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Phenology of selected woody species in a tropical dry deciduous forest in Rajasthan, India

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Abstract: Phenological observations were taken for 26 woody species for three years in the Bala-fort tropical dry deciduous thorn forest located in north-eastern Rajasthan (27°4' to 28°4' N and 76°7' to 77°13' E) in NW India. The phenological behavior of most of the woody species was almost similar in different years, however, drought conditions affected the various phenophases of several species. Leaf - fall in majority of woody species began in October with a peak in November and December. Leaf initiation began in February with a peak in May before pre-monsoon showers. Delayed leaf-initiation and leaf fall in response to the drought of 2002 was observed in several woody species. Flowering activity in these species continued throughout the year with two peaks; one in March and April and the second in July and August. Flowering in most of the woody species was not affected by the drought of 2002. Although the peak of fruit maturation for these species was observed in September and October, the dehiscence of fruits was completed before pre-monsoon showers in June.

Resumen: Se hicieron observaciones fenológicas para 26 especies leñosas durante tres años en el bosque tropical seco caducifolio espinoso de Bala-fort, localizado en el nordeste de Rajasthan (27°4' a 28°4' N y 76°7' a 77°13' E), noroeste de la India. El comportamiento fenológico de la mayoría de las especies leñosas fue muy similar en diferentes años; sin embargo, condiciones de sequía afectaron varias fenofases de algunas especies. En la mayoría de las especies leñosas la caída de hojas comenzó en octubre, con un pico en noviembre y diciembre. La producción de hojas comenzó en febrero con un pico en mayo, previo a los aguaceros premonzónicos. En varias especies leñosas se observó un retraso en la formación de las hojas y una caída de hojas como respuesta a la sequía de 2002. La actividad de floración en estas especies continuó durante el año con dos picos; uno en marzo y abril y el segundo en julio y agosto. La floración en la mayoría de las especies leñosas no fue afectada por la sequía de 2002. Aunque el pico en la maduración de los frutos para estas especies fue observado en septiembre y octubre, la dehiscencia de frutos llegó a su fin antes de los aguaceros premonzónicos en junio.

Resumo: Durante três anos foram efectuadas observações fenológicas em 26 espécies lenhosas na floresta seca espinhosa decídua tropical em Bala-fort, no noroeste de Rajasthan (27°4' to 28°4' N e 76°7' to 77°13' E) no NW, Índia. O comportamento fenológico da maior parte das espécies lenhosas foi praticamente similar em diferente anos, contudo, as condições de secura afectaram as várias fenofases de várias espécies. A queda de folhagem na maioria das espécies lenhosas começou em Outubro, com um pico em Novembro e Dezembro. A iniciação da folhagem começou em Fevereiro com um pico em Maio antes das chuvas de pré-monção. Em resposta à seca de 2002, observou-se um atraso em várias espécies lenhosas um atraso na iniciação e queda da folhagem. A actividade de floração nestas espécies continuou ao longo do

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ano com dois picos: um em Março e Abril e o segundo em Julho e Agosto. A floração na maior parte das espécies lenhosas não foi afectada pela seca de 2002. Embora o pico da maturação dos frutos para estas espécies tenha sido observada em Setembro e Outubro, a deiscência dos frutos completou-se antes das chuvas de pré-monção em Junho.

Key words: *Anogeissus pendula*, drought, monsoon, phenophases, woody species.

Introduction

Phenology is the study of relationship between climatic factors and periodic phenomena in organisms. Pattern of phenological events are variously used for characterization of vegetation type (Opler *et al.* 1980; Shimwell 1972). The study of plant phenology provides knowledge about the pattern of plant growth and development as well as the effects of environment and selective pressures on flowering and fruiting behavior (Zhang *et al.* 2006). Singh & Kushwaha (2005a) suggested that climate change forced deviations in the length of growing period, and competition among species may change the resource use patterns in different species. Karmer (1997) concludes that differences in tree species phenological responses to temperature changes can have long-term consequences on their geographic distribution. He further suggests that phenology and climate relationship can also reveal the potential impacts of future climate changes. The initiation of growth in plants and changes in phenology are governed by various environmental factors and the influence of temperature and moisture has been studied by several workers (Dewald & Steiner 1986; Walter 1973). Hamann (2004) suggested that climatic factors are not directly responsible for triggering and synchronization of phenological events.

