Print : ISSN 0970-7662
Online : ISSN 2455-7129

Journal of Tree Sciences
online available at www.ists.in

Volume 36 | No. 2 | December, 2017

Reproductive Phenology, Seasonality of Canopy and Understorey Trees in a Tropical Evergreen Forest

A. Nanda[1, 2]* H. S. Suresh[3] and Y. L. Krishnamurthy[1]

[1]*Department of Post graduate Studies and Research in Applied Botany, Bioscience Complex, Jnana Sahyadri, Kuvempu University, Shankaraghatta Shivamogga, 577451, Karnataka, India;* [2]*Biodiversity Education and Research Lab, Environmental Study Centre, Santhekaduru Shivamogga 577222, Karnataka, India* [3]*Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560012, Karnataka, India* * Corresponding author, Email- nandabotany@gmail.com

DOI: 10.5958/2455-7129.2017.00018.8

ABSTRACT

Phenology and seasonality of topical evergreen forest tree species (> 30 cm girth at breast height) of Kemmanugundi, Karnataka was studied. Tree species were identified and tagged with a number of approximately five km single transect comprising 177 individuals. Observations at community level were made at monthly intervals from June 2004 to May 2006 for flowering and fruiting phenophases in various tree species. At community level, initiation of flower bud was observed during November and January, pollination in December (winter). Fruit bud initiated during January (winter) and April (summer). Fruit ripened from January (winter) – April (summer) and in July (rainy). Fruit falling was recorded in June (rainy) and March (summer) with a major and minor peak. Rainfall had significant negative influence on reproductive phenologies. Flower initiation and pollinated flower had strong seasonality in canopy and understorey trees. Fruit initiation and fruit fall had same seasonality in canopy and fruit initiation in under storey trees.

Key Words:

Canopy, Flower, Fruit, Pollination, Understorey Trees

INTRODUCTION

Environmental changes have emerged as important questions globally as well as regionally and there is need to assess the impact precisely, due to the lack of basic scientific observations. Information on phenology is important for the study of plant - animal interactions and is useful indicators to assess the impact of environmental perturbations on trees (Singh and Singh 1992; Kushwaha and Singh 2005). Phenology affects nearly all aspects of ecology and evolution as phenology at the population or ecosystem level is ultimately a product of selection acting on variation among individuals. Phenological study is important in monitoring all aspects of ecosystems (Lechowicz 1984) and is essential to understanding the dynamics of plant communities, which of course impact animal populations as well. Different forest types are considered to be indicators of the amount and annual distribution of rainfall because seasonal variation in tree water status constitutes a major determinant of tropical tree phenology (Borchert 1994; Borchert et al. 2002). Plant phenological studies are fundamental to understand the forest as resource base (Prasad and Hedge 1986; Sundarapandian et al. 2005). Phenology is controlled by a number of factors such as rainfall, temperature, light and relative humidity (Singh and Singh 1992; Opler et al. 1976; Borchert 1994; van Schaik et al. 1993) and in turn it has its impact on herbivory (Aide 1988; Murali and Sukumar 1993) and on seasonality (Morelatto et al. 2000; Nanda 2009). Although it is now widely acknowledged that biological interactions and phylogenetic relations can shape phenological patterns (Wright and Calderon 1995). The vegetative phenology of mature trees varies with topography from evergreen to deciduous (Singh and Kushwaha 2006). Studies on reproductive phenophases of canopy, understorey trees and seasonality in tropical evergreen forest are very less with the present study we address following questions.

1. How rainfall plays a determinant role in canopy and understorey flowering and fruiting phenological patterns?
2. What is the strength of seasonality in canopy and understorey trees phenology?

MATERIALS AND METHODS

Study site

The study was conducted in Kemmanugundi (lat.13° 32' to13° 40'N, long. 75° 44' to 75° 45' E), popularly known as poor man's Ooty, is located in Bhadra wildlife sanctuary in the Western Ghats region of Chikmagalore district where the altitude ranges from 500 to 1500 m. These forests are on the windward side of the Western Ghats where the rainfall ranges from 2500 to 4500 mm. Detailed description of the study area (Raju and Hegde 1995) and draft management plan for Bhadra wildlife Sanctuary for the year 1996-2001 has already been published (Parameshwar 2001).

The vegetation of the sanctuary varies from southern hill top tropical evergreen forest to shola forests depending on the precipitation and geographical distribution. According to Champion and Seth (1968) this forest is classified as 'Southern hill top tropical evergreen forest'. The characteristic tree species of this site are top storey normally consists of trees like *Artocarpus hirsuta, Elaeocarpus tuberculatus*, *Cedrela toona*, *Mallotus tetracoccus*, *Syzygium cumini*, *Cinnamomum verum*, *Litsea floribunda*, *Macaranga peltata*, *Persea macrantha*, *Trichilia connaroides*, *Myristica malabarica*, *Gordonia obtusa*, *Acryonychia peduinculata*, *Cryptocarya bourdillonii* and other understorey trees are *Neolitsea zeylanica*, *Scolopia crenata*, *Glochidion velutinum*, *Canthium dicoccum*, *Flacourtia Montana*, *Nothapodytes foetida*, *Vernonia arborea*, *Vepris bilocularis*, *Litsea oleoides*, *Litsea mysorensis*, *Memecylon umbellatum*, *Rapanea* wightiana, *Celtis tetrandra*, *Isonandra perrottetiana*, *Callicarpa tomentosa*, *Mallotus philippensis*, *Litsea mysorensis.*

Methodology

Woody stems above 30 cm GBH (Girth at Breast Height) with clearly visible trees were marked with a unique tag on either side of transect. In total, 67 individuals comprising of 17 canopy tree species and 110 individuals comprising of 30 under storey trees species were marked. These marked individuals were observed for flowering and fruiting phenologies in the middle of month. Flowering phenology had different categories such as flower initiation / flower bud, opened flowers and pollinating flowers. Fruiting phenology had different categories such as fruit bud / fruit initiation, immature fruit, ripened / matured fruit and falling / senescence fruit. Each stage in different categories of phenology was scored qualitatively with respect to both spread and intensity on a 0 to 100 per cent scale. The marked individual species were identified using various regional floras (Gamble and Fischer 1998; Saldhana 1996; Ramaswamy et al. 2001; Neginhal 2004; Yoganarasimhan et al. 1990). Monthly rainfall data was collected from the nearby Baby coffee estate, no temperature data was available for this study site (Fig. 1).

