

Assessment of phenology in *Gmelina* (*Gmelina arborea* Roxb.) Populations in Nigeria.

Abstract

The phenological events of 68 reproductive mature *Gmelina arborea* trees were monitored at three different periods, every month along the year in Idemili South forests for two consecutive annual cycles. Leaf initiation started with the emergence of leaf buds in first March, coinciding with the transition between the end of dry season and the beginning of rainy season. Leaf flushing started mid-June and peaked later in June. The leafing duration lasted for approximately 5 months. Leaf fall phase started in December and ended in January. Flower initiation started in mid January and peaked in late February, concentrated in the dry months. The flowering duration lasted for approximately 1 month. Flowering intensity was slightly higher in 2018 in all the populations. Fruiting phenology proceeded from early to the end of March. Fruits were mature by the end of March immediately before early significant rains. Fruiting duration from initiation to fruit drop lasted for approximately 2.5 months. The time lag between leaf flushing and first visible flowers was approximately 4 months. Low average asynchrony index (A.I.) was recorded for leafing (A.I.: 0.23), flowering (A.I.: 0.22), and fruiting (A.I.: 0.19) events among the populations. The results of this study have provided some information on aspects of the reproductive biology of the species for breeding and biodiversity conservation purposes. Since the phenophases are periodic and follow weather patterns, probable climate change will have serious implications on future reproductive success of *G. arborea*. In view of this, multiannual quantitative documentation of phenological patterns in the species is recommended to quantify the levels of variance, and thus trace the impacts of climate changes on the vegetation of the area.

Key words: Phenology, *Gmelina arborea*, leafing, flowering, fruiting, phenophases, synchrony, climate change

1. Introduction

The study of the seasonal chronologies in the growth and developmental processes in plants (i.e. phenology) in relation to the environmental factors is yet to receive sufficient attention in ecological research. However, phenological studies provide knowledge about the patterns of plant growth and development, as well as the effects of the environment and selective pressures on flowering and fruiting behavior. The timing of these phenological events influences resource use efficiency and seed production in plants. An individual plant that flowers too early before it has had time to accumulate sufficient material resources will have a limited capacity for seed production (Khanduri, 2014). Conversely, one that delays flowering might gain higher capacity, but might also run out of time to use it before the end of the season. Thus, for plant reproduction, timing is everything (Milla *et al.*, 2006).

Phenological studies provide information on functional rhythms of plants and plant communities, where the timing of various phenological events may reflect biotic and/or abiotic environmental conditions. The phenological activity of tropical trees is mostly affected by seasonality in rainfall and drought, and this is evident from the seasonal duration of bud break (both vegetative and flowering), leaf flushing, flowering, fruiting and leaf fall, that are periodically observed in the tropics (Echereme and Mbaekwe, 2015). In the tropics, seasonal fluctuation in mean temperature is often less than fluctuations within a single day, and changes in photoperiod are very small. In contrast to temperate forests, where temperature and photoperiod are the major driving factors for phenology, periodic change in rainfall caused by movements of Inter-tropical Convergence Zone plays an important role as proximate and ultimate factors for tropical plant phenology (van Schaik *et al.*, 1993).

Knowledge of phenology and floral morphology are essential for conducting studies on breeding systems, particularly on pollination study (Igboabuchi *et al.*, 2018). Such studies would prove to be successful in planning various programmes specific to different habitats. Studies in reproductive biology will also help in developing strategies to preserve genetic potential of rare species, and are crucial for restoration and reintroduction (Igboabuchi *et al.*, 2018) and, as well, for a better understanding of plant species and community level interactions. Phenological records are some of the most sensitive data in identifying how plant species respond to regional climate conditions and to climate changes. Several studies have shown significant variation (advanced or delayed) in onset dates of flowering (Fitter and Fitter, 2002) and fruiting responses (Chapman *et al.*, 2005) in tree species, mostly as a result of seasonal variations in temperature and rainfall. Climate change will influence many aspects of the biology of tropical organisms, but the effects on plant phenology could be of particular significance (Corlett and Lafrankie, 1998).

Throughout its distribution in southeastern Nigeria, **Gmelina** population has undergone various degrees of **anthropogenic** disturbances and habit fragmentation as a result of rise in population growth and urbanization, more so within Idemili South forest ecosystem. As a result of these disturbances, the plant communities of Idemili South have been modified with increasing pressure on natural regeneration and evolutionary potential of **Gmelina**. These include the biological processes such as mating system (pollination and fruit setting) and gene flow. Consequently, such disturbed populations will require conservation and management practice that promote sustainable utilization. Thus, implementation of viable local conservation strategies, based on reproductive successes for **Gmelina** within the ecosystem, is therefore required if the ecological integrity of the species is to be preserved. This is basically because the success of the species in its habitat will largely depend on its ability to achieve both its vegetative and reproductive growths. In spite of the growing global interest in phenology as a bio-indicator to monitor the impacts of climate changes, no phenological study has focused on climate change impact in Idemili South, especially how climate change is impacting on the length of growing seasons of plants in the area. This is basically because climate change may force variation in timing and synchronization of phenological events with serious ecological consequences for population interaction and community structures. The present study aimed to carry out a preliminary evaluation of the leafing, flowering and fruiting phenology in **Gmelina** growing within Idemili South forest ecosystem. Specifically, the research was intended (1) to investigate the phenological events (2) to interpret the phenological events (3) to document the phenological events and (4) to provide baseline information on phenological activity for attempting correlation between phenology and climate change.