Progress made in the field of phenology of tropical tree species is encouraging (Borchert 1983; Croat 1975; Frankie *et al.* 1974; Putz 1979; Singh & Kushwaha 2005a&b; Sun *et al.* 1996). In India the phenology of tree species has been studied in the subtropical forests in north-eastern region (Boojh & Ramakrishnan 1981; Kikim & Yadava 2001; Shukla & Ramakrishnan 1982) and in western Himalayas (Ralhan *et al.*1985; Sundriyal 1990). However, a few attempts have been made to evaluate the phenology of tree species in the tropical dry deciduous forests (Khan 1999; Kushwaha & Singh 2005; Singh & Singh 1992). The present study was carried out over a three-year period (2001-2003) to evaluate the phenology of plant species of the tropical dry deciduous thorn forest of the Bala-fort in Alwar district of Rajasthan in north-west India to understand the response of plant species to climatic factors and periodicity of seasons with special reference to the effect of drought.

Study site and climate

The Bala-fort reserve forest is well protected and is situated in the north-eastern part of Rajasthan in the Aravalli hills (27°4' to 28°4'N and 76°7' to 77°13' E). The valley is at an altitude of 480 m and the peaks of surrounding hill slopes are as high as 570 m above sea level. It is a tropical dry deciduous thorn forest dominated by *Anogeissus pendula* (Yadav & Yadav 2005). The soil is sandy loam with brown colour gravel and shallow along hill slopes. Soil pH varies from 7.2 to 7.7 in different micro-environmental situations with a slight increase towards the top of hill slopes. Soil organic carbon is 0.4 and 1.0 percent at the base and top of the hill slopes, respectively. The climate is hot and dry with three distinct seasons. The summer season, from mid March to June, is extremely hot with temperature soaring to 47°C, the rainy season is from July to mid September with 90% of annual rainfall (650 mm) occurring during this period and the dry cold winter season is from October to February with temperature dropping to 4°C (Fig.1).

