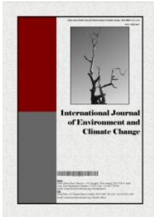

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# Community, Dominant Tree Species Leaf Phenology and Seasonality in a Tropical Dry Forest, India

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***Authors' contributions***

*This work was carried out in collaboration among all authors. Author AN designed the study, managed and analyzed the data and wrote the manuscript. Author HSS assisted in making the calculations and analysis and helped in writing the manuscript. Authors AN, HSS and YLKM discussed the different topics. All authors read and approved the final manuscript.*

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## ABSTRACT

**Aims:** Plant phenology is a tool to assess climate variability, but less is known about the differences in phenological sensitivity at community, life-form and individual species level. The aim of the present study is to know the contribution of individual, life-form leaf phenophases within the community.
**Methodology:** The leaf phenology of tropical dry forest trees in Bhadra wildlife sanctuary, Karnataka, India was observed during June 2004 to May 2009. A total of 277 trees belonging to 45 species were monitored on monthly basis for different phenophases of leaf phenology. Simple Spearman's correlations and multiple regressions were performed between different phenophases and environmental factors like rainfall and temperature. Seasonality was determined with circular statistics analyses using the phenological variables and dates of observation.
**Results:** The influence of temperature was stressed with multiple regressions. Seasonality of each of the phenophases was also tested with circular statistics. There is a strong seasonality observed

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in all phenophases, the strength of seasonality was highest with leafless phenophases. Leafing phenophases among some dominant species within the community was described for seasonality and differences among them were also analyzed. Understorey species had longer leaf life span compared to canopy species. At the community level different phenophases are distinctly seasonal, though the strength of seasonality varied considerably with flushing and expansion of leaves, the strength of the seasonality was high with leaf senescence for all species.

**Conclusion:** The results of this research are in agreement with previous study but the present study suggests that community, population and individual sensitivity might vary under the present context of increasing climatic variability and their adaptation helps to understand the climatic influence in shaping phenology at individual, species and community level.

*Keywords: Canopy; climate; leaf phenophases; leaf lifespan; rainfall; temperature; understorey.*

## 1. INTRODUCTION

Phenology is derived from the Greek word *Phiaino* meaning to show or to appear. Hence, phenology is defined as the study of the seasonal timing of life cycle events, and as a statistical distribution characterized by time of occurrence, duration, synchrony and skewness [1]. Diversity of leaf phenology depends on availability water, rainfall, temperature, soil moisture, the type of forest and species composition. The timing of leaf exchange varies in seasonal tropical forests around the world [2]. The timing of leafing patterns decides the flowering and fruiting as photosynthetic activity is governed by leaf activity. The understanding of factors that trigger and control the growth and productivity is significantly essential [3]. As some studies indicate phenology of dry forest trees is believed to be influenced by moisture mainly rainfall [4-6] temperature [7-10] or photoperiod [11-13].

However, biotic pressures such as herbivory are also shown to have influence on the timing of leafing in dry forests [14-15]. It is very important to distinguish between proximate factors that trigger a phenological event with ultimate factors that have been selected [16].

Dry forest community constitutes a large proportion of natural vegetation of India [17]. Studies addressing questions on factors influencing phenology, seasonality of various phenophases and species specific patterns of phenology are rather limited. However there are sporadic studies from dry forests both from peninsular India [18-20] north [6] and northeastern India [21-24]. Many of these studies describe patterns of phenology for two to three years and have not made efforts to analyze proximate causes for the patterns observed and seasonality of the phenophases. The phenology of some dominant species will help to assess the fitness and adaptation to the specific environment and the structure of particular species within the ecosystem. In the present five year study, the aim of the research was to examine the role of proximate factors and how they can influence the leaf phenology of trees in a tropical dry forest based on phenophases and available meteorological data. The hypothesis of this study was 1) to evaluate the influence of rainfall and temperature on leaf phenology; 2) the difference between phenophases seasonality; and 3) how the seasonality portioned between various life forms, especially among the dominant species that are selected.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

Present study was conducted in the Umblebailu (13°46'to 13°52'N, 75°36'to 75°42'E) region dry deciduous forests of Bhadra wildlife Sanctuary, localized in Shivamogga district, Karnataka, south India (Fig. 1).

### 2.2 Geology

The terrain is gently undulating with valleys and steep hillocks. The main underlying rocks and the resulting soils of the track may be roughly classified as: 1. Granite and quartzite giving rise to sandy loam: 2. Horneblende trap and haematite, the characteristic rocks of the Bababudans producing soft ferrugenous clay loam and: 3. Chlorite schist yielding a poor impervious-sort of clay, the altitude varies from 750 to 2100 m ASL [25].

