EXPLORING BURN SEVERITY OF SEASONAL FIRE IN YANKARI NATIONAL PARK, NIGERIA, USING LANDSAT DATA

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Abstract

Fire is generally used as an environmental management tool around the world but it also has devastating impacts on biodiversity and may cause drastic changes to carbon, energy and water fluxes. Although parks and games reserves are demarcated and protected from undue human influences such as fires, fires have continued to impact these protected areas. In many developing countries with poor data collection capacities, the use of Remote Sensing technologies offers a credible solution to monitoring the health of the environment. In this paper we apply the normalized difference burn ratio (dNBR) to Landsat 5 images for the dry season months to explore burn severity of fire in Yankari Games Reserve in Northern Central Nigeria. The games reserve is one of the most popular and well-known reserves in the West African sub-region. Results suggest that fires are started at the edges of the park, where many settlements are now established and spread towards the central area, which shows less severity probably as efforts are made to combat it. This pattern of spread may be responsible for the observed distribution of wildlife in the reserves in the dry season, with large concentrations at the center of the reserves. This has implications for policy at several levels including restrictions on settlements and farming activities within or near the reserve.

Keywords: Fire, Burn severity, NDVI, dNBR, Wildlife, Livestock

INTRODUCTION

Since the last century, the protection, preservation and conservation of environmental resources have become important endeavors of human efforts to achieve sustainable development. Understanding the tremendous influence of human activities in shaping the structure and function of the natural environment therefore has become central to environmental resources management. One of the most important factors that have significantly impacted the earth's physical and social systems, ecosystem and its environmental resources is fire (Eriksen, 2007; Malmstrom, 2010; Chuvieco, Mouillot, van der Werf, Miguel, Tanase, Koutsias, García, Yebra, Padilla, Gitas, Heil, Hawbaker & Giglio, 2019).

Over the course of human evolution and development, fire has played significant roles in the stability of human societies and their ability to domesticate and dominate their environment (Smith & Tunison, 1992; MacGregor, 2006). Fires help ecosystems maintain their vitality and sustainability (MacGregor, 2006), and have therefore become an important environmental resources management tool. Fire has been deliberately set to burn selected areas to achieve environmental management goals (Wakimoto, 1989; Parson & Botti, 1996; Parson, 2000) such as a reduction in the accumulated fuel loads that energize wild and accidental fires, promote regeneration of natural vegetative cover, improve wildlife habitat, and general sustainability in the ecosystem (Pyne, 1996).

Periodic low-intensity fires have been acknowledged to maintain certain forest types that would have been altered by occasional wildfire. Similarly, other ecosystems have not indicated any signs of long-term effects from infrequent, high-intensity fires (Heinselman, 1981; Kilgore, 1981; Smith & Tunison, 1992). In the savanna regions, fire consumes the litter which suffocates the grasses and reduces shading by killing young woody plants thereby exposing the grasses to more light (Geerling, 1985). This position has been partly supported by NCF and

WWF (1987), which posited that annual fires set at beginning of the growing season after the first rains would encourage development of open grasslands that may be beneficial for annual grasses but harmful to perennial grasses if the frequency of fire is high.

In developing countries like Nigeria, the employment of fire as a tool for preparing land for agricultural cultivation is well-known and documented. As human population and settlements grow, an increase in the frequency of fire burns has exerted a commensurate amount of pressure on the ecosystem (Geerling, 1985), especially since most of the population relies on agriculture and the environment for their livelihood (Abdullahi, Sanusi, Abdul & Sawa, 2009). Environmental resources are depleted as more forests are cut and grasslands are burnt to provide land both for settlement and agricultural cultivation. The wanton and uncontrolled use of fire however have had devastating consequences on environmental resources as drastic changes to carbon, energy and water fluxes are induced at the local scales thereby influencing species richness, the structure and composition of plant and animal habitats and communities, the amount of biomass and loss of biodiversity (Eriksen, 2007; Turshak, 2010; Picotte & Robertson, 2011; Veraverbeke, Willem, Stefaan, Ruben & Rudi, 2012). Consequently, the demarcation and management of protected areas has evolved into an important proactive strategy to conserve biodiversity in the ecosystem and manage the ubiquitous anthropogenic factors that have threatened the environment over time.

In Nigeria, many parks and game reserves have been demarcated and commissioned to safeguard and protect the environment from undue human influences and encourage the preservation of the natural environmental ecosystem. Understanding the governing principles and processes that influence ecosystems and the factors that threaten to unbalance the system is necessary to developing intervention measures to mitigate threats and conserve the protected areas. This requires a proactive ecosystem monitoring and surveillance system that would equip the managers with the necessary data and information to make informed decisions on intervention measures and mechanisms. Fire incidents are known to be a notorious presence in many of these parks and game reserves. Information on areas critically affected by fire that is accurate and up to date is important to discern the drivers of fire activity and how they affect biogeochemical factors, climate and air quality. They also aid effective management of fire (Chuvieco et al., 2019)

Developments in technology, especially Remote Sensing and GIS, provide both the platform and capability to monitor and manage vast areas of environmental resources in a timely manner. Furthermore, the employment of satellite remote sensing methods to measure and monitor burn incidences, severity and areas is less expensive than ground monitoring. It also allows for quick updating of information (Picotte & Robertson, 2011) for better environmental management. Remote sensing techniques have provided a reliable means for estimating both temporal and spatial dimensions of fire risk. Unfortunately, these resources (Remote Sensing and GIS capabilities) are still underemployed in Nigeria for environmental resources management. This study explores the use of satellite remote sensing technology to measure fire severity in the Yankari Games Reserve, one of the most popular game reserve in the West African sub-region. The study demonstrates the potentials of remote sensing technology for environmental resources management in developing countries where data for such purposes are generally scarce and unreliable.

Remote sensing techniques have been used to monitor fire regimes in several studies especially when the affected area has a complex topography, with steep slopes and inaccessible areas (Escuin, Navarro & Fernandez, 2008), as is the case with Yankari Games Reserve. The use of remote sensing technique is made possible by the fact that after the fire, a series of spectral changes takes place due to the fire consuming the vegetation, destroying the chlorophyll, leaving the soil bare, charring the roots and altering the soil's moisture. The reduction in chlorophyll results in an increase in the visible region of the electromagnetic spectrum and in a diminution in the near infra-red region (Escuin, Navarro & Fernandez, 2008). These changes are conspicuous and relatively easy to identify and monitor and therefore allows for the determination of the severity of fire incidences.

Fire severity is the degree of change in the soil and vegetation caused by fire (Escuin, Navarro & Fernandez, 2008). It has been used to describe both aboveground and belowground impacts of fire intensity, which is an important factor in seasonal and sometimes long term land cover change. Detecting changes in landscape characteristics resulting from fire severity is an important research area especially in the savanna regions of Africa where bush fires are incessant as a result of farming practices and other activities that involve bush burning such as hunting and the management of parks and games reserves. It is clear, for example, that the severity of burns to organic soil layer has direct bearing with carbon emissions and post-fire carbon sequestration, the potential of the vegetation to recover and the structure and function of the ecosystem post-fire (French, Graham, Whitman & Bourgeau-Chavez, 2021).

