GeoResJ 13 (2017) 17–26

Contents lists available at ScienceDirect

GeoResJ

journal homepage: www.elsevier.com/locate/georesj

Fire occurrence on Mount Kenya and patterns of burning

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ARTICLE INFO

Article history:
Received 30 March 2016
Revised 12 October 2016
Accepted 31 December 2016
Available online 7 January 2017

Keywords:
Fire history
Fire severity
Tropical alpine
Wildfire

ABSTRACT

Tropical alpine areas serve important roles in the areas of biodiversity, hydrology, and carbon storage. These unique ecosystems are threatened by climate change and fire. Mount Kenya is one such area that has been faced by numerous large fires in recent years. The extent and patterning of these fires is analyzed in this study. Fires for the last 16 years were mapped with satellite imagery to create a fire history map and determine the current fire regime for the mountain. In addition, the major moorland fires over this period were mapped for severity using a spectral index. The results show that fire is a dominant force in Mount Kenya burning over 10% of the mountain in the past 16 years, and 33% of the alpine moorland areas. The fires are concentrated in the lower moorland just above the treeline, and likely play a role in determining the position of the treeline. The severity of the fires is largely low to moderate. There is no clear trend in fire quantity over this period, but the seasonality appears to have shifted from a bimodal pattern to a unimodal pattern. Also the inter-annual variability has increased considerably in the past few years. It is not clear how the vegetation, and in particular the Ericaceous vegetation which characterizes these moorlands, will respond to changing fire patterns.

1. Introduction

The moorland of Mount Kenya is a unique and important ecosystem in several ways. First of all, it experiences a tropical alpine climate which is quite rare globally. The only other areas with this type of climate are portions of the Andes mountains in South America, the Maoke mountains in New Guinea, and other isolated mountains of East Africa [7]. Thus there is a high degree of endemicity in these areas, as the life forms have uniquely evolved to deal with the harsh conditions. The plant forms show remarkable similarities between mountain ranges, however, due to the process of convergent evolution [34]. The African alpine areas are doubly unique in that they are small and geographically isolated from each other, and thus act as islands with respect to species biodiversity. These so called ’sky-islands’ are interesting case-studies in island biogeography [11]. Finally the African mountains are important because of their hydrological role as ’water-towers’ or highland catchment areas. Although all mountains contribute heavily to the hydrology of the broader regions, in the greater Nile river valley these isolated mountains account for over 90% of the discharge. Much of the lowland surrounding areas are arid or semi- arid, making these mountains crucial to the function of the entire Nile basin [7,38].

Fire has the potential to affect the function of these important ecosystems. On Mt. Kilimanjaro, fires have been associated with large scale changes in vegetation, and in particular, a major loss in Ericaceous vegetation (heather and related species). Ericaceous vegetation generally occurs as a belt of vegetation just above the treeline, and it was found that this belt had been reduced to 17% of its original area over the past 30 years [14]. In a pollen analysis on Mt. Wilhelm in New Guinea, it was determined that much of the current grassland/moorland had originally been forest, and was replaced by grassland due to fire. The presence of charcoal in the soil correlated with the switch to grassland [9]. The very level of the treeline may be more a function of fire than climate. Jacob et al. [17] examined the treelines of mountains in the tropics, and found a great variability in their level, even those occurring at the same latitude. For example, the treeline in Mt. Kenya currently occurs at an average elevation of ∼3400 m, whereas in the Rwenzori Mountains of Uganda, which are roughly the same height and at the same latitude, the treeline is ∼3900 m [17]. Furthermore, the treelines of most of the mountains have receded over the past few decades, whereas due to climate change one might expect tree lines to be expanding upward. This is likely due to an increase in fire.

This change in vegetation communities may also affect the biodiversity of the area. Although Wesche et al. [39] did not find a significant reduction in species diversity after fire in Mt. Elgon, they did note that relative species abundances had changed due to the fire, in particular promoting grasses at the expense of shrubs. Two

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http://dx.doi.org/10.1016/j.grj.2016.12.003
2214-2428/

years after the fire, grasses had been able to recover completely whereas heather species had hardly even begun to recover. Janzen [18] found the same pattern in high elevation fire in Cost Rica. The harsh environment in the alpine areas makes recruitment difficult except for pioneer grass species. The characteristic life forms in these alpine areas are the heather (*Erica spp.*) and rosette plants (*Dendrosenecio spp.* and *Lobelia spp.*) and both of these do not appear to recover well after fire [34].

Fires can also alter soil properties, which affects both the vegetation and hydrologic function of the area. Soils generally act as a giant sponge, holding water that comes in as precipitation and releasing it slowly throughout the year [6]. This regulatory function can be disrupted by fire if the physical and chemical properties of the soil are significantly altered. In mountainous areas around the world there is often large-scale flooding in the immediate aftermath of fires [29], followed by the potential for decreased dry season flows [26]. Soils also store a significant amount of carbon in the high altitudes due to the cold and wet climate which fosters the formation of peat soils. Fires have the potential of releasing this carbon to the atmosphere [7].

