlands, and it is presumed that beekeeping started in Ethiopia about 5000 years ago [50]. Some CFA members are involved in bee keeping within Gathiuru Forest. Their practice has been registered and licensed to established apiaries within the forest and some have been trained by KWS on bee keeping, honey harvesting, and processing. The Ogiek tribe in the Great Rift Valley of Kenya is one of the honey hunter-gatherer peoples in East Africa and honey plays a central part in the Ogiek society, being used for food, beer brewing, and trade. Besides using beehives of hollow logs placed in tree branches, the traditional honey collectors in Gathiuru Forest illegally hunt for honey in tree hollows. They use fire to produce smoke and keep away the bees (*Apis mellifera* Linnaeus) before collecting honey

and sometimes this causes fires during the dry season, especially when the honey collectors act carelessly [24].

5.2. Positive Social and Environmental Benefits of Precsribed Fires

Gathiuru forest has some fire-dependent species like *Juniperus procera*, *Bambusa vulgaris* (Schrad Ex J.C. Wendl.) and *Hagenia abyssinica* that usually regenerate after fire. Native perennial grasses also regrow from root systems that are rarely damaged by fires that occur in Gathiuru Forest. Fire is the only natural factor which also supports the reproduction of the subalpine forests as the grass layer of larger areas is cleared by occasional burning [51]. Some scavenger animals like hyenas (*Crocuta Crocuta* Erxleben) and bird species like the black eagles (*Ictinaetus malaiensis* Temminck) have been seen to move to burned areas in Gathiuru Forest as the reduced vegetation allows them to catch prey easily [52]. The use of prescribed fires for fuel management is not practiced in Gathiuru Forest. These prevention measures would help to decrease the risk of catastrophic fires. However, the current banning of all fires from current land use practices might lead to an accumulation of fuel loads, which will have a major role in future outbreaks [53].

5.3. Negative Social and Environmental Effects of Catastrophic Fires

In the last 35 years, catastrophic fires have been occurring during the dry season in January, February, March, July, August, and September, and have burned 4509.10 ha of Gathiuru Forest, destroying plant material and the litter layer. KFS records show that from 1980 to 2015, the total damage caused by catastrophic fires in Gathiuru Forest plantations for timber and pulpwood was $443,837 and the cost incurred while fighting these fires was $41,917 [21].

Plantations of exotic tree species have been established by the KFS for the pulp and timber industry in Kenya. Several studies have been done on how exotic tree species contribute to changes in the patterns of anthropogenic ignitions, flammability of exotic species, forest ecosystem structure, and process and fuel loads [54]. Fire also stimulates the release of large amounts of seeds from the serotinous cones of Pinus radiata and can create favorable conditions for germination and establishment [55]. The principal mechanisms of recovery in fire-resistant Eucalypt species are resprouting from epicormic strands (i.e., regeneration from meristem strips, usually extending from the inner to outer bark on aboveground branches and stems, which produce buds), and/or from basal buds [56]. Therefore unmanaged fires may contribute to an increase of exotic species in the natural environment of the forest and national park of Kenya.

Shrubs, forbs, grasses, trees, and the litter layer break up the intensity of severe rainstorms. The stabilisation of the soil by the plant roots, stems, and leaves slows down the water drops and provides time to percolate into the soil profile. The subsequent rains after fires have caused landslides, flash floods, and soil erosion in Gathiuru Forest [57]. The ash from burned sites caused water pollution affecting trout fish farming and heavy sedimentation has been recorded in the seven folk dams that rely on water from rivers in Mt. Kenya Forest [9]. Other studies have also proved that surface water coming from burned areas causes serious water quality problems in streams, lakes, and reservoirs by introducing hazardous chemicals into the water bodies [58].

Fires occurring in Gathiuru Forest have been causing smoke that is spread by wind several kilometres away. Wildfire smoke composition depends on many factors, including the types of vegetation burned and the pollutants in smoke can include deadly gases, e.g., carbon monoxide and many solid and liquid elements often known as particulates or particles [4]. Forest fires have been polluting the air, irritating the eyes, reducing the visibility of travelers, and causing difficulty in breathing to communities living around Gathiuru Forest and several kilometres further away.