Fada (2015) reported that except for a fire report (Green, 1986) and a fire management plan (Green & Amance, 1987) no studies have been undertaken on fire incidences and severity in the Yankari Games Reserve. Using MODIS Active Fire and burnt area products downloaded for a fourteen year period (2000-2014), she calculated that 94% of the Games Reserves area exhibited fire scars. She, however, did not examine burn severity, which is important to understanding vegetation recovery and regrowth with attendant implications for conservation and management of the reserves. For example, Pourreza, Hosseini, Sinegani, Matinizadeh and Alavai (2014) asserted that high severity fires negatively affect plant species abundance and richness. Murphy, Vidal, Smith, Hallagan, Broder, Rowland and Cepero (2018) have also provided evidence that fire severity has significant negative impact on plant quality. These have important bearings on conservation and management of both the vegetation and wildlife in the reserves. Unfortunately, such studies in the Yankari Games Reserves are not available. It is probable that the fact that field studies of fire incidents and severity are expensive to carry out, especially for a large area like the Yankari Games Reserves contributes to the dearth of research work in his area. Alternative methods that are more cost-effective may help in this regard.

This paper explores the employment of remote sensing techniques using Landsat data to estimate burn severity in the Yankari reserves, which may be significant in two ways. First, Landsat data are easy to acquire. They can readily be downloaded from several websites, e.g., the United States Geological Survey (USGS) website (http://glovis.usgs.gov/), for free. Second, it provides a more pragmatic choice to detect severity of burned areas in a timely and much wider scale of coverage than field sketches allowed. It should be quickly acknowledged that the methods advanced in the paper are no substitute for actual rigorous ground work and field studies. However, they provide a guide towards identifying where emphasis and priority on data collection work may be placed to save time, effort, energy and financial costs.

MATERIALS AND METHODS

Study Area

Yankari Games Reserve lies in the southern part of the Sudan Savanna. It is composed of savanna grassland with well-developed patches of woodland. It is also a region of rolling hills, mostly between 200m and 400m above mean sea level. It falls within the latitudes 9º 34′ N and 10º 05′ N and longitudes 10º 10′ and 10º 50′ E, lying in the south-central area of Bauchi state in central Nigeria (Fig 1). It covers an area of about 2,244 sq. km (866 sq. miles), with an elevation range between 150 and 700 m above mean sea level. The vegetation is composed mainly of combretaceous trees and shrubs, *Afzelia*, *Anogeissus* and *Detarium* savanna woodlands. Along the Gaji river, which bisects the reserve, is vegetation typical of the forest ecosystem. This consists of evergreen swamp and riparian forest (Green & Amanche, 1987). Annual rainfall in the park is between 900 mm and 1,000 mm. The rainy season is from May to September. Temperatures range between 18 º C and 38 º C. During the dry season, the Harmattan wind blows from the Sahara, often bringing dusty skies and night temperatures fall as low as12 º C. The hottest period falls in March and April, when temperatures can rise above 40 º C in the day (Geerling, 1973).The vegetation is dried in the dry season and most of the reserve is devastated by fire (Fada, 2015).

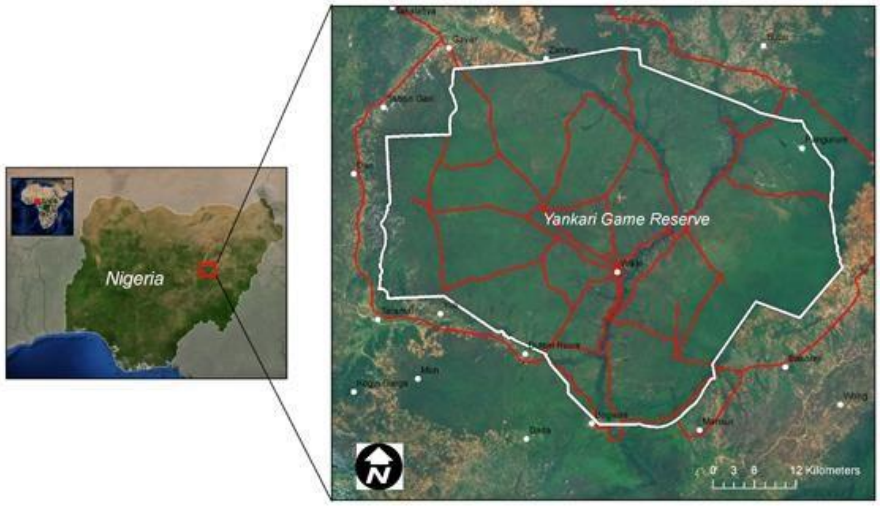

Figure 1 Yankari National Park in Central Nigeria
Source: http://www.fieldtripearth.org/media_image.xml?object_id=3188&file_id=8172

The savanna has both dry and rainy seasons. Seasonal fires play a vital role in the savanna's biodiversity. Goldammer & de Ronde (2004) identified lightning and humans to be responsible for starting fires, but were quick to observe that the share of fires caused by human intervention is rapidly increasing. Fire is used by pastoralists to stimulate grass growth for livestock while subsistence farmers also use fire to remove unwanted biomass when clearing agricultural lands and to eliminate unused crop residue after harvest. In the Yankari, as in most forest reserves and national parks across the region, fire is set by the Rangers (Fada, 2015) for environmental management purposes.

Fires are commonly used as an environmental management tool in the Sudan and Guinea savanna zones. Annual fires set early in the growing season after the first rains, with trees sprouting but grass still dormant, will result in more open grassland after a few years, as woody plants are killed off. This may be good for grazing species, but harmful to perennial grasses if done on a yearly basis (NCF & WWF 1987). Turshak (2010) observed during a study of mammals and primates of the Yankari Game Reserve that the whole reserve is burnt annually. The fire regime seems to be carried out haphazardly and is usually set between November and February of every year.

Fire is a widespread seasonal phenomenon in the African continent. In the savanna grassland region it is estimated that 168 million hectares are burnt annually, which is about 17% of the total land base and accounts for the burning of 37% of dry matter globally (Goldammer & de Ronde, 2004). Savanna fires account for 50% of this total with the remainder caused by the burning of fuel wood, agricultural residues, slash and burn agriculture, and from land clearing.

Acquisition of adequate Landsat TM or ETM+ scenes

Five Landsat 5 TM scenes for October, November, December 1986 and January and March 1987, were acquired from the USGS website. The choice of the dates for the acquisition of the images were based on availability of the images and the fact that the fires in Yankari games reserve usually occur between November and February of every year. There was no Landsat 5 image available for the month of February.

Procedure for Data Analysis

Data preprocessing

Indices derived from LANDSAT bands are among the techniques used to estimate the ratios and normalized differences as well as pre-/post-fire temporal differences in vegetation. These indices include the normalized difference vegetation index (NDVI) and the difference normalized burn ratio (dNBR). Several studies have demonstrated the relationship between pre-/post-fire NBR difference (dNBR) and fire severity (Key & Benson, 1999; Wagtendonk, Root & Key, 2004; Cooke, Fule & Crouse, 2005; Kokaly, Rockwell, Haire & King, 2007).

The normalized difference burn ratio (dNBR) was applied to Landsat 5 images for the dry season months to monitor the severity of fire in Yankari Games Reserve during the 1986-87 dry season months. The results were then compared to NDVI changes for the same time period. The dry season in this region in Nigeria starts from October and ends around March. The month of April normally marks the beginning of the rainy season.

