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Seasonality, Flowering and Fruiting Patterns in a Tropical Dry Deciduous Forest of Bhadra Wildlife Sanctuary, Southern India

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ABSTRACT

We examined 24 months' data of flowering and fruiting phenophases of 277 individuals of 45 species at the community level. We determined the timing of the phenophases in relation to seasonal rainfall and temperature. Regression analysis was performed to examine how variations in rainfall and temperature influenced the peaks and troughs of phenology cycles. We also investigated seasonality of various phenophases to understand their cyclicity and strength. Flower initiation begins in November and continues until June with a peak during April to June. Flower opening of pollination peak occur in April and May, respectively. Fruiting initiation peaked twice, in February to April in the dry season and after rainfall in September to October. Fruit maturity peaked in March in the dry season and after rainfall maturation in August and November. Deviations from phenology cycles were largely attributable to short-term fluctuations in rainfall and/or temperature. Overall our study suggests that the response of reproductive phenophases is an indication of regional environmental changes.

Keywords: flowering and fruiting phenophases, mean temperature, rainfall

INTRODUCTION

The timing of many phenological events and seasonality represent resource availability, pollinator availability and competition, abundance of herbivores, suitable conditions for seed germination and establishment, and phylogenetic constraints, although it is now widely acknowledged that biological interactions and phylogenetic relations can shape phenological patterns (Ollerton and Lack 1992; Poulin *et al.* 1992; van Schaik *et al*. 1993; Wright and Calderon 1995; Davies and Ashton 1999; Poulin *et al*. 1999).

Phenological variation has led, on one hand, to an expectation that phenological patterns are adaptive, leading to the synchronization of reproductive activity with the availability of biotic resources (i.e. pollinators, predators) and with the peak availability of abiotic resources (e.g. sunlight, water). Alternate theories are based on evidence that phenological patterns are not adaptive, and are therefore conserved among closely related taxa. Numerous hypotheses have been formulated regarding the influence of various factors on flowering phenology (Wright and van Schaik 1994; Bawa *et al.* 2003; Bolmgren *et al.* 2003).

Phenological patterns may be influenced by the temporal abundance of pollinators, seed dispersers, seed predators, or herbivores (Frankie *et al.* 1974; Rathcke and Lacey 1985; Wheelwright 1985; Aide 1992; Murali and Sukumar 1993; Curran and Leighton 2000). Information on reproductive phenology and seed production (reproductive output) is necessary for understanding vegetative functioning and dynamics, since the reproductive potential of vegetation is fundamental in landscape evolution (McLaren and McDonald 2005). Like temperate trees, most tropical trees flower for relatively short periods at certain times of the year and during specific phases of seasonal vegetative development. Less is known about the environmental or endogenous controls of periodic flowering in temperate or tropical trees (Borchert 1983, 1992, 1996; Owens 1991; Dick 1995; Thomas and Vince-Prue 1997).

Understanding flowering and fruiting patterns and their underlying determining mechanisms is a key to assessing the ecosystem health of a forest. Here we made an attempt to assess the short-term fluctuation in flowering and fruiting phenophases, intensity and duration in relation to rainfall mean maximum and minimum temperature, because timing of one phenophase will affect that of another.

MATERIALS AND METHODS

Study area

The study was conducted in Umblebailu (13° 46′ to 13° 52′ N, 75° 36′ to 75° 42′ E) region of Bhadra wildlife sanctuary located in Chikmagalur and Shimoga districts (13° 25′ and 13° 50′ N, 75° 15′ and 75° 50′ E) of Karnataka, Central Western Ghats. The terrain is gently undulating with valleys and steep hillocks. A detailed geological account of the sanctuary is given by Parameshwar (2001). The altitude varies from 750 to 2100 m asl. Rainfall and temperature data for the study area was collected from meteorological station, Bhadra River Project. Rainfall is mainly from the southwest monsoon during June-September. Mean annual rainfall and temperature varies depending on the topography and aspect (**Fig. 1**).

