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Time Series Monitoring of Bush Encroachment by *Euclea divinorum* in Ol Pejeta Conservancy Laikipia, Kenya

Cyrus Mutunga Kavwele[1, *], Mwangi James Kinyanjui[1], Johnstone Kithiki Kimanzi[2]

[1]Department of Natural Resources, Karatina University, Nyeri, Kenya

[2]Department of Wildlife Management, University of Eldoret, Eldoret, Kenya

Email address:

cyruskavwele@yahoo.com (C. M. Kavwele)

[*]Corresponding author

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Abstract: Bush encroachment refers to the invasion of woody species in Savannah ecosystems driven by either anthropogenic and/or natural factors. This study sought to examine land cover changes and topographic features attributable to patterns of encroachment in Ol Pejeta Conservancy (OPC) where, *Euclea divinorum* unpalatable woody species has colonised former grasslands and other habitats which provide grazing grounds for herbivore wildlife species. Here, we monitored vegetation cover trends in the period 1987-2016 using five vegetation classes on Landsat images acquired during the dry season. Additionally, slope based NDVI maps and digital elevation models were used to identify topographic influences on vegetation change. Results revealed that *E. divinorum* increased significantly between 1987 and 2016 (Mann Kendall test for trend analysis tau 1, n=6, p< 0.01). On the other hand, *Acacia drepanolobium* and *Acacia xanthophloea* decreased from 49.72% and 5.31% in 1987 to 17.00% and 0.29% in 2016 respectively. Further, areas in low elevation were more colonised by *E. divinorum*. The colonising *E. divinorum* is unpalatable hence lacks natural predators whilst, *A. drepanolobium* and *A. Xanthophloea* which are alternative herbivory species decreased. Understanding dynamics of woody vegetation in savannah is crucial for management of healthy and sustainable ecosystems.

Keywords: Bush Encroachment, Savannah Grassland, Land Cover Change

1. Introduction

Increasingly, savannah ecosystems are gradually changing from open grassland to woody dominated landscapes [1]. This biome shifts consequently result to variations in vegetation composition and structure notably increase in woody species [2]. Research has amassed evidence that savannah ecosystems are changing due to a phenomenon referred to as bush encroachment [3]. Literature has mooted potential drivers of bush encroachment in these ecosystems. As such, over grazing has shown positive correlation with increase in woody species in savannah ecosystems [4]. Other possible causes include precipitation rates particularly, increase in rainfall favouring establishment of woody species [4], fire suppression and favourable edaphic factors [5, 3]. This phenomenon varies remarkably making it difficult to revert forested areas to grasslands [6]. Proliferation of woody species in grassland ecosystems threatens the resident biodiversity, biodiversity conservation measures [7] and pastoralism which is major source of livelihood in these ecosystems is also adversely affected [7].

In Ol Pejeta Conservancy (OPC) Laikipia Kenya, increase in unpalatable woody species of *Euclea divinorum* has become a major concern for conservationists. The encroacher species has been expanding into other habitat types such as *Acacia drepanolobium*, *Acacia xanthophloea*, Open grass land among others affecting key resource for mega fauna such as African Elephants (*Loxodonta africana*, vulnerable International Union for Conservation of Nature IUCN 2008 Red Listing), critically endangered Eastern Black Rhino (*Diceros bicornis,* (IUCN 2011 Red Listing), Vulnerable Giraffes (*Giraffa camelopardalis* IUCN 2016 Red Listing) among other herbivores. This encroachment can potentially reduce carrying capacity of the range land and by larger extend eliminate wild flora and fauna. The main objective of this study was to determine landcover changes in OPC from 1987-2016 and topographic features attributable to encroachment patterns. The findings of this research work are vital for rangeland and conservancy managers in decision making regarding realisation of healthy ecosystems for sustainable development.

2. Methods and Materials

2.1. Study Site Description

The study was undertaken at Ol Pejeta Conservancy (OPC) which covers 90,000 acres (360km^2), a classic example of an African savannah. It lies between Mt. Kenya and the Aberdare Mountains (0°7.288'N, 36°42.384'E and 0°8.634'N, 37°0.605'E) (0°1.831'S, 36°46.578'E and 0°5.7025'S 37°2.492'E), at an average altitude of 1810m, mean annual rainfall of 739mm, mean maximum and minimum temperatures of 28°C and 12°C respectively. It is a private owned conservancy chiefly, a sanctuary for black rhinos (*Diceros bicornis*). However, other wild animals are also conserved in the same property composed of various feeding guilds such as mixed feeders, carnivores, grazers and browsers. It is also a sanctuary for chimpanzee (*Pan troglodytes*) providing refuge site for seized chimps from black markets. It has one permanent river flowing through the conservancy as well as various man made water holes to supplement water scarcity in dry spells.

Major land cover types include grasslands, *Acacia drepanolobium*, *A. xanthophloea, Euclea divinorum*, and mixed bushlands. The conservancy is surrounded by an electric fence with three "corridors" to allow movement of wild animals in and out of OPC (but movement of rhino species is restricted due to the risks involved). The conservancy is surrounded by agro-pastoral communities and towards the north by other adjoining conservancies. The map of the study site is as in figure 1.