The specific impacts of fire in an area depend on the fire severity and fire return interval, otherwise known as the fire regime [37]. A fire regime is the characterization of wildfire activity in an area, and it incorporates measures of frequency, intensity, size, season, type, and extent of fires [36]. Mapping fire regimes is usually done in order to better understand how spatial processes such as climate, topography and vegetation influence fire dynamics. This can provide land managers with a baseline for resource management decisions: departure from a historical regime can indicate profound changes in the ecosystem [30]. The two most important parameters for mapping fire regimes are frequency and intensity. There is a direct relationship between the two, as typically high frequency fires are of a low intensity and vice versa. Fire rotation is the amount of time it takes for the whole study area to be burned- so it is the total area divided by the area burned during that study period [1].

Data for reconstructing a fire regime map can come from historical records, paleoecological evidence (charcoal in the soil, tree scars), or from satellite data [30]. Due to the availability, spatial coverage, and relative cost, satellite imagery is often the preferred method for mapping fire regimes. However satellite data is a fairly recent phenomenon, so it can only provide a <30 year fire history. The first satellite that was used to map fires extensively was AVHRR (Advanced Very High Resolution Radiometer), which can pick up fire scars based on the effects on vegetation. It has global coverage and has been around since the 1980s, however its accuracy is limited especially at the finer scale [12]. More recently the MODIS (Moderate Resolution Imaging Spectroradiometer) has been used to map fires. This satellite has a 500 m spatial resolution and a better spectral resolution, so it is able to pinpoint the exact date of a burn and its extent. The algorithm for burned area detection is quite robust and has been extensively calibrated [19]. MODIS has now been used to map fires in many parts of the world with considerable accuracy [8,12,31]. When compared with ground-truth data, it has been shown to be very accurate although it can miss small fires in certain cover types [13], and in general has higher omission errors than commission errors [33].

For fire severity, however the Landsat satellite is better than MODIS as it has a finer spatial resolution and also a high spectral resolution [35], allowing for the mapping of the differential effects of a single fire across an area. Fire severity can be distinguished from fire intensity in that fire severity has to do with the effects of the fire on above and below-ground biomass, whereas fire intensity is just the heat released by the fire [21]. Fire severity is usually assessed by field investigations after the fire; a good fire severity index will incorporate several measurable parameters into a single aggregate index that indicates overall level of damage. These metrics may include litter/ground cover, mineral soil color, soil structure, soil water repellency, and any other char or ash characteristics [40]. In recent years, satellite imagery has also been used to estimate and map fire severity, and it has proved fairly accurate especially in identifying areas of above ground biomass loss, and even impacts on soils [21]. This satellite index is known as the difference Normalized Burn Ratio (dNBR). It uses the reflectance in the near infrared and short-wave infrared wavelengths to distinguish burnt and unburnt areas, as well as showing the continuous variation in the degree of burn [28]. Typically this is further classified into three classes of burn severity- high, moderate, and low. This technique has been shown to be very effective at determining fire severity in the western USA [24].

Mount Kenya is one of the 5 major ‘water-towers’ of Kenya (see Fig. 1[1]), and these 5 highland forested areas regulate most of the water coming into Kenya. Only about 2% of Kenya remains under natural forest cover, so that little bit that remains is vital in maintaining the quality and quantity of water in Kenya [16]. Furthermore, Mt. Kenya is a nature reserve with a pristine afro-alpine ecosystem home to numerous endemic species, and serves an important role for tourism. Mt. Kenya has experienced several large fires in the past couple decades, but most notably in 2012 when a single fire burned an area of over 100 km^2. It is thought that the frequency of fire has increased in Mt. Kenya due to anthropogenic impacts from tourism, poaching, and pastoralism [39]. However the actual fire situation on the mountain is not currently known. In particular the fire regime of the mountain has not been characterized yet. The questions for this study are: How frequent is fire on the mountain? Where does fire occur? And what is the severity of these fires? The specific objectives of this study are: To reconstruct the fire history of Mount Kenya using MODIS satellite imagery and to derive the fire severity for several larger fires using Landsat Satellite data.

2. Materials and methods

2.1. Study area

Mount Kenya is an extinct volcano located in central Kenya and is shared by Meru, Embu, Kirinyaga, and Nyeri counties. It lies on the equator and rises up to 5200 m in elevation (Fig. 2). The upper reaches of the mountain is administered by the Kenya Wildlife service, whereas the forested areas on the lower sides are under Kenya Forest Service jurisdiction. The mountain is the principle source of water for the two main rivers in north and eastern Kenya: the Upper Ewaso Ng’iro river and the Tana River [23].

The climate varies according to elevation and orographic effects. The north slopes of the mountain are in the rain shadow and thus are very dry- receiving around 900 mm/yr, whereas the southeastern side of the mountain receives up to 2300 mm/yr. The rainfall pattern is mostly diurnal with peak rains in March- June and October- November; the driest months being January and February. Temperature varies according to altitude, decreasing roughly 0.6 °C for every 100 m of elevation. At the base, mean temperatures can be as high as 20 °C, whereas at the top, temperatures are well below freezing [23]. The vegetation varies with climate in distinct bands around the mountain. The uppermost band is barren-just rock and ice, and below this is a band of moorland consisting

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[1] GIS data for this map and the other maps in this paper comes from: World Resources Institute (http://www.wri.org/resources/data-sets/kenya-gis-data) and International Livestock Research Institute (http://www.ilri.org/GIS). Topo maps come from Survey of Kenya (1971). Fire specific data comes from MODIS and Landsat satellites (www.earthplorer.usgsu.gov). All data was reprojected to WGS84 and UTM zone 37S. All maps were prepared with QGIS software.