Methods

Phenological observations were made on 26

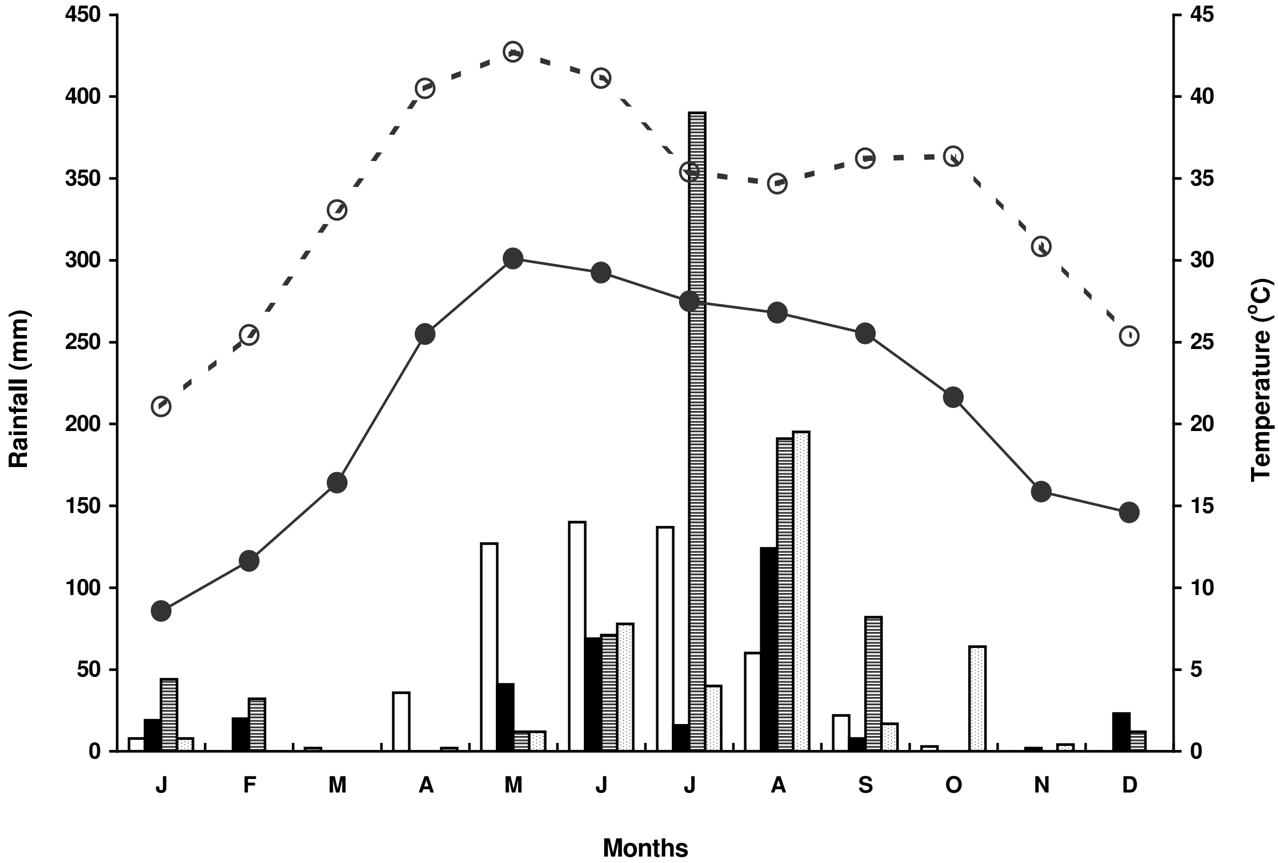

Fig. 1. Climatic diagram of the study site from 2000 to 2004. Average monthly maximum temperature (open circles with dotted line) and minimum temperature (solid circles with solid line) and total monthly rainfall 2001 (hollow bar); 2002 (solid bar); 2003 (bar with transverse lines) and 2004 (bar with dots).

woody species (17 deciduous tree species and 09 shrub species) of the Bala-fort tropical dry deciduous thorn forest. Observations were made on leaf initiation, leaf fall, flowering and fruiting of woody species at 15 day intervals from January 2001 to December 2003 (including drought year 2002) in ten permanent quadrats of 100 m^2 size each, located at the hill slope and in the valley of this forest. A species was considered in a particular phenophase when more than 80% of the individuals of that species present in the quadrats were passing through that phase. However, in the case of rare species, observations were made on the basis of individuals present. The observations on phenological events were expressed as number of plant species in a particular phenophase. Behavioral patterns of plant species were described following Kikim & Yadava (2001). The interphenophase duration for dominant woody tree species were calculated following Prasad & Hegde (1986).

Brief and extended activity indicates the periodicity of leaf initiation, flowering and fruiting activity by individuals of a species. Brief activity extends for 2 weeks or less while extended activity refers to periods more than 2 weeks. When 50% or more individuals of a tree species are simultaneously in the same phenophases it is referred to as "synchronous" activity (S), while showing same phenophases during distinct periods is known as "asynchronous" (A). On the basis of fruit maturation activity individuals of a species population are grouped into two categories i.e. rapid (r) and lengthy (L). When the fruit maturation period is of 4 months or less, it is considered as "rapid" activity and when it is more than 4 months "lengthy" activity (Kikim & Yadava 2001).