First, the data was processed by converting the image from DN to reflectivity by the atmospheric correction method, COST, (Chavez, 1996) for both pre-fire and post-fire images to enable comparisons in severity levels between the corresponding NBR and NDVI indices and also between the NBRpost and NDVIpost values.

The model by Chavez (1996), used to transform data to reflectance is represented as:

$$Model = \frac{((-2.8890805+(0.0602353*\$n1\_gb\_tm\_or(1)-0.15))*PI*0.9932554^2}{195.7*COS(\frac{PI}{180}*(90-52.21))^2} \quad (1)$$

This model is a combination of several inputs, which include converting each minimum DN value to an at-satellite minimum spectral radiance value using the following equation:

$$L_{\lambda min} = LMIN_\lambda + QCAL * (LMAX_\lambda - LMIN_\lambda)/QCALMAX \quad (2)$$

Where QCAL is minimum DN, QCALMAX = 255 and constants $LMIN_\lambda$, $LMAX_\lambda$ as given in Chander et al. (2009).

The theoretical radiance of a dark object assumed to have a reflectance of 1% by Chander et al. (2009) is computed for each band as follows:

$$L_{\lambda 1\%} = 0.01 * d^2 * \frac{cos^2\theta}{\pi * ESUN_\lambda} \quad (3)$$

Where $ESUN_\lambda$ = mean solar exoatmospheric spectral irradiance from d is the sun-earth distance and theta is the solar zenith angle (90-sun elevation).

A haze correction is computed using the computed dark object values (Chavez 1996):

$$L_{\lambda haze} = L_{\lambda min} - L_{\lambda 1\%} \quad (4)$$

The fundamental radiance to reflectance (ρ) equation (Chavez 1996) is:

$$\rho = \pi * d^2 * (L_{\lambda sat} - L_{\lambda haz}) \quad (5)$$

Indices of burn severity:

(i) NBRpre: NBR corresponding to the scene before the fire

(ii) NBRpost: NBR corresponding to the scene after the fire

(iii) NDVIpre: NDVI corresponding to the scene before the fire

(iv) NDVIpost: NDVI corresponding to the scene after the fire

(v) dNBR = NBRpre-NBRpost

(vi) dNDVI = NDVIpre-NDVIpost

Because November usually marks the beginning of the fire-setting season in the reserve (Turshak, 2010; Fada, 2015) the study adopts October 1986 as the pre-fire scene, while the remaining months (November, December, January and March) in the season are post fire.

Processing the Landsat Data

Monthly NDVI

NDVI is a vegetation index used to measure and monitor plant growth (vigor), vegetation cover, and biomass production obtained from satellite images. It is the ratio of the difference between the near infrared band (band 4) and the red band (band 3) and the sum of the bands.

$$NDVI = \frac{(NIR - RED}{(NIR + RED)} \qquad (6)$$

Normalized Difference Burn Ratio

The normalized difference burn ratio which gives the indication of the severity level of the burn is generated as follows:

a) Generate an NBR image of each of the scenes, i.e. pre- and post-fire. NBR is given as the ratio of the difference between the near infrared band (band 4) and the mid infrared band (band 7) and the sum of the bands:

$$NBR = \frac{(NIR - MIR)}{(NIR + MIR)} \qquad (7)$$

b) Generate the difference (Δ) for NBR, given as (Bourgeau-Chavez, Grelik, Billmire, Jenkins, Kasischke & Turetsky, 2020):

$$dNBR = NBR_{pre} - NBR_{post} \qquad (8)$$

The fire severity level is based on the following scale of the dNBR range:

Table 1 Fire severity levels for dNBR ranges

Severity Level description	dNBR range
Enhanced Regrowth, High	-500 to -251
Enhanced Regrowth, Low	-250 to -101
Unburned	-100 to +99
Low Severity	+100 to +269
Moderate-low Severity	+270 to +439
Moderate-high Severity	+440 to +659
High Severity	+660 to +1300+

Bands 3, 4 and 7 are analyzed because they are the bands that are relevant for the study. Bands 3 and 4 are used to calculate changes in the NDVI of the park while band 7 is useful for analyzing the normalized burnt ratio for the vegetation.

RESULTS AND DISCUSSION

Reflectance of Bands 3, 4 and 7

Fig. 2 shows maps of the reflectance values for the bands for the dry season months of October 1986 to March 1987. The maps show increase in the area with high reflectance in band 7. In figure 3 the box plots show changes in reflectance values of bands 3, 4 and 7 over the months. The month of Oct 1986 shows higher values of band 3 with an average reflectance value of almost 0.4 and a max of about 0.7. There is also higher reflectance in band 4 than band 7. The average reflectance in band 4 is almost 0.4 but the max reflectance in this band is 0.6.

Normalized Difference Vegetation Index

The result of the NDVI analysis shows that NDVI values are very high in the month of October with about 65% of the area of the park having NDVI values of between 0.4 and 0.5. As the dry season progresses the NDVI reduces drastically such that in March 1987 more than 80% of the area of the park has NDVI value of 0. The NDVI values for each month are shown in figs 4 and 5.