Vegetation

Vegetation of the sanctuary varies from dry deciduous to evergreen forests through moist deciduous type depending on the precipitation pattern. According to Champion and Seth (1968) dry deciduous forests are classified as 'southern dry mixed deciduous forests'. The most common tree species are *Terminalia paniculata* Roth., *Anogeissus latifolia* Wall., *Ziziphus xylopyrus* Willd., *Cassia fistula* L., *Albizia lebbek* Benth., *Tectona grandis* L.f., *Diospyros montana* Roxb., *Mitragyna parviflora* Korth. and *Pterocarpus marsupium* Roxb.

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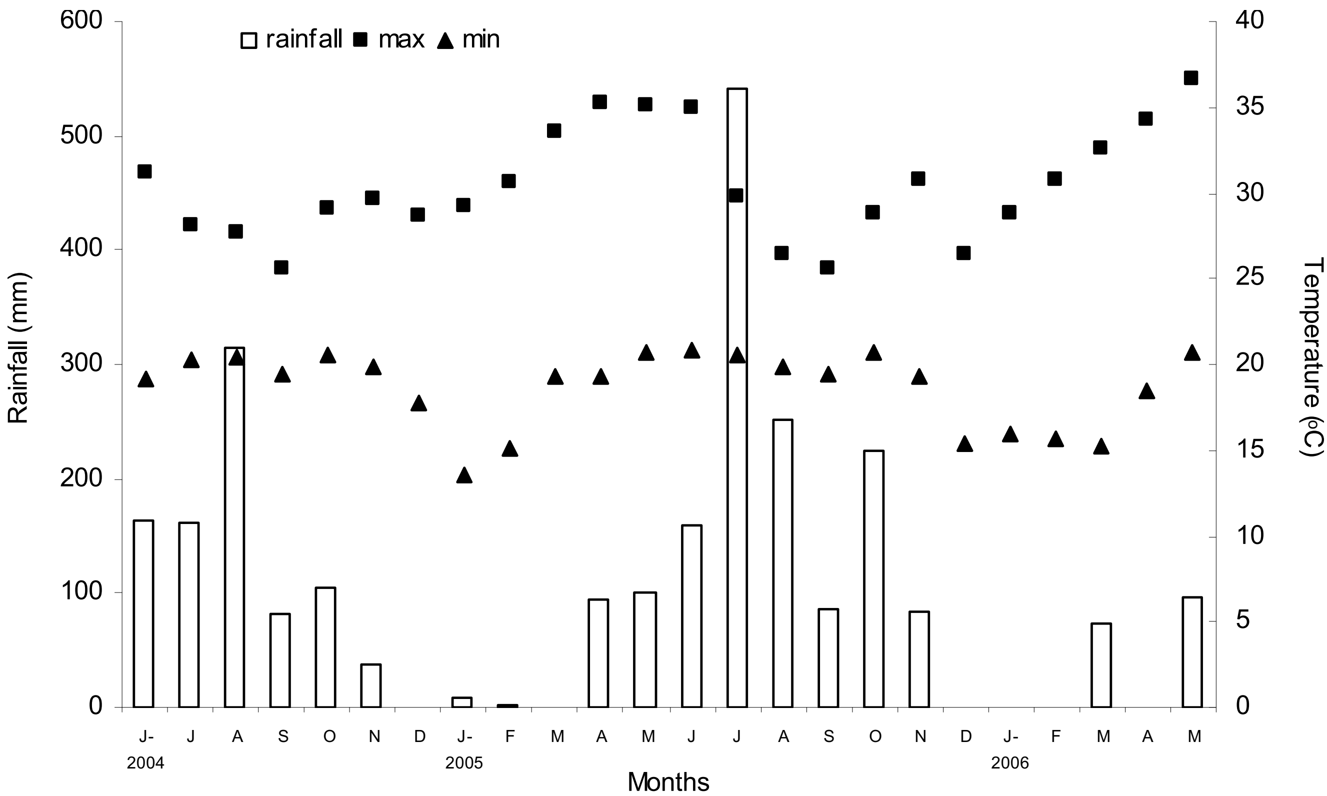

Fig. 1 Total monthly rainfall (mm), mean monthly maximum, and mean monthly minimum temperature (°C) at dry deciduous forest in Bhadra wildlife sanctuary during the study period.