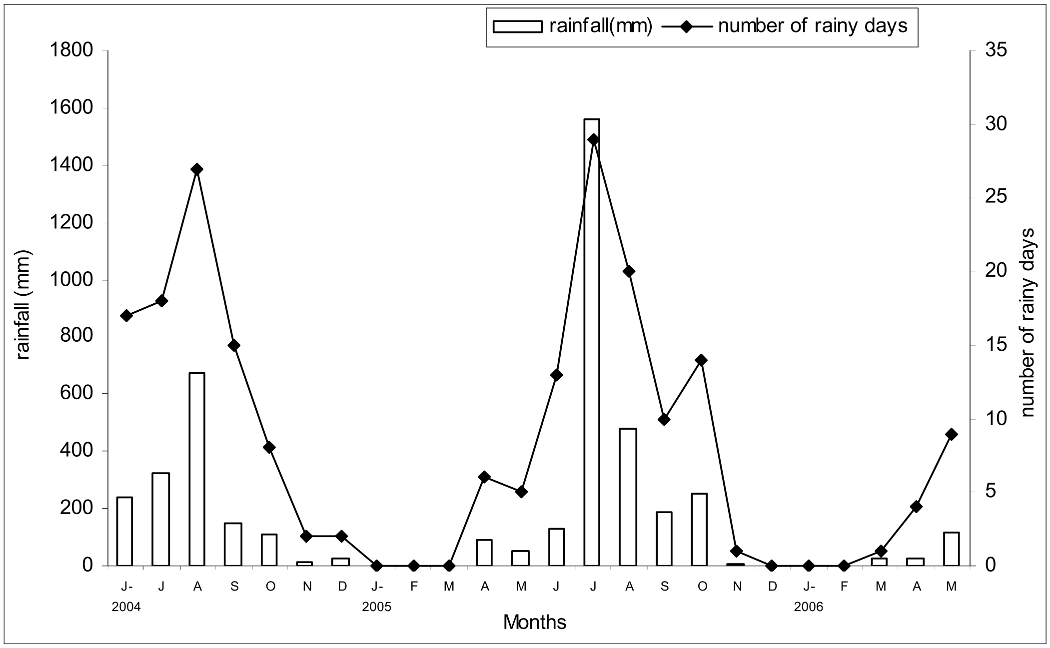

Fig. 1. Rainfall pattern and number of rainy days in the study area.

Statistical analyses

Spearman's rank correlation was performed to establish the relationship between number of species responding to flowering and fruiting phenology during current and one to three months lag periods with amount of total rainfall received in a month which was computed using procedures given by Zar (2007).

Seasonality is defined as repeated occurrence of a given event in a cyclic fashion. The question answered in this section includes a) are the different phenophases are cyclic b) how strong is cyclicity in a given event? Seasonility was calculated using Rayleigh's Z which tests significance of cyclicity in a given phenophase using "STASTIXL" software. The day of observation in a given month was converted to angles. Angles and number of species in a given month in a given phenophase were used to estimate Rayleigh's Z. Interpretation of Z statistic follows Zar (2007).

RESULTS

Flowering phenology

There was a significant inter-annual variation in flower bud among trees at canopy and under storey trees (KS test, $D = 0.958$, $p<0.0007$) with lesser mean number of species (2.41 ± 1.38) in the canopy trees (June, 2004 –May 2006) compared to under storey trees (8.91 ± 2.55) (June 2004 – May 2006). Mean number of species initiating flower bud was (Z test NS) in the life form and variability across months was also significant (ANOVA, $F= 120.42$, $p<0.0001$). Flower opening had a significant variation among life form (KS test, $D = 0.541$, $p<0.0009$), though mean number of species that are opening flowers was significantly different during the study period in canopy (1.12 ± 0.94), under storey trees (3.79 ± 2.82), ($Z = -4.38$, $p<0.0005$). Variability in number of species across different months was also significantly different (ANOVA, $F = 19.18$, $p<0.0001$). Pollinating flower pattern was significantly different across years among life forms (KS test, $D=0.583$, $p<0.0002$). With lesser mean number of canopy trees with pollinating flower (1.16 ± 1.04) and under storey trees (3.58 ± 2.63) was significantly different ($Z = -4.17$, $p<0.0001$), Variability in number of species across different months was significantly different (ANOVA, $F = 17.41$, $p<0.0001$).

Factors influencing canopy and under storey flowering phenology

In canopy trees flower bud / initiation of flower and rainfall had a significant negative influence during current months (r_s = -0.538, p<0.006), and one month (r_s = -0.569, p<0.004). Where as in under storey trees flower bud had significant negative influence during current months (r_s=-0.457, p<0.02) and had no significance with lag periods (Fig. 2). Open flowers had no significance during current and lag periods with rainfall in canopy trees, in under storey trees rainfall had a significant influence during one month (r_s = -0.452, p<0.03), and two month (r_s = -0.434, p<0.04), lag periods (Fig. 3). Pollinating flowers had no significance during current and lag periods with rainfall in canopy trees. Under storey trees had a significant negative influence during current months (r_s = -0.507, p<0.01), had a strong negative influence during one months (r_s = -0.723, p<0.00009), two months (r_s = -0.505, p<0.01), three months (r_s = -0.422, p<0.05) (Fig. 4).

