Influence of Climate Variation on Growth of Tropical Tree Species in Western Kenya

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Authors' contributions

This work was carried out in collaboration between all authors. Authors SC and DS conceptualized the study. Authors ETD and SC carried out the methodology of the study. Author ETD wrote the first draft of the manuscript. Authors ETD, SC and DD contributed to revisions and editing of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Growth-climate relationships were examined in 7 tropical tree species growing in the Yala river basin of western Kenya: *Acacia mearnsii, Cupressus lusitanica, Eucalyptus camaldulensis, Eucalyptus grandis, Eucalytus saligna, Mangifera indica*, and *Markhamia lutea.*
Methodology: Standardized basal area increments were correlated with monthly and seasonal (3 month periods) climate variables (precipitation, mean temperature, Climate Moisture Index) obtained from nearby meteorological stations.
Results: A majority of the tree species (*M. indica, C. lusitanica, E. camaldulensis*, and *E. saligna*) showed positive correlations with monthly and seasonal precipitation and moisture index during periods of the long and short rainy seasons. This study also revealed significant correlations between monthly and seasonal temperature data and radial growth of *M. indica, M. lutea* and *E. grandis*. Growth of M. lutea was negatively affected by cool growing season conditions while *M. indica* and *E. grandis* experienced high temperature stress.
Conclusion: Associations between radial growth of tropical tree species and temperature are generally rare in warm tropical regions, and for some of the species examined in this study that are non-native (i.e., *M. indica* and *E. grandis*), strongly suggests that they may be growing outside the optimal temperature conditions of their native geographical range.

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1. INTRODUCTION

Tropical trees can have distinct ring boundaries in response to environmental stressors [1]. Two of the main drivers for ring boundary formation are distinct dry seasons [2] and seasonal flooding in floodplain areas [3]. Seasonality due to flooding and/or drought have been shown to produce different patterns of ring formation including: either a single growth ring per year; non-annual rings in the case of complex rainfall distributions [4-5]; two rings per year in regions exhibiting a bimodal rainfall distribution [6-8]; or fewer than one ring per year when moisture is extremely limiting [9].

The development of long-term reconstruction of diameter increments of tropical species and their response to climate will support the development of sustainable silvicultural systems in developing countries [2]. Furthermore, climate-growth relationships can be used as a proxy to reconstruct historical climate data [1,10] and provide future growth projections to climate change. Annual diameter increments can also be extrapolated to estimate annual carbon sequestration rates which permits countries interested in implementing a carbon benefits project to begin earning tradable income immediately [11].

Several studies in Africa have examined the direct relationships between tree radial growth and climate variables to better understand the ecology of the various species studied, determine ring periodicity, and reconstruct historical climate conditions [9,12-16]. These studies have demonstrated that significant correlations exist between tree growth and climate parameters. However, very few such studies have been conducted in Kenya [17-18] and thus little is known about how the savannah and agroforestry systems in the western part of the country are responding to changes in climatic conditions. In a previous study, David et al. [18] examined the dendrochronological potential of 14 tree species growing in the Yala River basin of western Kenya.

This study aims to explore the growth responses to monthly and season climate of several commonly found tree species growing in the Yala River Basin of western Kenya, namely: *Acacia mearnsii, Cupressus lusitanica, Eucalyptus camaldulensis, Eucalyptus grandis, Eucalyptus saligna, Mangifera indica,* and *Markhamia lutea*. The objectives of this study are to evaluate the growth-climate relationships of these species in terms of the growth response to both monthly and seasonal changes in: a) precipitation, b) mean temperature, and c) climate moisture index.

2. MATERIALS AND METHODS

2.1 Study Area

This study was conducted within three 100 km2 blocks of land (i.e., Lower, Middle and Upper Yala regions) located in the Yala River Basin of western Kenya. The Yala River catchment covers an area of 3351 km2and drains into the Winam Gulf in Lake Victoria (Fig. 1). The elevation beginning in the Lower Yala region ranges from 1,200 m above sea level to 2,200 m above sea level in the Upper Yala region. The average annual rainfall for the entire Yala Basin is 1487 mm and follows a bimodal distribution. The timing of the long rainy season is generally from March-May and the short rainy season is generally from October-November [17]. There are several major soil types present within the Yala Basin, including acrisols, ferralsols and nitrosols [19], and are well drained, deep to very deep, and have variable fertility.