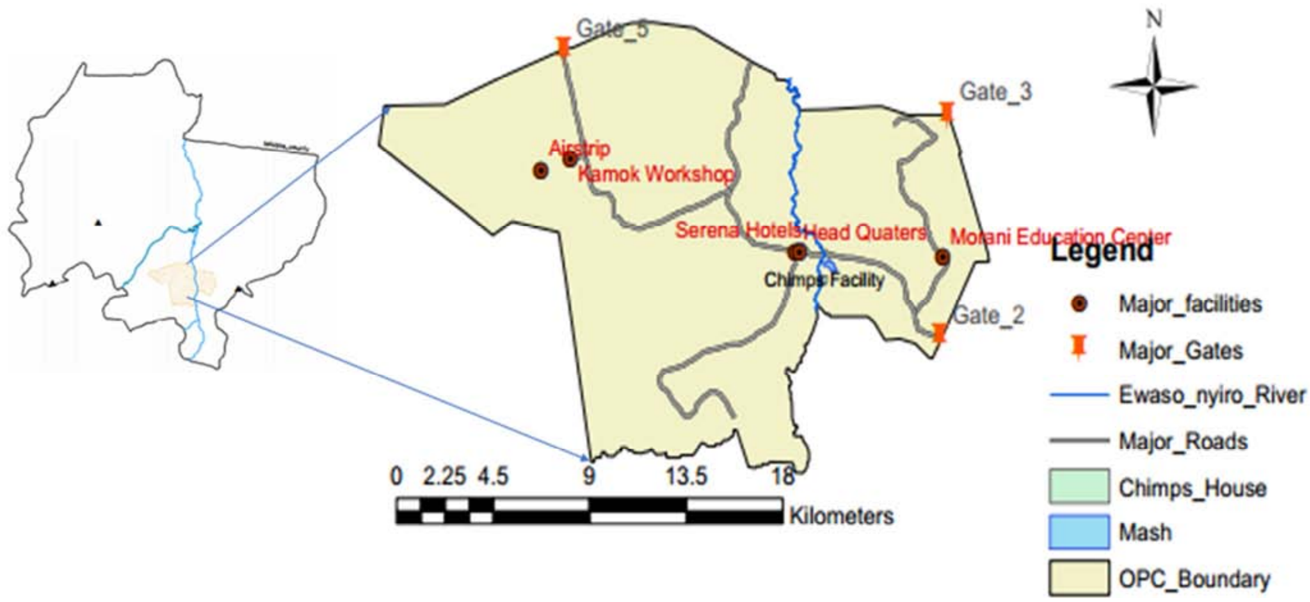


Figure 1. *Location of the study site showing major facilities in the conservancy.*

2.2. Image Acquisition

Multispectral Landsat images for 1987, 1995, 2000, 2005, 2010 and 2016 captured during dry seasons were acquired from United States Geological Survey (USGS). Auxiliary data were acquired using hand held Global Positioning System (GPS) for ground truthing purposes.

2.3. Image Pre-processing and Classification

As light passes through the atmosphere, it interacts with particulate matter such as haze, smoke, water vapour among others hence signal quality can be affected considerably before and after interacting with the target object/surface [8]. As such, in order to get clear Landsat images, top of atmosphere reflectance correction was performed using dark object subtraction algorithm in Quantum Geographic Information Systems (QGIS).

Multitemporal Landsat images Thematic Mapper, Enhanced Thematic Mapper+ and Operational Land Imager of 1987, 1995, 2000, 2005, 2010 and 2016 were used to study Land cover dynamics. Supervised classification technique was used to classify vegetation cover in to five land cover types namely *Euclea divinorum*, *Acacia drepanolobium*, *Acacia xanthophloea*, Open grassland and Mixed bushlands in the conservancy. This algorithm is preferred over the other algorithms due to its ability to use well developed probability theory. Here, four (4) regions of interest (ROI) per each habitat type identified after different colour composite combination were used to enhance image interpretation. This was made possible due to existence of various habitats types in clumps hence identifiable especially with prior user's knowledge of the spatial extent of cover types. This made it easy to identify and separate species composition prior to actual classification. Assessment of spectral distance (spectral separability) to minimise classification errors was executed using Jefferies-Matusita Distance where if asymptotic distance is 2 the signatures are completely different whilst, if it is 0 signatures are identical [9]. Further, Normalized Difference Vegetation Index (NDVI) display an option in QGIS platform was activated during classification to enhance accuracy of the results. Thirty (30) random points were also generated and loaded in to hand held GPS and points visited thereafter to compare spectral similarity between actual cover and classification output. This further enhanced assessment of species composition on the ground.

2.4. Accuracy Assessment

In order to improve on reliability of change detection results, accuracy assessment of the classification output is crucial. Accuracy assessment reveals correctness of the classification results with reality on the ground. Here, 30 random points were generated covering different land cover types and compared with the ground cover to ascertain that there was no landcover classification spectral mix up. Finally, classification reports were generated giving proportions of each land cover type in a given year.

3. Results

3.1. Vegetation Cover Types in OPC for 2016

Results of classification revealed that nearly half (49.65%) was covered by *E. divinorum*, followed by Open grassland (24.22%,), *A. drepanolobium* (17.00%,) mixed bushland (8.84%) and least cover being *A. xanthophloea (0.29*%) as shown in table 1and figure 2.

Table 1. *Proportion of various cover types for year 2016.*

Cover type	Area Cover (Ha)	(% of vegetation type)
E. divinorum	14,455.98	49.65
Open grassland	7,051.69	24.22
A. drepanolobium	4,950.32	17.00
Mixed_bushland	2,573.97	8.84
A. xanthophloea	85.45	0.29
Total	29,117.41	100%