Some wildlife has lost its life after huge catastrophic fires in Gathiuru Forest; especially slow moving, sick, or young birds/animals that cannot escape fire [52]. Fires cause a loss of their habitats and provoke them to escape to nearby farms, destroying crops and thus causing huge losses to CFA members who obtain their food and income from Gathiuru Forest. Tourism is also negatively affected

after huge fires, as the scenery is destroyed and some wildlife are forced to migrate to other parts of Mt. Kenya Forest.

Conflicts often occur between nomadic groups in Kenya, Uganda, Sudan, Ethiopia, and Somalia over the use of pastures in fragile ecological environments [59]. During years of extreme drought, migrant pastoralists usually come to graze in Gathiuru Forest, set fire to the old grass to facilitate the growth of new grass, and then move away in search of good pasture grounds. This practice has been causing huge fires and the loss of grazing grounds for the locals, who depend on the grasslands within Gathiuru Forest for grazing their livestock. Inter-community conflicts over water and pasture grounds between the locals (Kikuyu) and the pastoralists (Samburu and Maasai) are likely to increase [59].

The highest human fatalities from fighting fires occur in developing countries, with a figure of up to nearly 80% for the period between 1997 and 2006 [53]. This is also one of the most serious concerns in Gathiuru forest. Volunteer fire fighters suffer from the lack of proper firefighting equipment which can be a strong contributing factor in loss of life while fighting huge fires. Fires have also destroyed houses constructed by CFA members within Gathiuru Forest [24].

Loss of livestock has been reported after extreme shortages of pasture caused by drought and fires in the Gathiuru Forest. The poor nutritional status of the livestock does not allow the long distance movement of livestock for pasture and water. Wildfires suppress grass production for about two rainy seasons and it is recommended that pasture grounds must rest for at least one rainy season after a runaway fire, and for at least one rainy season before a prescribed burn. After huge fires, the leftover grass is grazed by wild animals, and may not be suitable for livestock grazing, and this makes weak livestock prone to death or the communities have to sell them at low prices [60].

5.4. External Drivers Influencing Fire Danger

From the discussions with the participants in the focus group, a lot of external drivers that have an influence on fire danger were identified. Besides the changing climatic conditions, government policy and the role of migrating pastoralists were identified. The Kenya forest policy stipulates rules for the establishment of forest management zones to guide the different management strategies and future planning of particular areas to avoid conflicts among different users [61]. The management zones reflect the priority of the different objectives, and generally provide a direction for daily management, as well as long-term decision making with respect to the land use patterns in the ecosystem. The zones include: protection zone (National Park, water catchments); biodiversity conservation zone (indigenous forest); plantation zone cypress (*Cupressus lusitanica* Mill.), patula pines (*Pinus patula* Schiede Ex Schltdl. & Cham), radiata pines (*Pinus radiata* D. Don), blue gum (*Eucalyptus saligna* Smith), and rose gum (*Eucalyptus grandis* W. Hill Ex Maiden); utilisation zone (glades, grasslands, NWFP, tourist sites); rehabilitation zone (these are degraded areas marked for regeneration); and intervention zones-conflict area [9]. The zoning of forests into management blocks affects the type of human activities allowed in those blocks. This has an influence on the ignition probability of forest fires. Blocks zoned for grazing usually experience more regular fires than blocks zoned for water catchment conservation [9]. During the rainy season, the grasses and shrubs usually grow very rapidly and dry up during the dry season. This increases fine fuel accumulation and continuity. The setting of grasslands on fire each year by pastoralists—especially to keep them open and to facilitate the growth of new grass for livestock before the rainy season begins—contributes to fires at Gathiuru Forest Station.

An analysis of KFS records shows that Gathiuru Forest Station has been zoned into three blocks and subdivided into compartments and sub-compartments for easier management. The Gathiuru Block has more plantations and less indigenous forests, the Mugeria Block has intensive PELIS activities, and the Burguret Block has indigenous forest and grasslands and is prone to fire caused by cattle grazers. The cattle grazers' user group has been formed to monitor the number of livestock entering the forest and to prevent any activities that are likely to cause fires in the forest. They also help the forest manager to collect a monthly grazing fee from all registered cattle grazers in Gathiuru Forest.

The Kenya forest policy also stipulates that there must be a forest fire protection unit within every forest station organizational structure. The Ecosystem conservator of the forests appointed at the headquarters helps forest managers to plan, organize, equip, train, and provide follow-up supervision of cost effective fire management at all levels with the KFS. They develop comprehensive nation-wide programs to create awareness about the need for fire protection and control and plan the implementation of risk and hazard reduction. In the field, the KFS Station Forest Managers organize and supervise the activities of the prevention and suppression of forest fires within their areas [61]. At the regional level, the minister for the environment in each county provides firefighting staff, as well as technical and financial support to communities and forest station managers during fire incidences [61].