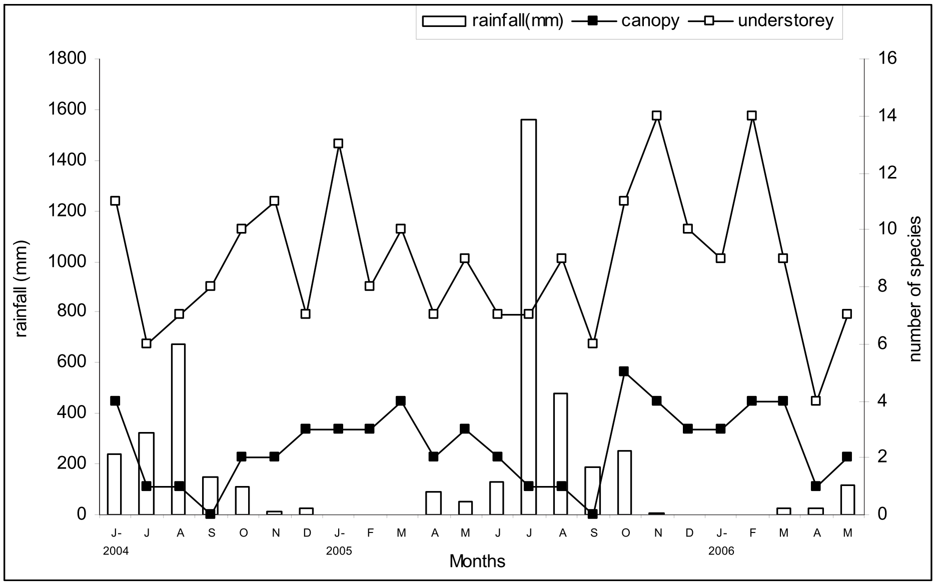

Fig. 2. Flower bud and rainfall in canopy and under storey trees.

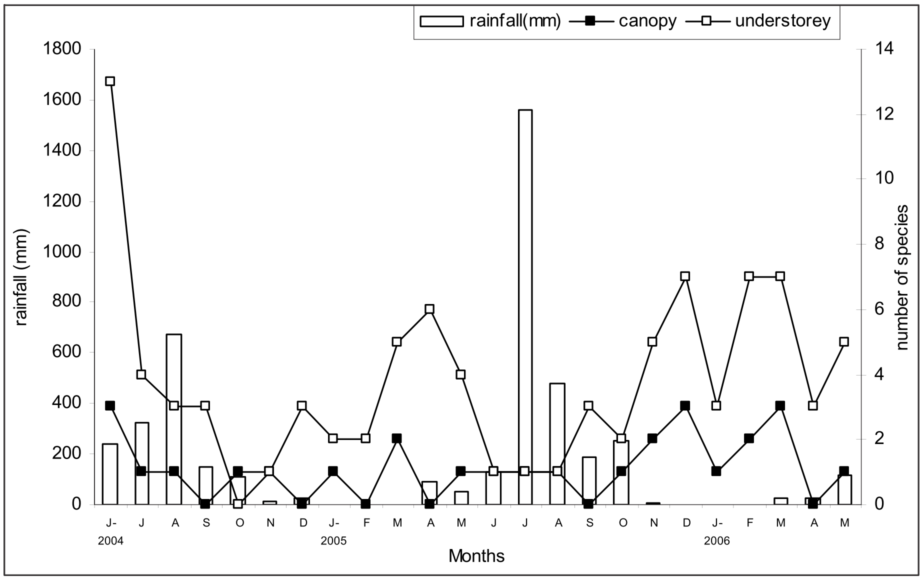

Fig. 3. Opened flower and rainfall in canopy and under storey trees.

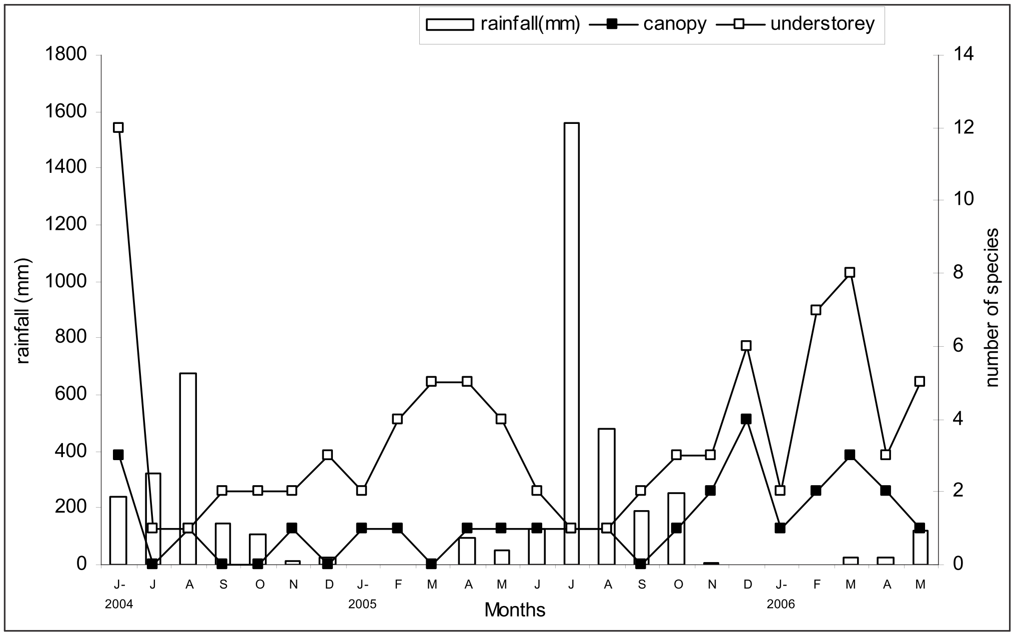

Fig. 4. Pollinated flower and rainfall in canopy and under storey trees.