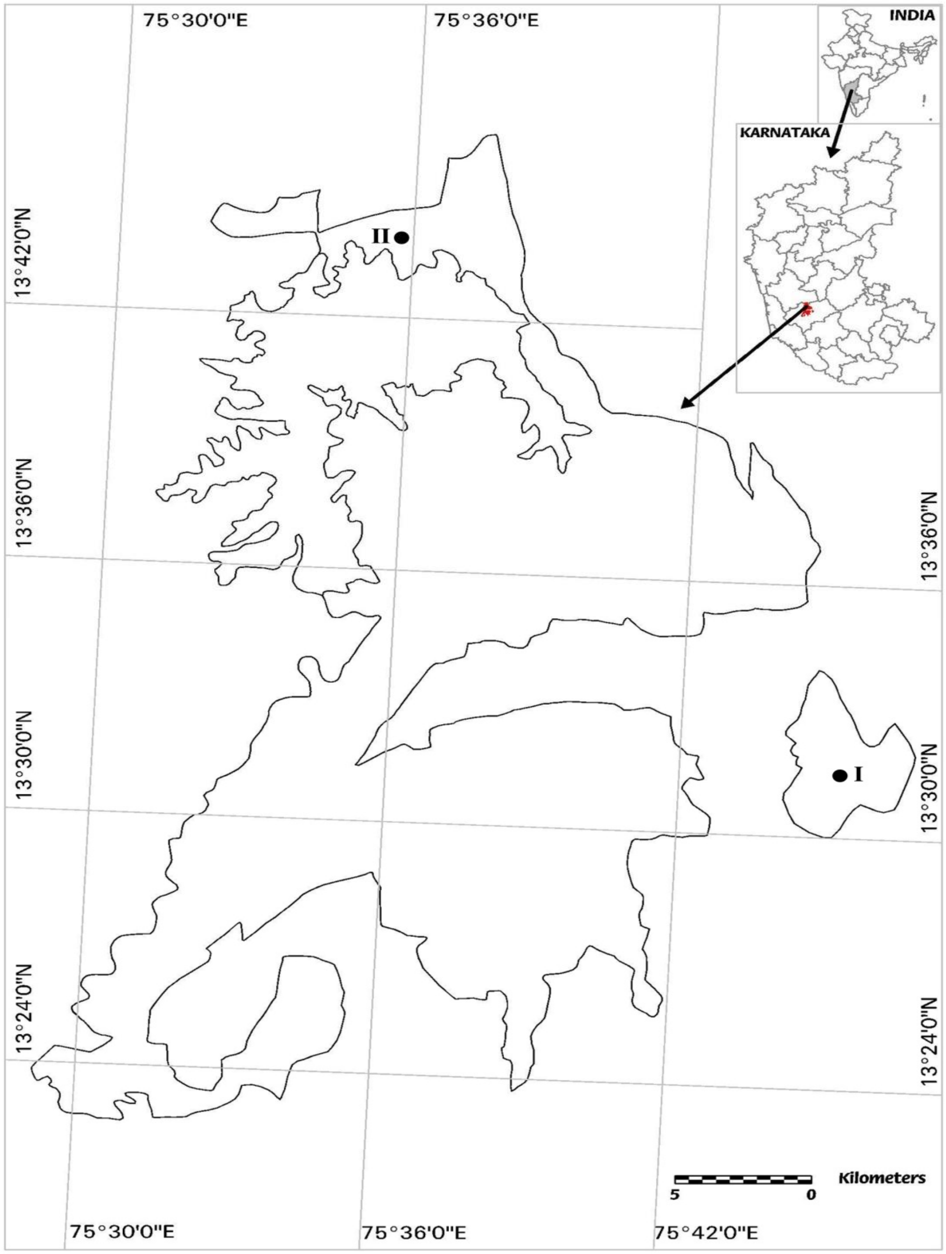



**Fig. 1. Location map of dry deciduous forest (∏●) Bhadra Wildlife Sanctuary, Karnataka, India**

## 2.3 Climate

The climate is monsoonic with marked seasonal variations in temperature and rainfall [8]. Depending on the variation in temperature, three seasons are observed in the area, namely pre-summer (November to January), summer (February to May), and rainy season (June to October) [8,25]. The cold or winter season starts from November and lasts until February with comparatively lower temperatures (15 to 19°C) and significantly less rainfall. The rainy season starts in the second part of May with interrupted rainfall, and incessant rain begins in June, continues until September, and ends in the first part of November. During the summer the temperature ranges from 30 to 35°C [8,25]. July and August are normally the months with highest precipitation, receiving about 50% of the annual rainfall (Fig. 2).

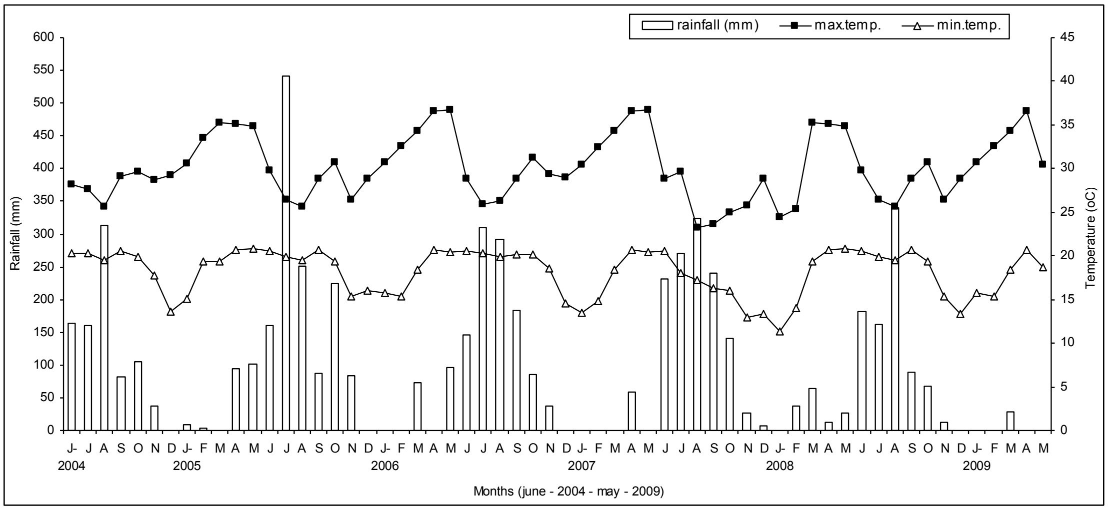



**Fig. 2. Monthly average rainfall, maximum and minimum temperature during the study period**

## 2.4 Vegetation

Dry deciduous forests are classified as southern dry mixed deciduous forests [26]. Quantitative descriptions of the vegetation are provided [27-28] as well as phenology study show that leafing, flowering activities occur in the summer or pre-monsoon and fruiting patterns occur during the monsoon to post - monsoon season [29-30]. Some dominant species of the present study are *Terminalia paniculata* (Roth.), *Anogeissus latifolia* (Wall.), *Adina cordifolia* (Roxb.), *Mitragyna parviflora* (Korth.), *Lannea coromandelica* (Houtt.), *Tectona grandis* (L.f.), *Terminalia tomentosa* (W. & A.), *Lagerstromia microcarpa* (Roxb.), *Careya arborea* (Roxb.), *Diospyrous montana* (Roxb.), and *Holarrhena antidysenterica* (Wall.).

## 2.5 Methodology

A total of 277 trees belonging to 45 species with clearly visible canopies were marked in the Bhadra Wildlife Sanctuary. Trees were monitored on the same date of every month from June 2004 to May 2009. The 2 hectares permanent plot describes the diversity and dynamics of tree species [27]. From the present permanent plot study tree species were tagged leaf phenophases were monitored to know the influence of rainfall and temperature, as phenology study describes response of individuals. Different leaf phenophases observed were: 1. Leafless/absence of leaf phase; 2. Leaf initiation/leaf bud; 3. Leaf expansion/ immature leaf; 4. Mature leaf; and 5. Leaf senescence/falling leaf phase. Each phase was scored qualitatively as percent of canopy so as the total sum of all stages is one hundred. Notes on herbivory were also realized. The species were identified using various regional floras [31-35]. Climate data collected from nearby Bhadra river irrigation project office (13°42'4"N 75°38'11"E). Total rainfall, maximum and minimum temperatures were collected from the Bhadra River Project meteorological station. Total rainfall is the sum of rainfall in a given month. Maximum and minimum temperature is the mean of daily temperatures recorded for a given month.

## 2.6 Data Analysis

A non-parametric Spearman's correlation with corresponding and two months lag were performed to assess the independent influence of each environmental factor to understand the explicit influence of an environmental factor when pooled. Multiple regressions were performed to examine how multiple independent variables (rainfall and temperature) are related to dependent variable (leaf) phenology. A Kolmogorov-Smirnov (KS) test was carried out with different life-form (canopy and understorey) at community level to understand that the observed pattern of phenology between different life forms is drawn from the same population and hence, the statistical significance in the phenological pattern of distribution of species. All statistical analysis were performed by Microsoft excel sheet procedure follows [36].

### 2.7 Seasonality Study

Seasonality was determined with circular statistics. Circular statistical analyses were conducted using the phenological variables and dates of observation with the software STATISTIXL ®. To calculate the circular statistical parameters, months were converted to angles, from 0° = January (number 1) to 330° = December (number 12) at intervals of 30°. The day of observation in a given month is converted to angles. The Rayleigh's Z test which indicates the seasonality, the Rayleigh's score was interpreted based on the significance of P value. If the P value is significant then the event was considered as cyclic or seasonal otherwise the event is random [10,30,36].