Results

Leaf-initiation

Leaf initiation started in February, continued up to July- August with a peak in May just before the onset of monsoon (Fig. 2a). Leaf flushing was also a periodic phenomenon in all the woody species with considerable temporal variation (Table 1). Among the 26 woody species, 40% showed brief leaf-flushing activity whereas 60% exhibited extended activity (Table 2). The observations indicated that most of the species

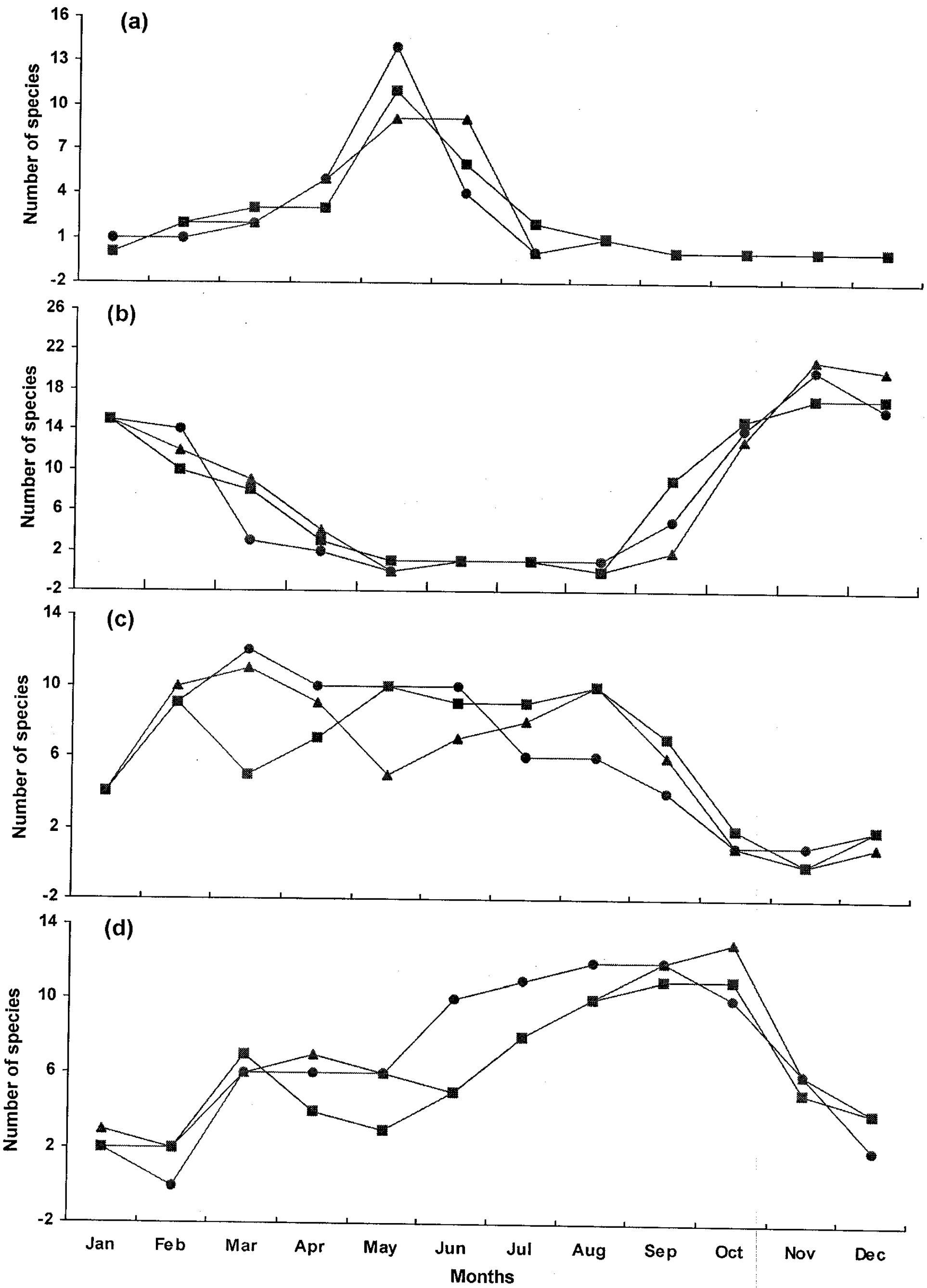

Fig. 2. Phenological periodicity of woody species in the Bala-fort reserve forest (a) number of species in leaf flushing, (b) in leaf fall, (c) in flower and (d) in mature fruits (circles for 2001; squares for 2002 and triangles for 2003).