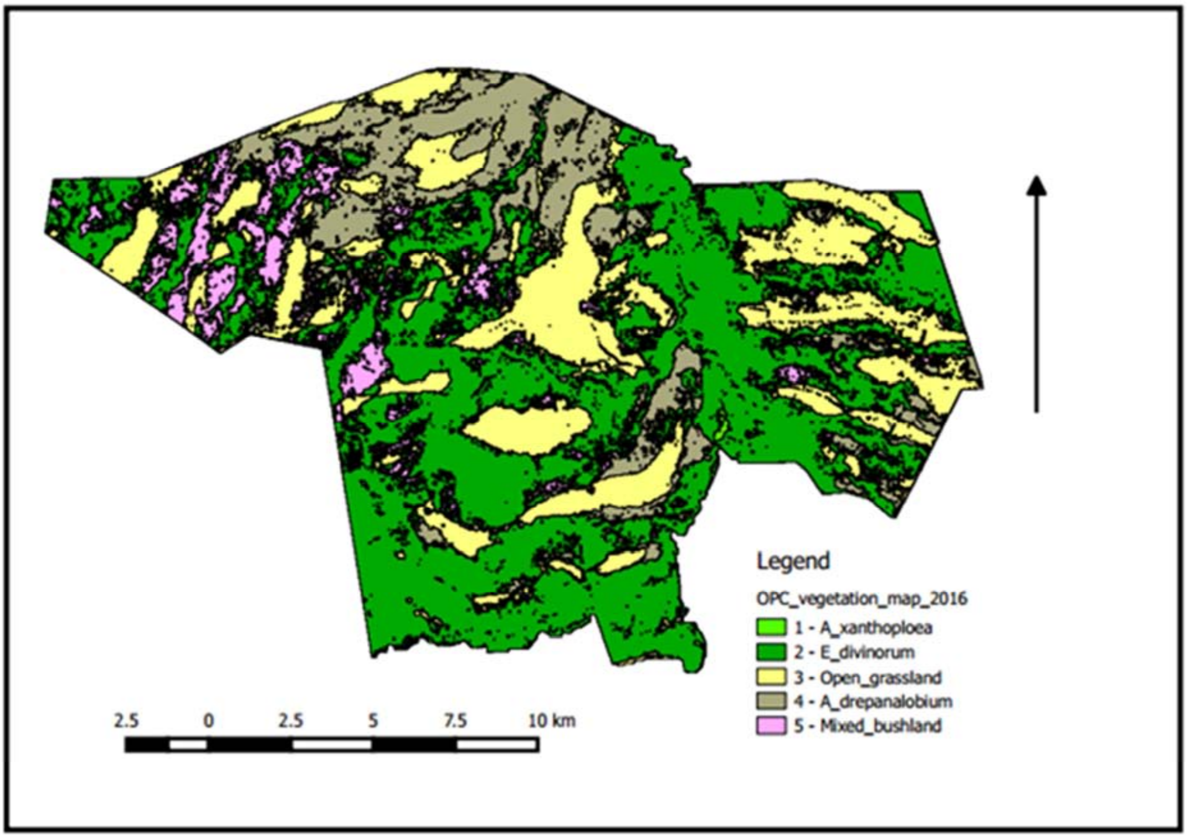


Figure 2. *Vegetation map of OPC in 2016 showing various classes coverage.*

3.2. Land Cover Changes with Respect to Euclea divinorum

Classification results revealed that *E. divinorum* cover increased from 12.35% in 1987 to 49.65% in 2016. This represents significant monotonic (upward) increase in *E. divinorum* cover from 1987 to 2016 (Mann Kendal test for trend analysis tau 1, n=6, $p < 0.01$) The rate of change between 1987 and 1995 annually was 66.42 Hectares/Yr whilst annual increment rate between 1995-2000 and 2000-2005 were at 161.374 Ha/Yr and 381.55Ha/Yr, respectively. Rates of change between 2005- 2010 and between 2010-2016 were 1024.228 Ha/Yr and 415.232 Ha/Yr. Overall, the rate of increment in cover between 1987 to 2016 stood at 387.89Ha/Yr.

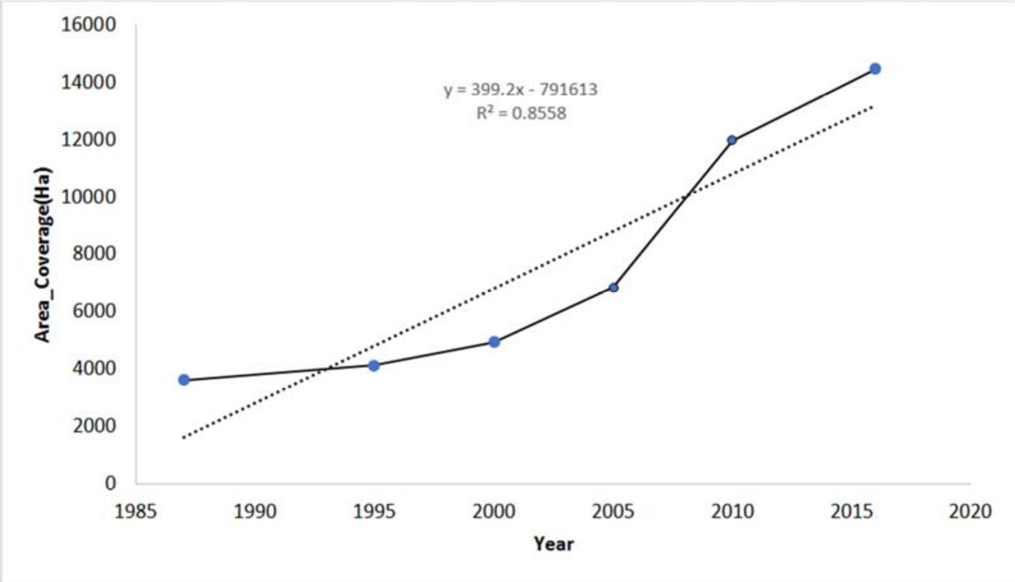


Figure 3. *E. divinorum cover trends between 1987 and 2016 on OPC.*

3.3. Overall Vegetation Cover Changes in OPC

Results from this study revealed that some class cover types either increased or decreased throughout the study period whilst other classes increased or decreased at different times (figure 4). Particularly, *E. divinorum* increased in cover throughout the study period whereas *A. drepanolobium* and *A. xanthophloea* decreased in cover over time. On the other hand, Open grassland, and mixed bushland either increased or decreased in cover in different time periods. Open grassland class, between 1987 and 1995 there was increase in cover by 1025.63 Ha followed by a decrease between 1995 and 2000 by 1060.47 Ha and an increase in between 2000 and 2005 by 1,665.406Ha, 2005-2010 by 645.1346 Ha and finally a decrease between 2010 and 2016 by 511.016 Ha. Overall, there was an increase in open grass cover in the entire study period 1987-2016 by 1,558.68 Ha.