## 3. RESULTS

### 3.1 Leafless Phase

There was no significant inter-annual variation between the studied years (KS test, $p$>0.05). Leafless stage is negatively influenced by rainfall (Fig. 3) and positively by maximum temperature (Fig.4) of corresponding months. Rainfall and minimum temperature had significant negative influence with lag periods (Table 1). Multiple regression with corresponding month was significant (R= 0.57, $F_{(3, 56)}$ = 9.20, $p$<0.00005) with maximum temperature having positive influence. Maximum temperature explains about 82% of total variation and remaining variation is explained by minimum temperature. One-month lag period regression is significant (R= 0.66, $F_{(3, 55)}$ = 14.48, $p$<0.00001) with maximum temperature (beta = 0.37, $p$<0.02) and minimum temperature (beta = -0.63, $p$<0.0001) as the significantly influencing factors. Minimum temperature explains 63% of total variation while maximum temperature explains 37% of variation. Two-month regression was also significant (R = 0.77, $F_{(3, 54)}$ = 26.624, $p$<0.00001) with minimum temperature having negatively influencing factor (beta = -0.70, $p$<0.0001), but with stepwise regression rainfall also becomes one of the significant factors explaining variation. However, Minimum temperature explains 90% of the variation. With simple and multiple regressions though rainfall, maximum and minimum temperature influence leafless stage independently, and the positive influence of minimum temperature that has the maximum influence.

### 3.2 Leaf Initiation Phase

Both maximum and minimum temperature had positive influence on leaf initiation with corresponding months. Rainfall (Fig. 5) had negative influence with both time lag periods while maximum temperature (Fig. 6) had negative influence with one-month lag period and minimum temperature (Fig. 7) had negative influence with two-month lag period (Table 1). Multiple regression with corresponding months was significant (R = 0.53, $F_{(3.56)}$ = 7.53, $p$<0.0002) had maximum temperature as influencing factor (beta = 0.54, $p$<0.004). Maximum temperature explained 95% of the total variation and remaining variation was explained

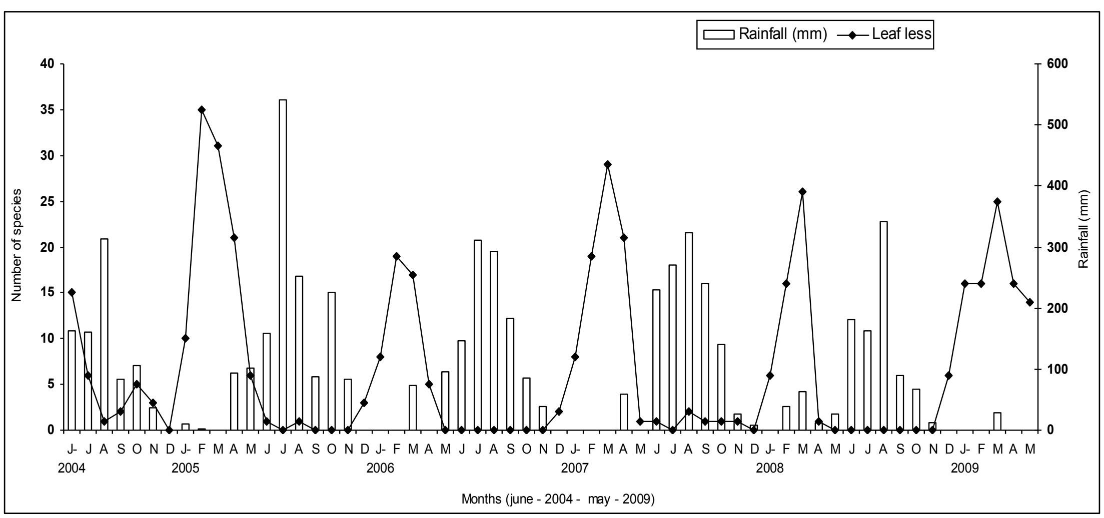



**Fig. 3. Number of species response to leafless/absence of leaf and rainfall**

by rainfall. Maximum temperature was the significant influencing factor with one month lag period (beta = 0.49, $p$<0.01) with one-month lag period regression that was significant (R =0.53, F- $_{(3.55)}$ = 7.37, $p$<0.003). Maximum temperature explained 69% of the variation and the rest is explained by minimum temperature. Two-month lag period regression was also significant (R = 0.69, F- $_{(3.54)}$ = 17.087, $p$<0.0001) with minimum temperature (beta = -0.54, $p$<0.0004) and maximum temperature (beta = 0.33, $p$<0.03) as influencing factors. Though rainfall does not explicitly explain the process of leaf initiation, it explains 72% of the inherent variation. Rainfall has negative influence remaining variation is explained by both maximum temperature (18%) and minimum temperature (10%). Negative influence of rainfall and positive influence of temperature is explicit from the simple regression. But with all environmental factors pooled maximum temperature explains the leaf initiation in dry forest. But the negative influence of rainfall becomes explicit with two-month lag period.

## 3.3 Leaf Expansion Phase

Maximum temperature influenced positively and minimum temperature negatively the expansion of leaves with corresponding months. With both lag periods maximum temperature had positive influence while rainfall had negative influence (Table 1). Multiple regression of all factors pooled with corresponding months was

