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TRENDS IN GROWING SEASON LENGTH UNDER CURRENT CLIMATE WITHIN THE NIGERIA FOREST-SAVANNA ECOTONE

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Abstract

Growing Season Length (GSL) is a bio-indicator of the thermal changes within any ecosystem and it changes from year to year in response to prevailing climate. In this study we aim to understand the trends of the GSL under prevailing Climate within the Nigeria forest-savanna ecotone from 2017-2022. The methodology involved characterizing key phenometrics; Start of Season (SOS), Peak, and End of Season (EOS) using Whittaker Henderson's smoothing and curve derivative method that incorporates a backward-looking or delayed moving average algorithm to analyze NDVI time series data. We used the open sourced Whittaker Henderson's Smoothing algorithm on Google Earth Engine (GEE) to analyze the vegetation indices data and characterize the Land Surface Phenology (LSP) of the study area. This led to the extraction of vegetation indices data and analyzing the temporal patterns of the vegetation indices on GEE. Furthermore, the phenology metrics were calculated, such as start of season, end of season, length of season, and amplitude of seasonality, for the study period. The Length of the first growing season ranges from 129-160 days whereas the second GSL ranges from 139-142. This implies that the first GSL lasts longer than the second GSL. This trend in GSL fits in with the climatic condition of this region which governs the agricultural crop's productivity and food availability. We further recommend constant monitoring of the phenology of the region using advanced techniques.

Keywords: Growing Season Length, Climate, Phenology, Food insecurity and Remote Sensing

Introduction

Phenology is the science that studies life cycle of plants and animals, such as the emergence of leaves and animal migration in the spring or the loss of leaves and animal hibernation in the fall. These events are sensitive to changes in temperature and other environmental conditions (Adole, 2018; White et al., 1997; Lieth, 1974), and can provide valuable information about the impacts of climate change on plants, animals and ecosystems (Zhao, et al., 2013; Juo, 2012; Zhang, Friedl, Tan, Goldberg, & Yu, 2012). Climate change which is the result of extreme variations in weather patterns in terms of frequency, duration, intensity, spatial extent, and timing (Ummenhofer & Meehl, 2017). These changes have negative impacts on human populations and other forms of biodiversity, including vegetation phenological cycles and associated biophysical parameters such as soil moisture content, and leaf area index (International Panel on Climate Change, 2012). The effects of climate change on the timing of key events in the life cycle of vegetation are impacting ecosystem services, hydrology, nutrients, and carbon cycles (Cui & Shi, 2021). This, in turn, is affecting agricultural productivity, food supply and local livelihoods. Local livelihoods often hinge on the sustainable utilization of natural resources, elevating the study of eco-climate resilience from a purely ecological concern to a matter of profound social and economic significance (Birkmann, et al., 2022; Oliveras & Malhi, 2016).

Biodiversity conservation on a global scale is increasingly imperative in the face of unprecedented climate shifts but Africa seems to have a peculiar situation as highlighted by increasing cases of drought, timing mismatch, and loss of biodiversity, pest invasions, and declines in agricultural productivity all leading to food security issues (Hirwa, et al., 2022). The forest-savanna ecosystem, renowned for its biodiversity and complex species interactions, faces an array of threats emanating

from both human activities and the changing climate (Oliveras & Malhi, 2016). Therefore tracking the phenophase of plants within the sensitive ecosystems, scientists can better understand and manage the effects of climate change on these least studied ecosystems and develop strategies to mitigate their negative effects (McCullum & Torres-Pérez, 2020; Oliveras & Malhi, 2016; Schröder, Schmidt, & Schönrock, 2014a).