Fruiting phenology

There was a significant inter-annual variation in fruit bud among trees at canopy and under storey trees (KS test, D = 0.541, p<0.0009) with lesser mean number of species (1.04±1.12) in the canopy trees (June, 2004 –May 2006) compared to under storey trees (4.20±3.14) (June 2004 – May 2006). (Z = -4.64, p<0.00003) was significant in the life form and variability across months was also significant (ANOVA, F= 21.54, p<0.0002). Immature fruit had a significant variation among life form (KS test, D = 0.791, p<0.0001), though mean number of species was significantly different during the study period in canopy (1.5±1.25), under storey trees (5.62±2.28), (Z = -7.76, p<0.000007). Variability in number of species across different months was also significantly different (ANOVA, F = 60.35, p<0.000006). Ripened/ mature fruit pattern was significantly different across years among life forms (KS test, D=0.541, p<0.0009). With lesser mean number of canopy trees with ripened fruit (2.66±1.46) and under storey trees (6.75±3.69) was significantly different (Z = -5.02, p<0.000004), Variability in number of species across different months was significantly different (ANOVA, F = 25.29, p<0.000006). Fruit senescence / fruit fall pattern was significantly different across years among life forms (KS test, D=0.541, p<0.0009). With lesser mean number of canopy trees with ripened fruit (1.75±1.48) and under storey trees (4.95±3.36) was significantly different (Z test Not significant), Variability in number of species across different months was significantly different (ANOVA, F = 18.24, p<0.0000005).

Factors influencing canopy and under storey fruiting phenology

In canopy trees fruit bud / initiation of fruit and rainfall had no significant influence during current months as well 1-3 months lag period. Where as in under storey trees fruit bud had significant negative influence during current months (r_s = -0.460, p<0.02), one month (r_s = -0.786, p<0.0008), two months (r_s = -0.726, p<0.0001) and three (r_s = -0.426, p<0.05) months lag periods indicates that most of the species initiate fruit before the rainfall begins (Fig. 5). Immature / unripened fruit in canopy trees and rainfall had no significant influence during current months as well 1-3 months lag period. Where as in under storey trees had no significant negative influence during current, one and three months lag periods. But had significant negative influence during two (r_s = -0.436, p<0.04), months lag periods indicates that most of the species had unripened fruit before the rainfall begins (Fig. 6). Ripened / mature fruit in canopy trees and rainfall had no significant influence during current months as well 1-2 months lag period but had a positive influence during three (r_s = 0.553, p<0.009) months lag period. Where as in under storey trees had significant negative influence during current (r_s = -0.434, p<0.03), one (r_s = -0.696, p<0.0002), two (r_s = -0.609, p<0.002), and three (r_s = -0.531, p<0.01) months lag period indicates that most of the species had ripened fruit before the rainfall begins in under storey trees (Fig. 7). Fruit senescence / fruit fall in canopy trees and rainfall had no significant influence during current and one month lag period but had a negative influence during two (r_s = -0.601, p<0.003) and three (r_s = -0.667, p<0.0009) months lag period. Where as in understorey trees had no significant influence during current months and had significant negative influence during one (r_s = -0.410, p<0.05), two (r_s = -0.696, p<0.0003), and three (r_s = -0.736, p<0.0001) months lag period indicates fruit senescence happenes in the absence of rainfall (Fig. 8).

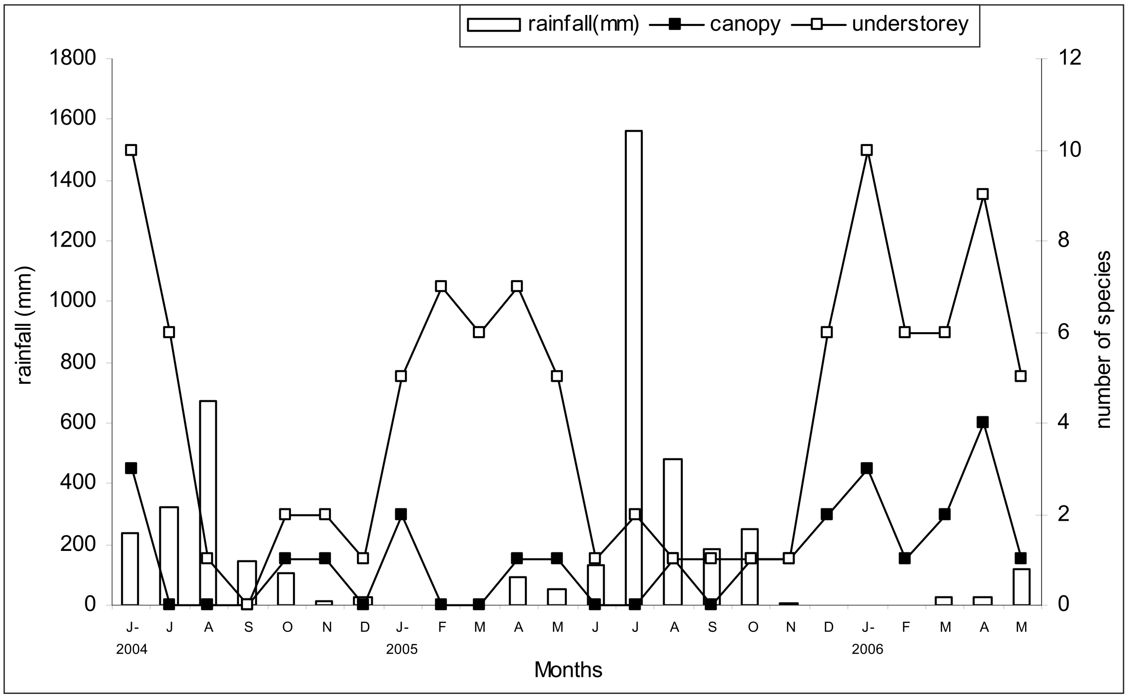

Fig. 5. Fruit bud / young fruit and rainfall in canopy and under storey trees.