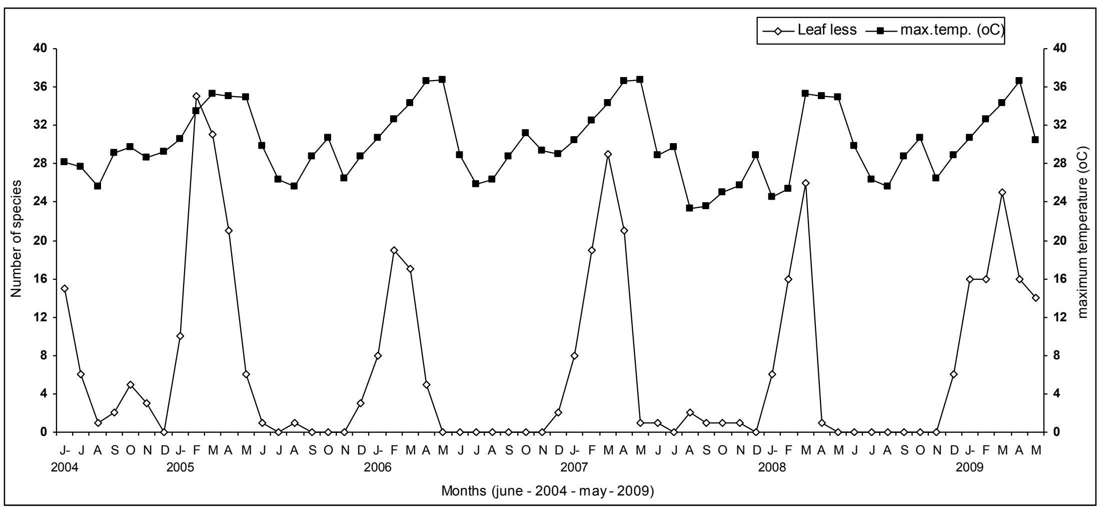



**Fig. 4. Number of species response to leafless/absence of leaf and maximum temperature**

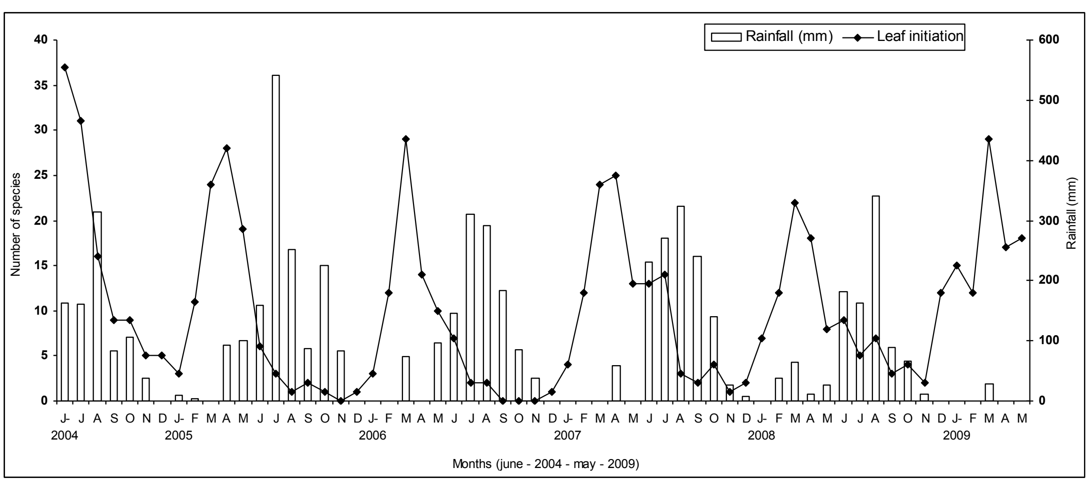



**Fig. 5. Number of species response to leaf initiation and rainfall**

significant (R = 0.67, $F_{(3, 56)}$ = 15.88, *p*<0.00001) with maximum temperature as the influencing factor (beta = 0.60, *p*<0.0003). Both minimum temperature (64%) and maximum temperature (28%) explain a total of 92% variation. The influence of minimum temperature is explicitly brought in stepwise regression. Maximum temperature was also a most influencing factor (beta = 0.66, p<0.0003) with one-month lag period (R = 0.59, $F_{(3, 55)}$ = 10.21, *p*<0.00002), being the only factor that explained the variation completely. With two-month lag period, the regression was also significant (R = 0.64, $F_{(3, 54)}$ = 12.61, *p*<0.00001) with maximum temperature (beta = 0.55, p<0.001) and minimum temperature (beta = -0.36, *p*<0.02) as the influencing factors. The influence of rainfall was clear with stepwise regression. Rainfall explained about 70% of the total variation (Fig. 8) and remaining variation was explained by both maximum (Fig. 9) and minimum temperature (Fig. 10).