2.0 Materials and Methods

2.1. Study Site

The present study was carried out in forests within Idemili South (between 5° 40' to 6° 35' north latitude and 7° 50' to 8° 30' east longitude; 219 m a.s.l.) in Anambra State, southeastern Nigeria. Four **Gmelina** populations, namely: Oba, Ojoto, Awka-Etiti and Alor, were selected for this study (Figure 1). Idemili South has total land area of approximately 145 km² (SYB, 2011). It is located in the southeastern lowland of Nigeria. Climate is almost homogeneous and is characterized by two seasons: rainy season and dry season. As a result of effect of prevailing seasonal wind, nearness to the sea coast, and the relatively flat topography of the environment, a humid Tropical Maritime (mT) from across the Atlantic Ocean in the south, dominates the region in the longer wet season (April-October). **Tropical** Continental (cT) air mass blowing from Sahara desert (in the northeast direction) controls the climate and meteorology of the area during the dry season (November- March). Annual rainfall is between 1520 to 2030 mm (ESMP,

2017). Rainfall pattern begins with a steady increase from March to July, higher and more persistent during September, after which emerges decreasing rain in October and November (Nnadi *et al.*, 2013). Rainfall is accompanied by a short dry period in August, referred to as 'August break,' lasting two to three weeks, with the rains resuming in September to October. Though for years now this has not been consistent in August due to climate change impacts. Dry season is accompanied by a short period known as Harmattan. Harmattan is characterized by cold and dry wind with grey haze, which limits visibility and blocks the sun's rays from dissipating heat, leading to extreme dry weather. On the average, the ambient maximum air temperature varies from 28^o C to 34.5^o C, while the minimum temperature varies from about 22^o C to 27^o C. Average relative humidity is 80 % with the peak value occurring in July (rainy period), while the least value occurs in December (dry period). The vegetation ecosystem of Idemili South falls under tropical humid forest (Nnadi *et al.*, 2013). Natural vegetation is fragmented and is at present available only in narrow strips and patterns. Soil is almost homogeneous, ferrallitic, with poor chemical contents.

