J.Natn.Sci.Foundation Sri Lanka 2011 **39** *(4):333-343*

RESEARCH ARTICLE

Vegetative phenology of tropical montane forests in the Nilgiris, South India

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Revised: 28 August 2010 ; Accepted: 20 May 2011

Abstract: Spatial and temporal variation in foliar phenology plays a significant role in growth and reproduction of a plant species. Foliar phenology is strongly influenced by environmental factors such as rainfall. A study on phenology of tropical montane forests was undertaken in three different forest patches of the Nilgiri Mountains in peninsular India above 2000 meters ASL. Since August 2000, 500 trees belonging to 70 species of angiosperms were monitored for both vegetative and reproductive phenologies on a monthly basis. Climate data were collected from nearby weather stations. This paper reports results of the study from August 2000 – August 2003 on foliar phenology. Non-parametric correlations and multiple regressions were performed to analyse the influence of environmental factors such as rainfall, temperature and sunshine on foliar phenology. It was found that moisture related factors had a negative influence on the leaf initiation. Circular statistical analyses were performed to understand the seasonality in different phenophases of foliar phenology. Different phenophases of leafing were not significantly seasonal. Results are discussed and compared among three different forest patches on the Nilgiri plateau and also with other montane forest patches across the globe.

Keywords: Environmental factors, foliar phenology, India, Nilgiris, seasonality, tropical montane forest.

INTRODUCTION

Traditionally phenology includes a description of seasonal activities in plants and animals in relation to environmental factors. Of late in the face of climate change, global modelling and monitoring, phenology has emerged as a major focus of ecological research (Schwartz, 1998). Phenological studies often address short-term responses of species or communities to environmental factors (Singh & Kushwaha, 2005). Documentation of timing and duration of phenological events are essential to understand species interrelations and their links to environmental perturbations. Such knowledge of phenological events, variations in phenophases among individuals of the same species as well as among different species, is essential to understand the impact of environmental perturbations on tropical trees. Thus long-term phenological records help in the understanding of not only species specific patterns but also responses of various species to environmental disruptions.

The association of climatic factors or interactions with pollinators or dispersers on the seasonal patterns of leaf flush, flowering and fruiting is well known (Frankie *et al*., 1974; Opler *et al*., 1976; van Schaik *et al*.,1993). In more seasonal forests such as tropical dry forests, rainfall is a crucial environmental factor that triggers the process of leaf flush or flower initiation (Reich & Borchert, 1984; Prasad & Hegde, 1986; Bullock & Solis-Magallenus, 1990; Murali & Sukumar, 1993) while Wright & van Schaik (1994) and Wright (1996) highlighted the influence of solar irradiance along with rainfall. Van Schaik (1993) proposed the insolation - limtation hypothesis, which predicts that unless limited by water availability, community-wide leafing and flowering phenology in tropical forests should coincide with the period of maximal insolation. But Reich and Borchert (1984) found no evidence for this hypothesis in neotropical dry forests. However, Borchert (1992) found that leafing and flowering events in tropical forest trees are more related to changes in water status of individual trees. The role of biotic factors such as herbivory on the evolution of timing of leafing events has also been examined in tropical forests (Aide, 1988; Lieberman & Lieberman, 1984; Murali & Sukumar, 1993).

Tropical montane forests or cloud forests are unique ecosystems in the world where the environment has a very

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strong influence on the physiognomy and biotic processes of the community. Most of the studies on phenology were restricted to either lowland tropical moist forests (Medway, 1972; Frankie *et al*., 1974; van Schaik, 1986; Ashton *et al*., 1988; Bhat, 1992), which are extremely rich in species and aseasonal, or in dry forests (Prasad & Hegde, 1986; Bullock & Solis-Magallenus, 1990; Murali & Sukumar, 1993, 1994; Borchert, 1994) where a strong seasonality exists and comparatively species poor. There are only a few studies on the phenology in montane cloud forests (Koptur *et al*., 1988; Sun *et al*., 1996; Berlin *et al*., 2000; Funch *et al*., 2002; Kudo & Suzuki, 2004).

The present paper describes the patterns observed on the vegetative phenology of tropical montane forest patches in the upper Nilgiri plateau. It addresses the following questions; 1. What is the influence of abiotic factors on leafing phenology of the montane forest? and 2. What are the patterns of seasonality observed in various leafing phenophases? This study is part of our long-term ecological studies on the tropical montane forest patches of the Nilgiri Biosphere Reserve and probably the first report on the phenology of tropical montane forest patches of the Nilgiris.