2.2 Field Sampling

Sampling plots (30 x 30 m) were randomly chosen in each regional block and all trees within each plot were sampled. Trees were randomly selected across a range of 6 dbh classes: 2.5 – 10; 10.1 – 20; 20.1 – 30; 30.1 – 40; 40.1 – 60 and > 60 cm. In each diameter class, 12 trees were harvested and consisted of 3 trees sampled from each of the lower Yala and Upper Yala, and 6 trees sampled from the middle Yala. Of the trees chosen for destructive sampling, a stem disc was taken at breast height (1.3 m). A subset of the 72 total trees destructively sampled was used for the dendrochronological analysis to assess growth-climate relationships in the current study. This subset consisted of 50 trees spanning 7 species (*Acacia mearnsii, Cupressus lusitanica, Eucalyptus camaldulensis, Eucalyptus grandis, Eucalyptus saligna, Mangifera indica,* and *Markhamia lutea*) (Fig. 2). The criteria for species selection of the subset was sufficient sample size and reliability of crossdating [18].
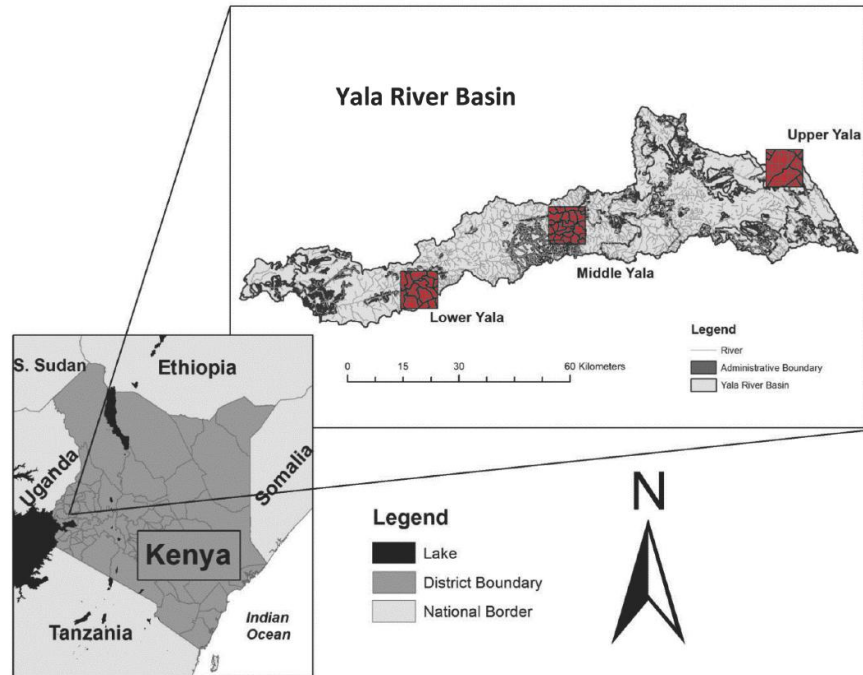
Fig. 1. Smaller map shows the location of the Yala River Basin in western Kenya. Enlarged maps shows locations of three sampling blocks in Yala River Basin of Western Kenya: lower Yala, middle Yala, and upper Yala (highlighted in red).

2.3 Sample Processing

Wood samples were first sanded with progressively finer grits of sandpaper (up to 1200 grit) to highlight ring width patterns. Each sample was visually cross-dated along 4 radii to identify missing and/or false rings. Each ring boundary was verified circumferentially between the other three radii of the disc. Following verification of cross-dating, annual ring widths were measured using a stage micrometer connected with a binocular microscope to the nearest 0.001 mm (Velmex: Bloomfield, New York). Disc samples were measured along 4 radii (or as many as were successfully crossdated).

2.4 Dendrochronological Measurements and Chronology Development

At the end of each growth period, the ring width measurements for each radius were converted to cumulative measures of diameter inside bark (DIB) and cumulative measures of basal area. Annual basal area increment (cm^2 $year^{-1}$) was calculated by subtracting cumulative growth in the previous year (t-1) from the current year (t).

Each basal area increment series were detrended using a locally weighted regression with a neighborhood span equivalent to 10 years using the function loess (package STATS) in the program R (the open source version of program S) [20-21]. Following detrending, indices were standardized by dividing the observed values by the predicted values. Standardization amplifies the climatic signal (high frequency or interannual variation) and removes the effect of non-climatic factors (low frequency or long-term variation) [22-23]. Annual standardized stem basal area indices (BAI) calculated for radii of the same disc were averaged together.