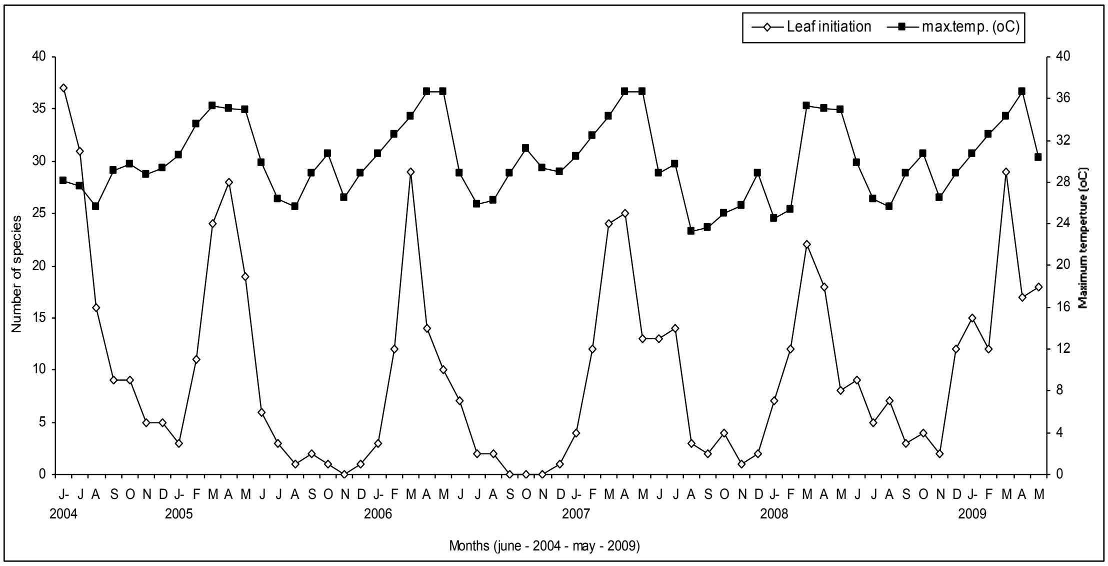



**Fig. 6. Number of species response to leaf initiation and maximum temperature**

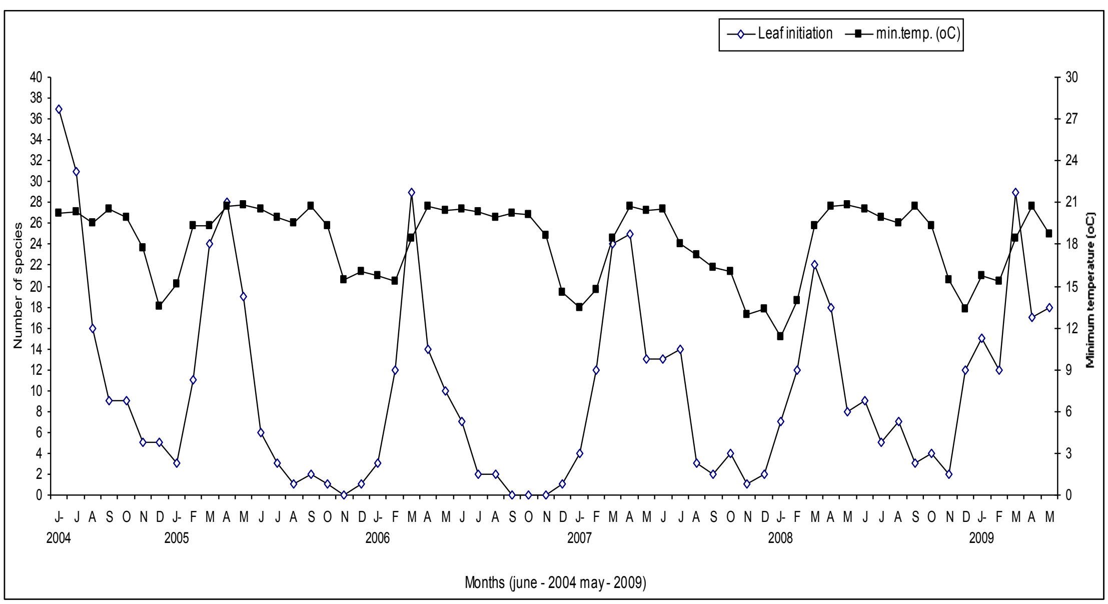



**Fig. 7. Number of species response to leaf initiation and minimum temperature**

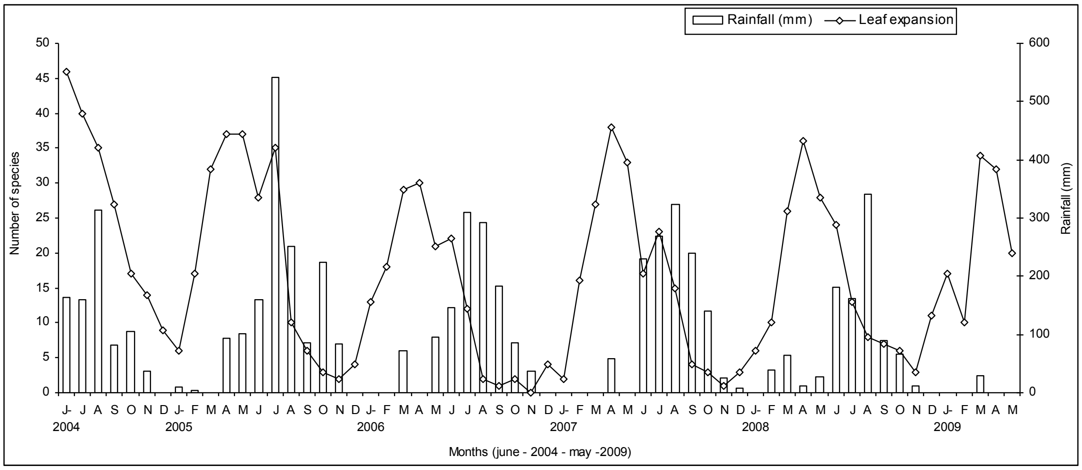



**Fig. 8. Number of species response to leaf expansion and rainfall**

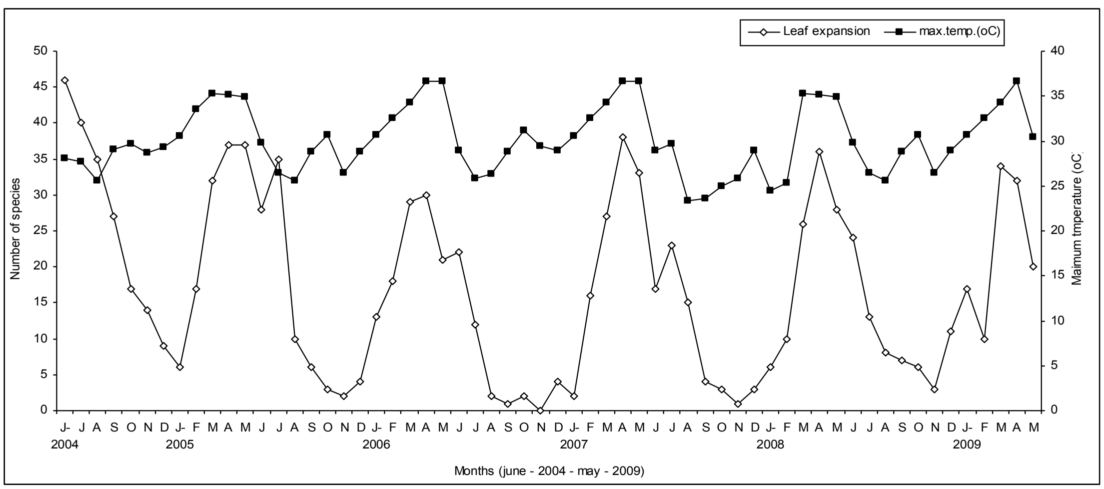



**Fig. 9. Number of species response to leaf expansion and maximum temperature**

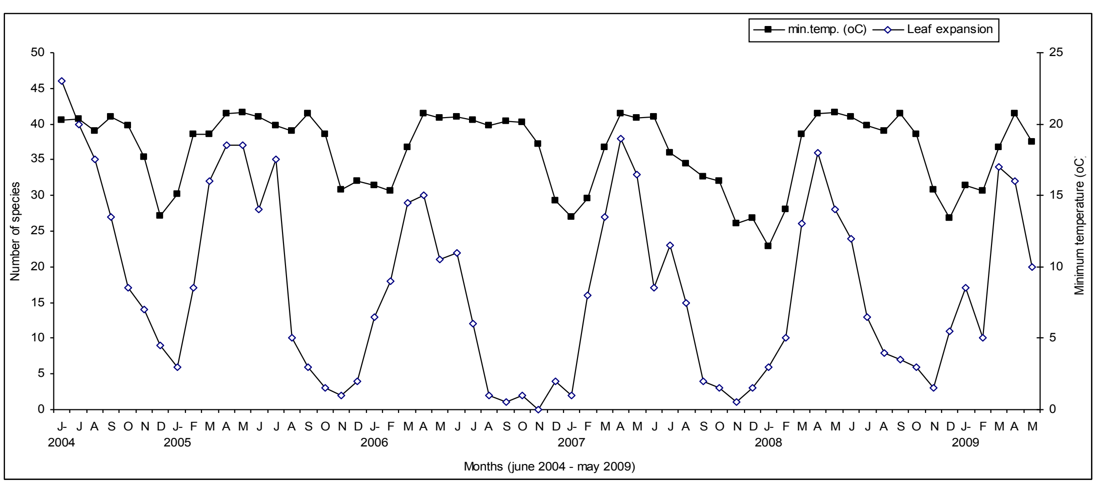



**Fig. 10. Number of species response to leaf expansion and minimum temperature**

### 3.4 Leaf Senescence Phase

Rainfall and minimum temperature had significant negative influence with corresponding months. With one-month lag period all three of them had significant negative influence while rainfall (Fig. 11) had no influence with two-month lag period (Table 1). Multiple regression with corresponding months was significant (R = 0.82, $F_{(3,\ 56)}$ = 39.64, $p$<0.0001) with minimum temperature as the influencing factor (beta= -0.78, $p$<0.0004). A total of 99% variation is explained by both minimum and maximum temperature, which minimum temperature alone explains about 87% of variation. Negative influence of minimum temperature is highly significant with corresponding months (Fig. 12). One-month lag period regression was significant (r = 0.82, $F_{(3,\ 55)}$ = 38.29, $p$<0.00001) with all factors significantly negatively influencing. Minimum temperature explains about 86% variation in the regression. Regression with two-month lag period was also significant (r = 0.63, $F_{(3,\ 54)}$ = 12.41, $p$<0.00001) with rainfall (r = -0.53, $p$<0.003) and maximum temperature (beta= -0.63, $p$<0.0001) having significant negative influence. Minimum temperature explained about 55% of the variation though not listed as a significant factor. Along with maximum temperature they explained about 75% of the total variation and remaining variation was explained by rainfall.