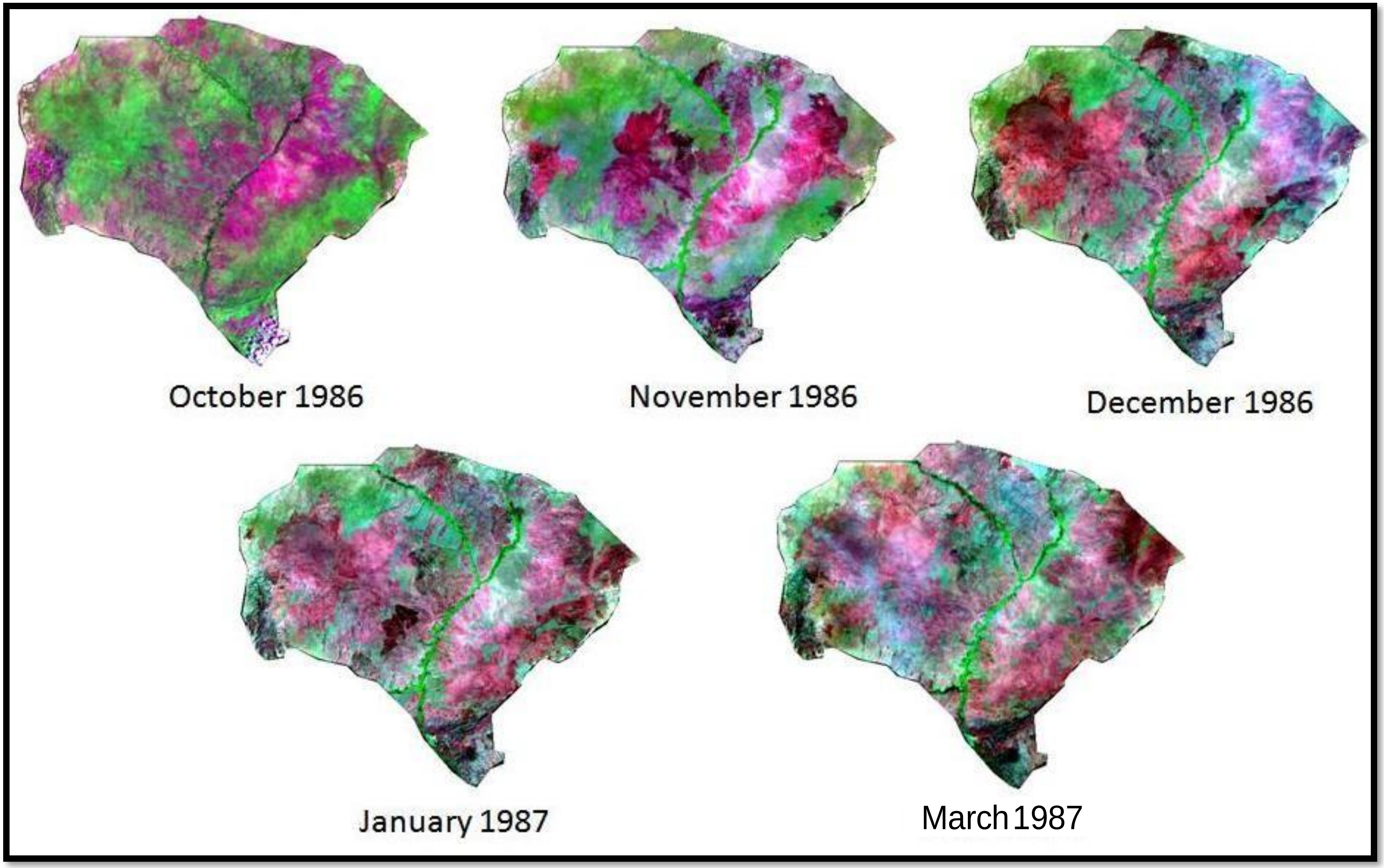

Figure 2 Reflectance Maps for Bands 3, 4 and 7 for the Study Area

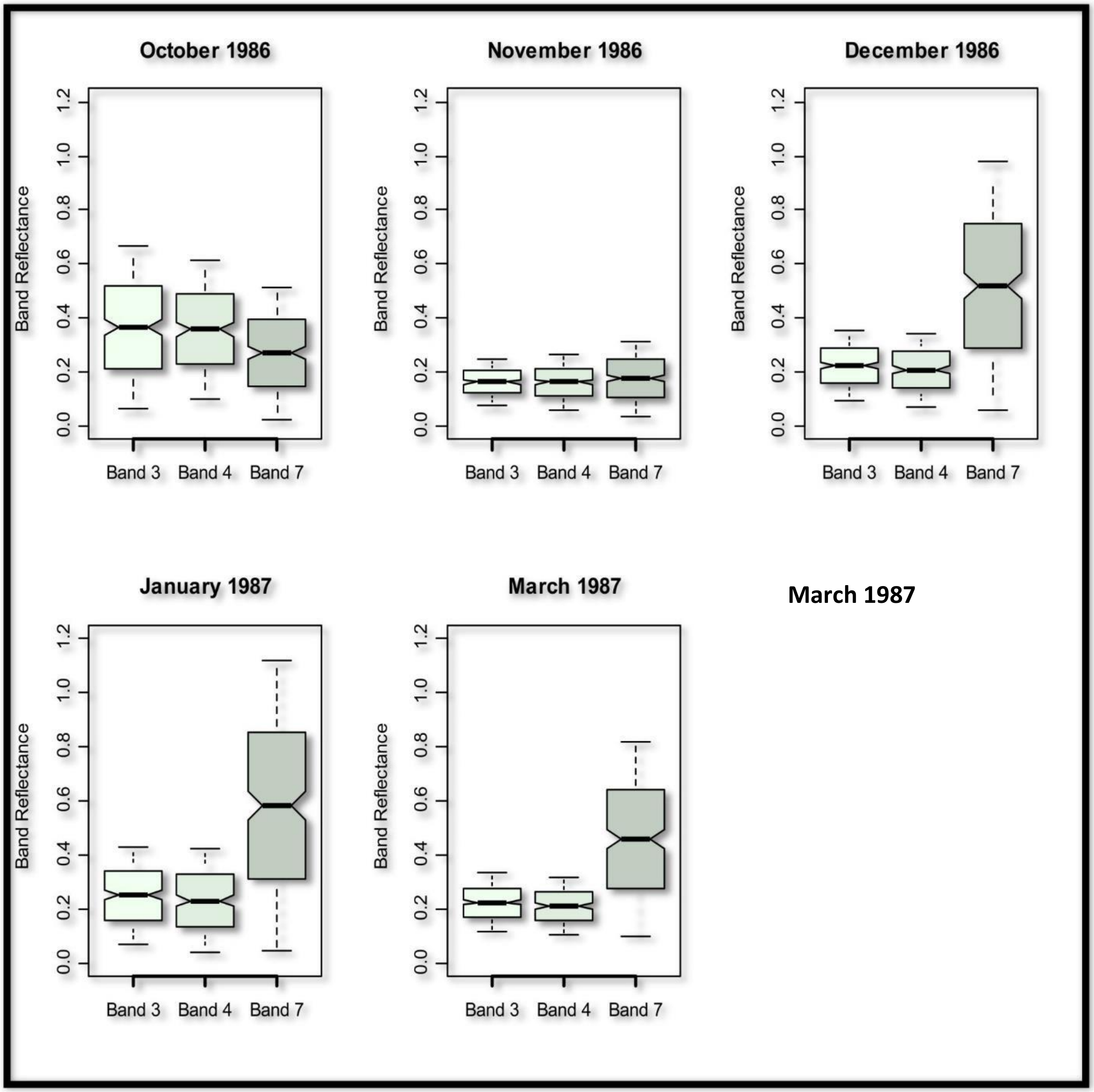

Figure 3 Box Plots Showing Changes in Reflectance Values of Bands 3, 4 and 7 over the Season