Study area

The present study was carried out in three sites, namely Longwood (11° 43' N, 76° 87' E) 2100 masl, Thaishola-Carrington (11° 21' N, 76° 87' E), 2200 masl and Upper Bhavani (11° 24' N, 76° 56' E), 2300 masl, in the upper plateau of the Nilgiri hills in southern India. The plateau is undulating with hills and valleys having a mean elevation of 1800 masl and its highest point is Doddabetta peak (2640 m). The plateau receives rainfall mostly from southwest monsoon which accounts for more than 50% of the rainfall. The retreating monsoon, i.e. northeast monsoon, and convectional rain brings the rest. The mean annual temperature of the plateau is 14.2 °C with May being the hottest month and December the coldest. Thermographs installed by Blasco and Legris (French Institute, Pondicherry, India) on grasslands have recorded a temperature of (-9 °C) during cold months. Von Lengerke (1977) recorded incidence of frost in the plateau. Detailed climate analysis of the plateau is available (Von Lengerke, 1977).

Vegetation

The natural vegetation of the plateau is a mosaic of forest and grasslands. Forests of the plateau are locally called *Shola* (dense woods) or tropical stunted montane evergreen forests (TSMF). Meher-Homji (1967) recognizes three types of physiognomic formations. 1.) *Shola*, 2.) Tree and shrubby zone at the edge of the forest, i.e. ecotone, and 3.) the shrub-savanna or the grasslands. *Shola* or TSMF is a distinct patch of forest with stunted trees confined to folds or ridges of mountains and surrounded by grasslands. The crown is dense and the leaves are coriaceous. Tree trunks are covered with mosses, lichens and epiphytes. The canopy is dominated by Lauraceaous species such as *Cryptocareya nessiana, Cinnamomum malabathrum, Beischemedia wightii* and *Litsea* spp. Other species in the canopy include *Syzygium* spp., *Elaeocarpus* spp. and *Isonandra candolleana*. *Shola* are rich in undergrowth of Rubiaceaous shrubs. The ecotone is dominated by more light demanding species such as *Strobilanthus* spp., *Hedyotis* spp. and *Mahonia leschenaultiana*. The shrub-savanna is dominated by shrubs belonging to species such as *Gaultheria fragrantissima, Rhododendron nilagiricum* and *Hypericum* spp. Grass flora include *Chrysopogon* spp., *Andropogon* spp. and *Eragrostis* spp. Herbaceous flora is dominated by species belonging to Fabaceae, Rosaceae, Asteraceae and Apiaceae. With the advent of British rule during 19th century, the landscape has undergone several modifications. The area under plantations and agriculture has increased. Forestry plantations of Eucalypts (*Eucalyptus* spp.), Wattle (*Acacia* spp.) and Pines (*Pinus* spp.) have been added to the landscape.

METHODS AND MATERIALS

Trees with clearly visible canopies were identified, measured for girth and marked with a unique tag for monitoring phenology along a transect. Trees were monitored once a month for both vegetative and reproductive phenologies. Vegetative phenology involved various stages of leafing such as leafless stage, leaf flushing, expanding leaves, mature leaves and senescent leaves. All individuals were scored on a 0 – 100 scale qualitatively based on the intensity of a given phenophase in the canopy. A note on the herbivory was also made. Information on pollination, dispersal and predation of fruits was also collected. Data on climate were collected from the closest tea estates maintained by Tamilnadu Tea Corporation (Longwood site), Thaishola Tea Estate (Carrington site) and Korakundah Tea Estate (Upper Bhavani site). Data on soil moisture were estimated by collecting 500 g of soil from ten locations in each transect. The soil thus collected was air dried for a sufficient time and weighed to obtain a dry weight. The difference was expressed as a percentage and the mean value was taken as soil moisture for a given month.

Spearman's rank correlation was performed during corresponding months and time lag periods to test the influence of environmental factors on various phenophases independently. Multiple regressions were performed, both during corresponding months and during time lag periods, to elucidate the influence of all factors in combination. Stepwise regression was performed to highlight the degree of influence of environmental factors that affect the phenophase. The differences in distribution of species in each phenophase across different sites with the Kolmogorv –Smirnov test (KS Test) were examined. Circular statistical analysis was also performed to examine the seasonality of the leafing in different forest patches.

RESULTS

The different phenophases of vegetative phenology showed uni-modal distribution unlike the bi-modal distribution reported from other studies (Sun *et al*., 1996). There was no difference in leaf flushing pattern, expansion or leaf senescence over years at Thiashola-Carrington, Upper Bhavani and Longwood sites (KS test, not significant) (Figures 1a,b,c) .

Factors affecting phenology

Leaf flushing phenology: When environmental factors were analysed independently for their influence on leaf flush at Thiashola-Carrington site, rainfall (r_s = -0.466, p<0.003) (Figure 2a) and soil moisture (r_s = -0.620, p<0.00004) had a significant negative influence during the corresponding months. During one month lag period, rainfall (r_s = -0.488, p<0.002) and the number of rainy days (r_s = -0.409, p<0.01) had negative influence on leaf flush. Correlations during the two month lag period were not significant.

Multiple regression during the corresponding months was significant [r = 0.603, F (6, 30) = 2.867, p<0.02] with soil moisture as the factor that had a significant influence on leaf flush. Soil moisture alone accounted for more than 95% of the variability in the pattern observed with leaf flushing at Thaishola-Carrington site. Multiple regressions during the time lag period were not significant.