The meteorological factors that influence the fire weather include high temperatures along with dry, low humidity, and windy weather. Natural, cyclical weather occurrences, such as El Niño events, affect the likelihood of fires by influencing precipitation and the moisture content of plants, and lead to year-by-year variability. Changes in climate are likely to alter the two fire seasons in Gathiuru Forest. According to the Kenyan government [12] projections, temperature and precipitation levels are likely to further alter in Kenya over the course of this century. However, despite compelling evidence on the role of climate in influencing fire ignitions, the majority of ignitions in Kenya are caused by humans, as noted in different parts of the world [11].

Droughts associated with climate change will cause annual flow reductions in most rivers, conflicts over water resources and pasture; and the complete disappearance of the Kilimanjaro, Ruwenzori, and Mount Kenya glaciers by 2015–2020 [62]. Conservation reports indicate that during years with prolonged dry spells, the forests and national parks of Kenya will continue to experience the huge pressure of livestock from pastoral communities, thereby over stretching the available resources [9]. This means that in all likelihood, the pastoralists (Samburu and Maasai) will continue to graze in Gathiuru Forest without considering the local CFA grazers' user group agreements. The setting of old dry grass on fire by migrant pastoralists also contributes to fires at Gathiuru Forest Station.

6. Conclusions

This study investigated an Integrated Fire Management (IFM) framework to address both damaging and beneficial fires. It also evaluated the various uses of fire, the underlying perceptions and the traditional ecological knowledge of the local people. The risks posed by fires were then balanced with the beneficial ecological and economic effects, which will thus support the development of effective fire management approaches. The proposed IFM framework helps in implementing cost-effective approaches to prevent damaging fires and maintain desirable fire regimes in Kenya. The IFM framework is scalable and can be applied in places with fire-dependent ecosystems, as well as in places with fire-sensitive ecosystems in Kenya. However, the fact that exotic tree species are still being established in Kenya's forest raises the concern that needs to be addressed when developing and implementing IFM approaches. Exotic tree species like *Pinus radiata* and Eucalyptus in Kenya's forests may pose a serious threat of changing the fire regimes in the future and may also affect the regeneration of native tree species if proper IFM strategies are not established and fully implemented. The effectiveness is dependent on the active participation, formulation, and implementation of the IFM activities by the main stakeholder groups (Kenya Forest Service (KFS), Kenya Wildlife Service (KWS), and the Community Forest Associations (CFA). The proposed IFM framework also emphasises the need for the government of Kenya to finance, educate, train, equip, and motivate resource managers, rangers, CFA members, and forest scouts that are involved in fire prevention and suppression activities to achieve sustainable IFM strategies. Identifying potential stakeholders and their interests will help to mitigate conflicts over the use of forest resources in Kenya by following the traditional and legal arbitration mechanisms at the village, regional, and national level. It highlights the need to implement the relevant international, national, and county laws and policies for establishing or improving the legal, regulatory, and institutional framework required for responsible IFM activities in Kenya's forests.

The information from the proposed IFM framework may be used by resource managers, policymakers, and researchers to improve or advocate for sustainable land and resource management programmes that consider the fire history of the areas; the ecologically appropriate use and management of fire; and the suppression of unwanted, damaging fire in Kenya's forests.

Appendix A

Table A1. Stakeholders Involved in the Management of Gathiuru Forest.