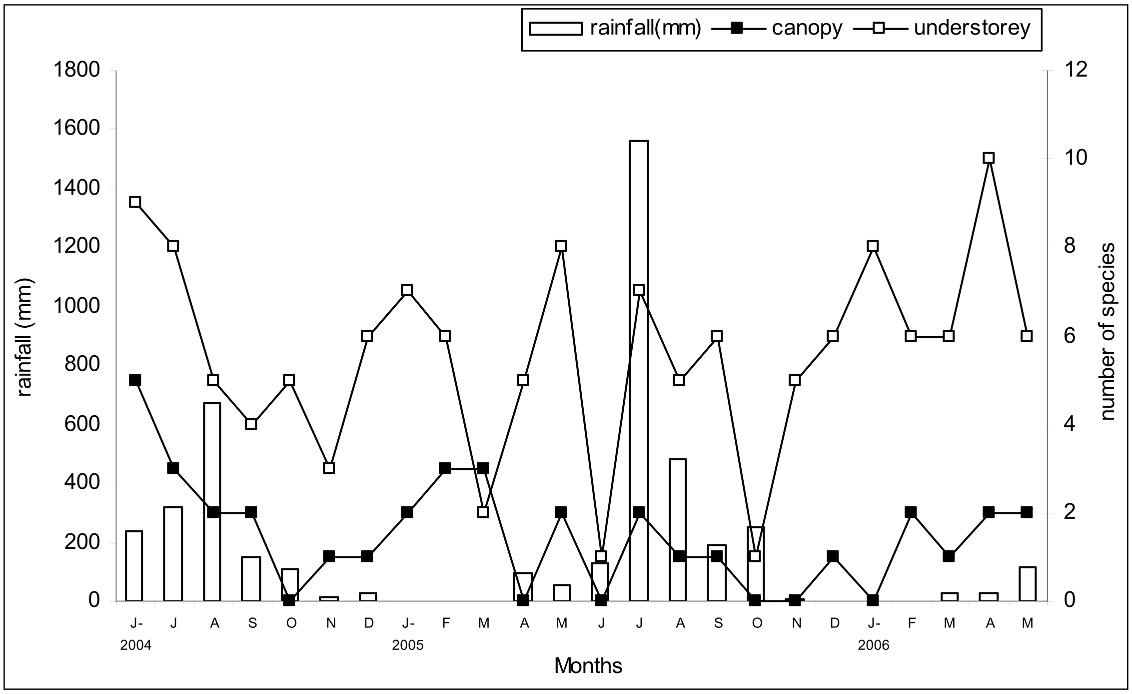

Fig. 6. Immature fruit and rainfall in canopy and under storey trees.

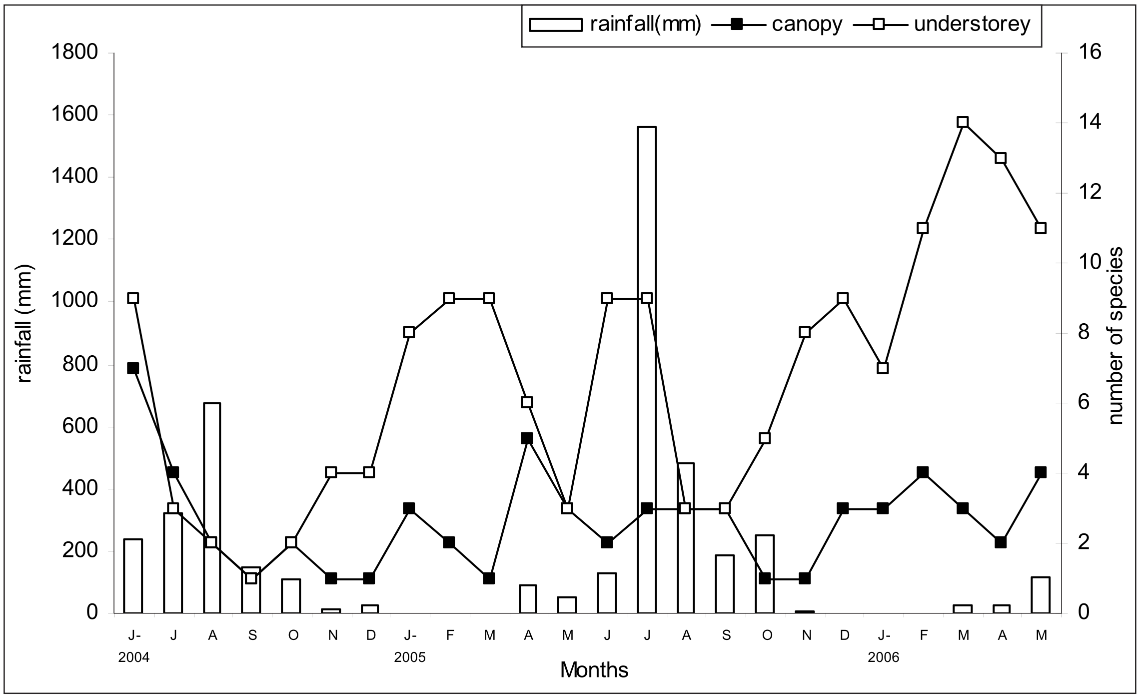

Fig. 7. Ripened / matured fruit and rainfall in canopy and under storey trees.