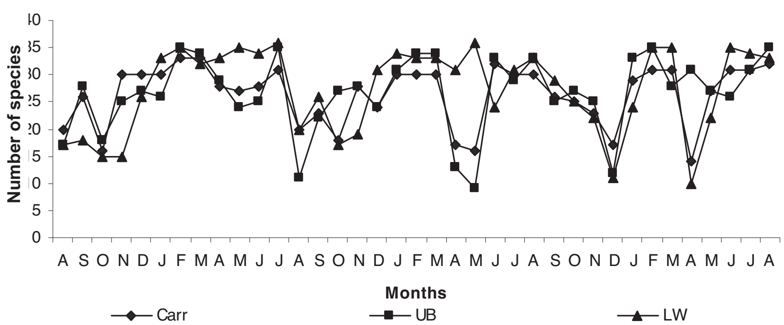

Figure 1 a: Leaf flush pattern across three montane forest sites in the Nilgiris

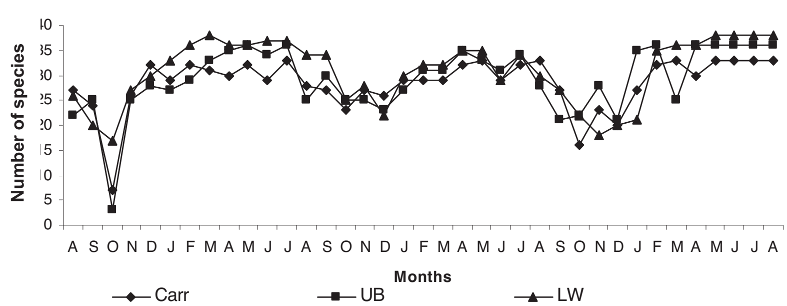

Figure 1 b: Leaf expansion pattern across three montane forest sites in the Nilgiris

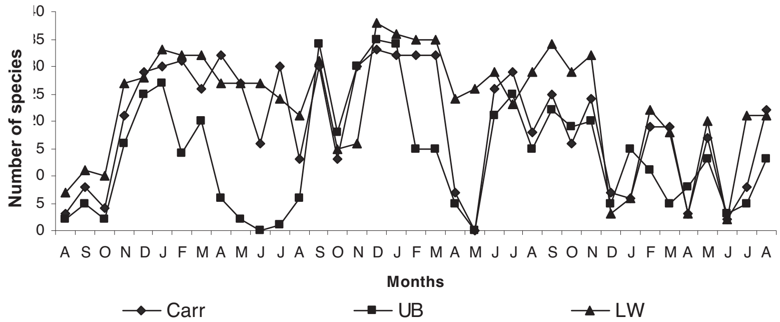

Figure 1 c: Leaf senescence pattern across three montane forest sites in the Nilgiris.

At Upper Bhavani site, soil moisture (r_s = -0.351, p<0.03) had a significant negative influence during the corresponding months, while rainfall (r_s = -0.389, p<0.01) (Figure 2b) significantly influenced leaf flush during the one month lag period. Rainfall and the number of rainy days (r_s = -0.362, p<0.03) had a significant negative influence during the two month lag period. Although rainfall had a negative influence during the two month lag period, the strength of the correlation was strong during the one month lag period.

Multiple regressions either with corresponding months or time lag periods were not significant. But moisture related factors had a negative influence.

None of the factors had a significant influence on leaf flushing during the corresponding months when analysed independently at Longwood site. Rainfall (r_s = -0.456, p<0.005) (Figure 2c) and the number of rainy days (r_s = -0.444, p<0.006) had a negative influence, while sunshine (r_s = 0.408, p<0.01) positively influenced the leaf flush during the one month lag period. During the two month lag period, moisture related factors had a significant negative influence but the strength of the correlation was strong for sunshine (r_s = 0.473, p<0.004).

Multiple regression during the corresponding months was not significant. Multiple regression during the one-month lag period was significant [r = 0.672, F(6,29) = 3.99, p<0.004] though no single factor had any influence. Rainfall explained the maximum variability in the regression (stepwise regression). The two month lag period regression was not significant.

Leaf expansion phenology: Maximum temperature (r_s = 0.458, p<0.004) (Figure 4) had a positive influence while soil moisture (r_s = -0.436, p<0.006) had a negative influence on leaf expansion at Carrington site during the corresponding months, when analysed independently. During the one month lag period, it was rainfall (r_s = -0.372, p<0.02) that had a negative influence while other factors had no influence. The number of rainy days (r_s = -0.450, p<0.006) and sunshine hours (r_s = 0.590, p<0.0001) had a significant influence during the two month lag period. Although rainfall and maximum temperature had an influence, the strength of the correlation was weak.

Multiple regression during corresponding months was significant [r = 0.654, F (6, 30) = 3.74, p<0.006] with soil moisture as the significant environmental factor. Regression during the one month lag period was significant with soil moisture significantly influencing leaf expansion. Soil moisture explained the maximum variance in the data (stepwise regression).