2.5 Growth-Climate Relationships

Climate data was obtained from the Kenya Meteorological Department in Nairobi, Kenya [24] and included minimum and maximum monthly temperature and total monthly precipitation. The primary climate stations from which data was used were the Kisumu Meterological Station (ID#9034025; 0°6' S, 34°45' E) and Yala Tree Nursery (ID#8934189; 0°8' N, 34°32' E) for the Lower Yala. The Kakamega Meteorological Station (ID#8934096; 0°16' N, 34°45' E) and Kaimosi Farmer's Training Center (ID#8934078;

0°13' N, 34°57' E) represented the climate for the Middle Yala. The Kakamega Meteorological Station (ID#8934096; 0°16' N, 34°45' E) and the Eldoret Meteorological Station (ID#8935181; 0°32' N, 35°17' E) represented the climate conditions for the Upper Yala [24]. Precipitation data for the lower block spanned from 1962-2003 and the temperature data spanned from 1967-2009. Precipitation and temperature data for the middle block both spanned from 1979-2009. Precipitation data for the upper block spanned from 1972-2009 and temperature data spanned from 1979-2009. Missing values in the data were estimated from neighboring stations. Climate moisture indices (CMI's) were calculated by subtracting monthly values of potential evapotranspiration (PET) from monthly precipitation (P) values and CMI provides an effective measure of the net water balance for trees. PET values were determined as a function of minimum and maximum temperature [25].
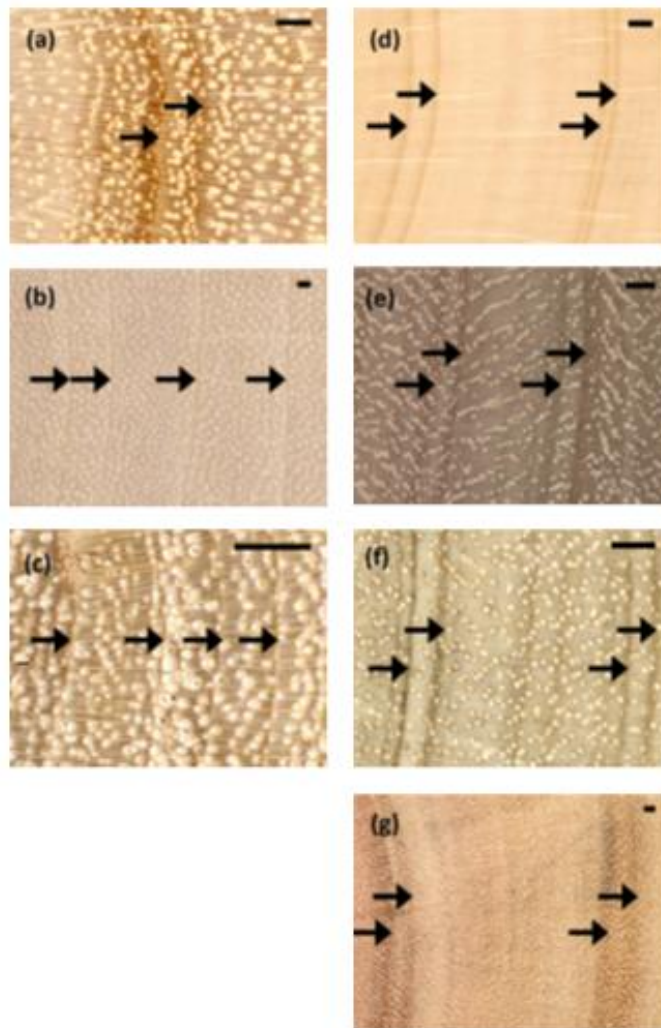
Fig. 2. Images of the transverse surface of wood samples of three tropical tree species showing annual tree rings: *Acacia mearnsii* (a), *Mangifera indica* (b), and *Markhamia lutea* (c); and four tropical tree species showing bi-annual tree rings: *Cupressus lusitannica* (d), *Eucalyptus camaldulensis* (e), *Eucalyptus grandis* (f), and *Eucalyptus saligna* (g). The boundaries for one year of growth in the unimodal species and for a partial year's growth in the bimodal species are indicated by the tip of the black arrows. The direction of the arrows indicates the direction of growth from the start to the end of a growing season. The scale bar in the top-right corner of each sub-figure is equivalent to a length of 1 mm.

Growth-climate relationships were examined between basal area indices (BAI's) of each of the 7 species and the climate variables over the period of March of the previous year (t-1) to November of the current year (t). Tree species that had a bimodal ring structure consisting of ring boundaries between the long and short rainy seasons (*C. lusitanica, E. camaldulensis, E. grandis,* and *E. saligna*) were difficult to reliably crossdate in terms of the intra-annual ring boundaries. Consequently, the growth-climate relationships were conducted only with the full annual ring area for these species. A Pearson correlation analysis using Systat (version 10.2) [26] was conducted for species in which the BAI chronology was greater than or equal to 15 years. A non-parametric Spearman rank correlation analysis using Systat (version 10.2) [26] was carried out for species in which the BAI chronology was shorter than 15 years. Furthermore, the correlation analysis was conducted between BAI's and seasonalized climate data. Seasonal precipitation and CMI data were calculated as the summation of 3 month periods, beginning with March, April, and May of the previous year (t-1) and ending with September, October, and November of the current year (t). Seasonal temperature data was calculated as the average of 3-month seasonal periods.