Table 1. The leaf-initiation (Li), leaf-fall initiation (Lfi) and flower-initiation (Fli) in the woody species in 2001, 2002 and 2003 in the Bala-fort forest.

Species	2001			2002			2003		
	Li	Lfi	Fli	Li	Lfi	Fli	Li	Lfi	Fli
Acacia catechu (L.f.) Willd.	May	Oct	Jun	Apr	Oct	Jun	Apr	Nov	Jun
Acacia leucophloea (Roxb.) Willd.	May	Dec	Aug	May	Jan	Aug	May	Mar	Aug
Acacia senegal (L.) Willd.	May	Oct	Jun	Feb	Jan	Aug	May	Nov	Aug
Anogeissus pendula Edgew.	May	Nov	Jun	Jun	Oct	Jul	Jun	Nov	Aug
Boswellia serrata Roxb. Ex Coleb.	Apr	Sep	Jan	Jun	Sep	Jan	Jun	Oct	Dec
Butea monosperma (Lam.) Taub.	May	Nov	Mar	May	Sep	Feb	Jun	Nov	Apr
Capparis sepiaria L.	Mar	Nov	Mar	Apr	Nov	Apr	Apr	Jan	Apr
Commiphora wightii (Arn.) Bhandari	May	Oct	Apr	May	Oct	Apr	Jan	Oct	Jul
Crataeva nurvala Buch – Ham.	May	Oct	Apr	Jun	Oct	May	Jun	Oct	May
Dichrostachys cinerea (L.) Wight & Arn.	Jun	Dec	Aug	Jun	Nov	Jun	May	Nov	Jun
Ehretia laevis Roxb.	May	Nov	Mar	Mar	Sep	May	Mar	Sep	Feb
Ficus mollis Vahl.	May	Nov	Jan	Jul	Nov	Dec	May	Dec	Jan
Grewia flavescens A. Juss	May	Oct	May	May	Nov	Jul	May	Nov	Jul
Grewia tenax (Forsk.) Fiori.	Feb	Sep	Mar	Mar	Oct	May	Feb	Oct	Apr
Holoptelea integrifolia (Roxb.) Planch.	May	Oct	Feb	May	Oct	Feb	May	Oct	Feb
Lannea coromandelica (Houtt.) Merr.	Jun	Sep	Feb	Jun	Sep	Apr	Jun	Oct	Mar
Sterculia urens Roxb.	May	Aug	Dec	May	Sep	Dec	Jun	Oct	Jan
Wrightia tinctoria R.Br.	Apr	Oct	May	May	Sep	May	May	Oct	Apr
Zizyphus nummularia (Brum.f.) Wight & Arn.	Apr	Dec	Aug	Apr	Dec	Aug	Apr	Dec	Aug

completed leaf development by July and August. There was a complete absence of leaf flushing in most of the plant species from September to January.

Leaf-fall

Leaf-fall initiation was a periodic activity in all species, however, the onset of leaf fall initiation is different in various woody species (Table 2). In most plant species, leaf shedding begins in the month of October with peak in November – December (Fig. 2b). *Lannea coromandelica* and *Sterculia urens* also shed their leaves with the onset of dry period from September onwards. The failure of monsoon in 2002 hastened initiation of leaf fall in *Butea monosperma, Lannea coromandelica, Sterculia urens, Boswellia serrata* and *Anogeissus pendula* by one month (Table 1). This shows that the growth period of these species is regulated by soil moisture.