Growing Season Length (GSL) is a bio-indicator of the thermal changes within any ecosystem and it changes from year to year in response to prevailing climate (Song, Linderholm, Chen, & Walther, 2010; Carter, 1998). It is defined as the duration of phenological cycle which its beginning is characterized as the Start of Season (SOS) and the ending as End of Seasons (EOS). Therefore GSL is the time it takes for a seasonal cycle to be complete. For some part of the world especially in the cooler regions, the impacts may be beneficial in cases such as longer growing season (Ludwig, et al., 2007) with non-forest areas becoming forested in the Western world (Christiansen, Markstrom, & Hay, 2011). In this study we aim to understand the trends of the GSL under prevailing Climate within the Nigeria forest-savanna ecotone from 2017-2022.

Methods

Study Area

The study area falls between latitude 6°0'0" N to latitude 7°09'0" N and longitude 6°36'0"E to longitude 7°42'0" E (Figure 1). The forest-savanna ecosystem in Nigeria embodies a delicate juncture between two distinct ecosystems; the Lowland Rainforest (wetter type) and Mosaic of Lowland Rainforest and Secondary Grassland, where the intricate interplay of forest and savanna landscapes creates a unique and ecologically sensitive transition zone. The Guinea and derived

savanna subzones occupy some 90% of the area. The areas of Nigeria where man's influence on the vegetation lies to the north and south of the sub-humid zone, exemplified by conditions in the Sahel and by the diminishing rain forest (Mohamed-Saleem, 1983). Blair-Rains (1968) stated that the existing vegetation in Nigeria, in general, may bear little resemblance to the original zonal categories, because of the combined effects of human activity: burning, cultivation, tree felling and cattle grazing. Extensive areas of medium to high levels of land-use intensity are found on the northern border of the sub-humid zone extending northwards, with the highest cultivation density being associated with major towns. The same pattern is found on the southern border, around Enugu, and southwards, where the proportion of land cultivated reaches its highest, at 25%.

The land in between these two areas falls within the sub-humid zone, where cultivation declines to some 17%. Here the pattern of vegetation and land use can best be described as a mosaic of varying levels of cultivation, grassland and woodland. An interconnecting patchwork of more intense cultivation links the northern and southern cultivated regions of Nigeria, through a broad belt north of Lokoja including Bida, Minna, Abuja, Lafia, Shendam, Kafanchan, the Jos Plateau, Kaduna and Saminaka. In this belt, cultivation reaches a peak of 35%. To the west and east of it, cultivated areas are generally more scattered (10%) with woodland tending to predominate.