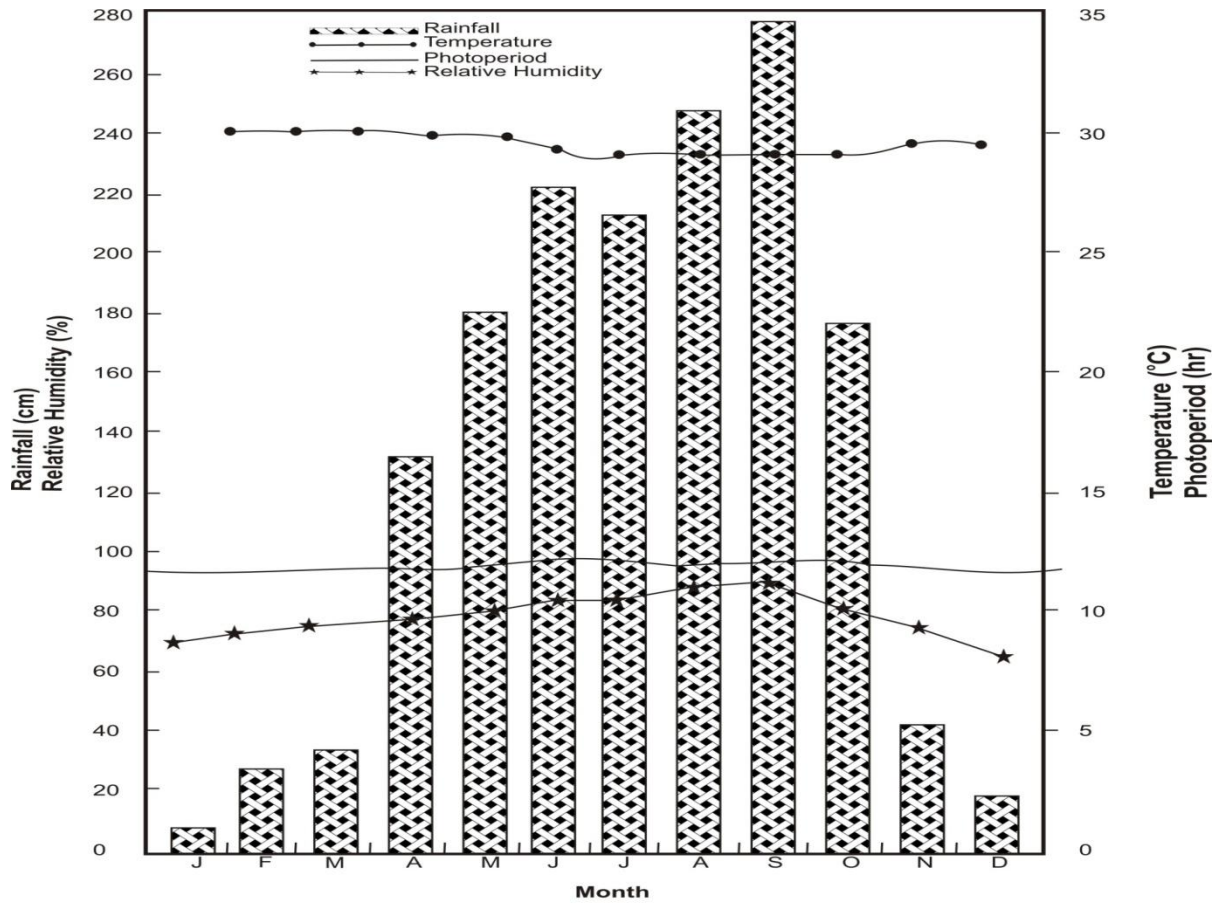


Fig. 2: Long-term Climatic Conditions at Idemili South, southeastern Nigeria

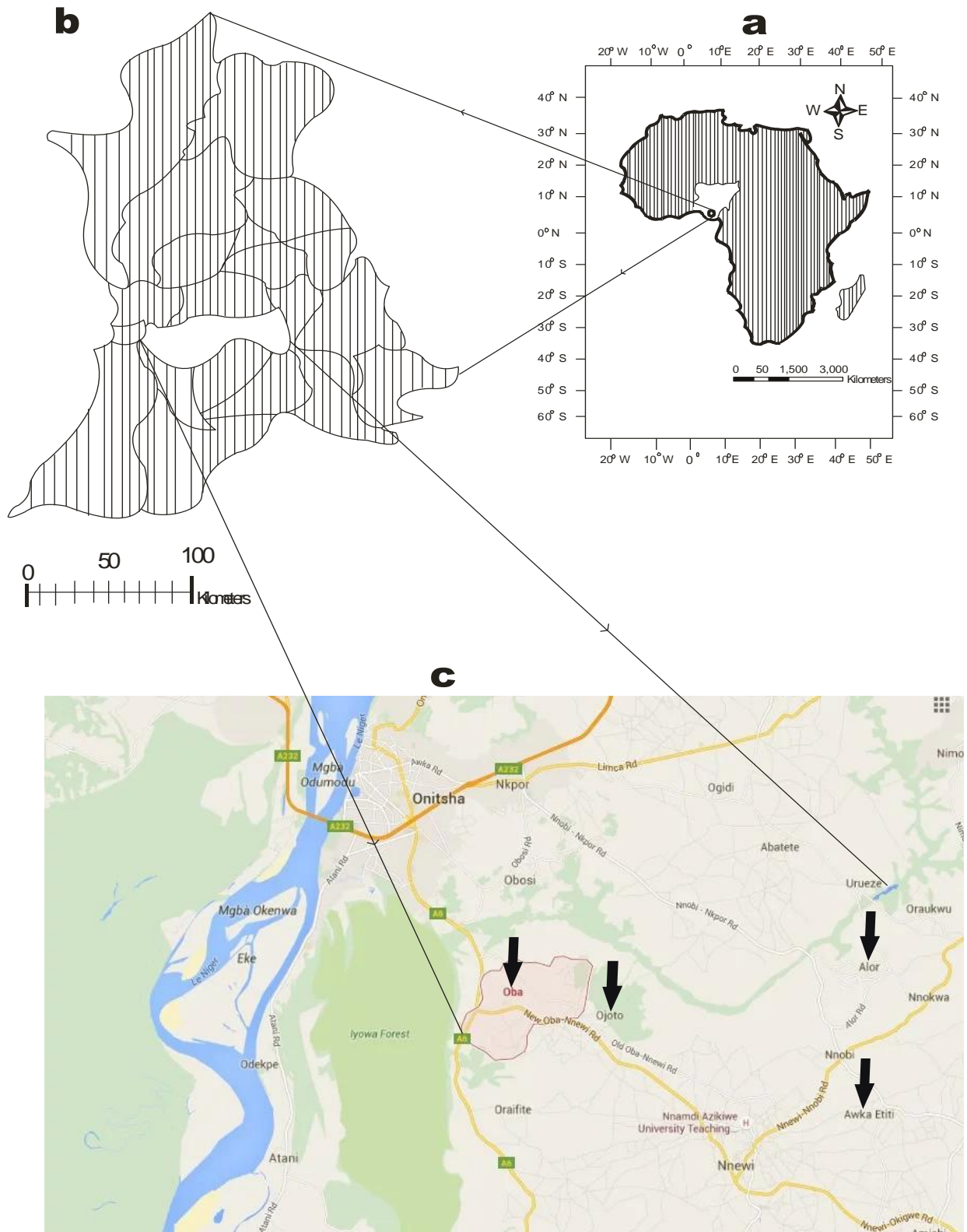


Figure 1: (a) The location of Anambra State on the map of Nigeria, (b) the location of the study area on the map of Anambra State, (c) the location of the sampling sites.

2.2. The Study Species

Gmelina arborea Roxb. (Verbenaceae), commonly known as Gmelina, is a fast-growing, moderately sized to large deciduous tree, with a wide spreading canopy and numerous branches forming a large shady crown. It can grow from 3 m to 30 m tall, sometimes even taller. The straight cylindrical stem is commonly around 50 cm in diameter, but specimens up to 140 cm have been recorded (<tropical.theferns.info/viewtropical.php?). It occurs naturally throughout greater part of India at altitude up to 1,500 m. It also occurs naturally in Myanmar, Thailand, Laos, Cambodia, Vietnam, and in southern provinces of China, and has been introduced as a plantation species in many countries, and large plantations are found in south-East Asia, West Africa and South America. The species is the most commonly planted exotic tree species in Nigeria. In Nigeria it is often grown as an ornamental, being planted as an avenue tree. Its growth is particularly promising in the rainforest and derived savanna zones, where most of these plantations are found (Adegbehin *et al.*, 1988). The fruit is edible (<http://www.prota.org>) and has a bitter-sweet taste (Rogier, 2012). The dark purple to yellow fruit is an obovoid drupe, 18-25 mm long with an aromatic, succulent flesh (Rogier, 2012). The flowers are used as a mix with rice to make a delicious cake-like festive dish, that is eaten on the traditional New Year (Facciola, 1998). The bark, leaves and roots contain traces of alkaloids, and are used medicinally in the plant's natural range (World Agroforestry Centre). The leaf sap is used as a demulcent to treat gonorrhoea and cough, and is also applied to cure wounds and ulcers. The flowers have been used to treat leprosy and blood diseases (<http://www.prota.org>). The species is reasonably strong for its weight, and once seasoned, it is a very strong timber and moderately resistant to decay and termites. It is used in construction of furniture, carriages, sports and musical instrument and artificial limbs (Adegbehin *et al.*, 1988).

2.3. Study Design

The whole area of Idemili South was surveyed and sampling plots were established at Oba, Ojoto, Awka-Etiti and Alor for data collection. These sites were chosen as they represent most of the plant diversity of Idemili South. Figure 1 shows the locations of the study area and the sampling sites on the map of Anambra State, southeastern Nigeria. Climate data was obtained from the Weather Spark website: <http://weatherspark.com/y/52942/Average-Weather-in-Ojoto-Nigeria-Year-Round>. At each site, one mature and healthy tree with signs of previous year seed production from the population of Gmelina, was fixed as a reference for the study. Phenological observations were visually made on the reference tree and 15-18 of its closest neighbours (minimum of 16 trees if more trees were not available for a particular species at a particular site) per population for a period of two consecutive annual cycles (24 months - from January, 2017 to the end of December, 2018). A total of 68

reproductive mature trees were selected for the study. This selection regime was based on a study by Pilar and Gabriel (1998). The areas with the trees under study were visited fortnightly to observe and record presence/absence of different phenophases. The information on the initial and last dates, when these various phenophases were observed, was recorded. A phenophase was considered to be active in the population just when it was observed, in at least 5% of the crown in a minimum of 20% of the population. Trees were counted as being in flowering mode when presenting open flowers. A tree was considered to be in flushing leaves mode when, at least, 5% or more of the leaves in the crown were new leaves.