Mixed bushland increased in cover between 1987-1995 and 1995-2000 by 7184.7 Ha and 1691.54 Ha, respectively followed by decrease from 2000-2005 by 3,001.33 Ha, 2005-2010 a decrease by 5,556.69 Ha and a further decrease between 2010 and 2016 by 1,747.85 Ha. However, there was an overall decrease in mixed bushland cover in the entire study period by 1,429.73 Ha.

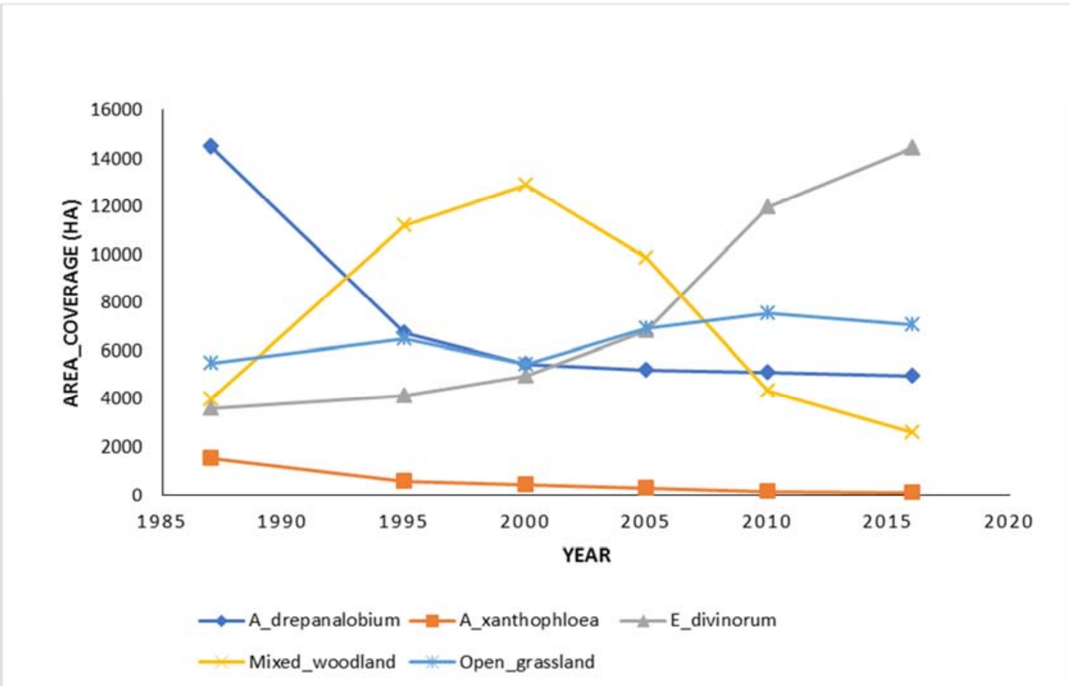
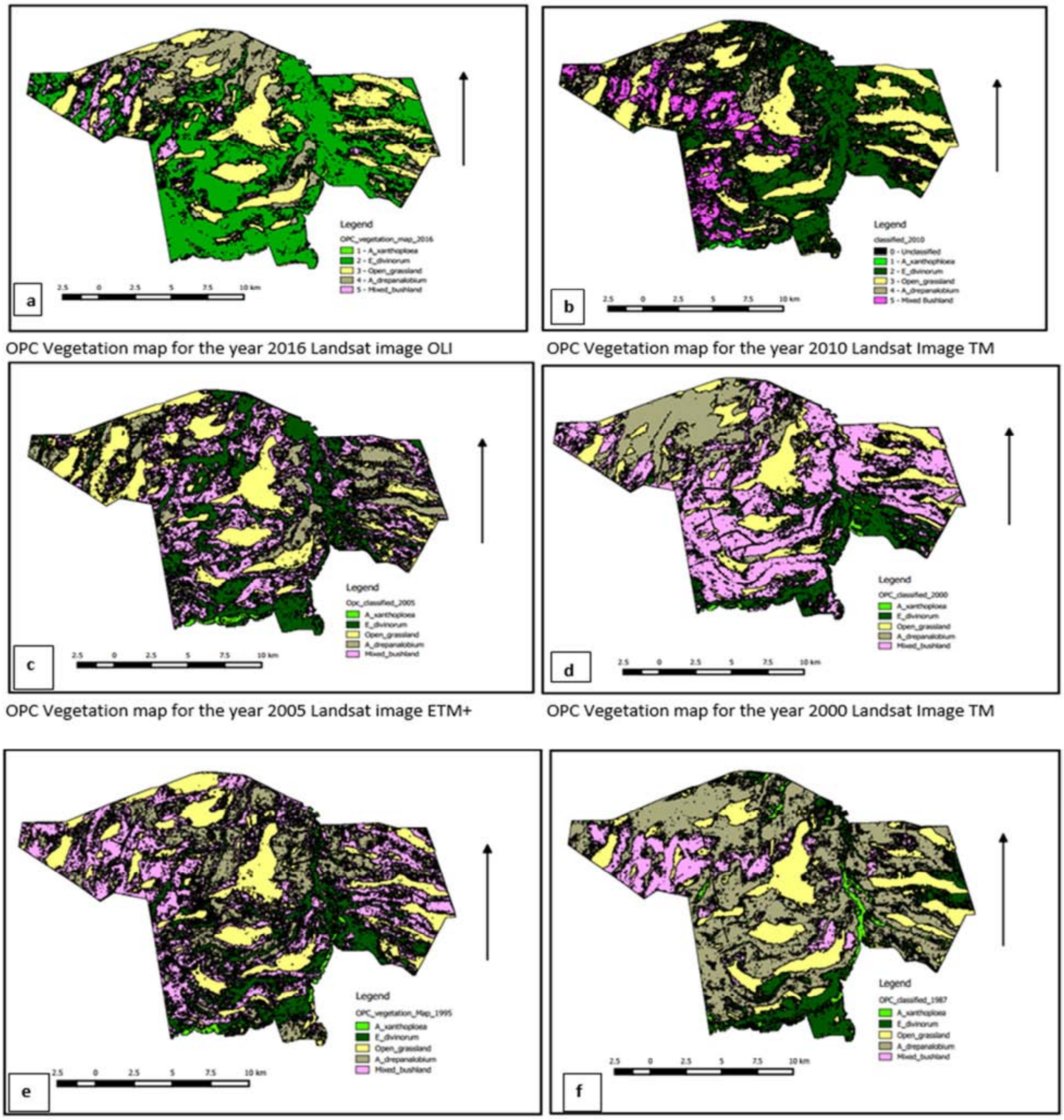