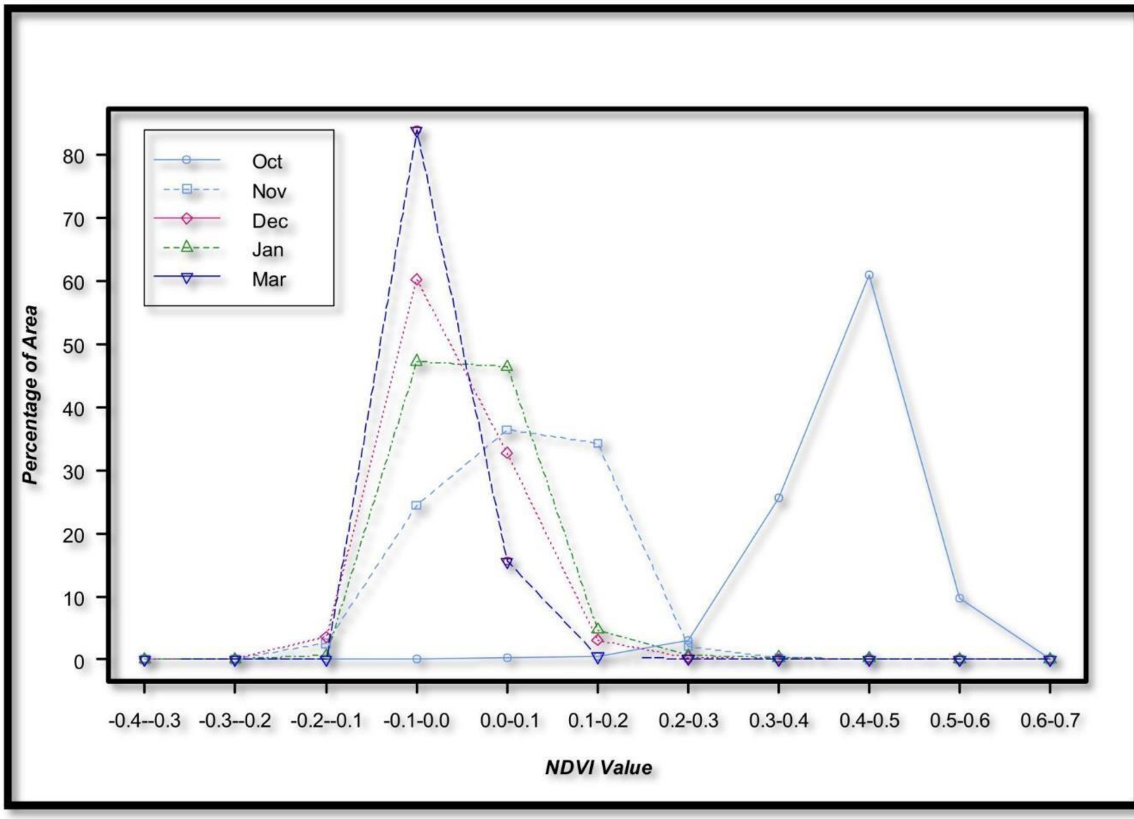

Figure 4 Plot of Percentage Area of Monthly NDVI Values

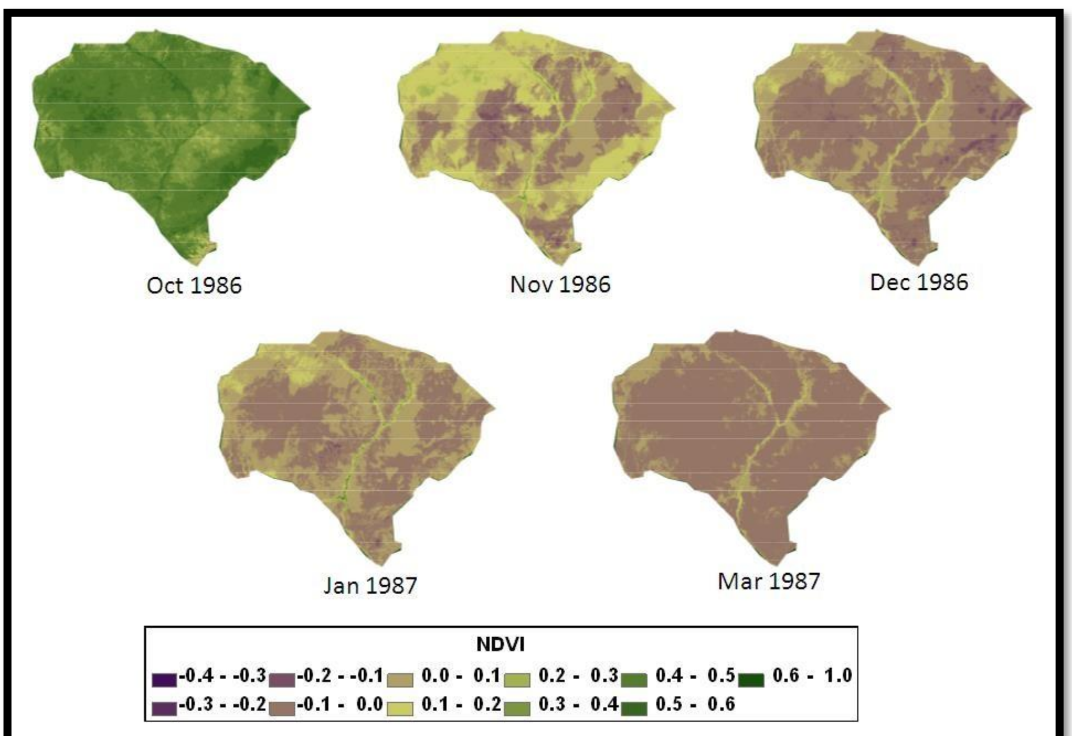

Figure 5 Monthly NDVI Maps

Normalized Difference Burn Ratio

The normalized difference burn ratio for the park between the months of October and March are shown in figures 6 and 7. As shown in equation 8, the normalized difference burn ratio is the difference between the pre- and post-fire normalized burn ratios. In this analysis it is the difference between the NBR for the month of October and the other months, given that the fire season starts in November. The maps on figure 6 show that fires started at the edges, and spread towards the central area, which shows less severity as the fire weakens over time or efforts are made to combat it.