Stakeholder	Interests	Activities	Strengths	Weaknesses
KFS	Protection and conservation of forests	-tree planting, establishment of tree nurseries, revenue collection, awareness creation, carrying out patrols, zonation/mapping of forest areas, enforcing forest law and policy	-Forest Act and policy -expertise -support from lobby groups and donors	-inadequate machinery and equipment, inadequate staff, political interference, inefficiency among KFS staff
KWS	Protection and conservation of wildlife	-electric fencing, promotion of tourism, patrolling, enforcement of the wildlife act, establishment of tree nurseries, translocation of wildlife, information dissemination	-Forest Act and policy, Wildlife Act and policy, expertise, support from lobby groups and donors, adequate resources	-poor response to incidences, poor compensation laws, poor collaboration with the community
Saw millers	Profit making	-logging, conversion of logs to timber products, creation of employment, selling timber based products	-have money, Forest Act and policy	-They do not plant trees, illegal access to trees, big contributors to environmental degradation
CFA	Protection and conservation of the forest for community benefits	-tree planting, establishment and management of tree nurseries, controlling forest fires, community policing, generating revenue for the government, managing forest resources	-support from KFS, Forest Act and policy, support from community, support from donors and lobby groups	-lack of finances, poor awareness of CFA activities, among the community members, lack of commitment from CFA officials
Greenbelt Movement	Increased tree cover	-tree planting -promoting community awareness -funding tree planting activities	-community support, support from lobby groups, forest act and policy, have expertise	-failure to fulfil promises -top-down approach in project activities implementation
Nature Kenya	Conservation of the biodiversity	-awareness creation	-adequate resources, support from government bodies such as KWS & KFS, have expertise	-not well known by the community, ineffective community outreach programme
BRWUA	Management and conservation of Burguret River	-supplying water tanks, regulation of water use, supplying drip kits, construction of water pans, construction of foot bridges and livestock watering troughs, tree planting on riparian land	-water act 2002 -support from water users -support from NGOs -support from KFS	-failure to fulfil promises -poor community representation -lack of direct link between BRWUA and the beneficiaries
TIST	Mitigation against climate change	"Promoting" tree planting	-has international funding	-not well known by the community
LWF	Environmental conservation	-creating awareness, funding CBOs	-have adequate financial resources, have expertise	-not known to the community, poor community representation

Table A1. *Cont.*

Stakeholder	Interests	Activities	Strengths	Weaknesses
Ministry of Agriculture	Food security & facilitating agro-business	-offering extension services	-Government policy, support from the community, have expertise	-inadequate staff
Ministry of Defense	Defending the country	-tree planting, road and bridge construction -water abstraction from Rongai River	-Government policy, have adequate machinery &equipment	None
Ministry of Fisheries & Livestock	Promotion of livestock development	-offer extension services -treatment and vaccination	-have expertise -Government policy	-inadequate staff -services are expensive
Bantu Lodge	Profit making	-tourism -entertainment	-have money, support from Government, create employment	-No tree planting, no community involvement, poor security
UNDP-GEF	Environmental conservation	-establishment of tree nurseries, funding community groups, awareness creation on environmental conservation	-have funds, support from the international community, Government support through KFS and KWS	-lack of follow up project implementation activities, not well known by the community

Source: Gathiuru Forest management plan 2010–2019.