Flowering activity

Flowering continued in different woody species throughout the year (Fig. 2c). However, two peak periods of flowering were distinguished; the first peak in the month of March and April when *Butea monosperma, Lannea coromandelica, Holoptelea integrifolia, Cassia fistula, Cordia dichotoma, Ehretia laevis, Capparis sepiaria* and *Commiphora wightii* exhibited flower initiation in response to increasing length of photoperiods. The second peak of flowering was observed in August when *Anogeissus pendula, Acacia senegal, Acacia leucophloea* and *Zizyphus nummularia* produced flowers. The flowering activity in *Sterculia urens* begins in the month of November-December. The flowering initiation in *Ehretia laevis* was delayed during drought year 2002.

Fruiting activity

The peak period of maturation of fruits was September-October in most of the woody species (Fig. 2d). In comparison to flowering activity, 64% woody species exhibited brief fruiting activity, whereas 36% species showed extended activity (Table 2). Out of 26 woody species, 72% showed rapid fruit maturation, whereas, 28% had lengthy process of fruit maturation. The fruit development phase was shortened in *Ficus mollis*, *Grewia*

Table 2. Phenological patterns of woody species in the Bala-fort forest. (P=Periodic, b=Brief periods, less than 2 weeks per episode, e=Extended periods, equal or more than 2 weeks per episode, S=Synchronous, A=asynchronous, D=Deciduous, E=Evergreen, r=Rapid fruit maturation, less than 4 months, L= Lengthy fruit maturation, equal to or more than 4 months).

Species	Behavioral patterns			
	Leaf drop	Leaf flushing	Flowering	Fruiting
Acacia catechu (L.f.) Willd.	PD	Pb	PeS	Per
Acacia leucophloea (Roxb.) Willd.	PD	Pb	PeS	Per
Acacia senegal (L.) Willd.	PD	Pb	PeS	Per
Anogeissus pendula Edgew.	PD	Pe	PbA	Per
Bauhinia racemosa Lam.	PD	Pe	PeS	PeL
Boswellia serrata Roxb. Ex Coleb.	PD	Pe	PbS	Pbr
Butea monosperma (Lam.) Taub.	PD	Pe	PbS	Pbr
Bombax cieba L.	PD	Pb	PbS	Pbr
Capparis sepiaria L.	PE	Pe	PeA	PbL
Cassia fistula L.	PD	Pe	PeS	PeL
Commiphora wightii (Arn.) Bhandari	PD	Pb	PeA	PeL
Cordia dichotoma Forst.f.	PD	Pe	PeS	Per
Crataeva nurvala Buch - Ham.	PD	Pb	PeS	Per
Dichrostachys cinerea (L.) Wight & Arn.	PD	Pb	PbS	PbL
Ehretia laevis Roxb.	PD	Pe	PbA	Pbr
Ficus mollis Vahl.	PD	Pe	PbS	Per
Flacourtia indica (Brum.f.) Merr.	PD	Pe	PbA	Pbr
Grewia abutilifolia Vent. Ex Juss.	PD	Pe	PeS	Pbr
Grewia flavescens A. Juss	PD	Pe	PeS	Pbr
Grewia tenax (Forsk.) Fiori.	PD	Pe	PeS	PbL
Holoptelea integrifolia (Roxb.) Planch.	PD	Pe	PbS	Pbr
Lannea coromandelica (Houtt.) Merr.	PD	Pb	PbS	Pbr
Maytenus emarginatus (Willd.) Ding Hou	PD	Pe	PbS	Pbr
Sterculia urens Roxb.	PD	Pb	PbS	Pbr
Wrightia tinctoria R.Br.	PD	Pb	PeS	PbL
Zizyphus nummularia (Brum.f.) Wight & Arn.	PD	Pb	PeS	Pbr

abutilifolia, *Holoptelea integrifolia* and *Lannea coromandelica* whereas it was extended in *Ehretia laevis*, *Commiphora wightii* and *Acacia senegal* during drought year 2002. At the community level two peak periods for fruit initiation were observed; first during the month of March and the second in the month of June. Usually the species in which fruit maturation begins during the month of March, fruit dehiscence is completed before pre-monsoon period and species in which fruit maturation begins during the month of June have a lengthy period of fruit retention and their fruit dehiscence is completed before the following pre-monsoon period. The interphenophase duration for dominant woody species is highly variable (Table 3). Leaf-fall and leaf-initiation interphase (leafless period) is long for 85% species, indicating the deciduous nature of the study site. The leaf initiation-flowering interphase was also long for 70% of tree species except *Crataeva nurvala*, *Acacia senegal*, *Anogeissus pendula* and *Wrightia tinctoria*. Out of total species, 85% showed short flowering-fruiting interphase.