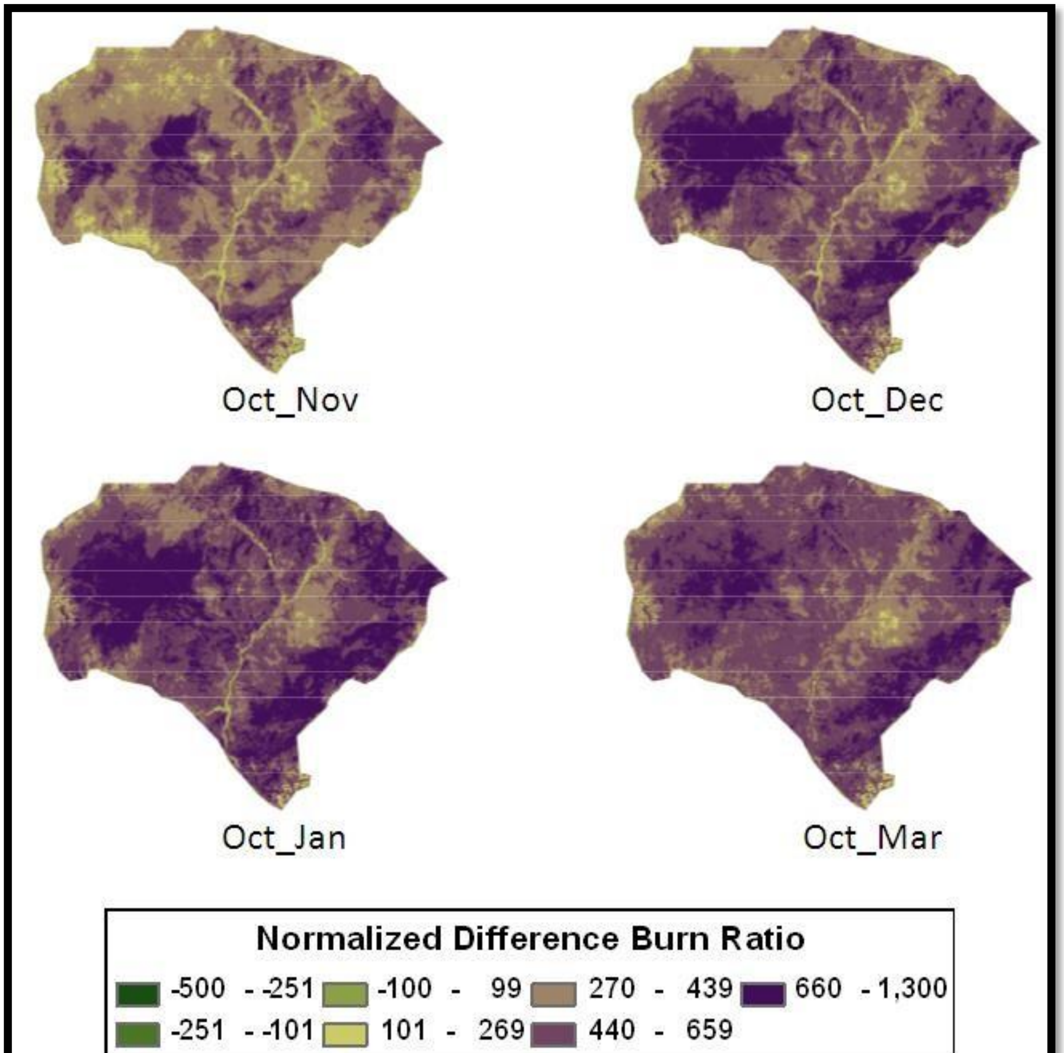

Figure 6 Normalized Difference Burn Ratio (dNBR) Maps over the Season

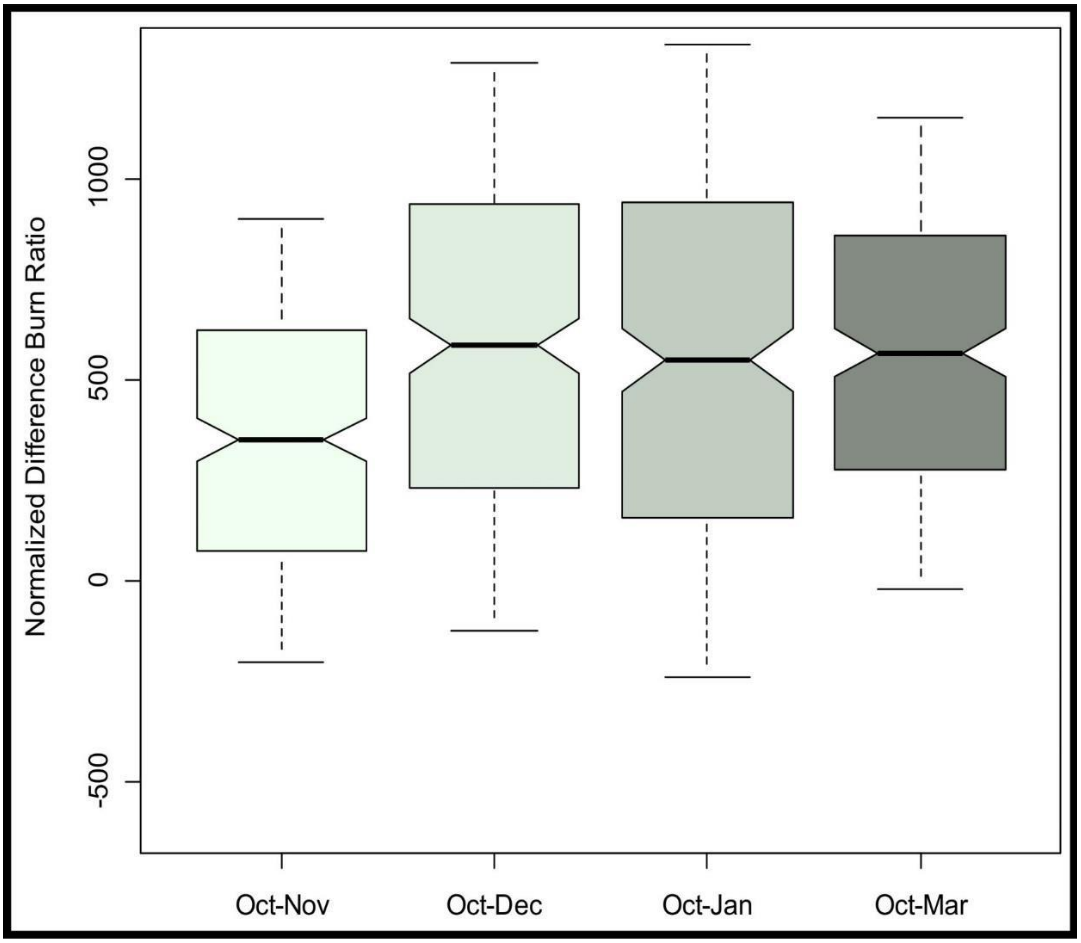

Figure 7 Normalized Difference Burn Ratio October 1986 - March 1987

Fada (2015) also noted that since the periphery of reserve areas are less protected and usually heavily inhabited, illegal fires could easily start from the edges of the reserves. This pattern of spread may have contributed to the observed distribution of wildlife in the reserves in the dry season (April 29 – May 2), with large concentrations around the Gaji River at the center of the reserves (Bergl, Dunn, Haruna, Mshelbwala & Nyanganji, 2011). In contrast, Omondi, Mayienda, Mshelbwala and Massalatchi (2006) reported a much wider spread of wildlife population in Yankari Games Reserve during the rainy season (July).

Generally, the area along the length of the river possesses the most robust vegetation during the dry season because of the abundance of water resources. It is natural therefore for most wildlife to congregate along the river and be found there because of abundance of food resources as well. However, there may be several wildlife species that would prefer the open grassland or periphery areas away from the river for predatory reasons. The non-availability of vegetation at the fringes due to fire burns precludes this choice and forces these animals into unfriendly territories. And if so (pattern of spread from edges to center) we could speculate on arson by poachers being probably responsible as it is common to have fires started for hunting purposes, to frighten animals out of hiding thereby exposing them. There are settlements and farmsteads at the perimeter of the reserve as well and these people may be responsible for starting some of the fires either accidentally or for farming purposes as well – the peak being in January may well serve both purposes because that is the farmland preparation period and the hunting season since farm work is completed.

Mohammed (2010) reported an increase in the number of settlements at the periphery of the reserves due to an increasing number of internally displaced persons (IDP) due to the serious security threats in the region. This situation has the potentials to exacerbate the problem. For example, Toepfer (2005) observed that large numbers of fires in reserves in the Congo were started by internally displaced persons (IDPs) who had settled around the reserves and wanted to prepare land for farming activities. Umar, Abdullahi, Ezra and Auwalu (2015) reported that over 80% of residents of communities adjoining Yankari Games Reserves are farmers. The potential and risks of starting a fire for land preparation purposes is therefore high. Arhyel, Daful and Ezeamaka (2019) concluded from their study of vegetation community composition in the reserve that there has been a decreasing trend in land cover in the reserve due principally to anthropogenic activities. The implications for conservation of the reserve therefore appear grim if no proactive measures are taken to stop these practices.

By the month of January the only parts left without the effect of fire in Yankari Park are the riparian zones of the Gaji River and its tributaries. This finding agrees with Fada (2013) who reported that more than 90% of the reserve has been affected by fire between 2000 and 2014. Apparently, this trend has been ongoing for much longer than this period as suggested by the findings of this study. Also Estes, Knapp, Skinner, Miller and Preisler (2017) stated that in fire incidents, riparian and higher elevation forest areas burn less frequently than other sections, which agrees with this study. Figures 8a-8d show the areas (in sq. kms) of the park under various categories of burn severity.