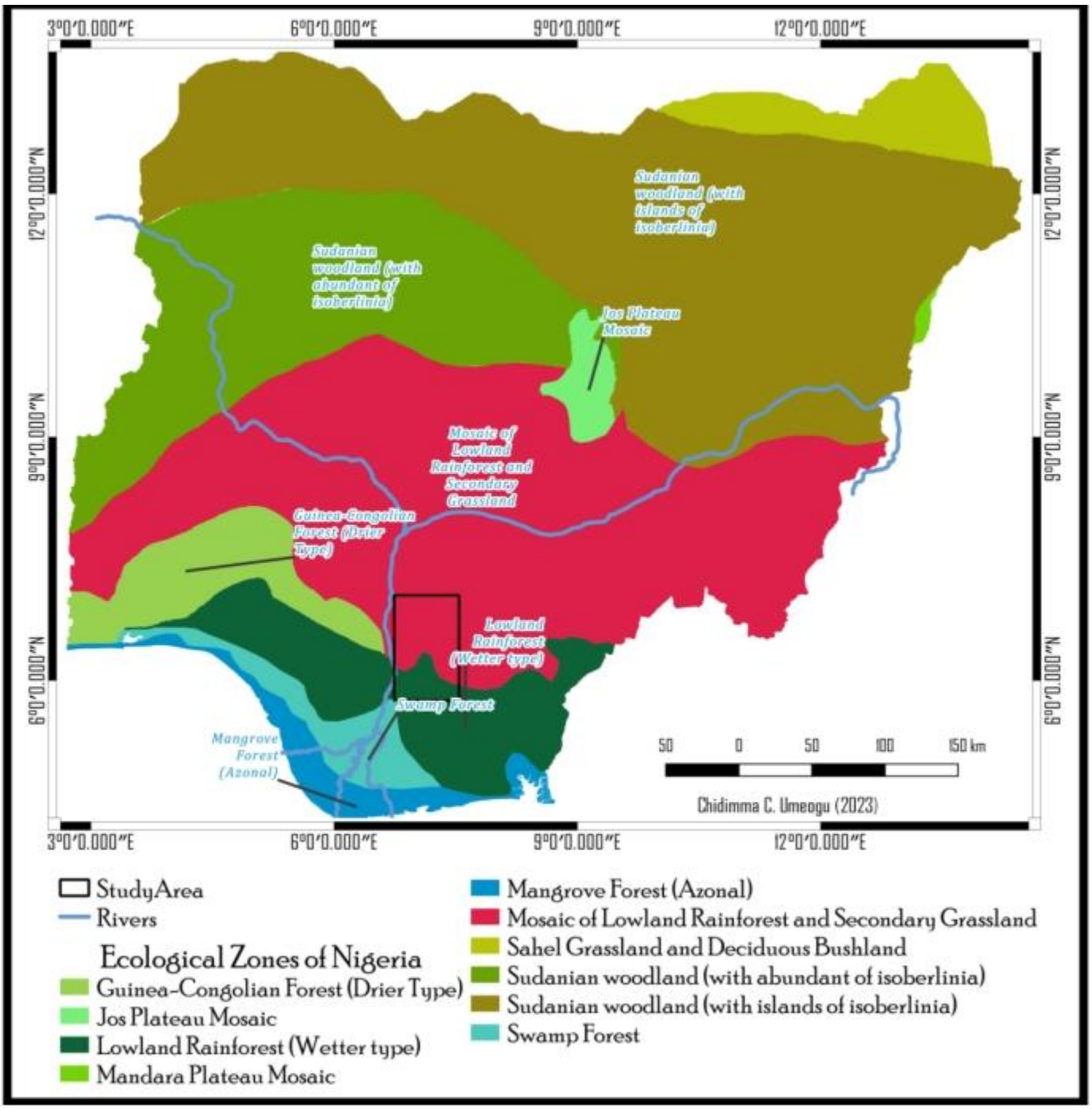


Figure 1: Study Area Map. The Black box delineates the study boundary

Data Source and processing

For this study, we characterized the Land Surface Phenology (LSP) of the study area using satellite vegetation indices data. We collected satellite vegetation indices data from reliable source, MODIS. These data covered the study area, which includes the two eco-zones understudy: the lowland rainforest (wetter type) and Mosaic of Lowland Rainforest and Secondary Grassland. We defined detailed boundaries on the ten eco-zones of Nigeria based on climate and vegetation patterns. This was done by adapting from an existing agro-ecological zone map from the research paper of Keay, (1953) and Nwosu & Ugwuoti, (2009). We used the open sourced Google Earth Engine (GEE) scripts to analyze the vegetation indices data and characterize the LSP of the study area. This led to the extraction of vegetation indices data for the study area and analyzing the temporal patterns of the vegetation indices using the web tool. Furthermore, the phenology metrics were calculated, such as start of season, end of season, length of season, and amplitude of seasonality, for the study. To be able to extract the metrics the raw NDVI data was smoothed using Whittaker- Henderson smoothing algorithm and threshold-based pheno-metrics extraction methods.

The Whittaker Smoother is a computational algorithm used in time-series analysis to minimize fitting error while simultaneously penalizing the roughness of the resulting curve (Equation 1 - 3). It operates on the principle of penalized least squares, where the goal is to find the curve that best fits the observed data points while also ensuring smoothness. This smoother is particularly useful for removing noise and extracting underlying trends from noisy remotely sensed time-series data (Atzberger & Eilers, 2011).

$$Q = S + kR \qquad \textit{Equation (1)}$$

$$S = \sum_i (y_i - z_i)^2 \qquad \textit{Equation (2)}$$

$$R = \sum_i ((z_i - z_{i-1}) - (z_{i-1} - z_{i-2}))^2 \qquad \textit{Equation (3)}$$

Q represents the fitting effect.