2.4. Phenological observations and collection of data

In each individual, two major branches were marked and assessed for phenological activity. On each branch, four twigs (currently growing shoot of last-order branches) were observation for changes in phenophase (see Singh and Kushwahs, 2006). Phenological events were monitored and phenophases data were recorded under the following phenological phases: bud initiation; leaf-flush initiation; leaf-flush completion; leaf fall initiation, leaf fall completion; flower initiation; flowering completion; fruiting initiation; fruit mature. However, for phenophases, three different periods of each month were taken: first, mid and late. For example, the period from 1st January to 10th January as first January; from 11th to 20th January as mid January; and from 21st to 30th January as late January. Phenological observations and collection of data in all the sites were made starting from 1 hour to 3 hours PM in each observation day. The observation time was so scheduled because at this time the sun is high and behind the observer. Thus, at this time, optimum brightness for colour vision was improved.

2.5. Analyses of phenological data

Phenological data were summarized by recording occasions separately and for the four populations combined. Phenological calendars for Gmelina were prepared and were studied for the interpretation of the overall results. Peaks were used to refer to the months in which the number of individuals observed in a particular phenophase reached a maximum. Synchrony Index (S.I.), as was described by Devineau (1999), was used to quantify the temporal coincidences in the occurrence of the phenophases, within and among populations. According to Devineau (1999), S.I. for leafing, flowering and fruit development of each species, it was calculated as the ratio between the individual's mean duration of a phenological phase and the overall duration of the phase. Thus:

$$\text{S.I.} = \frac{\sum_{i=1}^n \text{tph}_i}{\frac{n}{\text{Tph}}}$$

Where **S.I.** = Synchrony index; **tph_i** = timing of a particular phenophase; **Tph** = longest duration of a phenophase; and **n** = number of samples.

The higher the ratio, the greater the coincidence between different individuals of a species (i.e., the ratio 1.0 denotes perfect synchrony amongst individuals, and as the ratio decreases from 1.0 asynchrony increases). The value of the **S.I.** was subtracted from 1.0 to get the asynchrony index (A.I.).

3.0 Results

Environmental Factors

The rainfall distribution mainly followed the typical bimodal pattern, with the months of higher precipitations being June/July and August/September. Overall, the annual rainfall differed slightly between the two years, with the year 2018 recording more rainfall amounts (1,608 mm) than the year 2017 (1,582 mm). The mean temperatures varied significantly and followed the rainfall patterns, with the rainy months recording lower temperatures than months with no rainfall. The maximum day temperatures ranged between 28 °C and 31 °C, and the minimum day temperature from 19° C to 24° C. Mean daily relative humidity for each month ranged from 71% to 87%. The soil moisture content was high during the rainy months and low during the dry months. These trends were similar during the two consecutive years of the study.

Leafing Phenology

Table 1: Leafing events of Gmelina within Idemili South forests for years 2017 and 2018

Population	Year/Leafing Event									
	2017					2018				
	BI	LFI	LFC	LFLI	LFLC	BI	LFI	LFC	LFLI	LFLC
Oba	First	Mid	Late	Late	Mid	First	Mid	Late	First	Late
	Mar	Jun	Jul	Nov	Jan	Mar	Jun	Jul	Dec	Jan
Ojoto	First	Mid	Late	Late	Mid	First	Mid	Late	First	Late
	Mar	Jun	Jul	Nov	Jan	Mar	Jun	Jul	Dec	Jan
Awka-Etiti	Mid	Late	Mid	Late	Mid	Mid	First	Mid	Late	First
	Mar	Jun	Jul	Nov	Dec	Mar	Jun	Jul	Nov	Dec
Alor	First	Mid	Late	Late	Mid	First	Mid	Late	First	Late
	Mar	Jun	Jul	Nov	Jan	Mar	Jun	Jul	Dec	Jan

BI: bud initiation, **LFI:** leaf flush initiation, **LFC:** leaf flush completion, **LFLI:** leaf fall initiation, **LFLC:** leaf fall completion

The results of the leafing event in **Gmelina** are as presented in Table 1. Within Idemili South forests, leaf initiation in *G. arborea* started with the emergence of leaf buds. This occurred in first March for both 2017 and 2018, in all the sites, except for Awka-Etiti, where bud initiation started approximately 10 days later (Table 1). This month coincides with the transition between the end of dry season and the beginning of rainy season. Leaf flushing started in mid June at Oba, Ojoto and Alor. **But** at Awka-Etiti, it started approximately 12 days later in 2017, **and** 10 days earlier in 2018. Flushing peaked in the month of June **in all the sites**. **Average leafing duration** (bud initiation to completion of flushing) in all the sites lasted for approximately 5 months for both 2017 and 2018. **But** Awka-Etiti population had a shorter leafing duration (approx. **four and a half months**). A high percentage of mature leaves was retained almost throughout the rainy season. Leaf fall started in late November but earlier, in 2017 in all the populations. In the year 2018, leaf fall started **in first December in** all the populations, except at Awka-Etiti, where it started in late November (approx. 10 days delay). The peak leaf fall (complete **fallen leaves**) was observed to occur during December/January in both 2017 and 2018, coinciding with the peak of dry season. The leaf fall was followed by leaf

buds emergence at the transition between the end of the dry period and the starting of rains in (March). Individual trees did not show any significant difference in the pattern of deciduousness along the two years of this study. Average leafless duration (period of complete fallen leaves) was approximately 2 months for all sites.