References

1. Laris, P.; Wardell, D.A. Good, bad or 'necessary evil'? Reinterpreting the colonial burning experiment in the savanna landscapes of West Africa. *Geogr. J.* **2006**, *172*, 271–290. [CrossRef]
2. Aragón, R.; Morales, J.M. Species composition and invasions in NW Argentinian secondary forests, Effects of land use history, environment and landscape. *J. Veg. Sci.* **2003**, *14*, 195–204. [CrossRef]
3. Eriksson, O.; Cousins, S.A.; Bruun, H.H. Land-use history and fragmentation of traditionally managed grasslands in Scandinavia. *J. Veg. Sci.* **2002**, *13*, 743–748. [CrossRef]
4. Nyongesa, K.W. Fire management if Forests and National Parks of Kenya: Case studies at Kakamega, Mt. Elgon and Mt. Kenya Forest and National Park. In *Forestry*, 1st ed.; Ivan, G., Ed.; OmniScriptum Publishers: Saarbrücken, Germany, 2015; pp. 1–124, ISBN 978-3-639-79212-6.
5. Downing, T.A.; Imo, M.; Kimanzi, J. Fire occurrence on Mount Kenya and patterns of burning. *GeoResJ* **2017**, *13*, 17–26. [CrossRef]
6. Seijo, F.; Millington, J.D.A.; Gray, R.; Sanz, V.; Lozano, J.; García, S.F.; Sangüesa, B.G.; Julio, C.J. Forgetting fire: Traditional fire knowledge in two chestnut forest ecosystems of the Iberian Peninsula and its implications for European fire management policy. *Land Use Policy* **2015**, *47*, 130–144. [CrossRef]
7. Flatley, W.T. Fire Regimes of the Southern Appalachian Mountains: Temporal and Spatial Variability and Implications for Vegetation Dynamics. Ph.D. Thesis, Texas A&M University, College Station, TX, USA, December 2012.
8. Sally, A.A.; Carla, S.; Simon, A.L. Evolution of human-driven fire regimes in Africa. *Ecol.* **2012**, *109*, 847–852. [CrossRef]
9. GoK (Government of Kenya). Mt. Kenya Forest Reserve Management Plan 2010–2019. Available online: http://www.kenyaforestservice.org/documents/MtKenya.pdf (accessed on 31 August 2017).
10. Imo, M.; Imo, M. Forest degradation in Kenya: Impacts of social, economic and political transitions. In *African Political, Economic and Security Issues*, 1st ed.; Adoyo, J.W., Wangai, C.I., Eds.; Nova Science Publishers: New York, NY, USA, 2012; pp. 1–38, ISBN 9781620810859.
11. Dube, O.P. Linking fire and climate: Interactions with land use, vegetation, and soil. *Curr. Opin. Environ. Sustain.* **2009**, *1*, 161–169. [CrossRef]
12. GoK (Government of Kenya). National Climate Change Action Plan 2013–2017. Available online: https://cdkn.org/wp-content/uploads/2013/03/Kenya-National-Climate-Change-Action-Plan.pdf (accessed on 31 August 2017).
13. Aguilar, S.; Montiel, C. The challenge of applying governance and sustainable development to wildland fire management in Southern Europe. *J. For. Res.* **2011**, *22*, 627–639. [CrossRef]
14. Gadgil, M.; Rao, P.R.S.; Utkarsh, G.; Pramod, P.; Chhatre, A. New meanings for old knowledge: The people's biodiversity registers program. *Ecol. Appl.* **2000**, *10*, 1307–1317. [CrossRef]
15. Bollig, M.; Sculte, A. Environmental Change and Pastoral Perceptions: Degradation and Indigenous Knowledge in Two African Pastoral Communities. *Hum. Ecol.* **1999**, *27*, 493–514. [CrossRef]
16. Butz, R.J. Traditional fire management: Historical fire regimes and land use change in pastoral East Africa. *Int. J. Wildland Fire* **2009**, *18*, 442–450. [CrossRef]
17. FAO (Food and Agriculture Organization of the United Nations). Fire Management Voluntary Guidelines-Principles and Strategic Actions. 2006. Available online: http://www.fao.org/docrep/009/j9255e/j9255e00.htm (accessed on 31 August 2017).
18. British Columbia. Wildland Fire Management Strategy. 2010. Available online: http://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/wildfire-management/governance/bcws_wildland_fire_mngmt_strategy.pdf (accessed on 15 May 2018).
19. Wangari, F. The Effects of Fires on Plants and Wildlife Species Diversity and Soil Physical and Chemical Properties at Aberdare Ranges, Kenya. Master's Thesis, University of Nairobi, Nairobi, Kenya, 2016.
20. Vale, T.R. The pre-European landscape of the United States: Pristine or humanized? In *Fire, Native Peoples, and the Natural Landscape*; Vale, T.R., Ed.; Island Press: Washington, DC, USA, 2002; pp. 1–39, ISBN 1597266027, 9781597266024.
21. Downing, T.A.; Imo, M.; Kimanzi, J.; Otinga, A.N. Effects of wildland fire on the tropical alpine moorlands of Mount Kenya. *CATENA* **2017**, *149*, 300–308. [CrossRef]

22. Heydari, M.; Faramarzi, M.; Pothier, D. Post-fire recovery of herbaceous species composition and diversity, and soil quality indicators one year after wildfire in a semi-arid oak woodland. *Ecol. Eng.* **2016**, *94*, 688–697. [CrossRef]

23. Wade, D.D.; Lundsford, J. Fire as a Forest Management Tool: Prescribed Burning in the Southern United States. Available online: http://www.fao.org/docrep/t9500e/t9500e07.htm (accessed on 24 July 2018).

24. KFS (Kenya Forest Service). Participatory Forest Management Plan for Gathiuru Forest. Available online: http://xa.yimg.com/kq/groups/23491130/1315364834/name/Gathiuru (accessed on 31 August 2017).