At Upper Bhavani site, maximum temperature had a positive influence during corresponding months (r_s = 0.52, p<0.0008) (Figure 5) and the one month lag period (r_s = 0.47, p<0.003). However, during the two month lag period, both rainfall (r_s = -0.52, p<0.001) and the number of rainy days (r_s = -0.62, p<0.00005) had a highly significant negative influence while sunshine (r_s = 0.59, p<0.0001) had a significant positive influence.

Multiple regression during corresponding months is significant [r = 0.59, F (6,30) = 2.73, p<0.03] with minimum temperature being a significantly influencing factor. Forward stepwise regression was significant. It was the combination of four factors such as maximum temperature, minimum temperature, the number of rainy days and soil moisture that explained the influence on the process of leaf expansion.

Multiple regression during the one month lag period is also significant [r = 0.59, F (6, 29) = 2.59, p<0.03] with no factor having significant influence according to the analysis. It was the combination of factors such as maximum temperature, minimum temperature and the number of rainy days that influenced the process of leaf expansion. Multiple regression during the two month lag period is significant [r = 0.78, F (6,28) = 7.34, p<0.00009] with no single factor having influence. Thus it was the influence of the number of rainy days that explained the process of leaf expansion during this period.

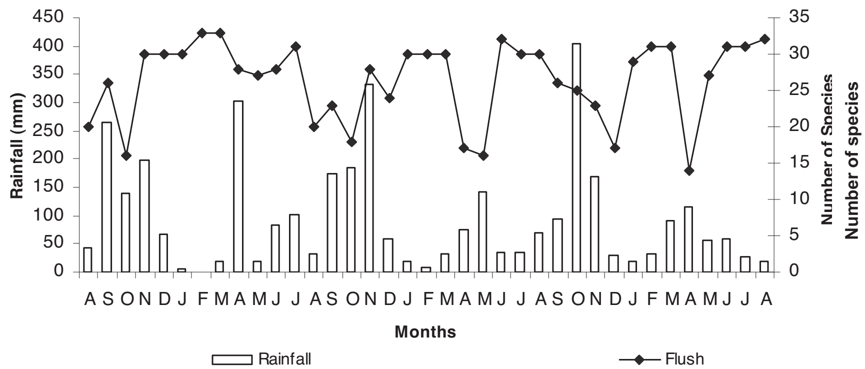

Figure 2 a: Leaf flush and rainfall at Carrington site, Nilgiris (bars represent total monthly rainfall and line represents the number of species flushing in different months)