Flowering and Fruiting Phenology

Table 2: Flowering and fruiting events of *Gmelina* within Idemili South forests for years 2017 and 2018

Population	Year/Flowering and Fruiting Events									
	2017					2018				
	FLI	FFI	FLC	FRI	FRM	FLI	FFI	FLC	FRI	FRM
Oba	Mid	First	Late	First	Late	Mid	First	Late	First	Late
	Jan	Feb	Feb	Mar	Mar	Jan	Feb	Feb	Mar	Mar
Ojoto	Mid	First	Late	First	Late	Mid	First	Late	First	Late
	Jan	Feb	Feb	Mar	Mar	Jan	Feb	Feb	Mar	Mar
Awka-Etiti	Late	Mid	First	Mid	First	Late	Mid	First	Mid	Mid
	Feb	Feb	Mar	Mar	April	Feb	Feb	Mar	Mar	April
Alor	Mid	Mid	Late	Mid	First	Mid	Mid	Late	First	Late
	Jan	Feb	Feb	Mar	Mar	Jan	Feb	Feb	Mar	Mar

FLI: flower initiation, **FFI:** flower full initiation, **FLC:** flowering completion, **FRI:** fruiting initiation, **FRM:** fruit mature

The species exhibited annual flowering pattern with flowering occurring once in each year, with one synchronous peak in all the populations. Flowering started almost synchronously in all the populations for both years, with the peak occurring synchronously with the peak of drought along the season (February). Generally, flower initiation started in mid January and ended in late February (Table 2). However, flowering at Awka-Etiti started in late January and ended in first March for both years. Flowering intensity was slightly higher in 2018 in all the populations. The flowering duration (bud initiation to end of flowering) lasted for approximately 1 month in all populations combined for both years. Flowering started during the peak of leaf fall.

Fruiting phenology proceeded in early March at Oba and Ojoto, after the completion of flowering (Table 2). The delay in flowering recorded for Awka-Etiti reflected on the fruiting initiation, as approximately, 10 days delay in fruiting initiation, was recorded in both studied years. The peak fruiting month, when majority of the individual trees had many fruits, was in late March for both the years 2017 and 2018. For the two years combined, the fruiting peak occurred in the month of March. Average fruiting duration (i.e. fruiting initiation to fruit maturity) generally lasted for, approximately, 1 month. The time lag between leaf flushing and first visible flowers was, approximately, 5 months.

Synchrony of Phenological Events

The results of the leafing, flowering and fruiting synchrony in Gmelina are as shown in Table 3.

Table 3: Asynchrony indices for leafing, flowering and fruiting events in Gmelina within Idemili South forests

Population	Asynchrony index for ¹		
	Leafing	lowering	Fruiting
Oba	0.24 <i>ns</i>	0.22 <i>ns</i>	0.19 <i>ns</i>
Ojoto	0.24 <i>ns</i>	0.21 <i>ns</i>	0.18 <i>ns</i>
Awka-Etiti	0.23 <i>ns</i>	0.23 <i>ns</i>	0.20 <i>ns</i>
Alor	0.22 <i>ns</i>	0.22 <i>ns</i>	0.17 <i>ns</i>
Overall	0.23	0.22	0.19

Values are mean of two annual cycles

¹In order to get the asynchrony index, the synchrony value was subtracted from 1.0. The higher the ratio, the greater the coincidence between different individuals of a species (i.e., the ratio 1.0 denotes perfect synchrony amongst individuals, and as the ratio decreases from 1.0 asynchrony increases), *ns* = differences within site not significant.

Leafing was observed to have relatively higher asynchrony among the studied phenological events (Table 3). However, asynchrony in leafing did not differ significantly among sites. The average overall inter-population asynchrony index for leafing, flowering and fruiting was 0.23, 0.22 and 0.19, respectively (Table 3). Low asynchrony (high synchrony) index indicates greater coincidence of the event among individuals or sites.

4.0 Discussion

Leaf Phenology

Leafing initiation in the species started towards the end of dry season (Table 1). Studies show that in most tropical forests leafing initiation during dry periods has some adaptive significance to the survival of the trees (Singh and Kushwaha, 2006; Daubenmire, 1972). Some other studies (van Schaik and Terbor, 1993; Coley and Barone, 1996) have reported that herbivorous insects biomass is greater in the wet months due to susceptibility to desiccation in dry months. Predictably, leaf damage by insects has been shown to be greatest in the wet months (Aide, 1992; Murah and Sukumar, 1993). Thus, leaf initiation during the dry period, when water stress is still high, and before the seasonal increase in insect biomass, may be an adaptive strategy of *Gmelina* to minimize attack of herbivory on young developing leaves. It is generally believed that occurrence of rainfall after a period of drought or long dry spell usually initiates plant growth. Flushing as it was observed in the present study coincided with rainfall period (Table 1). Maturation of leaves requires adequate amount of soil water for enhanced photosynthesis. Leaf flushing in species coincided with the period of adequate water. The species recorded complete leaf cover in the mid of the rainy season and thus coincided with high water availability, both in terms of rainfall amount and soil water content.

Some studies have reported delay or advance in phenological events in the tropics (Khanduri, 2014; Omondi *et al.*, 2016; Miao *et al.*, 2017), and have attributed it to variation in environmental conditions. The delayed bud initiation and flushing at Awka-Etiti in 2017 may be attributed to low soil moisture content of the site, or due to delay in the early rains relative to other sites. However, the advance in leaf flushing of *Gmelina* in 2018 can also be attributed to temporal occurrence of early significant rains in the study area. The first significant rains may have advanced in 2018 at Awka-Etiti. Some other studies have reported that the leafless period is an adaptation to avoid water stress (Singh and Kushwaha, 2005; Omondi *et al.*, 2016 (Table 1). The present study has shown that leaf fall in the species starts and peaks along the dry season, when the soil moisture content is very low and atmospheric temperatures are high. As a defense mechanism to ward off the harsh effects of drought, *Gmelina* drops its leaves during the dry periods in order to conserve water in the other live tissues. The delay in leaf fall phenophase, as recorded for the population at Awka-Etiti in 2018, can be attributed to variation in stem water status, or soil moisture content at the site, and this is a parameter associated with rainfall.