3. RESULTS

3.1 Growth Chronology

Basal area index chronologies of the 7 tree species are provided in Fig. 3. The interannual growth variation explained by the first principal component was significantly high for all species except *E. saligna* (Table 1). Further, *A. mearnsii* and *C. lusitanica* had significant inter-tree correlation.
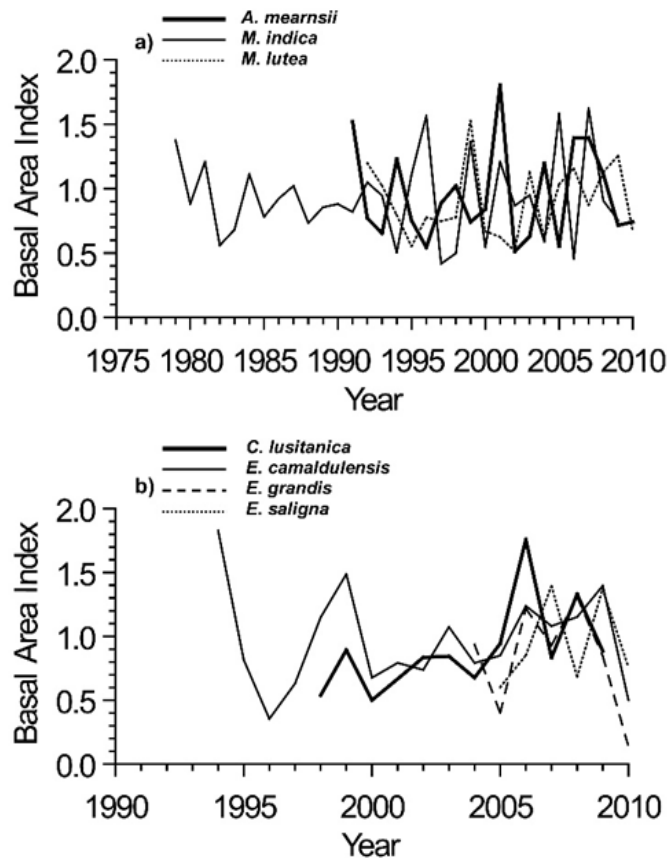
Fig. 3. Basal area index (BAI) patterns summarized by a) non-plantation species: *A. mearnsii, M. indica,* and *M. lutea* and b) plantation species: *C. lusitanica, E. camaldulensis, E. grandis, and E. saligna*

Table 1. List of studied tree species and statistical properties of basal area index chronologies (chronology time span, inter-tree correlation, and percentage of total variance explained by first principal component)

Species	Region	Plots	N	dbh (cm)	Time span	Inter-tree correlation	Variance (%) in first principal component
Acacia mearnsii	Upper Yala	3	6 (6)	12.8-29.0	1991-2010	0.61*	66.1**
Mangifera indica	Lower Yala	2	6 (6)	20.5-58.9	1979-2009	0.37	60.4**
Markhamia lutea	Middle Yala	1	4 (4)	10.4-26.1	1992-2010	0.27	55.7**
Cupressus lusitanica	Middle Yala	2	4 (4)	29.7-35.7	1998-2009	0.62*	60.1**
Eucalyptus camaldulensis	Middle Yala	6	21 (20)	3.9-48.5	1994-2010	0.45	46.6**
Eucalyptus grandis	Middle Yala	2	6 (6)	6.7-29.3	2004-2010	0.53	73.4**
Eucalyptus saligna	Middle Yala	2	6 (4)	4.8-17.7	2005-2010	0.33	55.0

Note: N = number of stem discs investigated with successfully cross-dated trees in parenthesis; diameter at breast height (dbh) range of stem discs.
** Corrrelation coefficient significant at P < 0.05.*
** Observed growth variance (%) explained by first principal component axis exceeds expected growth variance from broken stick null model [27].

3.2 Response to Precipitation

Many of the species showed a significant correlation to monthly precipitation with the exception of *A. mearnsii, M. lutea, E. grandis* (Fig. 4a). A majority of the growth-climate correlations were positive and associated with the rainy season months. *M. indica* was positively correlated with precipitation during April of the previous year (t-1). The basal area index (BAI) chronology of *C. lusitanica* showed mainly positive correlations with respect to precipitation during the months (i.e., March, April) of long rainy season of the current year (t). *C. lusitanica* also had a negative correlation with October (t) precipitation during the short rainy season. *E. camaldulensis* was positively associated with monthly precipitation in May (t) and September (t).