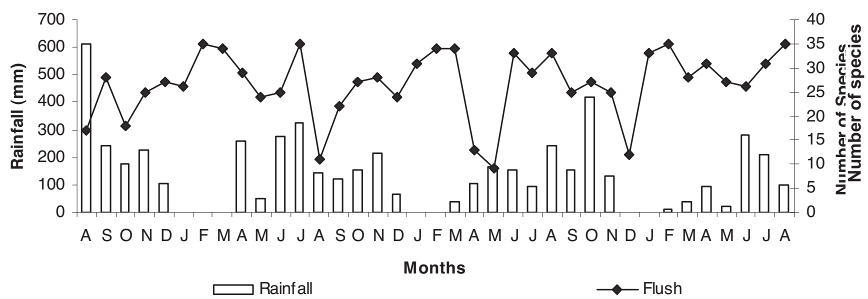

Figure 2 b: Leaf flush and rainfall at Upper Bhavani site

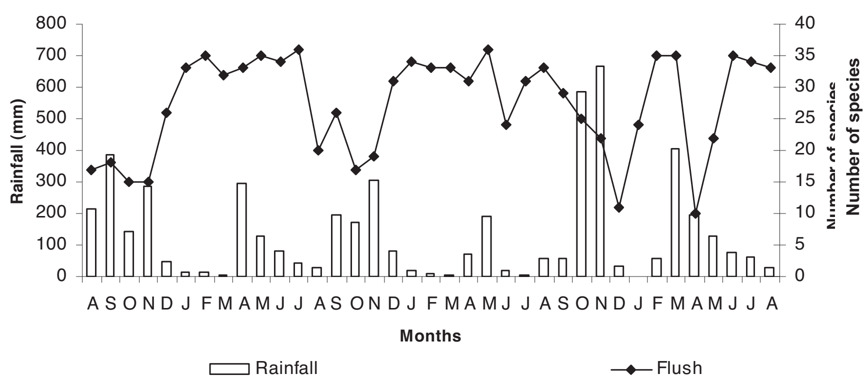

Figure 2 c: Leaf flush and rainfall at Longwood site

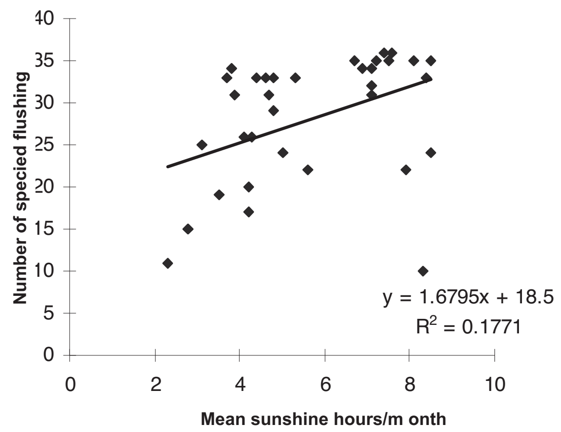

Figure 3: Two month lag influence of sunshine on leaf flush at Longwood site

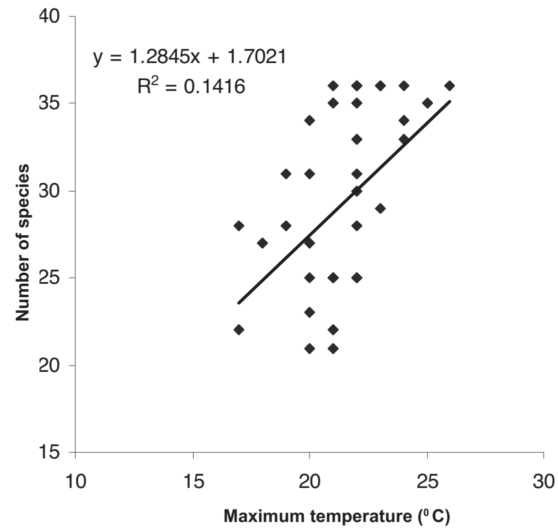

Figure 5: Influence of maximum temperature on leaf expansion at Upper Bhavani

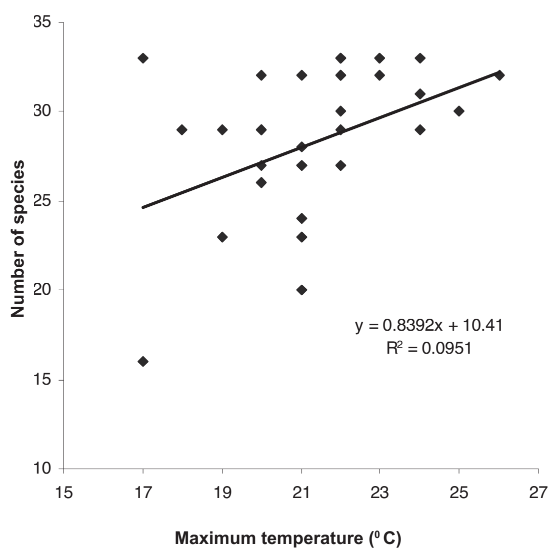

Figure 4: Influence of maximum temperature on leaf expansion at Carrington site

At Longwood site, leaf expansion was positively influenced by maximum temperature ($r_s = 0.47$, $p<0.002$) (Figure 6) during the corresponding months. During the one month lag period moisture related factors such as rainfall and the number of rainy days had a negative influence. Sunshine had maximum influence during the two month lag period ($r_s = 0.65$, $p<0.00001$) though its influence was significant during the one month lag period as well ($r_s = 0.53$, $p<0.0008$).

Multiple regression during the corresponding months was significant [$r = 0.59$, $F(6,30) = 2.73$, $p<0.02$] with no single factor influencing the process. It was maximum temperature (positive) and rainfall (negative) that influenced the process (stepwise regression). Multiple regressions during both time lag periods were significant [$r = 0.72$, $F (6,29) = 5.32$, $p<0.0008$, one month lag] [$r = 0.73$, $F (6,28) = 5.45$, $p<0.0007$, two month lag] with sunshine having a significant positive influence while rainfall had a negative influence.

Leaf senescence phenology: Dropping of leaves is a continuous process in montane forests of Nilgiris. Yet environmental factors influence this event. At Carrington site soil moisture had a negative influence on the event during corresponding months ($r_s = -0.41$, $p<0.01$) (Figure 7). Time lag correlations were not significant.

Multiple regression during corresponding months was not significant (at $p<0.05$ level) but soil moisture turned out to be a significantly influencing factors. Soil moisture explained most of the variability in the regression (stepwise regression). The one month lag regression was also not significant. But soil moisture had a significant influence, soil moisture along with sunshine and minimum temperature explained the influence on the process of leaf senescence. The two month lag period regression was not significant.

At Upper Bhavani site maximum temperature had a significant negative influence ($r_s = -0.51$, $p<0..001$) (Figure 8) during the corresponding months and the one month lag period (r_s = -0.41, p<0.01). Correlations during the two month lag period were not significant.

Multiple regression during the corresponding month was significant [r = 0.64, F(6,30) = 3.50, p<0.009] with maximum temperature having a negative influence. The negative influence exerted by maximum temperature and rainfall explained the process of leaf senescence (stepwise regression). Multiple regressions during both the one month and the two month lag periods were not significant. But maximum temperature having a negative influence during the one month lag period and sunshine having a negative influence during the two month lag period explained the process of leaf senescence.