S is the fitting error, which measures the discrepancy between the observed data points *yi*and the smoothed values *zi*.

R is the roughness penalty, which penalizes deviations in the smoothed values to encourage smoothness in the resulting curve.

k is a parameter that controls the trade-off between fitting error and roughness penalty; the larger the *k* is, the worse the fidelity of the *y* data and the smoothing *z* are, and vice versa (Liang, et al., 2023).

Results

The LSP metrics we derived are; Start of Season (SOS), End of Season (EOS) and the Length of Season (LOS) which represents the Growing Season Length (GSL) for all the time periods studied. We considered the first half of the phenology cycle which includes the SOS I and EOCS both for the raw and fitted dataset as represented in tables 1 and 2 before examining the second half that spilled over to the subsequent year (tables 3 and 4).

Table 1: Raw NDVI table: LOS I

Year	SOS I	EOCS	LOS I
2017	81	257	129
2018	49	209	160
2019	81	241	128
2020	65	257	160
2021	65	241	176
2022	81	241	145

The tables 1 provide information on the Length of Season (LOS) I for each year, indicating the duration of vegetation activity from the start of the growing season (SOS I) to the end of the current season (EOCS). In Table 1, which represents the Raw NDVI data, LOS I varies across the years. For instance, in 2017, the SOS I occurred on day 81, and the EOCS was on day 257, resulting in a LOS I of 129 days. Similarly, in 2018, the LOS I was 160 days, with the SOS I on day 49 and the EOCS on day 209. The LOS I fluctuates between 128 and 176 days across the years in this table.

Table 2: Fitted NDVI table: LOS I

Year	SOS I	EOCS	LOS I
2017	65	225	145
2018	65	225	160
2019	49	241	145
2020	65	241	176
2021	65	241	161
2022	65	241	161

In Table 2, which presents the Fitted NDVI data, the LOS I values show consistency and alignment with the general trend observed in the Raw NDVI table. However, there are slight differences in the calculated LOS I values. For example, in 2017, the LOS I is calculated as 145 days, whereas it was 129 days in the Raw NDVI table which is a difference of 16 days. Similarly, in 2019, the LOS I is also calculated as 145 days, differing from the 128 days indicated in the Raw NDVI table. The difference between the raw (unprocessed data) and the smoothed dataset varies from 15 to 18 days. This suggests that the smoothing process has altered the timing of events within the data, showing that certain patterns have been adjusted or shifted as a result of the smoothing technique.

Table 3: Raw NDVI II table: LOS II

Year	SOS II	EOPS	LOS II
2017	273	17	139
2018	257	33	141
2019	257	49	189
2020	273	33	142
2021	257	49	142
2022	257	-	-

**The gap in data for the year 2022 is because the EOPS and LOS II are to be derived from the subsequent cycle that runs into year 2023*

LOS II (Length of Season II) represents the duration, typically measured in days, between the Start of Season II (SOS II) and the End of Previous Season (EOPS), indicating the period of vegetation activity following a dormancy phase. Table 3, showcasing the Raw NDVI II data, illustrates the variations in LOS II across different years. For instance, in 2017, LOS II spans 139 days, highlighting a relatively shorter period of vegetation activity following the previous dormancy phase. Similarly, 2018 and 2020 exhibit durations of 141 and 142 days, respectively, reflecting comparable periods of vegetation activity after dormancy. However, in 2019, LOS II extends to 189 days, indicating a notably longer period of vegetation activity compared to other years. Subsequently, 2021 displays a LOS II of 142 days, resembling patterns observed in previous years.