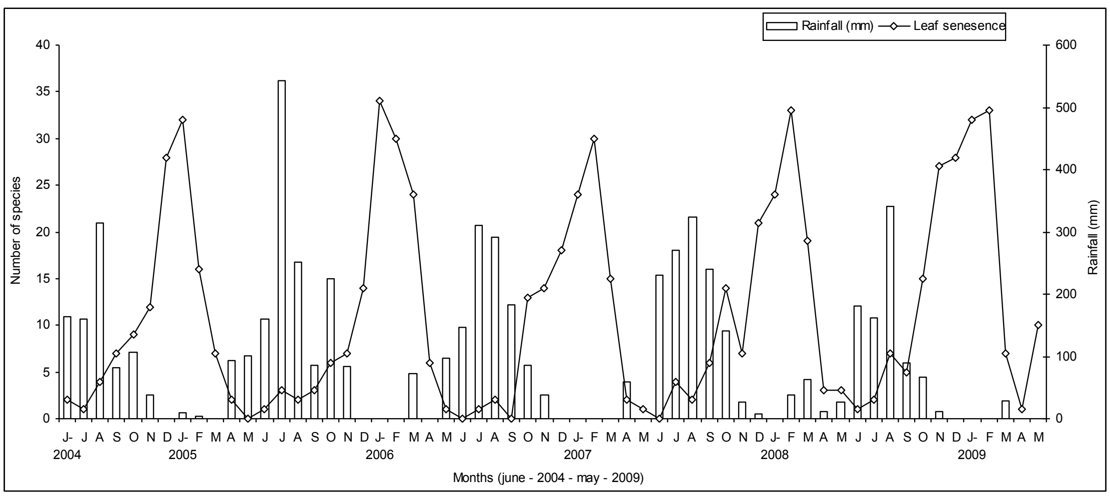



**Fig. 11. Number of species response to leaf senescence and rainfall**

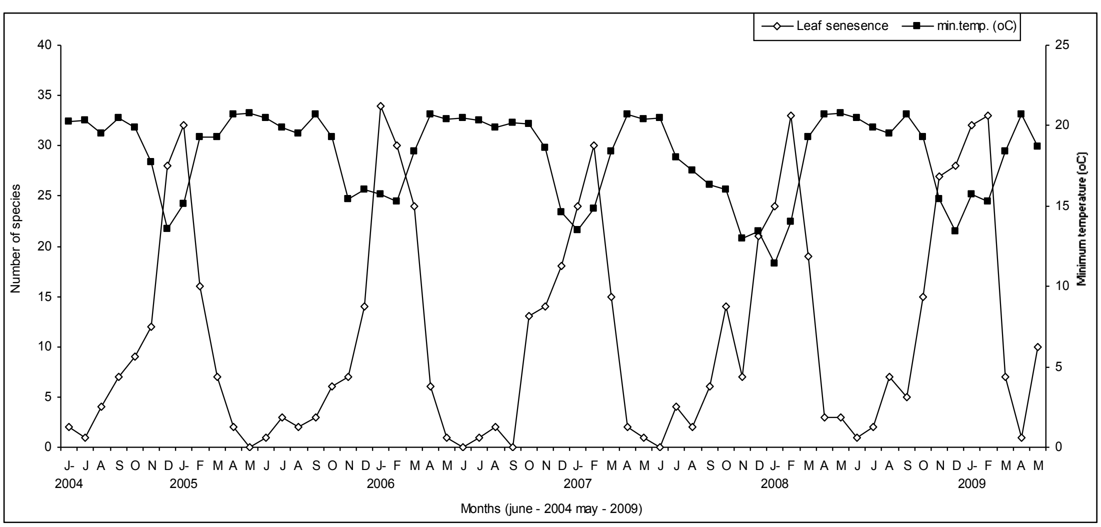



**Fig. 12. Number of species response to leaf senescence and minimum temperature**

**Table 1. Spearman's correlations between different leaf phenophases and environmental factors in dry forests of Bhadra wildlife sanctuary, Karnataka, India**

| Leaf phenophases / Environmental factor | Corresponding months (N= 60) | One-month lag period (N= 59) | Two-month lag period (N= 58) |
|---|---|---|---|
| **Leaf-less phase** | | | |
| Rainfall (monthly) | - 0.509*** | - 0.62*** | - 0.603*** |
| Mean maximum temperature (°C) | 0.414** | 0.18 NS | 0.0006NS |
| Mean minimum temperature (°C) | 0.191 NS | - 0.591*** | - 0.716*** |
| **Leaf initiation phase** | | | |
| Rainfall (monthly) | - 0.181 NS | - 0.51*** | - 0.745*** |
| Mean maximum temperature (°C) | 0.511*** | 0.454*** | 0.329* |
| Mean minimum temperature (°C) | 0.270* | - 0.096 NS | - 0.487** |
| **Leaf expansion phase** | | | |
| Rainfall (monthly) | 0.037 NS | - 0.278 * | - 0.616*** |
| Mean maximum temperature (°C) | 0.474** | 0.555*** | 0.506*** |
| Mean minimum temperature (°C) | 0.542*** | 0.201 NS | - 0.194 NS |
| **Leaf senescence phase** | | | |
| Rainfall (monthly) | - 0.625*** | 0.029 NS | - 0.789*** |
| Mean maximum temperature (°C) | - 0.443** | - 0.318* | - 0.706*** |
| Mean minimum temperature (°C) | - 0.072 NS | - 0.482** | - 0.490*** |

**** = p>0.0001, ** = p>0.001, *=p>0.05, NS = Non Significant*

**Table 2. Seasonality at community, canopy and understorey trees leaf phenophases of Bhadra wildlife sanctuary, Karnataka, India**

| Parameter | Leafless | Leaf initiation | Leaf expansion | Leaf senescence |
|---|---|---|---|---|
| **Community pattern** | | | | |
| Mean angle | 68.54 | 108.18 | 129.5 | 12.03 |
| Mean Data | 8 March | 17 April | 8 May | 12 January |
| SD | 43.3 | 60.0 | 62.1 | 52.6 |
| Vector ® | 0.71 | 0.45 | 0.41 | 0.57 |
| Rayleigh's Z | 212.5 | 123.5 | 174.5 | 225.2 |
| N | 417 | 608 | 1032 | 675 |
| **Canopy species** | | | | |
| Mean angle | 67.1 | 118.6 | 135.8 | 11.6 |
| Mean Data | 7 March | 27 April | 14 May | 11 January |
| SD | 45.7 | 59.5 | 62.6 | 51.6 |
| Vector (r) | 0.72 | 0.45 | 0.40 | 0.59 |
| Rayleigh's Z | 108.3 | 70.29 | 54.6 | 114.6 |
| N | 208 | 333 | 521 | 326 |
| **Understorey species** | | | | |
| Mean angle | 70.6 | 95.4 | 123.15 | 12.95 |
| Mean Data | 10 March | 4 April | 2 May | 13 January |
| SD | 44.0 | 59.5 | 61.5 | 53.7 |
| Vector (r) | 0.70 | 0.46 | 0.42 | 0.56 |
| Rayleigh's Z | 102.4 | 57.4 | 90.9 | 108.2 |
| N | 206 | 272 | 508 | 345 |

### 3.5 Seasonality

At the community level different phenophases are distinctly seasonal results of seasonality are presented in the (Table 2). Species remain leafless around early March which is highly seasonal, species would be flushing leaves around mid April, expanding their leaves around late April. Mean senescence date for leaves in this forest is early January. The scores of mean vector indicate that the strength of the seasonality was high with leafless stage followed by senescence stage, leaf initiation and leaf expansion stage. The seasonality among different life-forms and some dominant species were analyzed. Different phenophases with both canopy and understorey life-forms were significantly seasonal (Table 2). This seasonality pattern observed for canopy species closely reflected the community pattern. Most canopy species remain leafless around early March. Leaf initiation was around early April and expansion of leaves was observed in early May, leaf senescence was observed during early January. Among the understorey species the seasonality of different species was significant. Most understorey species remained leafless during early March. Leaf initiation was observed during early March and expansion happened around late April and early May. Most understorey species dropped their leaves around early January. The strength of seasonality followed the community pattern. Both life-forms showed strong leaf seasonality with leafless stage (Table 2).