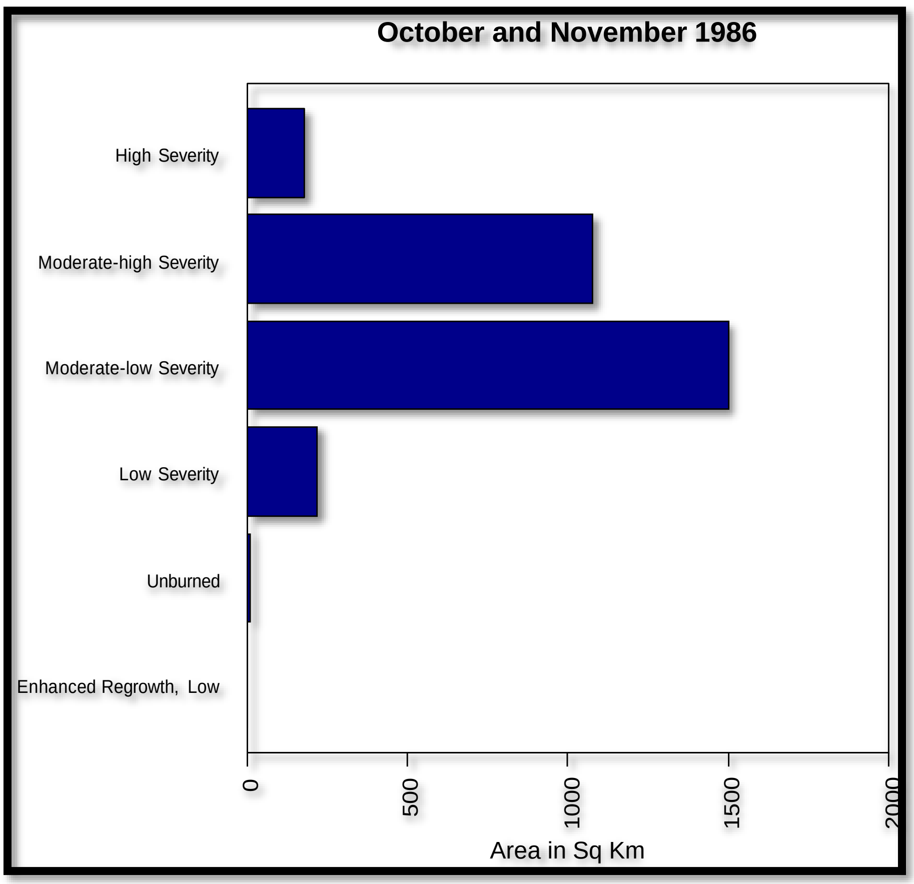

Figure 8a

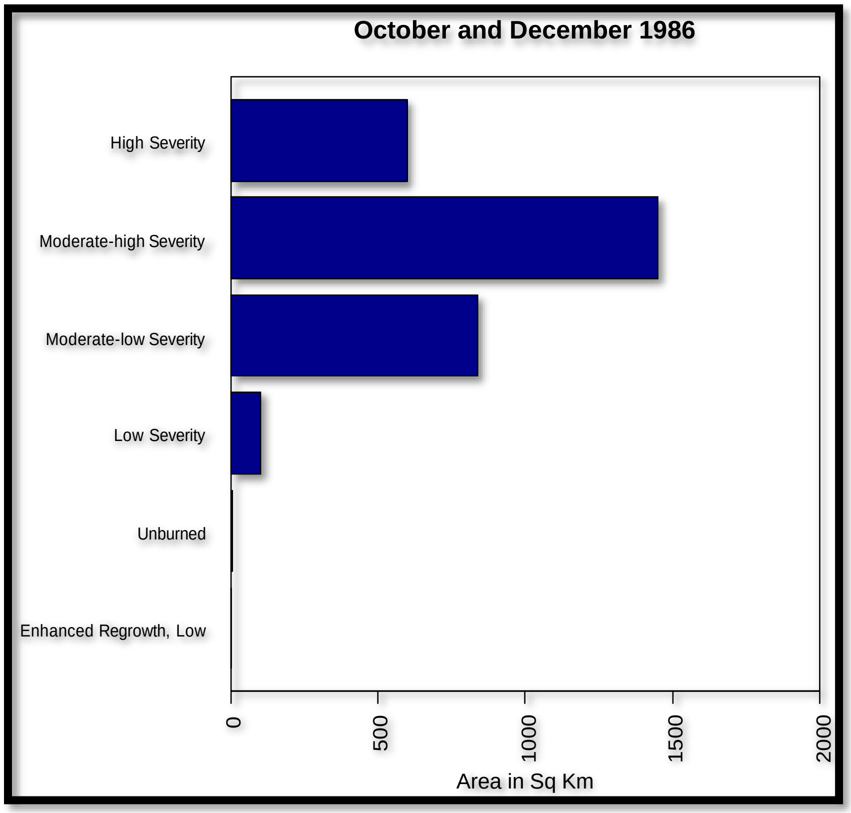

Figure 8b

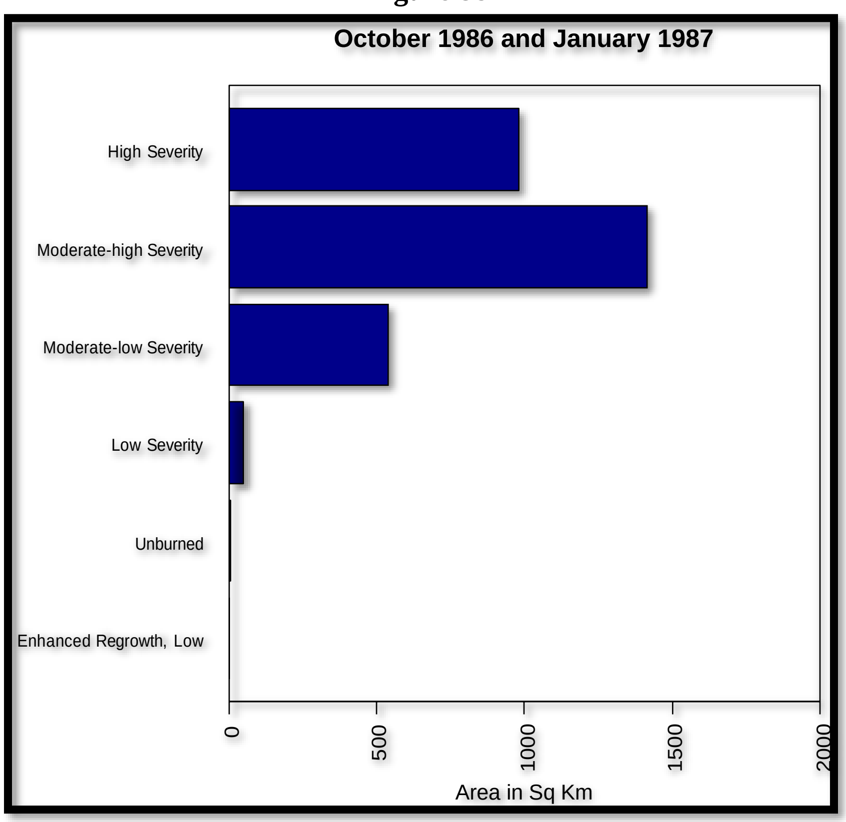

Figure 8c

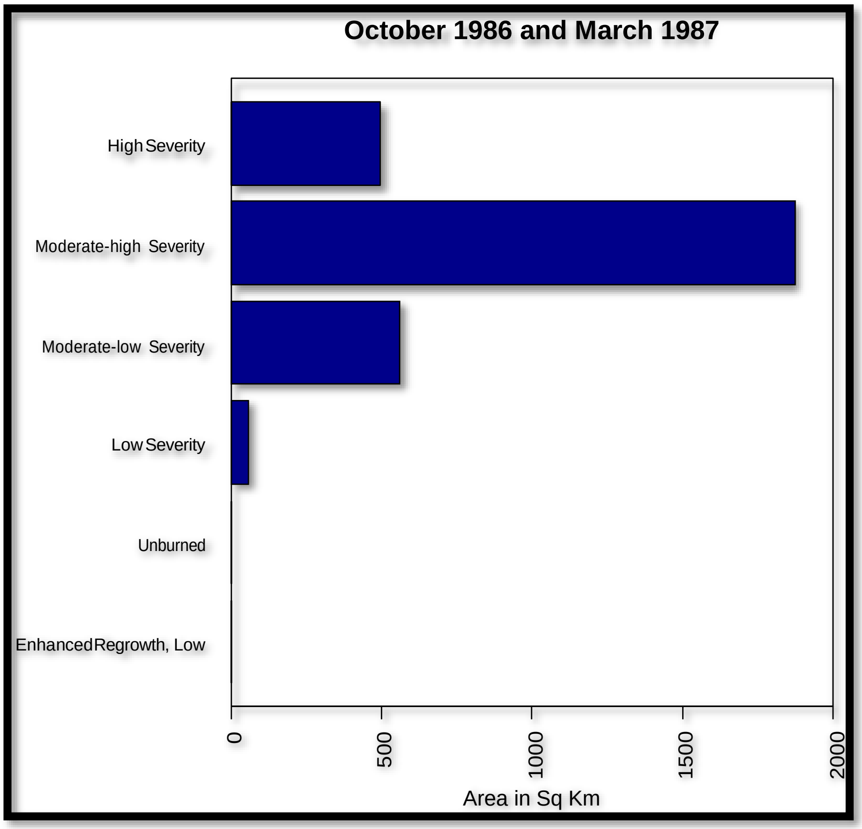

Figure 8d

Fgures 8a-8d Barplots showing severity of burn (dNBR)

In November, about 1500 square kilometers (sq. km) of the park is under moderate to low burn severity and about 1100 sq. km is under moderate to high severity. As little as about 100 sq. km is under high severity. In December the area under High burn severity increases to about 600 sq. km, moderate to high severity increases to about 1500 sq. km while the moderate to low severity level decreases to about 900 sq. km. Fig. 8 shows that close to 1000 sq. km of the park is severely burnt in the month of January, with over 1500 sq. km with moderate to high level of burn severity. Almost no part of the park is left unburned except the riparian areas. In the month of March, there are no forest fires and probably some regrowth which show most of the area (about 1900 sq. km) as moderate to high severity of burn.

Bergl, Dunn, Haruna, Mshelbwala and Nyanganji (2011) reported that the west and eastern part of the reserve are dominanted by Afzelia savanna woodland and combretaceous shrub savanna vegetation types (Geerling 1973; Green & Amance 1987; Abdullahi, 2011). These roughly coincide with areas of severe fire burns (see Fig. 6). The reported incursion of large numbers of domesticated livestock into the reserves during this period (the dry season) by nomads poses additional problems to the herds of wildlife in the reserves. With considerably less vegetation due to fire burns, there is additional competition for the remaining vegetation from livestock. Cattle are currently by far the largest livestock population in the reserve (Nyanganji, Saidu, Hensche l& Dunn, 2012; Arhyel, Daful & Ezeamaka, 2019). This has the potentials to increase food stress, overgrazing and consequently instability in food reserves for the wildlife in the reserve. Risks of wildlife contracting diseases such as rinderpest from livestock are also real. Namathe and Lamorde (1983) and Mohammed, Shehu, Adamu and Saleh (2010) reported significant loss of herbivorous wildlife due to rinderpest in the 1980s. The fact that the most affected wildlife species were herbivores lends credence to the fear that contacts with livestocks, which are also herbivores, could have resulted into the near purge of some species. For example, according to Mohammed, Shehu, Adamu and Saleh (2010) only 25 buffalos survived the epizootic outbreak of rinderpest in the reserve in the 1983/84 season.

The use of fire to encourage growth of annual grasses has been well-documented. However, excessive employment of fire to boost annual grasses endanger perennial grasses and woody plants, which are important sources of food for many wildlife such as the elephants. The loss of these plant covers also expose the land to erosion and eventual degradation with serious consequences for sustainable food production for wildlife in the reserves (Mohammed, Shehu, Adamu & Saleh, 2010). These concerns have generated discussions on the necesity to employ fire as a tool to boost annual grasses in the reserves (Abdullahi, Sanusi, Abdul & Sawa, 2009).