Table 4: Fitted NDVI table: LOS II

Year	SOS II	EOPS	LOS II
2017	241	17	142
2018	241	33	142
2019	257	33	142
2020	257	33	142
2021	257	49	141
2022	257	-	-

**The gap in data for the year 2022 is because the EOPS and LOS II are to be derived from the subsequent cycle that runs into year 2023*

Table 4, representing the Fitted NDVI data, also demonstrates variations in LOS II, although with slightly different values. In 2017 and 2018, LOS II remains consistently estimated at 142 days, which is similar with the durations observed in the raw data. Notably, 2019 and 2020 displayed consistent LOS II durations of 142 days, indicating stability in vegetation activity after dormancy. However, 2021 shows a slightly shorter LOS II of 141 days, which contrasts with the patterns observed in the raw data. The comparison between LOS II in the raw and fitted data highlights the significance of this parameter in delineating the periods of vegetation activity following dormancy and underscores the consistency or discrepancies in estimating this essential phenological metric.

We therefore concluded that the first half of the phenology cycle experiences longer growing season up to 176 whereas the second half experiences shorter growing season with an average of 142 days. The longer growing season length falls within the wet “rainy” season and comparable

moderate temperature while the short growing season length falls within the dry "harmattan" season with very high temperature most often leading to droughts (Odekunle, 2004).

Discussions

The results indicate distinct variations in the length of the growing season across different years, with significant implications for food security and climate resilience. The first half of the phenology cycle, which experiences a longer growing season (up to 176 days), coincides with the wet season, a critical period for crop cultivation due to ample moisture and favorable temperatures (Hatfield et al., 2011; Odekunle, 2004; Debaeke & Aboudrare, 2004). This extended growing season supports increased agricultural productivity, allowing for longer crop growth periods and higher yields. However, the fluctuation in the Length of Season (LOS) across years, particularly the differences between the raw and fitted datasets, suggests potential uncertainties in crop production timing, which can impact planning for planting and harvesting (Haruna & Ibrahim, Trend of Onset Dates, Cessation Dates and Length of Growing Season Analysis in the Sudan Savanna Ecological Zone of Nigeria as a Way Forward to Agriculture and Food Security in Nigeria, 2016).

In contrast, the second half of the cycle, with an average growing season of 142 days, falls within the dry season, where extreme temperatures and droughts are prevalent. Shorter growing periods during this phase can severely limit crop cultivation, particularly for crops that require longer maturation periods, increasing vulnerability to food insecurity (Haruna & Murtala, 2019). The correlation between shorter growing seasons and high-temperature periods emphasizes the need for drought-resistant crops and adaptive agricultural practices to mitigate the risks posed by shorter growing cycles in dry seasons (Ugbah, Olaniyan, Francis, & James, 2019).

The observed differences between the raw and fitted data, with variations of 15 to 18 days in growing season length, underline the sensitivity of vegetation phenology to climate fluctuations. Smoothing techniques that alter event timings reflect the impact of climate variability on vegetation cycles, potentially shifting the start or end of growing seasons (Ati, Stigter, & Oladipo, 2002). These shifts are likely influenced by changes in precipitation patterns and temperature extremes, which are characteristic of broader climate change impacts (Sagang, et al., 2024). The longer growing season during the wet period indicates a stable, favorable climate window for agriculture. However, the shortening of the growing season in the dry, harmattan phase aligns with expected stress from rising temperatures and reduced rainfall, consistent with findings from previous climate studies (Cui & Shi, 2021; Andrieu, 2017; Enete & Amusa, 2010). These shifts could exacerbate drought conditions and reduce soil moisture, leading to lower crop yields and more frequent crop failures, further threatening food security in regions highly dependent on rain-fed agriculture.

Conclusion

The study highlights the important link between growing season length, food security, and climate. As climate change continues to intensify, adaptive strategies such as altering planting schedules, diversifying crops, and investing in water-efficient technologies will be critical in managing the shorter growing seasons during drought-prone periods and maximizing the productivity of the longer, wetter growing seasons. Furthermore, addressing these challenges requires a multi-disciplinary approach, incorporating climate modeling, soil management, and the development of climate-smart agricultural techniques to improve resilience and sustainability within the Forest-Savanna Ecotone.

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