Methods

Woody stems > 20 cm in diameter at breast height (dbh) with clearly visible canopies were marked with a unique tag number on either side of the transect of about 2 Km. A total of 277 individuals of 45 species of these marked individuals were monitored for reproductive phenophases once a month from June 2004 to May 2006. Reproductive phenology includes both flowering and fruiting phenologies. Flowering phenology included five different stages: 1. flowerless/no flowers (FL1), 2. flower initiation/flower buds (FL2), 3. opening flower/unpollinated flowers (FL3), 4. mature flowers/pollinated (FL4), 5. falling/senescent flowers (FL5). Fruit phenology involved 1. fruitless/no fruits (FR1), 2. initiating fruits/fruit buds (FR2), 3. ripening fruits/immature fruits (FR3), 4. mature fruits/fully ripened fruits (FR4) and 5. falling fruits/senescent fruits (FR5) (for dispersal). Each stage in different categories of phenology was scored qualitatively with respect to both spread and intensity on canopy on a 0 to 100 scale. The marked individual species were identified using various regional floras (Yoganarasimhan *et al*. 1990; Saldhana 1996; Gamble and Fischer 1998; Ramaswamy *et al.* 2001; Neginhal 2004). Representative plant specimens were collected and deposited in the Herbarium of the Department of Applied Botany, Kuvempu University.

Data analyses

We performed Spearman's rank correlations as well as multiple regressions during corresponding months and time lag periods to test the influence of rainfall and temperature on various reproductive phenophases, computed using procedures given by Zar (2004). Seasonality is defined as a repeated occurrence of a given event in a cyclic fashion. The questions asked in this section include: a) Are the different phenophases cyclic? b) How strong is cyclicity in a given event? Rayleigh's *Z*, which tests significance of cyclicity in a given phenophase, was calculated. The hypothesis tested was:

H_0 = the given phenophase is seasonal or cyclic.

H_A = the given phenophase is not seasonal.

Statistical software "*STASTIXL*," a package for spreadsheets to estimate seasonality in the data, was used. The day of observation in a given month was converted to angles, which were used, together with the number of species in a given month in a given phenophase, to estimate Rayleigh's *Z*. Mean vector **r** has no units and may vary from 0 (when phenological activity is distributed uniformly through out the year) to 1 (when phenological activity is concentrated around one single date or time of year), indicates the strength of the seasonality. Interpretation of the *Z* statistic follows Zar (2004).

RESULTS

Flowering phenology

Most of the species initiate flowering during the dry season. Flower initiation begins in November and continues until June with peaks during April to June. But some of the species initiate flower while having senescent leaves (LF5) or during the leafless (LF1) period.

Factors influencing flower initiation

All variables independently had a significant influence on flower initiation during a two-month lag period. Rainfall (r_s = -0.49, p<0.02), Number of rainy days (r_s = -0.57, p<0.005) and minimum temperature (r_s = -0.58, p<0.003) had a negative influence while maximum temperature had a positive influence both during lag periods and corresponding months (**Fig. 2**).

Multiple regression during the corresponding months was significant (r_s = 0.69, F = 4.48, p<0.01) with maximum temperature, number of rainy days and minimum temperature as influencing factors. Both time lag regressions were significant with maximum temperature positively influencing flower initiation. Hence flowering is a temperature-related event.

Fruiting phenology

Fruit initiation did not show any significant pattern with rainfall, but it was observed in one or a few other species during the study period, whereas fruit maturation peaked after the rainfall and fruit fall peaks during the dry season.