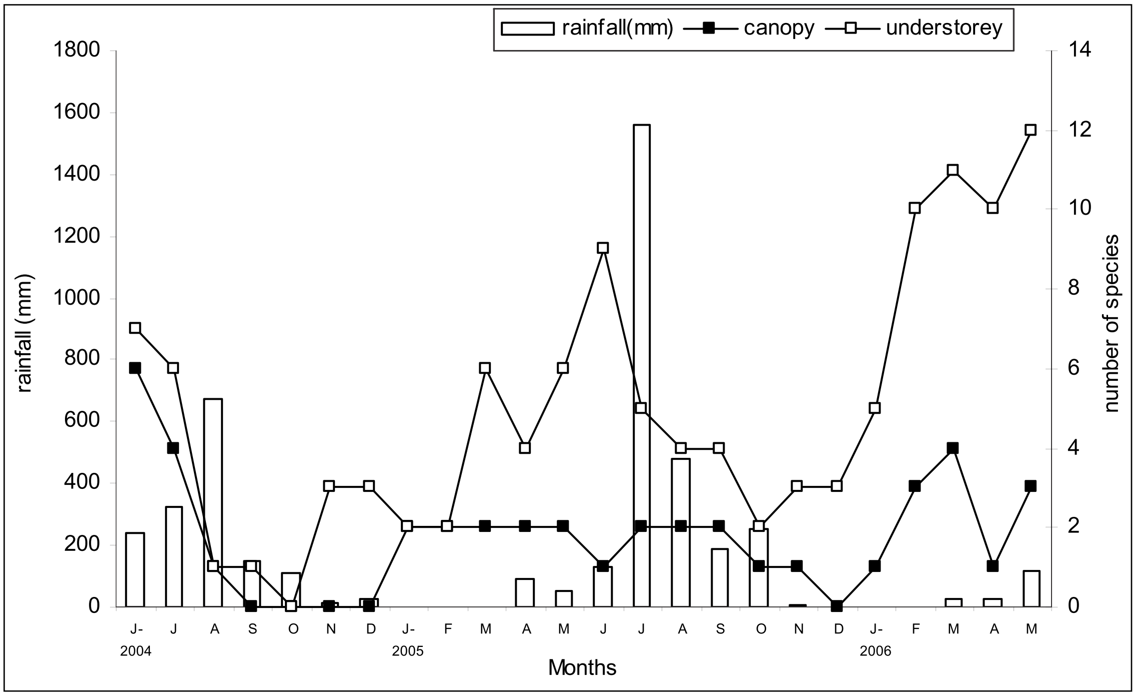

Fig. 8. Fruit senescence and rainfall in canopy and under storey trees.

Flowering seasonality of canopy and under storey trees in evergreen forests

In canopy tree species like *Artocarpus integrifolia*, *Cedrela toona*, *Cryptocarya bourdillonii*, *Elaeocarpus recurvatus*, *Gordonia* , *Mallotus tetracoccus*, *Myristica malabarica* and *Persea macrantha,* flower initiation started during the beginning of February with mean angle (32.96), flower bud opened in the middle of February (46.82) and pollination happened in the end of February month (53.73). Canopy trees responded to flowering pattern during pre-monsoon season. The strength of seasonality measured by the vector "r" indicated that flower initiation (r=0.26) as strong seasonality followed by pollinated flowers (r=0.23) and open flowers (r = 0.13). Whereas in under-storey tree species such as *Acryonychia pedunculata*, *Antidesma menasu*, *Canthium dicoccum*, *Cinnamomum verum*, *Flacourtia montana*, *Isonandra perrottetiana*, *Litsea floribunda*, *Macaranga peltata*, *Mallotus philippinensis*, *Nothapodytes foetida*, *Scolopia crenata*, *Trema orientalis* and *Vepris bilocularis,* flower initiation happened in the late of December month (353.82). Flowers open in the end of March (88.37) and pollination happened in the middle of March (77.03). The strength of seasonality measured by the vector **"r"** indicates that pollinated flowers (r=0.27) *Ligustrum roxburghii*, *Memecylon umbellatum*, *Trema orientalis* and *Trichilia connaroides* have strong seasonality followed by open flowers (r = 0.22) and initiation of flowers (r =0.13) (Table 1).

Fruiting seasonality of canopy and under storey trees in evergreen forests

In canopy tree species, fruit initiation happened in middle of February (56.14). Immature, matured fruits and fruit fall were found during the middle of May (130.56, 129.6 and 129.5). In canopy tree species fruiting pattern was observed during summer to onset of rainfall. The strength of seasonality measured by the vector **"r"** indicates that fruit initiation and fruit fall (r = 0.34) has strong and same seasonality followed by immature fruit and matured fruits (r = 0.24 and 0.18). Whereas in Under-storey tree species fruit initiation happened during the middle of March (79.12) such as *Cinnamomum verum, Isonandra perrottetiana* and *Trichilia connaroides.* Immature fruits and mature were found in the late and middle of March (85.63 and 70.71). Fruit fall was recorded during the middle of April (107.08). In under-storey trees fruiting pattern was peak during summer season. The strength of seasonality measured by the vector **"r"** indicate that fruit initiation (r=0.40) has strong seasonality followed by fruit fall (r = 0.32), mature and immature fruits (r = 0.29 and 0.09) (Table 2).

Table 1. Canopy and understorey trees flowering phenology and seasonality among species in evergreen forests.

Life form (canopy – under storey)	Phenophases Flower initiation	Open flowers	Pollinated flowers
Mean angle	32.96 – 353.82	46.82 – 88.37	53.73 – 77.03
Mean Data	2 February – 23 December	15 February – 28 March	23 February – 17 March
Mean vector **r**	0.26 – 0.13	0.13 – 0.22	0.23 – 0.27
Angular SD	93.99 – 114.67	114.68 – 99.31	97.01 – 92.02
Rayleigh's Z	3.93 – 3.89	0.491 – 4.50	1.59 – 6.51
P value	<0.019* - 0.02*	<0.616 – 0.01*	<0.205 – 0.001*

* Significant at <0.05

Table 2. Canopy and understorey trees fruiting phenology and seasonality among species in evergreen forests.

Life form (canopy – under storey)	Phenophases			
	Fruit initiation	Fruit immature	Fruit maturity	Fruit fall
Mean angle	56.14 – 79.12	130.56 – 85.63	129.6 -70.71	129.5 – 107.08
Mean Data	26 February – 19 March	13 May – 25 March	9 May – 10 March	9 May – 17 April
Mean vector **r**	0.34 – 0.40	0.24 – 0.09	0.18 – 0.29	0.34 – 0.32
Angular SD	83.97 – 76.79	95.77 – 123.17	104.7 – 89.99	84.14 – 85.80
Rayleigh's Z	2.91 – 16.75	2.20 – 1.32	2.26 – 13.74	4.85 – 12.63
P value	<0.053 - <0.000*	<0.110 - <0.265	<0.104 - <0.000*	<0.007* - <0.000*

* Significant at < 0.05

DISCUSSION

In the present study, evergreen forest flowering was noticed from January where seven species such as *Artocarpus integrifolia*, *Callicarpa tomentosa, Cedrela toona, Litsea floribunda* and *Trema orientalis* flowered. In April ten species such as *Cinnamomum verum*, *Glochidion velutinum*, *Macaranga peltata*, *Syzygium cumini* and *Trichilia connaroides* flowered before the rainfall (during summer period). Before the summer starts during December, eight species like *Croton malabaricus*, *Mallotus tetracoccus* and *Phoebe lanceolata* flowered.