Flowering Phenology

Gmelina flowered during the dry season, which was similar to many deciduous species within the communities and other tropical species so far. Most studies have reported that, for species flowering during the dry season, leaf shedding during the dry season

usually acts as a cue that triggers flowering (Borchert, 2000; Singh and Kushwaha, 2005; Couralet *et al.*, 2013). During the present study *Gmelina* is reported to initiate flowering during the mid of the dry season, when over 70% of the leaves has been dropped, thus indicating the prominent role of leaf shedding in triggering flowering, as a result of stem rehydration. Since leaf shedding triggers flowering in *Gmelina* in the dry period, in line with the above studies, the delay in flowering initiation recorded for Awka-Etiti population can be attributed to the relatively higher soil moisture content in the season which delayed leaf drop, relative to leaf drop in others. Very few studies have examined the possible functional significance of an interrelationship between leafing and flowering/fruiting phenophases in tropical trees (Van Schaik *et al.*, 1993). Occurrence of leaf flushing and flowering requires the availability of substantial amounts of resources within the tree. For instance, flower production and maintenance requires considerable expense of energy to form non photosynthetic tissues and nectar (Ashman and Schoen, 1997). Besides, the time lag between these two events reflects separation in time of use of resources for vegetative and reproductive functions. Singh and Kushwaha (2005) observed in deciduous trees, that the longer the leafless duration, the more delayed (greater time lag) is the initiation of flowering relative to flushing. This is not incompatible with the results of the present study, as the species recorded approximately 2 months of leaflessness, and this reflected in the time lag between flushing and first visible flowers, which stood at approximately 5 months. The time lag between these two events reflects temporal separation of resources use for leafing and flowering in the species. Various physiologically active sites or sinks (e.g. leaf buds and leaves, flower buds and flowers, and fruit) may compete for water, nutrients and metabolites (Lieberman, 1982), and such internal competition may result to the temporal separation in plant functions like leafing and flowering.

Fruiting Phenology

Most neotropical forest communities studied show flowering and fruiting peak near the end of the dry season (Opler *et al.*, 1980; Bullock and Solis-Magallanes, 1990). The pattern may be caused by high insolation and photosynthesis in dry seasons or by enhancement of germination and seedling survival by adjusting fruiting to precede the beginning of the wet season (van Schaik *et al.*, 1993). The present study is not incompatible with the above presumptions, as fruiting phase started in first March and fruits were mature by the end of March, before the onset of rainfall in the month of April. Thus, the completion of fruiting phenophase during the late dry season, before the onset of the succeeding rainy season, may be to ensure that some, if not all, seeds are available for germination when the soil will be sufficiently moist. These results support the hypothesis that adequate developmental time from flowering to fruit dispersal has been achieved. So, seeds are released in rainy periods, when germination is most likely to be induced and seedlings start growing with low probability of drought (Stevenson *et*

al., 2008). In order to optimize seed germination and growth, the species ensures that fruit maturation (in March/April) coincides with the period of optimum water availability, both in terms of soil moisture and stem water status. The delay in fruiting recorded for Awka-Etiti among other populations, can be attributed to the delay in flowering in the season.,

Synchrony of Phenological Events

The present study recorded significant inter-population and intra-population synchrony. This may be attributed to similar dynamics of environmental factors among sites. Synchrony at the population level may be essential for cross-pollination and escape from herbivores (Aide 1993), or seed predators (Auspurger, 1981). It is expected that synchronous individuals within the population should have a higher fitness than plants that flower out of synchrony, because of an increase in number of visiting pollinators, higher rates of pollen donated deposition, greater opportunities to find mates, a higher potential for out-crossing and/or larger number of seeds that escape predation (César *et al.*, 1995). Thus, synchrony is an indication of the plasticity of the individual trees that may contribute, to a large extent, to population maintenance and connectivity in the community. The low asynchrony indices for flowering events in *Gmelina* (Table 3) may constitute to the reproductive success and persistence, and of the species despite high degree of fragmentation in Idemili South. The very little variance noticed with respect to intra-site asynchrony in leafing, flowering and fruiting among populations, may be attributed to individual's inherent physiological capacity to use water.

Role of Phenology in Plant Conservation

Knowledge of plant reproduction is crucial to our understanding of the causes of rarity and for conservation of rare plant taxa (Drury, 1974; Kruckeberg and Rabinowitz, 1985). It has been demonstrated for some plant species, that reproductive success or mortality is correlated with phenology traits (e.g. for flowering, Auspurger, 1981). Moreover, reproductive characteristics such as germination capacity, seed dispersal, survival rate of seedlings, flowering, reproductive life span and number of flowers and seeds, refer to a set of responses that allow a species to adapt to a particular environment. Beside, these processes of gamete development, pollination, endosperm and embryo development and other reproductive features, can provide important clues regarding the reproduction constraints of plants that need conservation.

Agriculture and forestry sciences have applied phenological data for timing of agricultural work, selection of suitable crops and cultivars, and in conservation and management programmes. *Gmelina* has suitable characteristics for agroforestry, with fast growth, ease of establishment and relative freedom from pests outside its natural range (it can be browsed repeatedly without damage) (Orwa *et al.*, 2009). It is an

especially promising fuel wood species, because it can be established easily, regenerates well from both sprouts and seeds, and is fast growing. Thus, in the face of the progressively increasing rate of deforestation in Idemili South, that threatens extinction of some tree species in the area, including Gmelina, adequate knowledge of vegetative and reproductive phenology of the species will provide important clues about the reproductive constraints of the species, and will inform the foresters and conservationists against the environmental vagaries, for conservation and management purposes.

Potential Impact of Climate Change on Phenology

Many studies focus on the impact of climatic factors on plant phenophases such as leaf-out, flowering, fruiting, senescence and abscission (e.g. Morisette *et al.*, 2009; Tooke and Battley, 2010; Polgar and Primack, 2011). As noted by the IPCC's AR4 (Rosenzweig *et al.*, 2007), these studies provide incontrovertible evidence of some of the biological impacts of climate change, especially as related to warmer temperatures, on terrestrial ecosystem. In the tropics, although plants can also cue their activities to temperature and photoperiod, water availability is the main driving force of phenological patterns (Singh and Kushwaha, 2005). The importance of understanding the determinants of phenological patterns has been emphasized to predict responses of specific communities to global climate change (Van Vliet and Schwartz, 2002). Tropical trees are expected to respond variously to changes in rainfall and temperature, because they differ widely with respect to adaptations to seasonal drought and cues for bud break of vegetative and flower bud (Singh and Kushwaha, 2005b). Global climate change may force variation in timing, duration and synchronisation of phenological events in tropical forests (Reich, 1995), with indirect effects on those animal species, the majority that depend on periodically plant resources; young leaves, pollen, nectar, fruit and seeds.