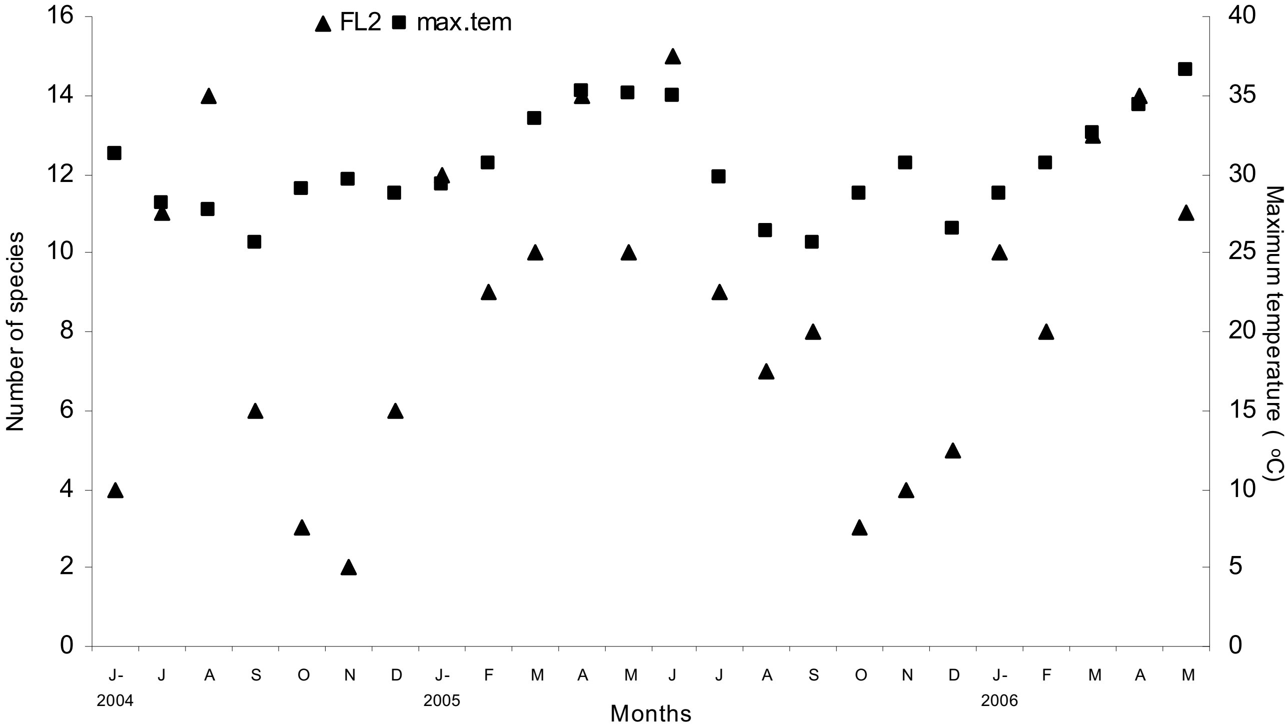

Fig. 2 Number of species initiating flower in relation to maximum temperature in dry deciduous forest of Bhadra Wildlife Sanctuary.

Factors influencing fruit initiation

Minimum temperature had a significant negative influence (r_s = -0.58, p<0.004) when analyzed independently, during the two-month lag period. None of the other variables influenced fruit initiation. Multiple regressions during corresponding months and the one-month lag were not significant. The two-month lag period regression was significant (r_s = 0.71, F = 4.32, p<0.01) with minimum temperature as the significantly influencing variable. Reduction in minimum temperature or heralding a warm period would trigger many species to set fruit (**Fig. 3**).

Number of rainy days had a significant negative influence on maturation of fruits during corresponding months while no other variables had any influence. Multiple regression during a one-month lag period was significant (r_s = 0.65, F = 3.43, p<0.02) with number of rainy days and rainfall influencing the event. Step wise regression was also significant (r_s = 0.65, F = 4.82, p<0.01) with number of rainy days, rainfall and maximum temperature influencing the event. Though rainfall influences maturation of fruits, it did not have a significant impact on the maturity of fruits (**Fig. 4**).

Fruit fall is influenced by all variables except for maximum temperature, which has a significant positive influence during corresponding months only (r_s = 0.43, p<0.03).