25. Matthew, W. Bushfires—How can we avoid the unavoidable? *Glob. Environ. Chang. Part B Environ. Hazards* **2005**, *6*, 93–99. [CrossRef]

26. Rodríguez-Trejo, D.A. Fire regimes, fire ecology, and fire management in Mexico. *Ambio* **2008**, *37*, 548–556. [CrossRef] [PubMed]

27. Cochrane, M.A.; Hoffmann, A.A.; Parry, J.E.; Cuambe, C.C.D.; Kwesha, D.; Zhakata, W. Climate change and wildland fires in Mozambique. *Trop. Fire Ecol.* **2009**, 227–259. [CrossRef]

28. Mistry, J.; Berardi, A.; Andrade, V.; Krahô, T.; Krahô, P.; Leonardos, O. Indigenous fire management in the cerrado of Brazil: The case of the Krahô of Tocantíns. *Hum. Ecol.* **2005**, *33*, 365–386. [CrossRef]

29. Myers, R.L. Living with Fire-Sustaining Ecosystems & Livelihoods Through Integrated Fire Management. Available online: https://www.frames.gov/catalog/701 (accessed on 31 August 2017).

30. Grau, H.R.; Gasparri, N.I.; Aide, T.M. Balancing food production and nature conservation in the Neotropical dry forests of northern Argentina. *Glob. Chang. Biol.* **2008**, *14*, 985–997. [CrossRef]

31. Obare, L.; Wangwe, J.B. Underlying Causes of Deforestation and Forest Degradation in Kenya. Available online: http://www.wrm.org.uy/oldsite/deforestation/Africa/Kenya.html (accessed on 31 August 2017).

32. FAO (Food and Agriculture Organization of the United Nations). A Decade of Wood Energy Activities within the Nairobi Programme of Action. 1997. Available online: http://www.fao.org/docrep/T0747E/t0747e02.htm (accessed on 31 August 2017).

33. Fuwape, J.A. Secondary forests and fuel wood utilization in Africa. In *Silviculture in the Tropics*; Springer: Heidelberg, Germany, 2011; Volume 8, pp. 369–376.

34. CIFOR. Firewood Collection Taking a Toll on Uganda's Forests. 2016. Available online: https://forestsnews.cifor.org/41271/firewood-collection-taking-a-toll-on-ugandas-forests?fnl=en (accessed on 31 August 2017).

35. Sassen, M.; Sheil, D.; Giller, K.E. Fuelwood collection and its impacts on a protected tropical mountain forest in Uganda. *For. Ecol. Manag.* **2015**, *354*, 56–67. [CrossRef]

36. Humphrey, J.W.; Patterson, G.S. Effects of late summer cattle grazing on the diversity of riparian pasture vegetation in an upland conifer forest. *J. Appl. Ecol.* **2000**, *37*, 986–996. [CrossRef]

37. Blackmore, M.; Vitousek, P.M. Cattle grazing, forest loss, and fuel loading in a dry forest ecosystem at Pu'u Wa'awa'a Ranch, Hawaii. *Biotropica* **2000**, *32*, 625–632. [CrossRef]

38. Roder, W.; Gratzer, G.; Wangdi, K. Cattle Grazing in the Conifer Forests of Bhutan. *Mt. Res. Dev.* **2002**, *22*, 368–374. [CrossRef]

39. Stern, M.; Quesada, M.; Stoner, K.E. Changes in composition and structure of a tropical dry forest following intermittent cattle grazing. *Rev. Biol. Trop.* **2002**, *50*, 1021–1034. [PubMed]

40. Savadogo, P.; Sawadogo, L.; Tiveau, D. Effects of grazing intensity and prescribed fire on soil physical and hydrological properties and pasture yield in the savanna woodlands of Burkina Faso. *Agric. Ecosyst. Environ.* **2007**, *118*, 80–92. [CrossRef]

41. Verschuuren, B.; Wild, R.; McNeely, J.A.; Oviedo, G. *Sacred Natural Sites: Conserving Nature and Culture*, 1st ed.; Earthscan: London, UK, 2010; pp. 2–10, ISBN 9781849711661.

42. Muriuki, J. Medicinal Trees in Smallholder Agroforestry Systems: Assessing Some Factors Influencing Cultivation by Farmers. Ph.D. Thesis, University of Natural Resources and Life Sciences (BOKU), Vienna, Austria, January 2011.

43. Acquah, E.; Nsor, C.A.; Arthur, E.K.; Boadi, S. The Socio-Cultural Impact of Ecotourism on Park-Adjacent Communities in Ghana. *Afr. J. Hosp. Tour. Leis.* **2017**, *6*, 1–14.