Discussion

The tropical dry deciduous forest of Bala-fort exhibited considerable diversity in leaf initiation, leaf fall, flowering and fruiting activity. However, as per climate of the study site, peaks for all phenophases were distinguished due to defined wet and dry seasons.

Leaf initiation peak in May, may be attributed to hot months of the year before rains. Leaf-

Table 3. Approximate Interphenophase duration (in weeks) of tree species in Bala- fort forest. LF-Li = Leaf fall - leaf initiation Li-Fl = leaf initiation-Flowering, Fl-Fr = Flowering-Fruiting (2003).

Species	LF-Li	Li-Fl	Fl-Fr
Acacia catechu (L.f.) Willd.	15	12	07
Acacia leucophloea (Roxb.) Willd.	09	11	06
Acacia senegal (L.) Willd.	27	09	05
Anogeissus pendula Edgew.	24	10	04
Bauhinia racemosa Lam.	13	06	11
Bombax cieba L.	36	28	10
Boswellia serrata Roxb. ex. Coleb.	30	25	09
Butea monosperma Taub.	28	40	03
Crataeva nurvala Buch – Ham.	29	05	08
Ficus mollis Vahl.	23	28	13
Holoptelea integrifolia Planch.	27	36	03
Lannea coromandelica (Houtt.) Merr.	31	36	03
Sterculia urens Roxb.	35	26	08
Wrightia tinctoria R. Br.	27	02	08

production towards the end of the dry season and before rains has also been observed in tree species by several workers (Frankie *et al.* 1974; Kikim & Yadava 2001; Shukla & Ramakrishnan 1982; Singh & Kushwaha 2005a&b; Singh & Singh 1992 ; Sundriyal 1990). This may be attributed to the triggering effect of the rising temperature (Walter 1968) and increase in length of photoperiods (Lawton & Akpan 1968; Njoku 1964). Borchert & Rivera (2001) also suggested that in dry summer season, the vegetative buds of spring flushing stem succulent species are in a state of endo-induced dormancy induced and terminated by declining and increasing photoperiod, respectively. The role of photoperiod has been confirmed by Rivera *et al.* (2002) who reported that spring flushing in tropical semi-deciduous trees is induced by an increase in photoperiod of 30 minutes or less. They further suggested that production of new foliage shortly before the rainy season is likely to optimize synthetic gain in tropical forests with relatively short growing season. This is also supported by Elliot *et al.* (2006) and Kushwaha & Singh (2005). In the present study, leaf-initiation in most species was regulated by length of photoperiod in *Butea monosperma, Holoptelea integrifolia, Acacia catechu, Grewia tenax, Zizyphus nummularia* and *Ehretia laevis*. However, leaf development is strongly related to the first shower of pre-monsoon rainfall in the last week of May or first week of June in *Anogeissus pendula, Acacia senegal, Boswellia serrata, Lannea coromandelica* and *Sterculia urens*. Elliot *et al.* (2006) also reported rain induced leafing in a deciduous tree species, *Antidesma*. The delayed leaf flushing was observed in *Anogeissus pendula, Boswellia serrata, Bombax cieba, Butea monosperma* and *Crataeva nurvala* in response to drought during the year 2002, which confirmed the role of rainfall in their leaf-development. The delayed leaf initiation due to drought in 1987 has also been reported in the woody species of the dry deciduous forests of Gir (Khan 1999).