It was soil moisture that influenced leaf senescence in Longwood site during the corresponding months (r_s = -0.41, p<0.01) (Figure 9). Correlations during either lag periods were not significant.

Multiple regression during the corresponding months was not significant. But it was soil moisture that influenced the process of senescence. Multiple regression during the one month lag period was not significant while it was significant during the two month lag period [r = 0.59, F (6,28) = 2.55, p<0.04] with no factor having significant influence. The duration of sunshine and rainfall influenced the process of senescence during the lag periods.

Seasonality of phenophases

Seasonality or cyclicity in a given phenophase was quantitatively measured. The question answered here is, are various phenophases in leafing phenology cyclic? How strong is the seasonality? Following are the parameters that characterize the seasonality. They include mean angle "a", the angular dispersion and vector "r", a measure of concentration around the mean angle, otherwise the strength of seasonality. To calculate these parameters dates of observations were transformed to angles following Zar (2004). A statistical software STATISTIXL version 4.1 for Windows was used to estimate the parameters. Rayleigh's Z test was used to determine whether the distribution of phenological activity was significantly nonrandom. The hypothesis tested here is

H_0 = dates are distributed uniformly (randomly) around the year consequently, no seasonality

H_A = dates are not distributed uniformly around the year consequently, there is seasonality.

If H_A is accepted the intensity of concentration around the mean angle denoted by r can be considered as the measure of seasonality. Parameter r has no units; it ranges from 0 (totally uniform or random) to 1 (strongly seasonal) and is a measure of temporal concentration of phenological activity.

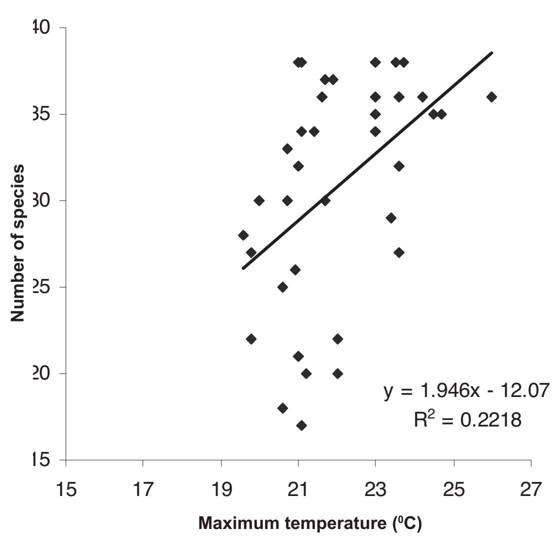

Figure 6: Influence of maximum temperature on leaf expansion at Longwood

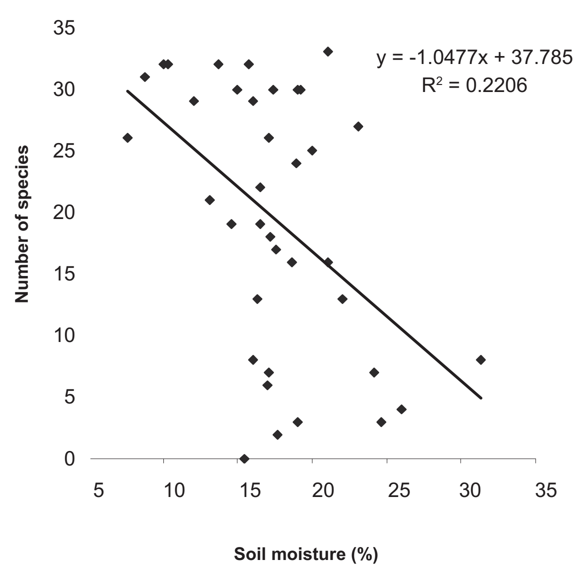

Figure 7: Influence of soil moisture on leaf senescence at Carrington site

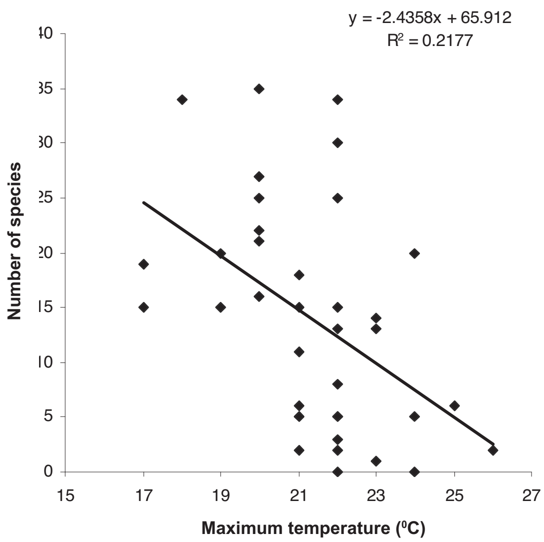

Figure 8: Influence of maximum temperature on leaf senescence at Upper Bhavani site