44. Ogato, G.S. Planning for Sustainable Tourism: Challenges and Opportunities for Ecotourism Development in Addis Ababa, Ethiopia. *Am. J. Hum. Ecol.* **2014**, *3*, 20–26. [CrossRef]

45. Vishwanatha, S.; Chandrashera, B. An Analysis of Socio-Cultural Impacts of Ecotourism in Kodagu District. *Am. J. Res. Commun.* **2014**, *2*, 135–147.

46. Global Fire Monitoring Center. Wildland Fire and Tourism Community-Based Fire Management (CBFiM). 2017. Available online: http://www.fire.uni-freiburg.de/Manag/TUI_1.htm (accessed on 31 August 2017).

47. Eby, S.L.; Anderson, T.M.; Mayemba, E.P.; Ritchie, M.E. The effect of fire on habitat selection of mammalian herbivores: The role of body size and vegetation characteristics. *Anim Ecol.* **2014**, *83*, 1196–1205. [CrossRef] [PubMed]

48. Dalu, M.T.; Dalu, T.; Wasserman, R.J. Africa: Restrict bush fires used in animal hunts. *Nature* **2017**, *547*, 281. [CrossRef] [PubMed]

49. GoK (Government of Kenya). Mt Kenya Ecosystem Management Plan 2010–2020. Available online: www.kws.go.ke/sites/default/files/parksresorces%3A/Mt.%20Kenya%20Ecosystem%20Management%20Plan%20%282010-2020%29.pdf (accessed on 6 August 2018).

50. Gupta, R.K.; Khan, M.S.; Srivastava, R.M.; Goswami, V. *History of Beekeeping in Developing World*, 1st ed.; Gupta, R., Reybroeck, W., van Veen, J., Gupta, A., Eds.; Springer: Dordrecht, the Netherland, 2014; pp. 3–62, ISBN 9789401791991.

51. Bussmann, R.W. Succession and regeneration patterns of East African mountain forests A review. *Syst. Geogr. Plants Geogr.* **2001**, *71*, 959–974. [CrossRef]

52. Gorte, R.W.; Bracmort, K. Forest Fire/Wildfire Protection. 2012. Available online: https://fas.org/sgp/crs/misc/RL30755.pdf (accessed on 31 August 2017).

53. Dube, O.P. Challenges of wildland fire management in Botswana: Towards a community inclusive fire management approach. *Weather Clim. Extrem.* **2013**, *1*, 26–41. [CrossRef]

54. Huffman, D.W.; Zegler, T.J.; Fulé, P.Z. Fire history of a mixed conifer forest on the Mogollon Rim, northern Arizona, USA. *Int. J. Wildland Fire* **2015**, *24*, 680–689. [CrossRef]

55. Moira, C.W.; Glenda, M.W. *Pinus radiata* invasion in Australia: Identifying key knowledge gaps and research directions. *Austral Ecol.* **2007**, *32*, 721–739. [CrossRef]

56. Filipe, X.C.; Francisco, M.; Rui, T.; Joaquim, S.S. Post-fire survival and regeneration of *Eucalyptus globulus* in forest plantations in Portugal. *J. For. Ecol. Manag.* **2013**, *310*, 194–203. [CrossRef]

57. Moench, R.; Fusaro, J. Soil Erosion Control after Wildfire. 2012. Available online: http://extension.colostate.edu/docs/pubs/natres/06308.pdf. (accessed on 31 August 2017).

58. Tecle, A.; Neary, D. Water Quality Impacts of Forest Fires. *J. Pollut. Eff. Control* **2015**, *3*, 140. [CrossRef]

59. Kumssa, A.; Jones, J.F.; Herbert, W.J. Conflict and human security in the North Rift and North Eastern Kenya. *Int. J. Soc. Econ.* **2009**, *36*, 1008–1020. [CrossRef]

60. Waal, H.O. Livestock Production during Drought. 2016. Available online: http://www.farmingportal.co.za/index.php/farming-interest/item/6137-livestock-production-during-drought?tmpl=component&print=1 (accessed on 31 August 2017).

61. GoK (Government of Kenya). The Kenya Forest Act 2005. Available online: http://www.fankenya.org/downloads/ForestsAct2005.pdf (accessed on 31 August 2017).

62. Thompson, L.G. Kilimanjaro Ice Core Records: Evidence of Holocene Climate Change in Tropical Africa. *Science* **2002**, *298*, 589–593. [CrossRef] [PubMed]