### 3.6 Species Characteristics

The leafing phenophases of some dominant tree species of Bhadra were also analyzed. All species showed significant seasonality with different phenophases of leaf phenology. Among the species that initiated leaves early was *Holorrhena antidysenterica* (Table 3), followed by *Diospyros montana* and *Careya arborea* these species had initiating leaves during early April, species such as *Anogesius latifolia*, *Lannaea coromandelica* and *Mitragyna parviflora* at the end of the April, *Terminalia paniculata*, *Terminalia tomentosa* and *Tectona grandis* at the beginning of May. *Adina cordifolia* at the end of May followed by *Lagerstroemia microcarpa* had leaves initiating in early June. All species expanded their leaves during mid-April to end of May (Table 3). Except for *Lannaea*

**Table 3. Selected dominant tree species seasonality (mean angle, vector and mean data) of Bhadra wildlife sanctuary, Karnataka, India**

| Species and Family | Leaf initiation mean angle - (vector r) / mean data | Leaf expansion mean angle - (vector r) / mean data | Leaf senescence mean angle - (vector r) / mean data |
|---|---|---|---|
| *Adina cordifolia* (Roxb.) (Rubiaceae) | 152.92 - (0.52) / 1 June | 158.93 - (0.48) / 7 June | 35.03 - (0.79) / 19 March |
| *Anogeissus latifolia* (Wall.) (Combretaceae) | 111.95 - (0.64) / 21 April | 152.22 - (0.59) / 31 May | 12.93 - (0.84) / 13 January |
| *Careya arborea* (Roxb.) (Lecythidaceae) | 105.99 - (0.79) / 15 April | 130.52 - (0.72) / 9 May | 21.89 - (0.75) / 22 January |
| *Diospyros montana* (Roxb.) (Ebenaceae) | 101.45 - (0.48) / 10 April | 131.12 - (0.22) / 10 May | 40.65 - (0.66) / 9 February |
| *Holarrhena antidysenterica* (Wall.) (Apocynaceae) | 92.02 - (0.74) / 1 April | 158.75 - (0.49) / 6-June | 29.14 - (0.78) / 29 January |
| *Lagerstroemia microcarpa* (Roxb.) (Lythraceae) | 157.16 - (0.65) / 5 June | 154.21 - (0.63) / 2 June | 46.32 - (0.86) / 15 February |
| *Lannaea coromandelica* (Houtt.), (Anacardiaceae) | 112.69 - (0.81) / 21 April | 133.82 - (0.82) / 13 May | 321.69 - (0.82) / 16 November |
| *Mitragyna parviflora* (Korth.) (Rubiaceae) | 121.07 - (0.55) / 30 April | 163.58 - (0.48) / 11 June | 38.83 - (0.69) / 8 February |
| *Tectona grandis* (L.f.) (Verbenaceae) | 132.06 - (0.77) / 11 May | 152.52 - (0.79) / 31 May | 22.64 - (0.78) / 23 January |
| *Terminalia paniculata* (Roth.) (Combretaceae) | 125.06 - (0.74) / 4 May | 130.78 - (0.79) / 10 May | 22.76 - (0.87) / 23 January |
| *Terminalia tomentosa* (W. & A.) (Combretaceae) | 126.65 - (0.86) / 6 May | 147.79 - (0.81) / 27 May | 27.92 - (0.86) / 28 January |

*coromandelica* that dropped leaves during mid November, the rest of the species dropped their leaves during January and February (Table 3). However, *Diospyros montana* and *Lagerstroemia microcarpa* are the species that dropped leaves during mid-February. Mean leaf lifespan in a given leafing cycle among various species was 270±19 days. Trees in deciduous forests have leaves for about 3/4$^{th}$ period of annual leaf cycle. Among the species studied *Diospyros montana* (305 days) and *Holarrhena antidysenterica* (302 days) had long leaf lifespan while *Adina cordifolia* (247 days) had short leaf lifespan. Dominant species of deciduous forest of peninsular India *Anogeissus latifolia* (266 days), *Lagerstroemia microcarpa* (254 days), *Tectona grandis* (256 days) and *Terminalia tomentosa* (266 days) did not show much variation with leaf lifespan. The frequency distribution of dominant species leaf phenology and seasonality with circular statistics indicates (Table 4) the species overlapping response is based on leaf lifespan influenced by climate and their impact on community phenology.

## 4. DISCUSSION

The present study demonstrates the role of temperature and rainfall in influencing the leaf phenology at community, canopy and understorey species, the timing of leaf phenology in dry forests of Bhadra wildlife sanctuary is in correlation with current and lag months [8]. Leaf phenology of dry forests is believed to be influenced by moisture and its related factors. The overall pattern of leaf phenology recorded for dry forests of Bhadra is consistent with the prediction that most leafing activity is largely confined to the arid (dry) period [37]. Moisture is shown to have a significant influence on various phenophases of leaf phenology when it is studied independently and also believed to be limiting factor for phenological activity in dry forests [2,5] Rainfall has a significant negative influence on most phenophases of leafing in Bhadra [29]. This pattern is in agreement with studies from Indian dry forests [6,15,17,18] and elsewhere in other tropical regions [38-39]. Most studies have considered rainfall as an environmental factor that influences phenology as it is an easily available and measurable factor [8,15]. However, Singh et al. [6] have mentioned the importance of temperature in regulating phenology of dry forest trees.

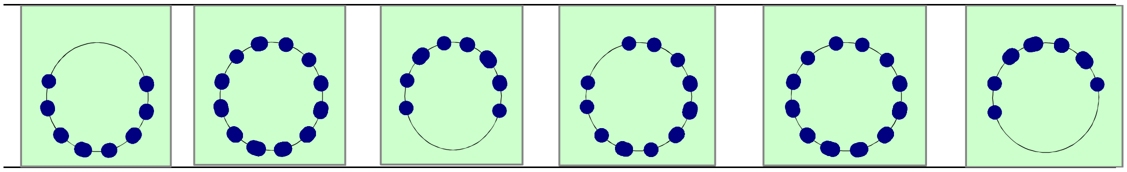
Increase in maximum temperature with corresponding months and reduction in rainfall and minimum temperature with lag period's influences trees to remain leafless [40] However, the influence of temperature is explicit with multiple regressions. Either maximum or minimum temperature explains large variation in the process within two years of observation [41] hence the role of temperature becomes extremely important in controlling this phenophase. Influence of soil moisture [42] to be an important factor in triggering leaf phenology. Inter-annual variations in rainfall and temperature affected the individuals and consequently, species degree of deciduousness indicating species adaptation to climatic variability [43].

Leaf flushing in a dry forest is reported to be triggered by several factors such as day length, temperature and rainfall [11,38]. Biotic factors such as herbivores also shown to influence the leaf flushing in dry forests [14-15] In Bhadra, rainfall had significant negative influence with lag periods when only rainfall was considered as a factor that triggers leaf flushes [8]. This pattern is consistent with previous studies [15,18]. Leaf flushing (bud break) of leaves in the dry forests happens in dry season and physiological reasons such as conversion of starch to sugar in roots were cited [21]. Whereas leaf flush in the dry-to wet transition in cerrado woody community of Savanna, Brazil [43].

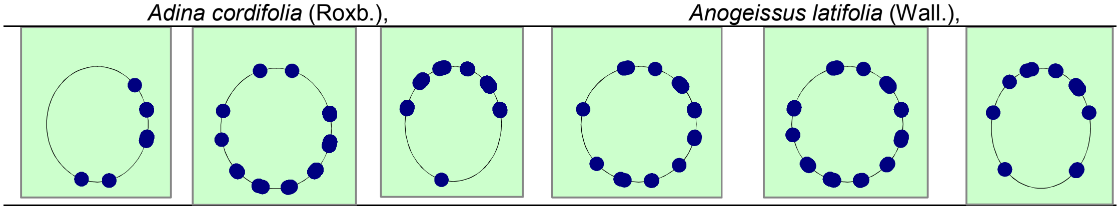
However, rainfall does not explain the process of flushing in dry forests of Bhadra. Leaf expansion is an important phase in leaf development. The expansion of the leaves from buds to mature leaf stage provides trees with a fully developed photosynthetic apparatus. Hence the expansion of leaves is a resource - intense activity and requires suitable environmental conditions. ---- Temperature also explained the process of leaf expansion with multiple regressions. Temperature probably facilitates physiological activities by enhancing metabolism [6]. Leaf expansion requires dry conditions so as to have fully developed leaves in seasonal rainy period for accumulation of resources for the next cycle. Rapid flushing of leaves after the El Niño related drought initiated cambial activity in deciduous species at Costa Rica [6]. The significant negative influence of rainfall can be explained as a strategy to escape herbivory [15].