The same species that showed growth responses to monthly precipitation also showed significant responses to seasonal precipitation and included *M. indica, C. lusitanica, E. camaldulensis,* and *E. saligna* (Fig. 4b). All of the seasonal relationships were positive correlations and coincided with the long rainy season period. *C. lusitanica* and *E. camaldulensis* showed significant positive correlations with the long rainy season period in the current year (t) while *M. indica* and *E. saligna* show positive correlations with long rainy season period in the prior year (t-1).
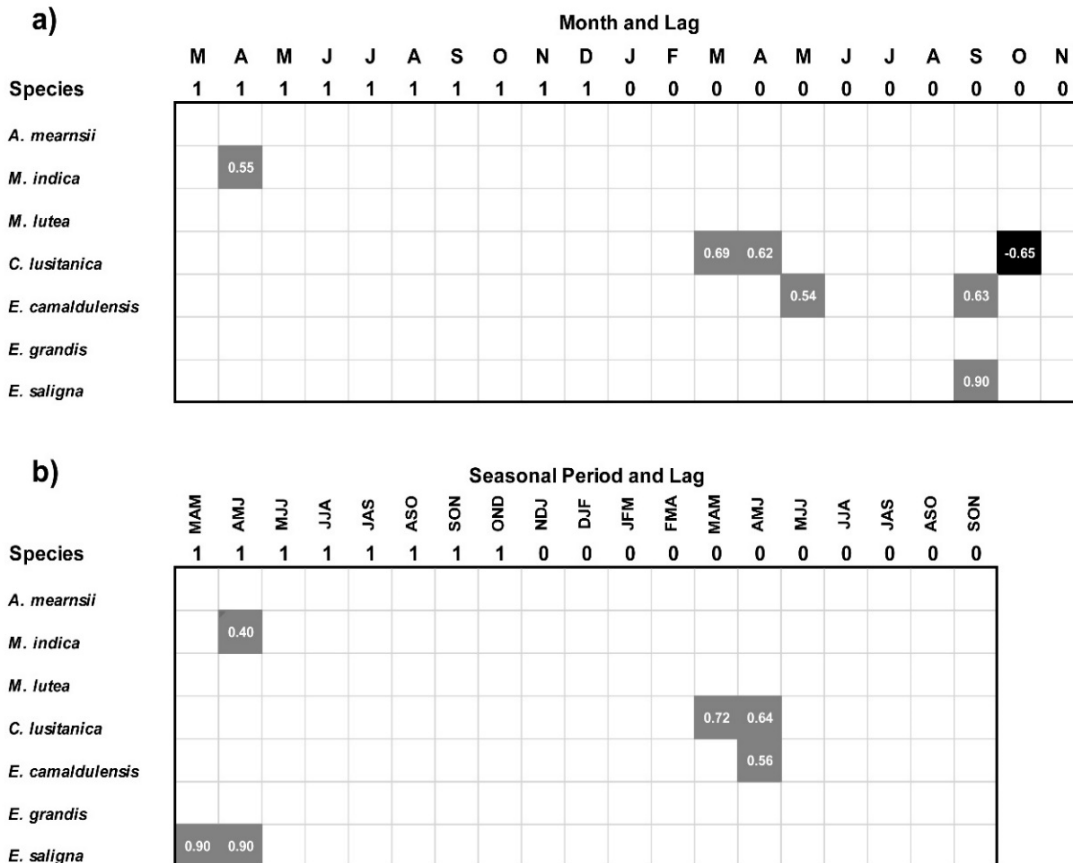
Fig. 4. Correlation diagrams of all studied species with a) monthly precipitation and b) seasonal precipitation spanning March of the previous year (lag 1) to November of the current year (lag 0). Significant positive correlations (p < 0.05) are denoted by grey boxes and significant negative correlations (p < 0.05) are denoted by black boxes. The value of the correlation coefficient was provided for each significant climate variable. *A. mearnsii, E. camaldulensis, M. indica,* and *M. lutea* were all analyzed using a Pearson correlation test, while *C. lusitanica, E. grandis*, and *E. saligna* were analyzed using a Spearman rank test

3.3 Response to Temperature

The only species to show significant correlations to monthly temperature data were *M. indica, M. lutea* and *E. grandis* (Fig. 5a). *M. indica* was negatively associated with March (t) and September (t) temperature, but negatively related to November (t) temperature. *M. lutea* was positively associated with April (t-1) and May (t-1) temperature. *E. grandis* was negatively related to April (t) temperature.