Since phenophases of Gmelina are periodic and follow weather patterns, trends of erratic rainfall or increasing temperature in Idemili South forests are likely to alter the length of the growing season in the species by affecting the timing and/or duration of leaf-fall and flowering phenophses, or by affecting the synchrony in phenological events. Climate change forced deviations in the length of growing season of the species, and competition with other species may alter the resource use pattern among species. Vegetative bud break in the studied species may be independent of rainfall pattern, but survival of young leaves and flowering initiation, and fruiting phenophases, may be affected seriously, if rainfall period is shifted. A rainy spell during the dry season or drought during the rainy season may cause a shift in leaf flushing and/or flowering.

Although in the tropics, water stress has frequently been cited as a primary triggering factor for leaf shedding, but little is known about its effect on reproductive phenology or flowering (Diaz and Granadillo, 2005). In dry-season, flowering trees like *Gmelina*, the flowering and fruit maturity may be affected adversely if the rainfall period is shifted. This is because of the indirect effect on the visiting pollinators, as a result of mistiming. As described by Corlett and Lanfrankie (1998), the direct effect of climate change will be less serious than the effect of changed phenology on pollinators and seed-dispersal agents. These shifts in the pattern of rains would indirectly have dire consequences on the pollinators, herbivores and predators that depend on the periodic availability of plant resources (e.g. young leaves, nectar, fruits and seeds), if the availability of these resources is tenaciously tied to periodicity of rainfall. For this phenomenon predator satiation, i.e. starving the predators in low seed years or swamping seed predators in high years (Janzen, 1971), is one of the reasonable explanations.

Conclusions

Although other abiotic factors may be involved, these results confirm the direct or indirect role of rainfall on the promotion of vegetative and reproductive phenology in *Gmelina*. The seasonal leafing, flowering time and fruiting duration, with linkages to leafing and leafless durations observed in the species, suggest the reproductive and survival strategies evolved by the species to survive. Despite the fragmentation of *Gmelina* population within Idemili South, the species reports high degree of phenological synchrony within and among populations. The synchrony may confidently be attributed to almost similar environmental condition within the forests. The synchrony may be an evolutionary strategy of the species to sustain reproduction and be successful in its habitat. Since environmental characteristics influence vegetative and reproductive phenology in *Gmelina*, either directly (through conditions in the habitat) or indirectly (e.g. through leafless period), probable global climate change will have serious implications on future reproductive success of tropical rainforest trees like *Gmelina*. In view of this, long-term quantitative documentation of phenological patterns in the species is suggested to quantify the levels of variance, and thus trace the impacts of climate changes on the vegetation of the area. This is the first phenological study of *Gmelina* at population level in Idemili South.

References

- Adegbehin, J.O., Abayomi, J.O.O. and Nwaigbo, L.C. (1988). *Gmelina arborea* in Nigeria. 67:159-166. Website: https://www.researchgate.net/publication/308524349_Gmelina_arborea_in_Nigeria
- Aide, T.M. (1992). Dry season leaf production - an escape from herbivory. *Biotropica*, 24: 532-537
- Aide, T.M. (1993). Patterns of leaf development and herbivory in a tropical understorey community. *Ecology*, 74: 455-466
- Ashman, T.L. and Shoen, D.J. (1997). The cost of floral longevity in *Clarkia tembloriensis*: an experimental investigation. *Evolutionary Ecology*, 11: 289-300
- Auspurger, C.K. (1981). Reproductive synchrony of a tropical shrub: experimental studies on effects of seed predators on *Hybanthus pruniformis* (Violaceae). *Ecology*, 62:775-788
- Borchert, R. (2000). **Organismic and environmental controls of bud growth in tropical trees**. In: Viemont, J.D., Crabble, J. (eds.). *Dormancy in plants: from whole plant behavior to cellular control*. Wallington: CAB International, 87-107
- Bullock, S.H. and Solis-Magallanes, J.A. (1990). Phenology of canopy trees of a tropical deciduous forest in Mexico. *Biotropica*, 22: 22-35
- César, A., Dominguez and Dirzo, R. (1995). Rainfall and flowering synchrony in a tropical shrub: variable selection on the flowering time of *Erythroxylum havanense*. *Evolutionary Ecology*, 9: 204-216
- Chapman, C.A., Chapman, L.J. Struhsaker, T.T., Zanne, A.E., Clark, C.J. and Poulsen, J.R. (2005). A long-term evaluation of fruiting phenology: Importance of climate change. *Journal of Tropical Ecology*, 21: 31-45
- Coley, P.D. and Barone, J.A. (1996). Herbivory and plant defences in tropical forests. *Annu. Rev. Ecol. Syst.*, 27: 305-335
- Corlett, R.T. and Lafrankie J.V. (1998). Potential impact of climate change on tropical Asian Forests through an influence on phenology. *Climate Change*, 39(2): 439-453
- Couralet, C., Van den Bulcke, J., Ngoma, L.M., Van Acker, J. and Beeckman, H. (2013). Phenology in functional groups of Central African rainforest trees. *Journal of Tropical Forest Science*, 25(3): 361-374

Daubenmire, R. (1972). Phenology and other characteristics of tropical deciduous forest in north-western Costa Rica. ***Journal of Ecology***, 60: 147-160

Devineau, J. L. (1999). Seasonal rhythms and phenological plasticity of savanna woody species in a fallow farming system (south-west Burkina Faso). ***Journal of Tropical Ecology***, 15: 497-513

Diaz, M. and Granadillo, E. (2005). The significance of episodic rains for reproductive phenology and productivity in trees in semiarid regions of northwestern Venezuela. ***Trees***, 19: 336-348

Echereme, C.B. and Mbaekwe, E.I. (2015). Tropical phenology: individual-level phenological study of Neem (*Azadirachta indica* A. Juss) occurring in Onitsha, Nigeria. ***International Journal of Advanced Research***, 3(11): 1032-1037