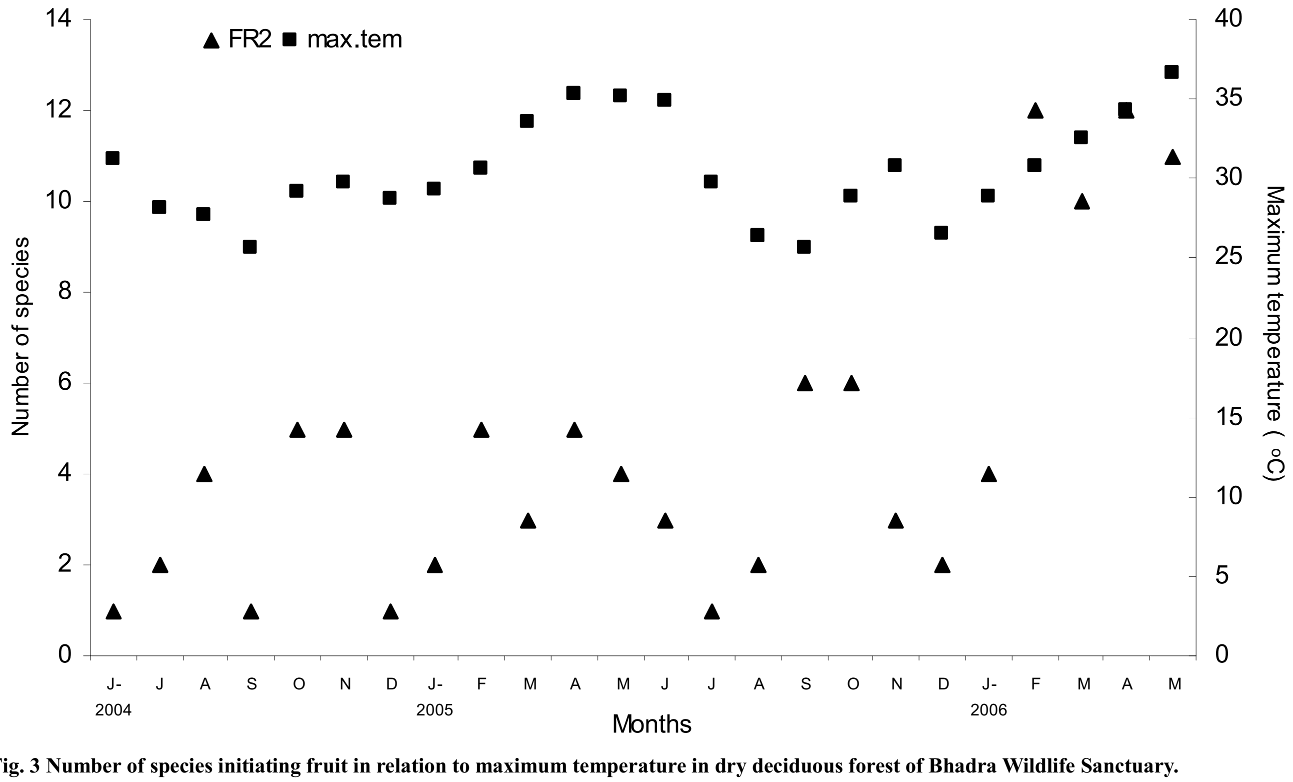

Fig. 3 Number of species initiating fruit in relation to maximum temperature in dry deciduous forest of Bhadra Wildlife Sanctuary.