The same species that showed growth responses to monthly temperature also showed significant responses to seasonal temperature and included *M. indica, M. lutea* and *E. grandis* (Fig. 5b). *M. indica* was negatively associated with January, February, March seasonal temperature in the current year (t). *M. lutea* was positively correlated with April, May, June seasonal temperature in the prior year (t-1). *E. grandis* was negatively correlated with seasonal temperature during the long rainy season period of the current year.

3.4 Response to Climate Moisture Index

Significant monthly correlations between basal area growth to climate moisture index (CMI) were very reflective of precipitation correlations for *M. indica, C. lusitanica, E. camaldulensis,* and *E. saligna* (Fig. 6a). Relationships between growth and seasonal CMI were also similar except that radial growth of *M. indica* was not signficantly related to seasonal CMI (Fig. 6b).

a)

Species	M 1	A 1	M 1	J 1	J 1	A 1	S 1	O 1	N 1	D 1	J 0	F 0	M 0	A 0	M 0	J 0	J 0	A 0	S 0	O 0	N 0
A. mearnsii																					
M. indica													-0.39						-0.37		0.39
M. lutea		0.48	0.49																		
C. lusitanica																					
E. camaldulensis																					
E. grandis														-0.89							
E. saligna																					

Month and Lag

b)

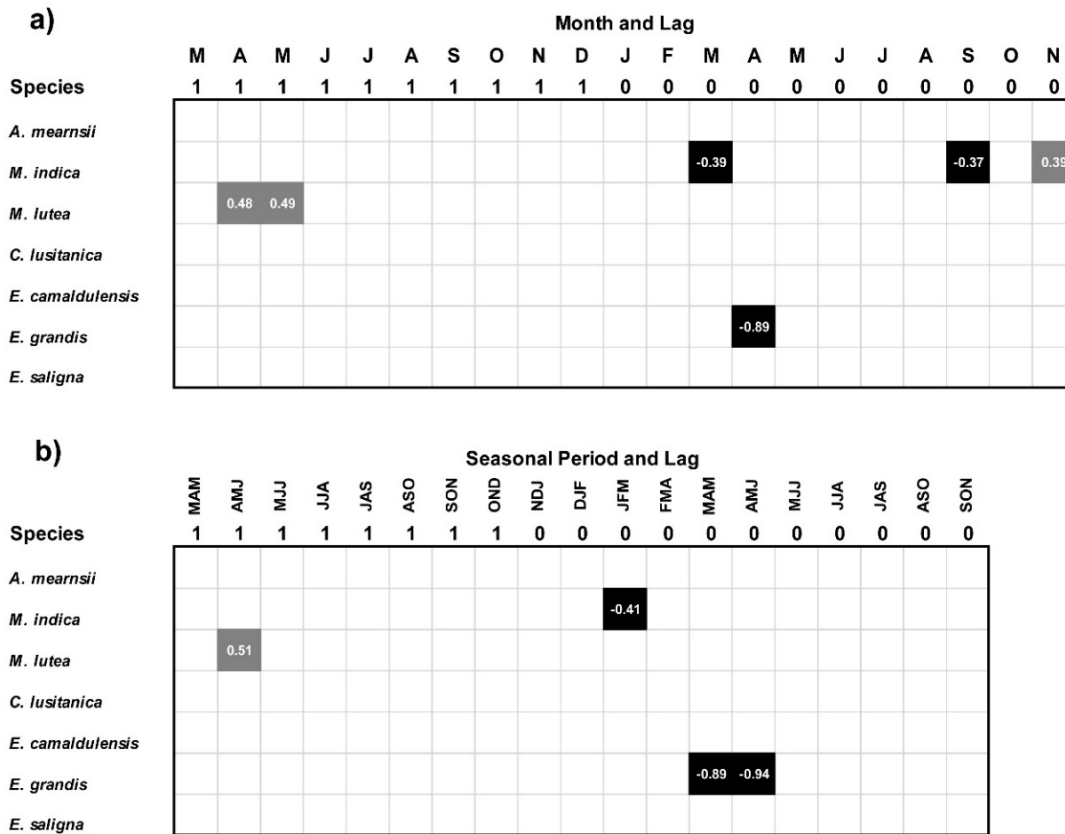| Species	MAM 1	AMJ 1	MJJ 1	JJA 1	JAS 1	ASO 1	SON 1	OND 1	NDJ 0	DJF 0	JFM 0	FMA 0	MAM 0	AMJ 0	MJJ 0	JJA 0	JAS 0	ASO 0	SON 0
A. mearnsii																			
M. indica											-0.41								
M. lutea		0.51																	
C. lusitanica																			
E. camaldulensis																			
E. grandis													-0.89	-0.94					
E. saligna																			