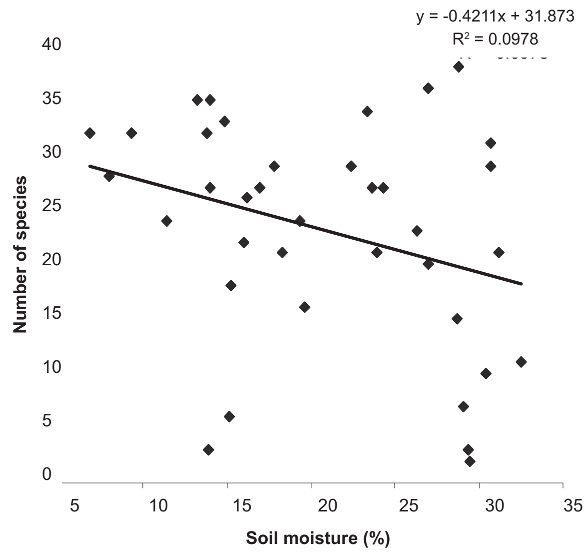

Figure 9: Influence of soil moisture on leaf senescence at Longwood site

Table 1: Results of the circular statistical analysis testing for the occurrence of seasonality in different phenophases of leafing among species in a montane forest site at Carrington

Parameter	Leaf initiation	Leaf expansion	Leaf senescence
Sample size (N)	977	1049	720
Mean angle (a)	131.954	145.83	41.25
Circular SD	144.81	121.96	122.09
Mean vector (r)	0.041	0.104	0.103
Rayleigh's Z	1.64	11.29	7.67
Significance level	<0.193 NS	<0.0001	<0.0001

Table 2: Results of the circular statistical analysis testing for the occurrence of seasonality in different phenophases of leafing among species in a montane forest site at Upper Bhavani

Parameter	Leaf initiation	Leaf expansion	Leaf senescence
Sample size (N)	986	1079	518
Mean angle (a)	112.7	144.07	348.113
Circular SD	141.67	115.98	93.88
Mean vector (r)	0.046	0.129	0.261
Rayleigh's Z	2.181	17.91	34.93
Significance level	<0.113 NS	<0.0001	<0.0001

Community-wide leaf flushing at Carrington site is not seasonal while leaf expansion and leaf senescence are seasonal. But the strength of seasonality ("r") is very low. The results are tabulated in Table 1. Leaf flush is a continuous process in forest patch at Carrington though many species have new leaves during early April. Most of the species have expanding leaves by the end of April, which is seasonal. Most species drop the leaves by mid February.

At Upper Bhavani site the community-wide pattern is similar to Carrington site. Results of seasonality are given in Table 2.

Table 3: Results of the circular statistical analysis testing for the occurrence of seasonality in different phenophases of leafing among species in a montane forest site at Longwood

Parameter	Leaf initiation	Leaf expansion	Leaf senescence
Sample size (N)	1012	1140	854
Mean angle (a)	136.77	150.74	83.34
Circular SD	116.19	112.83	137.47
Mean vector (r)	0.128	0.144	0.056
Rayleigh's Z	16.56	23.58	2.69
Significance level	<0.0001	<0.0001	<0.067 NS

Although species at Upper Bhavani site initiate leaves earlier than at Carrington site, expansion of leaves at both these sites takes place around the same time. Species drop their leaves much earlier than in the Carrington site. Strength of seasonality is comparatively high at leaf senescence stage.

At Longwood site, in contrast to Carrington and Upper Bhavani sites, the leaf flushing event is seasonal while leaf senescence is not seasonal. Most species at Longwood flush in mid April and expand during early May. Leaf senescence occurs during early March. Although some of the events are seasonal, the strength of seasonality is weak. The results of seasonality are given in Table 3.

DISCUSSION

Leaf phenology is a display of complex interactions between environmental factors. Most of the studies have examined the influence of rainfall on leafing, flowering and fruiting as rainfall is the most easily measurable variable and data is available for most sites. This study along with rainfall includes other environmental parameters such as temperature, soil moisture and sunshine that can potentially influence the leafing phenology. Leaf phenology involves phenophases such as flushing, expanding, and mature and senescent stages. This paper is concentrated on influences of environmental factors on flushing, expanding and senescent stages of leaf phenology. According to our study in three montane forest sites, trees reach a peak in leaf flushing during the dry season before the onset of rains. This pattern was also observed in the deciduous forest trees from the same region (Murali & Sukumar, 1993). Similar dry season leaf flushing was also observed in other montane forest sites (Koptur *et al*., 1988; Sun *et al*., 1996). Peak leaf flush has been reported during the period of heaviest rainfall in a Brazilian montane forest site (Funch *et al*., 2002). Moisture related factors such as rainfall, the number of rainy days and soil moisture had a significant negative influence on leaf flushing phenology either singly or in combination with other factors. Except at Longwood site where sunshine had a positive influence during the one month lag period, sunshine did not have any influence when environmental factors were combined. The results do not support van Schaik's (1993) insolation- limitation hypothesis but provide enough support for the water limitation hypothesis.