Figure 4. *Overall cover trend from 1987-2016 in OPC.*

Trends in cover change revealed that *A. xanthophloea* was nearly displaced in the year 2016 where much of the area initially covered by *A. xanthophloea* is currently under *E. divinorum* hence the dominant vegetation cover along the riverine. Additionally, *A. drepanaolobium* has also spatially reduced in coverage as well as mixed bushland shifting to more dominated *E. divinorum.* However, open grassland cover exhibited a combination of increase and decrease over time hence has remained relatively stable in spatial coverage. Significantly, spatial coverages of *A. xanthophloea*, *A. drepanalobuim* and mixed bushland changed. These trends in vegetation cover for the years 1987, 1995, 2000, 2005, 2010 and 2016 are as shown in figure 5.



OPC Vegetation map for the year 1995 Landsat image TM (1995), OPC Vegetation map for the year 1987 Landsat image TM (1987)

Figure 5. *OPC Vegetation maps for 1987,1995, 2000, 2005, 2010 and 2016.*

3.4. Topographic Features Attributable to Encroachment Patterns by Euclea divinorum

Slope based Normalized Difference Vegetation Index (NDVI) was performed to examine any influence of slope on encroachment patterns. The results showed that areas with high NDVI value (NDVI maps for 1987, 2000, 2005 and 2016) were those along deep channels and valleys, ideally areas in low elevation were covered by dense *E. divinorum* as in figure 6 a, b, c and d. Here, four Landsat scenes were deemed appropriate for the purposes of exploring encroachment patterns using NDVI ratios and consequently generating NDVI maps.

NDVI results revealed that in 1987, areas close to the river creating a thin band covered by evergreen *E. divinorum* whilst in the year 2000, the species spread outwards notably in the southern and southern eastern parts. In the year 2005, *E. divinorum* spread further especially in low elevated areas (deep valleys) covering larger part in southern and eastern as well in some parts in the northern region. In the year 2016, *E. divinorum* spread further towards the northern western parts in the conversancy predominantly in the low elevated areas.

Additionally, topology analyses using DEM and contours revealed the lowest point at about 1762.48 m ASL and highest point at about 1917.64m ASL translating to a range in altitude of 155.16m in the conservancy. Further, overlay of both topographic features, which include contours and elevation (observable features) on vegetation map of 2016 showed that areas below 1800m above sea level (ASL) were covered by *E. divinorum* as in figure 7 a, b, c and d. However, this encroachment appeared to be expanding towards areas even at higher altitudes than 1800m ASL.