In trees of evergreen forest of Kemmanugundi, average flower initiation were observed simultaneously with leaf flush. Flower initiation / bud during November and January, pollination in December. In seasonal forests of India dry season flowering is common in dry forests (Nanda 2014; Singh and Singh 1992) as well as monsoon forests (Boojh and Ramakrishnan 1981; Sundarapandian et al. 2005). There was a negative correlation between rainfall and flowering at Kemmanugundi. Similar pattern was observed in dry forests peninsular India (Prasad and Hegde 1986; Nanda 2009) and also in rainforests (Krishnan 2002; Sivaraj and Krishnamurthy 1989). Dry season flowering was also seen in other forests across globe (Anderson 2005; Heideman 1989). Dry season flowering is said to be advantageous for plants in seasonal climates as they have to partition resources for both vegetative and reproductive phases (Janzen 1974; Corlett and Frankie 1998). Lieberman (1982) predicted that in some species, time-lag between two events reflects partioning of resources for various physiological activities. Solar irradiance and rainfall are often considered as the main seasonal variables influencing the flowering phenology of tropical plants (Wright and Van Schaik 1994). Clear annual patterns of reproductive phenology has been reported in the montane cloud forest in tropical and subtropical regions where intensive annual fluctuations of rainfall in Costa Rica (Koptur et al. 1988) or irradiance in Hawaii (Berlin et al. 2000) are recognized as the major determinants of phenological events.

Burger (1974) reported that in Ethiopian dry forests, flowering response primarily in the wet season and it was in dry season in evergreen montane forest. But in Bhadra sanctuary, Karnataka; flowering phases were noticed in dry season in two forests. But the number of species responding to dryness varied. In evergreen forest, fruit initiation began in 7 species during January are *Artocarpus integrifolia, Callicarpa* *tomentosa*, *Ligustrum perrottetti* and *Trema orientalis* and with a peak in April are *Cinnamomum verum*, *Glochidion velutinum*, *Ligustrum roxburghii*, *Macaranga peltata*, *Syzygium cumini* and *Trichilia connaroides*. Fruit maturation occurred from December to July with a peak in January and February are *Callicarpa tomentosa*, *Celtis cinnamomea*, *Cedrela toona*, *Isonandra perrottetiana*, *Mallotus tetracoccus* and *Phoebe lanceolata*. Fruit fall from November to June with a peak in March and June are *Celtis cinnamomea*, *Mallotus tetracoccus*, *Ligustrum perrottetti*, *Nothapodytes foetida*, *Callicarpa tomentosa*, *Cedrela toona*, *Macaranga peltata*, *Mallotus philippinensis*, *Myristica malabarica*, *Sterculia guttata* and *Vernonia arborea* .

Fruit bud initiates during January (winter) and April (summer) as rainfall had negative influence on fruiting phenology at Kemmanugundi. Time lag correlations were significant. Similar pattern of fruiting was also observed in Tai National park, Cote d Ivoire (Anderson 2005). Fruit ripened with different seasonal peaks from January (winter) – April (summer) and in July (rainy). Fleshy fruited species in Kibale National Park showed positive correlation with rainfall and pattern of influence is dependent on the dispersal strategies of species (Chapman et al. 2005). Coastal vegetation in Brazil did not show correlation between rainfall and fruiting pattern (Medway 1972). Similarly there was no correlation between fruit production and monthly precipitation at Afromontane forests in South Africa (Wirminghaus 2007). Mast fruiting in Malaysian dipterocarp forest is influenced by temperature as drop in minimum temperature promotes heavy flowering (Ashton et al. 1988). Minimum temperature is also shown to influence fruit production in tropical forests of Gabon (Tutin and Fernandez 1993). At the community level both maximum and minimum temperature influenced fruiting in a Mexican lower montane forest (Williams – Linera 1997).

Fruiting phenology in moist forests of northeast India corresponds with rainfall periodicity though correlation with rainfall is not explicitly stated (Kikim and Yadava 2001). Moist forests of the Western Ghats also showed similar trend with rainfall and fruiting phenology. Fruit falling in June (rainy) and March (summer) with a major and minor peak. But fruiting in species that are dispersed by birds such as great pied horn bill was during the dry season in the rain forest of southern Western Ghats and they found that fruiting was scarce during the wet season (Kannan and James 1999). Hence it may be suggested that unlike other evergreen forests phenology of trees in Kemmanugundi show a significant negative correlation with environmental factor especially to precipitation.

ACKNOWLEDGEMENTS

We thank department of the Ministry of Environment and Forests, Government of India for financial support project No.14/10/2001-ERS-RE, 2003 as a research fellowship for the first author. Thanks to Forest department of Karnataka for permission to work in Bhadra wildlife sanctuary, and the Baby coffee estate Kemmanugundi for data on rainfall unfortunately no other climatic data is available.

REFERENCES

Aide TM 1988 Herbivory as a selective agent on the timing of leaf production in a tropical understorey community. Nature 336: 574-575.

Anderson DP, Nordheim EV, Moermond TC, Gon Bi ZO and Boesch C 2005 Factors influencing tree phenology in Tai National Park, Cote d Ivoire. Biotropica 37:631 – 640.

Ashton PS, Givinish TG and Appanah S 1988 Staggered flowering in the Dipterocarpaceae: new insights into the floral induction and evolution of mast fruiting in the aseasonal tropics. American Nauralist 132:44-66.

Berlin KE, Pratt TK, Simon JC and Kowalsky JR 2000. Plant phenology in a cloud forest on the island of Maui, Hawaii. Biotropica 32: 90-99.

Bhat DM 1992 Phenology of tree species of tropical moist forest of Uttara Kannada district, Karnataka, India. Journal of Bioscience 3:325-352.

Boojh R and Ramakrishnan PS 1981 Phenology of trees in subtropical evergreen mountain forest in north-east India. Geo-Eco-Trop 5: 189 -209.

Borchert R 1994 Soil and stem water storage determine phenology and distribution of tropical dry forest trees. Ecology 75: 1437-1449.

Borchert R, Rivera G and Hagnauer W 2002 Modification of vegetative phenology in a tropical semi-deciduous forest by abnormal drought and rain. Biotropica 34: 27-39.