**Table 4. Circular seasonality of the selected dominant tree species of Bhadra wildlife sanctuary, Karnataka, India**

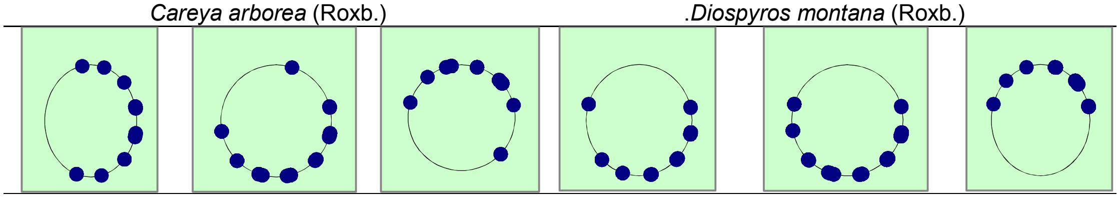
| Leaf initiation | Leaf expansion | Leaf senescence | Leaf initiation | Leaf expansion | Leaf senescence |
|---|---|---|---|---|---|



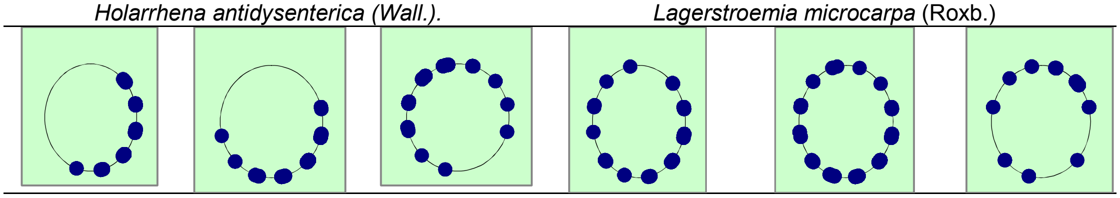
*Adina cordifolia* (Roxb.), *Anogeissus latifolia* (Wall.),



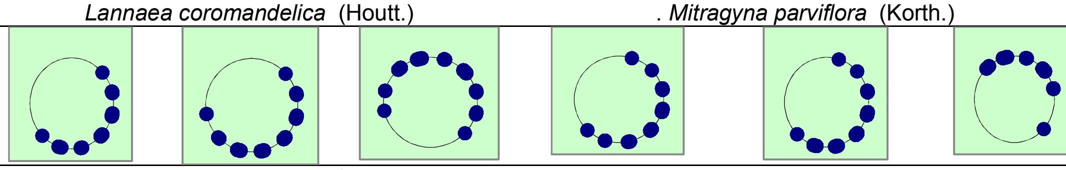
*Careya arborea* (Roxb.) .*Diospyros montana* (Roxb.)



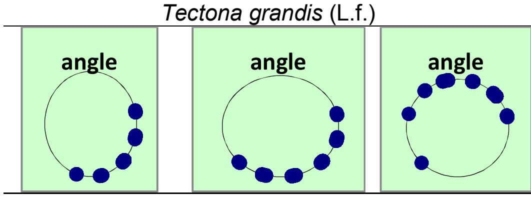
*Holarrhena antidysenterica (Wall.).* *Lagerstroemia microcarpa* (Roxb.)



*Lannaea coromandelica* (Houtt.) . *Mitragyna parviflora* (Korth.)



*Tectona grandis* (L.f.) *Terminalia paniculata* (Roth.)




*Terminalia tomentosa* (W. & A.)

Note – dots on circle indicate monthly representation of the leaf phenophases.

The negative influence of the minimum temperature plays a significant role in triggering leaf senescence in dry forests of Bhadra. Studies in other parts of tropics have also demonstrated synchronous leaf shedding as a response to drought [44] and soil moisture [45], but Wright and Cornejo [46] found that moisture is not the cue for leaf fall in tropics with their manipulation experiment. Essentially as a consequence of the rise in ambient temperature results in shedding of leaves in dry forests of Bhadra. The result of this research also does not support the moisture limitation hypothesis of [47]. Several studies on dry forest phenology have described period and length of each phenophases both at the community level [19,48] and species level [42]. Few studies have quantified the seasonality in tropical forests [10,45].

The phenology observed in different phenophases of leafing in Bhadra was significantly seasonal [8]. A similar pattern was also observed in other dry forests in peninsular India [49]. Most species remained leafless around March and started flushing around April, during the peak of the dry season. The evolution of strong seasonality of dry season flushing in dry tropics may be attributed to the availability of fully developed photosynthetic apparatus during the favourable conditions [48]. It was also observed that temperature influenced the initiation (flushing) of leaves in dry forests. Expansion of leaves follows flushing activity which is also temperature sensitive. Leaf senescence happens around the early part of January through several species would have started in December. The strength of the seasonality was highest with leafless phase and lowest with the expansion phase. It is seen that except for leafless phase, other phenophases are a more or less continuous process and hence the strength would be less. Seasonality in different phenophases with different life forms was also significant. Understorey species flushed and expanded their leaves earlier than canopy species. This could be an adaptation to the temporal advantage over canopy species as canopy species could potentially hamper resource utilization of understorey species [50]. There was no difference with either leafless or senescence phase. Individual species in Bhadra showed considerable variation in the timing of various phenophases in leafing. --- Among the selected dominant species *Holarrhena antidysenterica* was an early flushing species but took a long time for expansion of leaves. *Adina cordifolia* and *Lagerstroemia microcarpa* though flushed late simultaneously had expanding leaves as an adaptation for the favorable season. The other species had flushing leaves around the community mean date. Most of the species remained leafless during January except *Lannaea coromandelica* which shed its leaves by November. *Terminalia tomentosa* showed a strong seasonality with leaf initiation and *Diospyros montana* had more or less continuous initiation of leaves. Though the strength of seasonality varied considerably with flushing and expansion of leaves, the strength of the seasonality was high with leaf senescence for all species.

Based on phenology and seasonality at community and dominant species the phenophases indicates how an individual is sensitive to weather parameters and duration of leaf lifespan.

## 5. CONCLUSIONS

Leaf phenology of dry forests of Bhadra is strongly influenced by temperature, though rainfall has a strong negative influence independently, its influence is masked when different environmental factors included. Some studies in dry forests both in India and elsewhere have mentioned the influence of temperature; but this study has explicitly brought out the role played by temperature. In the present context of changing climate the influence of climatic factors on phenology helps to bridge the gap with other tropical forest. As seen in several dry forests, there is a strong seasonality in different phenophases of leaf phenology. Several species also have shown the same trend, shifts in the dates of different phenophases would affect carbon sequestration of trees and associated processes in the forest ecosystem. Hence plant phenology is fundamental to understand the plant response to climate variability at regional and at a larger global scale, it is essential to model forest community response to climate change. Although there are many speculations about change in phenology at global level depending on forest types and vegetation, the major missing link is lack of long term phenology data to connect within and between forest types in India and elsewhere.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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