Seasonal Period and Lag

Fig. 5. Correlation diagrams of all studied species with a) monthly temperature and b) seasonal temperature spanning March of the previous year (lag 1) to November of the current year (lag 0). Significant positive correlations ($p < 0.05$) are denoted by grey boxes and significant negative correlations ($p < 0.05$) are denoted by black boxes. The value of the correlation coefficient was provided for each significant climate variable. *A. mearnsii, E. camaldulensis, M. indica*, and *M. lutea* were all analyzed using a Pearson correlation test, while *C. lusitanica, E. grandis*, and *E. saligna* were analyzed using a Spearman rank test.
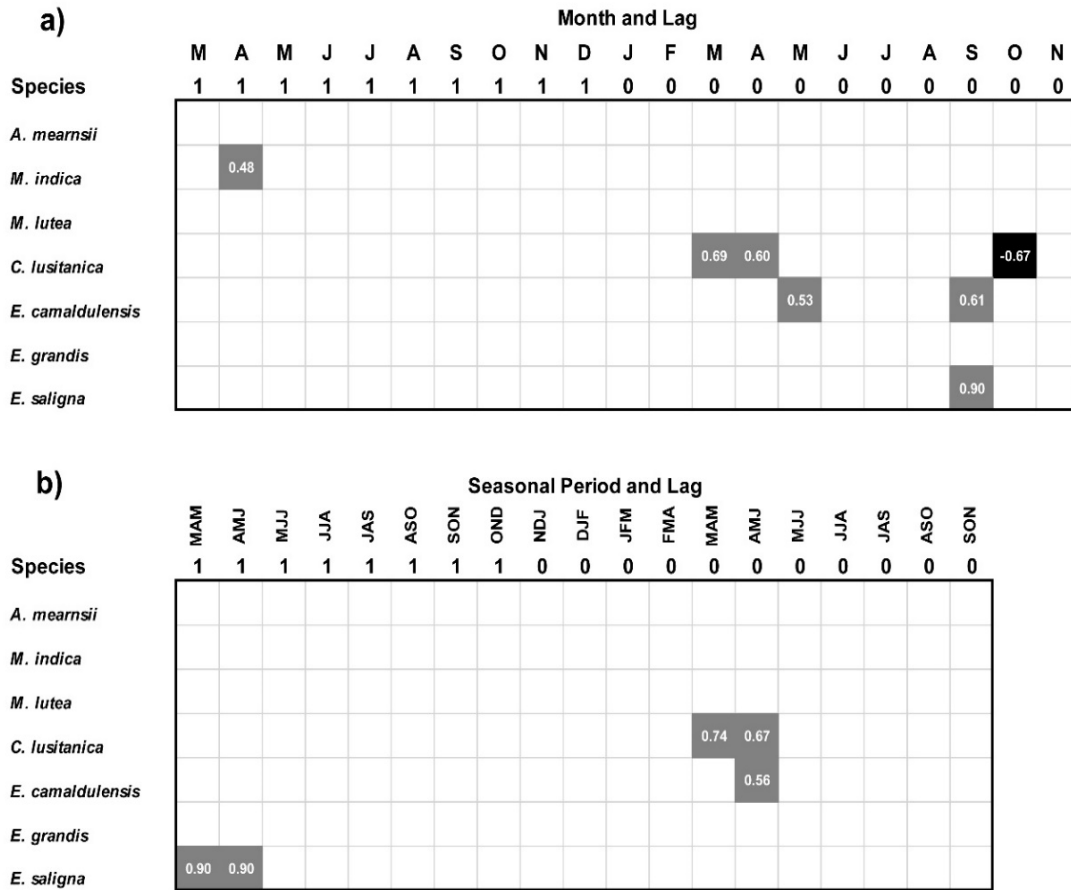
Fig. 6. Correlation diagrams of all studied species with a) monthly Climate Moisture Index (CMI) and b) seasonal CMI spanning March of the previous year (lag 1) to November of the current year (lag 0). Significant positive correlations ($p < 0.05$) are denoted by grey boxes and significant negative correlations ($p < 0.05$) are denoted by block boxes. The value of the correlation coefficient was provided for each significant climate variable. *A. mearnsii, E. camaldulensis, M. indica*, and *M. lutea* were all analyzed using a Pearson correlation test, while *C. lusitanica, E. grandis*, and *E. saligna* were analyzed using a Spearman rank test.