Environment and social management plan (ESMP) (2017). ***Erosion and Watershed Management*** Anambra State, Nigeria. Project SPG 1692, Vol. 35

Facciola, S. (1998). ***Cornucopia II***. Krampong Publications, California, USA

Fitter, A.H. and Fitter, S.R. (2002). Rapid change in flowering time in British plants. ***Science***, 296: 1689-1691

Janzen, D.H. (1971). Seed predation by animals. ***Annu. Rev. Ecol. Syst.***, 2: 465-492

Igboabuchi, N.A. Echereme, C.B. and Ekwealor, K.U. (2018). Phenology in plants: concepts and uses. ***International Journal of Science and Research Methodology***, 11(1): 8-24

Khanduri, V.P. (2014). Annual variation in floral phenology and pollen production in *Lagerstroemia speciosa*: an entomophilous tropical tree. ***Songklanakarin Journal of Science and Technology***, 36(4): 389-396

Kruckeberg, A.R. and Rabinowitz, D. (1985). Biological aspects of endemism in higher plants. ***Annual Review of Ecology and Systematics***, 16: 447-479

Justiniano, M.J. and Frederiksen, T.S. (2000). Phenology of tree species in Bolivian dry forests. ***Biotropica***, 32: 276-281

Lieberman, D. (1982). Seasonality and phenology in a dry tropical forest in Ghana. ***Journal of Ecology***, 70(3): 791-806

Miao, L., Müller, D., Cui, X. and Ma, M. (2017). Changes in vegetation phenology on the Mongolian Plateau and their climatic determinants. ***PLoS ONE***, 12(12): e0190313. <http://doi.org/10.1371/journal.pone.0190313>

Milla, R., Castro-Diez, P., Maestro-Martínez, M. and Montserrat-Marti, G. (2006). Costs of reproduction as related to the timing of phenological phases in the dioecious shrub *Pistacia lentiscus* L. **Plant Biology**, 8(1): 103-111

Morissette, J.T., Richardson, A.D., Knapp, A.K., Fisher, J.I., Graham, E.A. et al. (2009). Tracking the rhythm of the seasons in the face of global change: phenological research in the 21st century. **Frot. Ecol. Environ.**, 7: 253-260

Murah, K.S. and Sukumar, R. (1993). Leaf flushing phenology and herbivory in a tropical dry deciduous forest, southern India. **Oecologia**, 94: 114-119

Nnadi, F.N., Chikaire, J. and Ezudike, K.E. (2013). Assessment of indigenous knowledge practices for sustainable agricultural and food security in Idemili South Local Government Area of Anambra State, Nigeria. **Journal of Resources Development and Management**, 1: 14-21

Omondi, S.F., Odee, D.W., Ongamo, G.O., Kanya, I. and Khasa, D.P. (2016). Synchrony in leafing, flowering, and fruiting phenology of *Senegalia senegal* within Lake Baringo Woodland, Kenya: implications for conservation and tree improvement. **International Journal of Forestry Research**, Article ID 6904834, 11 pages

Opler, P.A., Frankie, G.W. and Baker, H.G. (1980). Comparative phenological studies of treelet and shrub species in tropical wet and dry forests in the lowlands of Costa Rica. **Journal of Ecology**, 68: 1167-1188

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., Anthony, S. (2009). Agroforest tree data base: a tree reference and selection guide. Version 4 (<http://www.wordagroforestry.org/sites/treedbs/treedatabase.asp>)

Pau, S., Wolkovich, E.M., Cook, B.I., Davies, T.J., Kraft, N.J.B., Bolmgren, K., Betancourt and Cleland, E.E. (2011). Predicting phenology by integrating ecology, evolution and climate science. **Glob. Change Bio.**, 17:3633-3643

Pillar, C.D. and Gabriel, M.M. (1998). Phenological pattern of fifteen Mediterranean phanaerophytes from *Quercus ilex* communities of NE-Spain. **Plant Ecology**, 139(1): 103-112

Protabase-Plant Resources of Tropical Africa. Website: <http://www.prota.org>

de Kok, R. (2012). A review of the genus *Gmelina* (Lamiaceae). **Kew Bulletin**, 67; 293-329

Rogier (13 July, 2012). A revision of the genus *Gmelina* (Lamiaceae). <http://link.springer.com/content/pdf/10.1007%2Fs12225-012-9382-4.pdf> **kewBulletin**, **67(3): 293-329**.

Rosenzweig, C.G., Casassa, G., Kardy, D.J., Imeson, A., Liu, C., Menzel, A. and Rawlings, A. (2007). *Assessment of observed changes in responses in natural and managed systems*. In: *Climate change, 2007: impacts, adaptations and vulnerability*. Contribution of working group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Parry, M.L., Canziani, O.F., Palutikof, J.P. and Van der Linden, P.J. (eds.) Cambridge University Press, 79 -131

Singh, K.P. and Kushwaha, C.P. (2005). Emerging paradigms of tree phenology in dry tropics. **Current Science**, 89(6): 964-975

Singh, K.P. and Kushwaha, C.P. (2006). Diversity of flowering and fruiting phenology of trees in a tropical deciduous forest in India. **Annals of Botany**, 97(2): 265-276

Stevenson, P.R., Castellanos, M.C., Cortés, A.I and Link, A. (2008). Flowering pattern in a seasonal tropical lowland forest in western Amazonia. **Biotropica**, 40: 559-567

Statistical Year Book Year Book (SYB) (2011). Ministry of Lands, Survey and Town Planning, AWKA, Anambra. **Chapter 2**.

Van Vliet, A.J.H. and Schwartz, M.D. (2002). Phenology and climate: the timing of life cycle events as indicator of climate change variability and change. **International Journal of Climatology**, 22: 1713-1714

van Schaik, C.P., Terbor J.W. and Wright, S.J. (1993). The phenology of tropical forests: adaptive significance and consequences for primary consumers. **Annual Review of Ecology and Systematics**, 24: 353-377

World Agroforestry Centre.Website: <http://www.worldagroforestry.org/>