Maximum temperature and sunshine have a positive influence on leaf expansion at all sites while moisture related factors had a negative influence. The expanding leaves require warm and bright days. This could be an adaptation to escape from herbivory by phytophagus insects. Studies have shown the correlation between emergence of phytophagus insects and rainfall (Aide, 1988; Murali & Sukumar, 1993).

However, there is no data on insect abundance to test this and the relationship between rainfall and mean percent herbivory, a proxy to insect abundance, is not significant in our study. Another plausible explanation would be enhanced photosynthetic rates under a bright and warm day, which makes the expanding leaves soon replenish the canopy to take full advantage of available sunlight.

This study shows that leaf senescence is influenced by soil moisture at Carrington and Longwood sites, while at Upper Bhavani site the drop in maximum temperature influenced leaf senescence. Most of the leaf fall in the study sites happens during the cold and dry period.

Jackson (1978) hypothesized that in an aseasonal environment maximum leaf fall occurs during the optimal growing season. Seasonal cold or drought stress is usually present and leaves must be shed to minimise the seasonal stress. The optimal strategy would be a combination of relative intensities of cold and drought stress. Where seasonality in temperature is high the strategy will emphasise the avoidance of cold stress by cold season leaf fall and where temperature seasonality is small, the strategy depends on moisture seasonality. The seasonality in temperature at our montane sites is high where the minimum temperature, as low as -1 °C, is recorded. Although there is a continuous leaffall as in evergreen forest communities, the peak leaffall is in the cold (winter) season. The species maintain leaves throughout the year, but rainfall at the montane forest sites is seasonal. Two of the study sites have shown significant difference in soil moisture levels between wet and dry seasons. The effect of seasonality in rainfall is probably masked by the seasonality in temperature because of the altitude (Sun *et al*.,1996). All sites are above 2000 m ASL. Hence temperature is expected to shape several phenophases in phenology of montane forest species.

Seasonality in leafing

Seasonality or repeatability of a given phenological event has both spatial and temporal significance. Spatial significance may be attributed to mast flowering and fruiting in Dipterocarps. But in more seasonal forests, such as monsoon forests of India and Sri Lanka, temporal significance of seasonality has a great role to mould reproductive biology of several species. The shifts in the mean date of a given phenological stage in relation to environmental factors have tremendous implications in ecosystem functioning. For example, the shift in leaf flushing date in relation to rainfall may upset the life cycle of phytophagus insect communities of a forest. Similarly the shift in the dates of flowering will affect the pollinator's activity and hence the fruit set in a forest community. Several studies on phenology have recorded the time of occurrence of particular phenological stages in a given year (Frankie *et al*., 1974; Lieberman, 1982; Lieberman & Lieberman, 1984; Williams - Linera, 1999). Only some studies have attempted to quantify the seasonality of a phenological stage at the community level (Morellato *et al*., 2000) and among species (Davies & Ashton ,1999). This study at the community level reveals that though there is a strong seasonality in rainfall, the leaf flushing is a random event except at Longwood site. Although other stages in leaf phenology showed significant seasonality, the strength of seasonality measured by the vector "r" is weak. The significance in seasonality of phenology may probably be a function of sample size. But in contrast, despite the lack of seasonality in climate, species in Atlantic forests showed significant seasonality (Morellato *et al*., 2000). Leaf flushing is concentrated around the dry season during March-April, though significant only at Longwood site. A similar pattern was also reported from an African montane site (Sun *et al*.,1996). Leaf expansion occured during April-May, which is significantly seasonal in all three montane sites. This period in our study site had clear and bright sunny days. Trees can take full advantage of this and furnish their canopy for maximising photosynthesis. Leaffall peaked during December - January in all three sites. Although leaffall is a continuous process, it was significantly seasonal in all three sites with very low seasonality as indicated by the vector "r". Measurement of shifts in a given phenophase in response to local perturbations in the climate is very important to understand the resilience of a community. Tropical montane ecosystems are one of the vulnerable ecosystems that respond to climate change. Such a study on seasonality would have broad implication in conservation of these vulnerable ecosystems of the world.

Our short-term data on phenology of montane forests suggest that environmental factors play a major role in influencing vegetative phenology. Tropical forests are known to exhibit a diversity of phenological patterns that present many short-term patterns influenced by environmental factors. Long - term studies are required to understand the patterns in both vegetative and reproductive phenologies stimulated by short-term climatic variations.

Acknowledgement

Authors thank the Ministry of Environemnt and Forests, India for financial support, the Forest Department of Tamilnadu for research permission, C. M. Bharanaiah and R. Mohan for their active support during field work, Krishnan, Bomman, Siddan and Kunmari, for field assistance, the Manager and staff members of Thaishola estate for weather data and hospitality, the Manager of Korakundah estate for weather data, and the Tea Hantation Corporation, (TANTEA) Chennai, India, for sharing weather data of Longwood estate. The authors also thanks the Ford Foundation and UNESCO for sponsoring the trip to Sri Lanka to attend the International Conference on Humid tropical Ecosytems: Changes, Challenges, Opportunities.

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