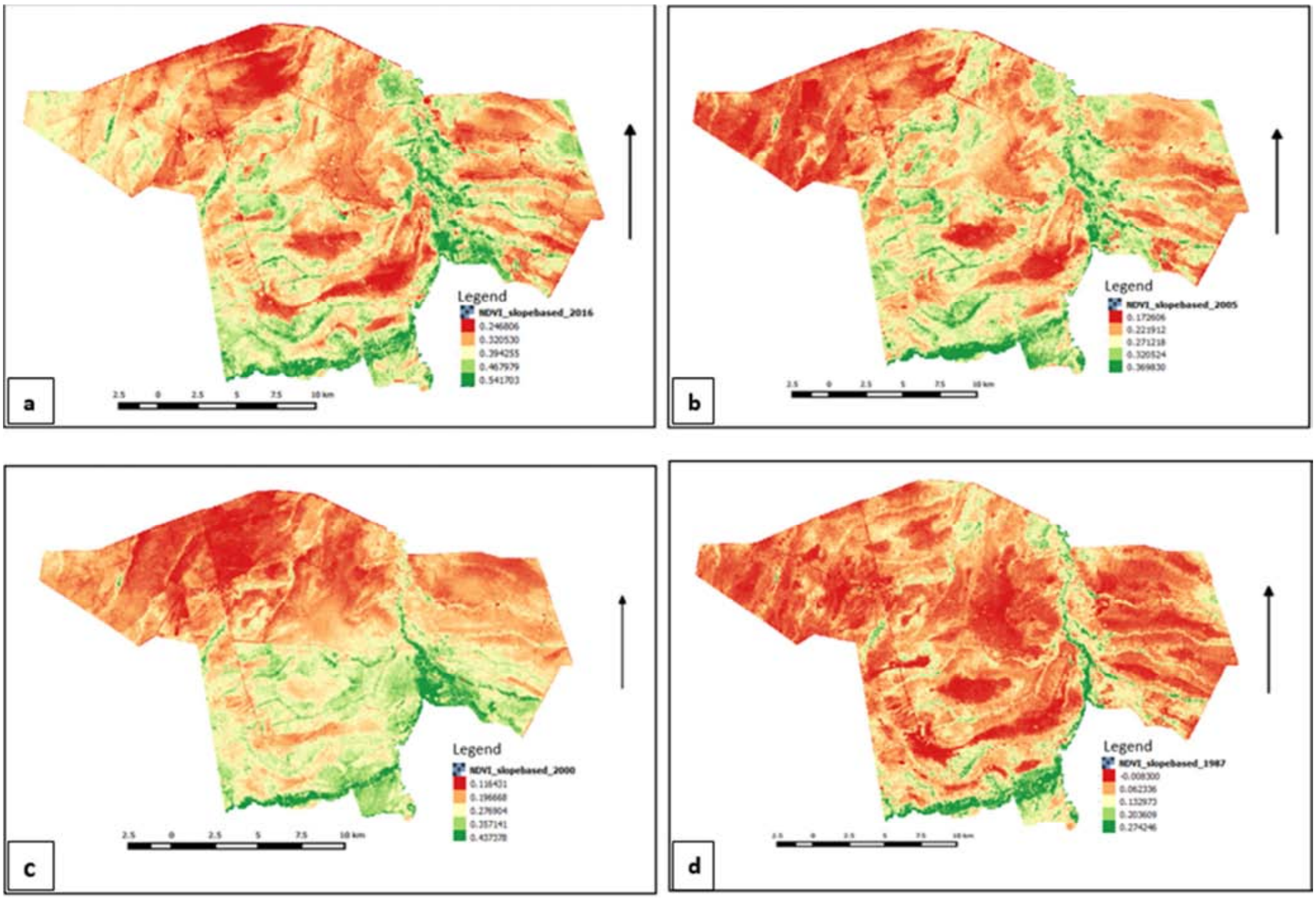
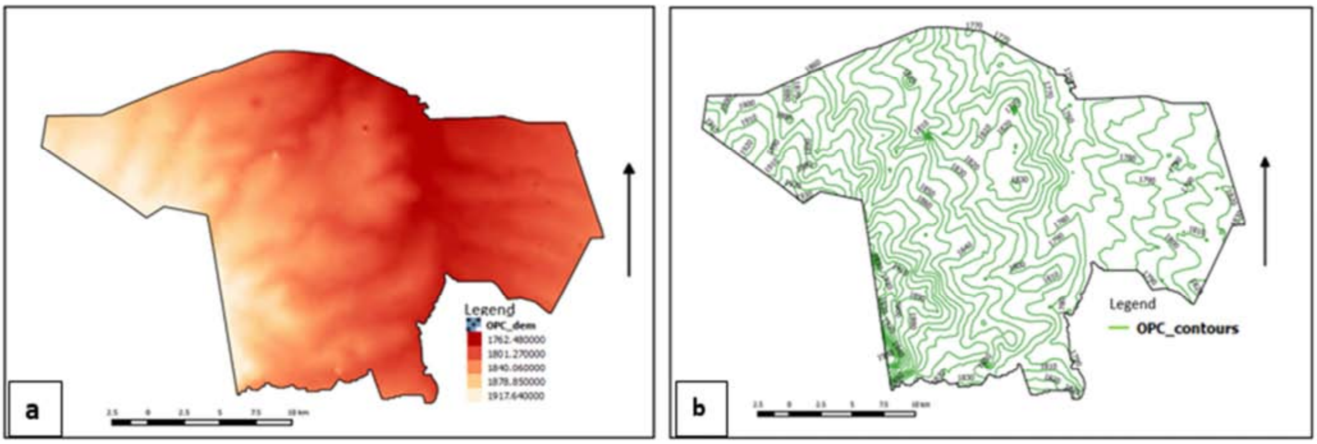


Figure 6. *NDVI map (Slope based) for 1987, 2000, 2005 and 2016.*



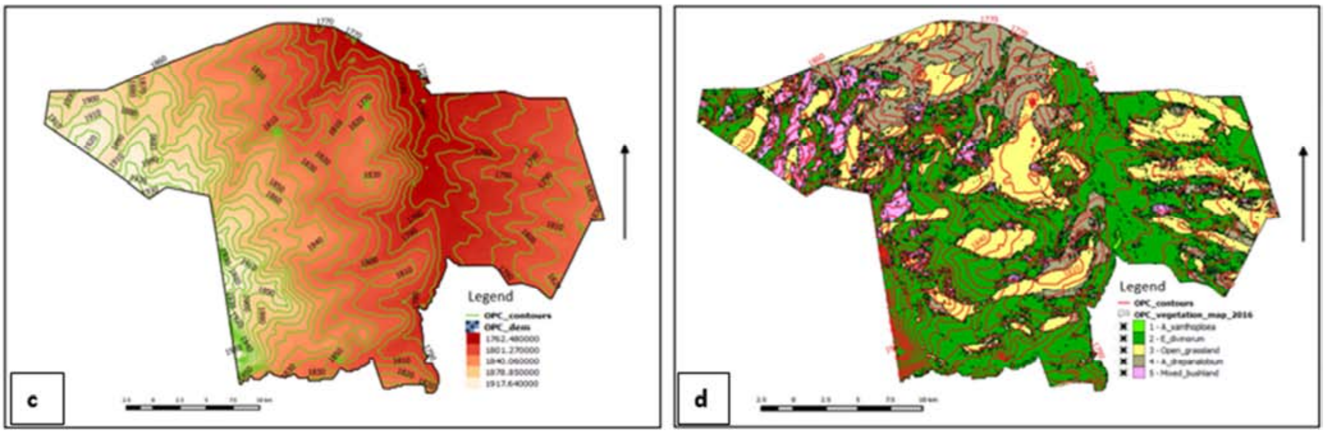


Figure 7. *DEM, contours and vegetation overlays for OPC.*

4. Discussion

4.1. Bush Encroachment by Euclea divinorum

Through the study period *E. divinorum* has increased whilst other habitat types have reduced in cover. The patterns exhibited by spread of *E. divinorum* are consistent with diffusion model [10] for invasive species whereby at the start there is low recruitment rates but over time the recruitment rate increases consequently and cover increases exponentially (encroachment from infested zones to transition zones and finally establishment in the un-infested zone).