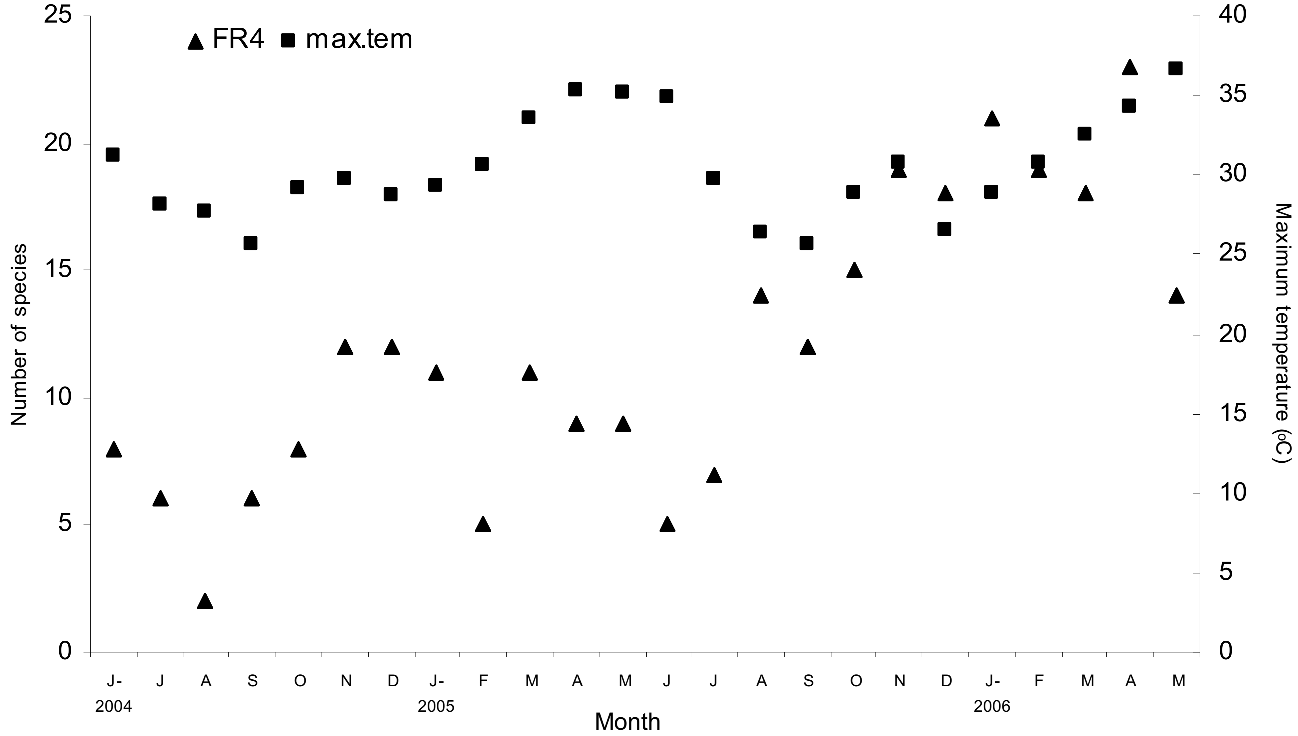

Fig. 4 Number of species with matured fruits in relation to maximum temperature in dry deciduous forest of Bhadra Wildlife Sanctuary.