CONCLUSION

Fire severity describes how fire intensity affects ecosystem following wild or regulated fires as is the case in Yankari Games reserves in Nigeria. The use of Landsat images and normalized difference burn ratio in this study provides useful information on the severity of fire in this forest that otherwise would not be possible through field work.

The study has tracked the intensity and severity of fire and the burn severity using the dNBR index and this capacity provides the prospects for predicting the impacts (positive or negative) such as soil erosion due to exposure or response of natural vegetation and the resultant effect on wild life. Describing ecosystem response would best be done quantitatively. Detailed experimental onsite studies would be needed to achieve this. Though many biotic and abiotic factors are involved in the relationship between fire intensity and ecosystem response, it is clear that forest fires are an important factor in ecosystem changes in the dry season in the game reserve.

It is important to understand the growth and development of fires in the reserve, the implications and its extent to be able to control it and its impacts. The application of remote sensing techniques provides a bird's eyeview of the reserve in ways that no other method can equal. This exploratory examinaton provides inkling of the variety of use to which remotely sensed data and its application can potentially bring to game reserve conservation in countries with limited data by highlighting the areas of severe fire intensities, the probable sources and therefore factors that may have generated fire incidents and especially, the probable degree of impacted areas by fire.

There are also several policy implications that suggest themselves even at this level of exploration. The results indicate that human settlements and activities both within and around the games reserve are important sources of fires in the park. In many instances these fires are generally uncontrolled and may have devastating impacts on biodiversity and wildlife. Legislation should include strict restrictions on human settlements and activities within and near the games reserves. This is vital to sustained protection, preservation and conservation of both plant and animal diversity in the park. Equipped and modern fire service stations should be established in strategic locations throughout the park and charged with the responsibility to combat and control unintended fires. With adequate training, the fire fighters may be charged with any environmental management efforts that require a controlled fire as tool. The necessity to be proactive in fire management in the games reserve is borne out of the near regularity with which uncontrolled fires occur in the park and their long term impacts on plant and animal diversity.

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