Whilst there has been increase in cover by *E. divinorum*, on the other hand *A. xanthophloea* and *A. drepanolobium* have also reduced in coverage notably. As these dynamics in cover changes take place, other habitats have increased or decreased over the entire study period as for the case of mixed bushland majorly composed of other woody species such as *Scutia myrtina, Rhamnus staddo, Euclea divinorum, Acacia drepanolobium, Rhus natalensis and Carissa edulis* with no relative abundance. Remarkably, *E. divinorum* has been spreading in to vacant niches in habitat with low densities or areas devoid of the encroaching species [11]. The finding of this study is in tandem with other research done in OPC where they reported increase in spatial coverage by *E. divinorum* [11] though they reported that there were no significant changes. Given that the woody species under consideration is unpalatable to both wild and domestics animals, there is a potential of affecting their resource base indirectly by augmenting loss of resources through replacement.

Disturbances in savannah ecosystems have been mooted as possible driver for changes in savannah landscapes [12]. These disturbances can range from human induced land cover changes such as prescribed burning, climatic induced factors such as droughts and rainfall to herbivory and pastoralism [13, 12]. As such in OPC, where there is an increasing population of elephants, giraffes and black rhinos (personal communication, EMU) their herbivory (with preference towards *A. drepanolobium*) impact is giving *E. divinorum* an advantage over *A. drepanolobium* with regards to their reestablishment.

Earlier research work conducted in the conservancy reported that there was high levels of damage (herbivory) to the *A. drepanolobium* whose net reduction can potentially explain the encroachment by *E. divinorum* [14]. Further, ill-grazing management systems/regimes such as over stocking can lead to degradation of the ecosystems functions thus altering grass-woody interactions. To this end, such land management systems can potentially suppress grass biomass consequently facilitate encroachment by woody species in arid and savannah ecosystems.

However, herbivory effect especially by mixed feeders has potential to determine heterogeneity of savannah fauna composition. This holds true if the woody species in question are palatable. According to past research by Wahungu *et al* [11] mega herbivores such as elephants have the ability to open up bushy habitats and regulate woody species density thus minimize net effect of encroachment. In OPC there is low levels *E. divinorum* damage owing to the fact that the species is unpalatable [15].

As such, elephant's herbivory net effect on this plant species is insignificant hence may not contribute significantly to opening up or suppressing of habitats under *E. divinorum*. This observation is consistent with other work done in Seregeti that elephants had no significant effect on *E. divinorum* [16]. In summary, elephants can suppress and/or open up closed woody vegetation especially if composed of palatable species whilst on the other hand pure grazers such as cattle can suppress grass hence alter its competitiveness with other plant species. Such interactions coupled with rainfall and other disturbances have potential to augment encroachment by woody species as well as determine dominant plant cover [17].

Increasingly, changes in structure of savannah and semi-arid ecosystems from grass to increased bushy or woody species has remained a subject of debate. As such, possible theories and supposition have been postulated to elucidate this phenomenon as observed over time in savannah ecosystems. Climate change, high levels of herbivory, changing fire regimes (fire severity, duration and frequency), changes in competitiveness of grass, seed dispersal by animals and combination of all these factors have been suggested as responsible for encroachment [18-20].

Chiefly, introduction of cattle (pure grazers especially in large numbers) in grassland ecosystems has been cited as the major driver of encroachment [18]. However, relatively low herbivory pressure can be tolerated by plants without conspicuous changes in plant productivity, biomass reproduction but higher pressure can affect these factors. In OPC, where there are mixed grazers, browsers and pure grazers, there is a potential that their herbivory effect has benefited spread of *E. divinorum* over time. However, the role of cattle in their indirect facilitation of encroachment in OPC has not been investigated and up to date remains unknown.

4.2. Topographic Features Attributable to Encroachment Patterns by Euclea divinorum

The study revealed that areas in low elevation had higher vegetation coverage as opposed to those in high areas. Micro topographic feature influences vegetation cover, distribution and even species present [21]. Relief and topographic variables such as slope, aspect and elevation can exert site specific microclimates hence affect landcover in some area [22]. This is in consistence with observed *E. divinorum* encroachment patterns and cover. This changes in elevation and slope indirectly affect net effect of solar radiation as such influencing soil temperature, near surface soil temperature and soil moisture [23]. Overall such differences on earth surface net effect is manifested in form on vegetation structure, distribution and growth [23, 24, 22]. These differences in topographic feature also influences water infiltration, run off, erosion, seed migration and other debris [25]. Elevation at regional scales constrains vegetation distribution [26] which is true for the case on bush encroachment by *E. divinorum* in OPC which is mainly in low elevations. However, it is important recognising there are other factors contributing significantly towards these vegetation distribution types such as soil factors though not examined in this study.

5. Conclusions

Based on the study findings we conclude that *E. divinorum* has increased in cover significantly whilst reducing coverage of *A. drepanolobium* and *A. xanthophloea* substantially. Additionally, elevation is attributable to encroachment patterns as revealed by the digital elevation models and NDVI results. As such, there is need to actively manage the encroaching woody species which comprises nearly half of the land cover in the conservancy. Further, some aspects have been identified hence recommend additional investigation on role of chemical and physical properties of soil in determining vegetation cover which will help mapping areas that can be potentially under threat of encroachment, as well as impact of bush encroachment on grass biomass and diversity.

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References

[1] Dickie, J. A., Schnitzer, S. A., Reich, P. B. & Hobbie, S. E. (2007). Is oak establishment in Old-fields and savanna openings context dependent. *Ecologia* 95, 309–320.