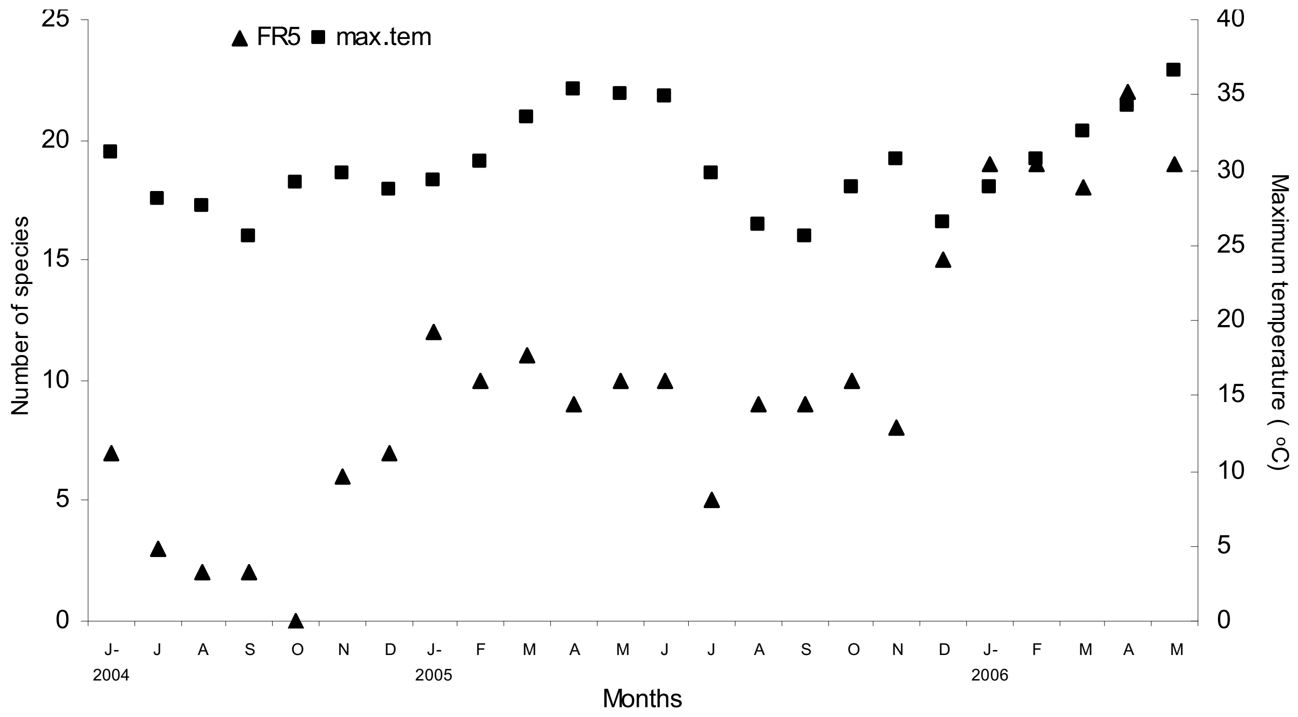

Fig. 5 Number of species with falling fruits in relation to maximum temperature in dry deciduous forest of Bhadra Wildlife Sanctuary.

Influence of these variables was highly significant during one month lag period: rainfall (r_s = -0.66, p<0.0005), number of rainy days (r_s = -0.77, p<0.00001) and minimum temperature (r_s = -0.67, p<0.0004).

Multiple regression during the corresponding months was significant (r_s = 0.73, F = 5.64, p<0.003) with max temperature being a significantly influencing variable. Stepwise regression was also significant (r_s = 0.73, F = 7.84, p<0.001) with number of rainy days, maximum and minimum temperature as influencing variables. Number of rainy days and maximum temperature explained largely the influence of these variables (**Fig. 5**). Therefore reduction in the number of rainy days and an increase in the temperature triggers species to drop their fruits. Multiple regressions during both lag periods were significant with number of rainy days having significant negative influence on the fruit senescent event. Therefore a reduction in the number of rainy days would trigger species to drop their fruits.

Seasonality

Flowering phenophases were seasonal. However, the strength of seasonality is low. Most of the species initiated flowers during late March. Many species would have had open pollinated flowers during the same time. The mean angle of mature flower stage is lower than the initiation phase. This is because some species initiate flowering by December-January and some others during June. There is a wide standard deviation which accounts for long flowering periods. The strength of seasonality is measured by the

Table 1 Results of the circular statistic analysis testing for the occurrence of seasonality in different flowering phenophases among species in Bhadra wildlife sanctuary.

Parameters	Flower initiation (FL2)	Open flowers (FL3)	Pollinated flowers (FL4)
Mean angle	119.66	113.9	110.09
Mean vector r	0.23	0.28	0.24
Angular SD	70.86	68.72	70.21
Rayleigh's *Z*	11.50	10.48	8.56
P value	<0.000	<0.000	<0.000

Table 2 Results of the circular statistic analysis testing for the occurrence of seasonality in different fruiting phenophases among species in Bhadra wildlife sanctuary.