Burger WC 1974 Flowering periodicity at four altitudinal levels in eastern Ethiopia. Biotropica 6: 38-42.

Champion HG and Seth SK 1968 Revised survey of the forest types of India. Government of India Press. Howrah.

Chapman CA, Chapman LJ, Struhsaker TT, Zanne AE, Clark CJ and Poulson JR 2005 A long-term evaluation of fruiting phenology: importance of climate change. Journal of Tropical Ecology l21: 31–45.

Corlett RT and J. la Frankie 1998 Potential impacts of climate change on tropical Asian forests through an influence of phenology. Climate Change 39: 439-453.

Gamble JS and Fischer CEC 1998 Flora of the Presidency of Madras (Vols 1-3), Adlard and Son, Ltd, 21, Hart Street, W.C. 2017p.

Heideman PD 1989 Temporal and spatial variation in the phenology of flowering and fruiting in a tropical rainforest. Journal of Ecology 77: 1059 – 1079.

Kannan R James DA 1999 Fruiting phenology and the conservation of the great pied hornbill (*Buceros bicornis*) in the Western Ghats of southern India. Biotropica 31: 167-177.

Kikim A and Yadava PS 2001 Phenology of tree species in the subtropical forests of Manipur in northeastern India. Tropical Ecology 42: 269 -276.

Koptur S, Haber WA, Frankie GW and Baker HG 1988 Phenological studies of shrub and treelet species in tropical cloud forests of Costa Rica. Journal of Tropical Ecology 4: 323-346.

Krishnan R 2002 Reproductive phenology of a wet forest understorey in the Western Ghats, south India. Global Ecology Biogeography 11: 179-182.

Kushwaha CP Singh SP 2005 Diversity of leaf phenology in a tropical deciduous forest in India. Journal of Tropical Ecology 21: 47-56.

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

Loechowicz MJ 1984 Why do temperate deciduous trees leaf out at different times? Adaptation and ecology of forest communities. American Naturalist, 124: 821-842.

Medway L 1972 Phenology of tropical rain forest in Malaya. Biological Journal of Linnean Society 4: 117-146.

Morellato LP, Talora DC, Takahasi A, Bencke CC, Romera EC and Zipparro VB 2000 Phenology of Atlantic rain forest trees: A comparative study. Biotropica, 32: 811-823.

Murali KS and Sukumar R 1993 Leaf flushing phenology and herbivory in a tropical dry deciduous forest southern India. Oecologia 94: 114-119.

Nanda A 2009 Vegetative and Reproductive Phenology of Tropical Forest Communities in the Areas of Bhadra

Wildlife Sanctuary, Karnataka, PhD Thesis. Kuvempu University, Karnataka. 183p.

Nanda A, Krishnamurthy YL and Suresh HS 2014 Phenology of a tropical dry deciduous forest of Bhadra wildlife sanctuary, southern India. Ecological Processes 3:1: 1-12.

Neginhal SG 2004 Forest trees of South India. Navbharath Press, Bangalore 447p.

Opler PA, Frankie GW and Baker HG 1976 Rainfall as the factor in the release, timing and synchronization of anthesis by tropical trees and shrubs. Journal of Biogeography 3: 321-336.

Parameshwar G 2001 Draft Management Plan for Bhadra Wildlife Sanctuary, (1996-2001), Publication: Wildlife Division, Chikmagalur, Karnataka Forest Department, 43p.

Prasad SN and Hegde M 1986 Phenology and seasonality in the tropical deciduous forest of Bandipur, south India. Proceedings of Indian Academy of Sciences 96: 121-133.

Raju R and Heggde S N 1995 Bhadra Wildlife Sanctuary, a Fragile Ecosystem. Indian Forester. 121: 938-948.

Ramaswamy SN, Rao MR and Govindappa DA 2001 Flora of Shimoga District Karnataka. Prasaranga University of Mysore, Manasagangotri, Mysore 753p.

Saldhana CJ 1996 Flora of Karnataka Vol-I-IV. Oxford and IBH Publishing Co. Pvt. Ltd, New Delhi, 839p.

Singh JS and Singh VK 1992 Phenology of seasonally dry tropical forest. Current Science 63: 684 -688.

Singh SP and Kushwaha CP 2006 Diversity of flowering and fruiting phenology of trees in a tropical deciduous forest in India. Annals of Botany 97: 265-276.

Sivaraj N and Krishnamurth, KV 1989 Flowering phenology in the vegetation of Shervroys, South India. Vegetatio 75: 85-88.

Sundarapandian SM, Chandrasekaran S and Swamy PS 2005 Phenological behavior of selected tree species in tropical forests at Kodayar in the Western Ghats, Tamilnadu, India. Current Science 88:805-810.

Tutin CEG and Fernandez M 1993 Relationships between minimum temperature and fruit production in some tropical forest trees in Gabon. Journal of Tropical Ecology 9: 241 – 248.

Van Schaik CP, Terborgh JW and Wright SJ 1993 Phenology of tropical forests: adaptive significance and consequences for primary consumers. Annual Review of Ecology and Systematics 24: 353-377.

Williams – Linera G 1997 Phenology of deciduous and broadleaved-evergreen tree species in a Mexican tropical lower montane forest. Global Ecology and Biogeography Letters 6: 115-127.

Wirminghaus JO, Browns CT, Symes CT and Perrin MR 2007 Fruiting in two afromontane forests in kwaZulu-Natal, South Africa: the habitat type of the endangered cape Parrot *Poicephalus robustus*. South African Journal of Botany 47: 325-332.

Wright SJ and Calderon O 1995 Phylogenetic patterns among tropical flowering phenologies. Journal of Ecology 83: 937-948.

Wright SJ and Van Schaik CP 1994 Light and the phenology of tropical trees. American Naturalist 143: 192-199.

Yoganarasimhan SN, Subramanyam K and Razi BA 1982 Flora of Chikkamagalur District, Karnataka, India, International Book Distributors, Deharadun, 407p.

Zar J 2007 Biostatistical Analysis. Pearson Education, London. 663p.