4. DISCUSSION

A majority of the species (*M. indica, C. lusitanica, E. camaldulensis,* and *E. saligna*) showed positive correlations with monthly and seasonal precipitation during periods of the long and short rainy seasons. It is commonly understood that moisture availability greatly impacts radial growth of tropical species in many regions [1]. The positive relationships between precipitation and radial growth during the rainy season found in this study coincide with the findings of several other tropical studies [e.g. 2,4,10,14-15,28-33]. David et al. [18] also reported that *E. camaldulensis* was positively associated with annual precipitation (January-December) of the

current year. Although *A. mearnsii* was not siginificantly conditioned by monthly or seasonal precipitation, David et al. [18] did observe that *A. mearnsii* was positively associated with annual precipitation (January-December) of the current year, and drought sensitivity has also been reported in Ethiopia for this species [10]. There were no significant associations between basal area growth and monthly and seasonal precipitation; in contrast, several studies conducted in Brazil found that annual wood increment growth of *E. grandis* plantation trees was positively correlated with precipitation [34-35]. Interestingly, for *M. indica* and *E. saligna*, some of the positive correlations were with precipitation in the long rainy season of the

previous year. Precipitation of the previous year may have a potential impact on foliage formation and carbohydrate reserve storage of a tree [36]. Thus, the lack of sufficient precipitation during the previous growing season can have negative impacts on radial growth of the current year.

Negative correlations were observed for *C. lusitanica* for the month of October (t) in the short rainy season period. Negative correlations between radial growth and precipitation could signify an excess of cloud cover [1,37-38] or flooded soils leading to anaerobic conditions [36]. In addition, excess cloud cover tends to insinuate possible large storm events, which create high wind and lightning conditions, causing damage to tree crowns and stem breakage [39]. Tree crown repair takes priority in carbon allocation over radial growth; therefore, large storm events can have negative impacts on radial growth the following year [36]. We also speculate that excessive precipitation may favor growth of competitor tree species and grasses that are better able to take advantage of the increase in precipitation [40]. Buckley et al. [37] reported negative correlations between growth and precipitation among *Pinus merkusii* trees near Vientiane, with the explanation that factors other than moisture, such as low light levels, could be limiting growth.

Although few tropical dendroecology studies have reported correlations between temperature and growth due to the relatively limited intra-annual and inter-annual variation of temperature patterns, some researchers believe that even in tropical zones, temperature can play a role in growth dynamics [1]. This study revealed several correlations between monthly and seasonal temperature data and growth, which is contrary to several studies that found no significant correlations [32-33]. Radial growth of *M. lutea* was positively associated with temperature in the long rainy season of the previous year (t-1) which suggests that cool temperatures may prevent photosynthetic processes from reaching an optimal temperature range which in turn could negatively affect foliage development or the buildup of carbohydrate reserves [22,36]. Growth of *M. indica* was positively associated with November (t) precipitation which suggests that cool temperatures prevent an optimal range for photosynthesis which in turn can shorten the length of the short rainy season [22,36]. Since *M. indica* is native to northern India and Burma [41], another possible explanation could be that tree

species that are growing outside of the temperature optimum of their native geographical range, growth could be negatively impacted [36].

Negative correlations between radial growth and temperature were present during a month at the beginning of both the long rainy season and the short rainy season for *M. indica*. *E. grandis* was also negatively related to April (t) temperature. A potential ecophysiological explanation for this effect is that the rate of respiration increases as temperature increases and (or) higher temperatures leads to greater evapotranspiration rates and increased moisture stress, ultimately resulting in a greater loss of assimilated carbon [36,42]. The negative correlations between growth and temperature have been observed in other studies in tropical regions [14, 43-44]. In contrast to the current study, Sette et al. [34] reported significant positive correlations between temperature and growth of *E. grandis* trees in the state of São Paulo, Brazil. The results suggest that both *M. indica* and *E. grandis* (which is native to coastal eastern Australia) are sensitive to temperature stress in regions outside of their native geographical range.

Although many studies have examined the effects of precipitation and temperature on growth as separate analyses, few studies have considered both climate variables simultaneously. Interannual tree growth is directly affected by the amount of available water. The net amount of available water accounts for both precipitation and the evapotranspiration from the plant [25]. Temperature plays a large role in the amount of evapotranspiration that occurs and thus, a 'moisture index,' which accounts for water loss due to higher temperatures, is actually a better predictor of tree growth [33,45]. The correlations observed between Climate Moisture Index and growth for both monthly and seasonal data are similar to that of precipitation data and thus have similar ecophysiological explanations.

5. CONCLUSION

The analysis of growth-climate relationships indicated that a majority of the tree species (*M. indica, C. lusitanica, E. camaldulensis,* and *E. saligna*) examined in this study showed positive correlations with monthly and seasonal precipitation and moisture index during periods of the long and short rainy seasons. This

study also revealed significant correlations between monthly and seasonal temperature data and radial growth of *M. indica*, *M. lutea* and *E. grandis*. Growth of *M. lutea* was negatively affected by cool growing season conditions while *M. indica* and *E. grandis* experienced high temperature stress. This study has important implications for adapting to climate change in this region of east Africa.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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