Parameters	Fruit initiation (FR2)	Fruit maturity (FR4)	Fruit fall (FR5)
Mean angle	83.57	28.85	71.31
Mean vector r	0.24	0.17	0.30
Angular SD	70.37	73.50	67.45
Rayleigh's *Z*	6.63	8.80	22.79
P value	<0.001	<0.000	<0.000

vector "r", which indicates that flowering is seasonal. Open flowers have strong seasonality followed by pollinated flowers and flower initiation in tree species of the dry deciduous forest (**Table 1**).

Various phenophases in fruiting phenology are significantly seasonal. However, the strength of seasonality is low. Most of the species initiate fruiting in the dry season around March. Fruit maturation occurred during early January. There is a long period from March to January for the maturation of fruits. Most of the species drop fruits during early March before the onset of the monsoon. The strength of seasonality measured by the vector "r" indicates that fruiting is seasonal. Fruit fall has strong seasonality followed by fruit initiation and fruit maturation (**Table 2**).

Flowering and fruiting events of bhadra wildlife sanctuary are seasonal, both the events takes place cyclicly without any overlap.

DISCUSSION

Flowering phenology

In deciduous forest of present study peak month of flowering in dry season during April. Similar patterns of flowering were observed in other tropical forests (Van Schaik *et al.* 1993; Foster 1982; Justiniano and Frederickson 2000).

Phenological studies in seasonal tropical forest ecosystems have indicated rainfall seasonality as being the major abiotic factor controlling the timing, intensity, and duration of flowering and fruiting periodicities (Singh and Singh 1992; Newstrom *et al.* 1994; Sun *et al.* 1996; Borchert *et al.* 2004). But in the present study rainfall has no significant influence on flowering phenophases. Lieberman (1982) predicted that in some species, time-lag between two events reflects partitioning of resources for various physiological activities. We can see some similarities with lag periods. Solar irradiance and rainfall are often considered as the main seasonal variables influencing the flowering phenology of tropical plants (Wright and Van Schaik 1994; Wright 1996).

Dry-season flowering period is a response to rapid resource-use rate during summer. Water storage in tree trunk may enable maintenance of high stem water potential and flowering during the dry season (Schongart *et al*. 2002). During dry season flowering most of the trees are in leafless stage so that they can advertise more to the pollinator. Seasonal trees receiving of over a 100 cm of rain annually tend to have the peak of flowering in the dry season (Koelmeyer 1959; Janzen 1967; Daubenmire 1972; Frankie *et al*. 1974).

Fruiting phenology

Fruit initiation begins from January and February, whereas Fruit maturation began in March and increase in maturity with the onset of the wet season from August to September. Studies in the tropics in which fruiting peaks have been reported to occur in the wet season (Foster 1982; Heideman 1989; Chapman *et al*. 1999). Ripening or maturity of fruits in the latter part of pre-monsoon dry period or close to rainfall, to gain post dispersal success (Rathcke and Lacey 1985), enhance dispersal (Prasad and Sharathchandra 1984) to avoid pathogen infection (Augspurger 1983).

Fleshy fruited species produced fruits preferentially during the wet season in dry tropical forest in Ghana (Lieberman 1982). Explosive dispersed fruits dehisce during dry months when relative humidity was low (Murali and Sukumar 1994). A similar observation was true for dry deciduous forest of the Bhadra sanctuary in the present study (Nanda 2009).

Seasonality in flowering and fruiting phenophases

Seasonality study helps in the assessment of environmental factor and their shift in mean angle of different phenophases, even though the flowering and fruiting events are seasonal, but the strength of the seasonality is low in flower initiation and fruit maturity, as both are favoured by the maximum temperature. Even though the low climate seasonality and the absence of a dry season, phenological pattern were seasonal in Atlantic rain forest trees (Morellato *et al*. 2000). According to Heideman (1989) divergences in the phenological response is due to greater differences, diversity in tree species composition in tropical forests. This study shows that reproductive phenophases are adapted to dry season to onset of rainfall as indicating reproductive pheophases are an adaptation to their local climate (Nanda 2009).

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