[2] Wangen, S. R., & Webster, C. R. (2006). Potential for multiple lag phases during biotic invasions: reconstructing an invasion of the exotic tree Acer platanoides. *Journal of Applied Ecology*. 43, 258–268.

[3] Oba, G., Post, E., Syvertsen, P. O., & Stenseth, N. C. (2000). Bush cover and range condition assessments in relation to landscape and grazing in southern Ethiopia. *Landscape Ecology* 15,535-546.

[4] Joubert, D. F., Rothauge, A., & Smit, G. N. (2008). A conceptual model of vegetation dynamics in the semiarid Highland savanna of Namibia, with particular reference to bush thickening by *Acacia mellifera*. *Journal of Arid Environments* 72, 2201-2210.

[5] Sankaran, M., Ratnam, J., & Hanan, N. (2008). Woody cover in African savannas: the role of resources, fire and herbivory. *Global Ecological Biogeography* 17, 236-245.

[6] Bond WJ. (2008). What Limits Trees in C4 Grasslands and Savannas? *Annual Review of Ecology, Evolution and Systematics* 39, 641–659.

[7] Gemedo, D. T., Maass, B. L., & Isselstein, J. (2006). Encroachment of woody plants and its impact on pastoral livestock production in the Borana Lowlands Southern Oromia, Ethiopa. *African Journal of Ecology* 44, 237–246.

[8] Lillesand, T. & R. Kiefer. (2004). *Remote Sensing and Image Interpretation*. Fifth Edition. John Wiley &Sons, Incorporated, New York.

[9] Richards, J. A. & Jia, X. (2006). Remote Sensing Digital Image Analysis: An Introduction. Berlin, Germany: *Springer*.

[10] Skellam, J. G. (1951). Random dispersal in theoretical populations. *Biometrika* 38, 196–218.

[11] Wahungu, G. M., Gichohi, N. M., Onyango, I. A., Mureu, L. K., Kamaru, D., Mutisya, S., Mulama, M., Makau, J. K., & Kimuyu, D. M. (2012). Encroachment of open grasslands and Acacia drepanolobium Harms ex B. Y. Sjöstedt habitats by Euclea divinorum Hiern in Ol Pejeta Conservancy, Kenya. *African Journal of Ecology* 51,130-138.

[12] Van Langevelde F., Van De Vijver CADM., Kumar L., Van De KoppelJ., De Ridder N, Van Andel J., Skidmore AK., Hearne JW., Stroosnijder L., Bond WJ., Prins HT & Rietkerk, M. (2003). Effects of fire and herbivory on the stability of savanna ecosystems. *Ecology* 84, 337–350.

[13] Jeltsch, F., Weber, G. E., & Grimm, V. (2000). Ecological buffering mechanisms in savannas: a unifying theory of long-term tree grass coexistence. *Plant Ecology* 150, 161–171.

[14] Birkett, A., & Stevens-Wood, B. (2005). Effect of low rainfall and browsing by large herbivores on an enclosed savannah habitat in Kenya. *African Journal of Ecology* 43, 123–130.

[15] Smith, T. M., & Goodman, P. S. (1987). Successional dynamics in an *Acacia nilotica-Euclea divinorum* savannah in Southern Africa. *Journal of Ecology* 75, 603–610.

[16] Sharam, G., Sinclair, A. R. E., & Turkington, R. (2006). Establishment of broad-leaved thickets in Serengeti, Tanzania: the influence of fire, browsers, grass competition, and elephants. *Biotropica* 38, 599–605.

[17] Accatino, F. C. D., Vezzoli, M. R., Donzelli, D., & Scholes, R. J. (2010). Tree–grass coexistence in savanna: interactions of rain and fire. *Journal of Theoretical Biology* 267, 235–242.

[18] Van Auken, O. W. (2000). Shrub invasions of North American semi-arid grasslands. *Annual Review of Ecology and Systematics*. 31, 197-215.

[19] Herrmann, S. M., Anyamba, A. & Tucker, C. J. (2005). Recent trends in vegetation dynamics in the African Sahel and their relationship to climate. *Global Environmental Change* 15,394–404.

[20] Scanlon, T. M., Caylor, K. K., Manfreda, S., Levin, S. A., & RodriguezIturbe, I. (2005). Dynamic response of grass cover to rainfall variability: implications for the function and persistence of savanna ecosystems. *Advancement in Water Resources*. 28, 291–302.

[21] Ma, X., Zhang, S., Su, Z., Ou, Y. & Liu, G (2010). Community structure in relation to microtopography in a montane evergreen broadleaved forest in Chebaling National Nature Reserve. *Acta Ecologica Sinica* 30, 5151–5160.

[22] Zhao, N., Yang, Y., Zhou, X. (2010). Application of geographically weighted regression in estimating the effect of climate and site conditions on vegetation distribution in Haihe Catchment, China. *Plant Ecology* 209, 349-359.

[23] Bennie, J., Huntleya, B., Wiltshirea, A., Hill, M. O., Baxtera, R. (2008). Slope, aspect and climate: Spatially explicit and implicit models of topographic microclimate in chalk grassland. *Ecological Modelling* 216, 47-59.

[24] Hofer, G., Wagner, H. H., Herzog, F., & Edwards, P. J. (2008). Effects of topographic variability on the scaling of plant species richness in gradient dominated landscapes. *Ecography* 31, 131-139.

[25] Jiao, J., Zou, H., Jia, Y., & Wang, N. (2009). Research progress on the effects of soil erosion on vegetation. *Acta Ecologica Sinica*, 29, 85–91.

[26] Moeslund, J. E., Arge, L., Bøcher, P. K., Dalgaard, T., Odgaard, M. V., Nygaard, B., & Svenning, J. C. (2013). Topographically controlled soil moisture is the primary driver of local vegetation patterns across a lowland region. *Ecosphere* 4, 1–26.