The leaf fall was concentrated in cool and dry winter months i.e. from October to February. Prasad & Hegde (1986) observed a similar pattern of leaf-fall in tropical deciduous forests in the Bandipur Tiger Reserve, South India. Reich & Borchert (1982) suggested that the leaf-fall during the dry season was directly influenced by the decline in soil moisture and increasing water stress conditions. The results are also in conformity with Singh & Singh (1992) who reported that initiation of leaf fall coincides with the onset of the post-monsoon low temperature dry period and can be a mechanism maintaining turgidity of shoots. The failure of monsoon in 2002 hastened initiation of leaf fall in *Lannea coromandelica* and *Sterculia urens*. Similar observations were made by Khan (1999) in Gir forest, Gujarat. Wright (1991) has also suggested that water stress could affect the timing of growth without reducing total annual growth. However, Borchert & Rivera (2001) and Borchert *et al.*

(2002) suggested that in Argentina leaf shedding of several species is probably caused by a combination of increasing leaf age and declining photoperiod rather than increasing drought.

Synchrony type of flowering was quite common in woody species of this forest. Flowering was a brief activity in 50% woody species, and most of the population of these species exhibited synchronous activity, whereas that of *Anogeissus pendula, Capparis sepiaria, Commiphora wightii, Ehretia laevis* and *Flacourtia indica* showed asynchronous activity. As majority of species produced flowers during leaf-less phase, which favours wind pollination as well as floral display to attract pollinators (Singh & Singh 1992). Synchronization of flowering and leaf flushing seems to be related to moisture, temperature and day length, which is in conformity with observations made by other workers (Boojh & Ramakrishnan 1981; Murali & Sukumar 1994). Delayed flowering in *Ehretia laevis* during drought indicates the role of soil moisture in its flowering activity. Borchert (1994) also suggested that the stored water buffers the impact of seasonal drought and enables flowering and flushing during the dry season. Wright (1991) suggested that changes in moisture availability may affect other physical factors, such as nitrogen mineralization, and the possibility that seasonal flushes of phosphorus from decaying litter synchronize with plant activity cannot be discounted. *Sterculia urens* produced flowers shortly after leaf fall in November and December in response to increased moisture content of leafless branches either from the water stored in stem or obtained from the water table. Borchert (1994) also suggested that the stored water buffers the impact of seasonal drought and enables flowering and flushing during the dry season.

Woody species present in the study site exhibited four basic patterns of flowering in relation to leaf flushing as described by Kikim & Yadava (2001); (I) Flowering before leaf flushing in *Boswellia serrata, Butea monosperma, Crataeva nurvala, Commiphora wightii, Ehretia laevis, Lannea coromandelica* and *Sterculia urens;* (II) Simultaneous flowering and leaf flushing in *Capparis sepiaria*; (III) Flowering soon after leaf flushing in *Anogeissus pendula* and (IV) Flowering long after leaf flushing in *Acacia senegal, Acacia leucophloea, Acacia catechu, Dichrostachys cinerea, Grewia flavescens, Grewia tenax* and *Zizyphus nummularia*. However, in *Bombax cieba* and *Holoptelea integrifolia* the flower initiation occurred long before the leaf flushing. However, Singh & Kushwaha (2006) recognised five flowering types in 119 tropical tree species.

The fruiting activity was completely absent from November to January indicating that it continues for 9 months during the annual cycle which is in conformity with the observations made in the dry tropical forest of Varanasi (Singh & Singh 1992). In several species initiation of fruit ripening begins in post-monsoon period and continues upto the end of cool and dry winter period, that may be due to the difference in fruit maturation activity of different species as reported for sub-tropical forests in north-eastern India (Kikim & Yadava 2001). Thus fruit dehiscence of tree species coincides with the onset of monsoon to allow optimal germination (Frankie *et al.* 1974; Primack 1987; Singh & Kushwaha 2006; Singh & Singh 1992). The pattern of fruiting activity maintains the availability of fruits to herbivores throughout the year. The edible fruits of *Acacia catechu, Acacia senegal* and *Zizyphus nummularia* are available in winter season whereas those of *Butea monosperma* and *Holoptelea integrifolia* are available in summer season to the wild animals.

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