ISSN (Online): 2349-1183; ISSN (Print): 2349-9265
TROPICAL PLANT RESEARCH
The Journal of the Society for Tropical Plant Research
6(3): 365–375, 2019
DOI: 10.22271/tpr.2019.v6.i3.046

Research article

Phenology of deciduous tree species in traditional Meitei homegardens of Barak valley, Assam, northeast India

Ningthoujam Linthoingambi Devi*#, Dipendra Singha and Ashesh Kumar Das

Department of Ecology and Environmental Science, Assam University, Silchar-788011

#Present address: Department of Forestry, Mizoram University, Aizawl-796004, India

*Corresponding Author: linthoi10@yahoo.com [Accepted: 25 October 2019]

Abstract: Phenological characteristics of dominant deciduous tree species were investigated in the traditional Meitei homegardens at Bantarapur village, Barak valley, Assam, northeast India. A considerable variation was recorded in leaf flush, leaf fall, flowering and fruiting pattern of the tree species that could be attributed to climatic factors. The peak periods of leaffall occur in the months of November–January, leaf flush and flowering peaks in the months of February - March, and the peak fruiting occurs in the months of May-June. The leaf flushing and leaf fall periods were delayed during second year of observation for all the deciduous tree species. The leaf flush period of all the tree species showed a positive correlation with rainfall and temperature, while a negative correlation was observed between leaf fall and rainfall. Synchrony indices for leaf flush phenophase of the entire deciduous tree species ranged from 0.68–0.95. The leaf strategy index increased as a function of deciduousness duration and ranged from 0.61–1.00 for all the deciduous tree species. Present findings significantly enhanced in understanding the phenology of selected deciduous tree species growing homegarden in relation to varying climatic parameters. The outcomes of the present study could well be utilized significantly for further study in broader levels to understand the adaptive response of trees growing in the homegarden to changing climatic factors and their better management for sustainable use.
Keywords: Climatic factors - Deciduous - Homegarden - Meitei - Phenology.

[Cite as: Devi NL, Singha D & Das AK (2019) Phenology of deciduous tree species in traditional Meitei homegardens of Barak valley, Assam, northeast India. *Tropical Plant Research* 6(3): 365–375]

INTRODUCTION

Plant phenology is considered to be one of the strongest indicators of global warming (IPCC 2014). Variations in plant phenology can have robust consequences on ecosystem processes, greenhouse gas emissions, and species interactions (Cleland *et al.* 2007, Post & Forchhammer 2008, Richardson *et al.* 2013, Ernakovich *et al.* 2014, Chaturvedi & Raghubanshi 2016). Globally, climate change has significantly altered the timing of seasonal events, or phenology (Parmesan & Yohe 2003, Bajpai *et al.* 2015a).

Homegarden is an important land use component of the Meitei community (an ethnic group settled over the states of Manipur, Assam and Tripura in northeast India) which fulfills the sociocultural and economic need of a family and thus helps in conserving plant diversity through utilization (Devi & Das 2010). Diverse tree species with multiuse and varied phenological behavior were recorded in home gardens. The selection of species with varied phenology, leaf area and density, fruit, flower, and branch production to nurture in homegarden let a family have products which can assure many of their needs throughout the year (Benjamin *et al.* 2001). Plant phenology is poorly known for the homegarden although this ecosystem has the greatest diversity of phenological patterns (Devi 2011). Phenology of tree in any ecosystem and community strongly determines the flowering periods which is indirectly dependent on the environmental variations (Zhang *et al.* 2006)

The study of plant phenology provides facts 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). Phenological studies are also important to understand ecosystem processes such as plant growth pattern, biomass production, plant water stress (Kikuzawa & Lechowicz 2011). Phenological events of plant species

Received: 20 March 2019 Published online: 31 December 2019
https://doi.org/10.22271/tpr.2019.v6.i3.046

responds to a variety of environmental factors, comprising temperature, day length, insolation, precipitation, and soil nutrients (Bajpai *et al.* 2012, Fu *et al*. 2015, Piao *et al*. 2015, Shen *et al*. 2016, Bajpai *et al.* 2017). The effects of global warming on plant phonological traits have been found to be species-specific (Fu *et al*. 2015). Study also suggested that climate change enforced variation in the length of growing period, and competition among species may alter the resource use patterns in different species (Singh & Kushwaha 2005). The occurrence of various phenological events reflects the biotic and abiotic environmental conditions and helps to understand the impact of changing global climate. The management and conservation of natural systems can be significantly enhanced with a greater understanding of the phenology of species (Morellato *et al.* 2016, Sudip *et al.* 2017).

The present study is an attempt to explore the phenology of important deciduous trees in the traditional homegardens. The objectives of the present study were (1) to describe the vegetative and reproductive phenology of important deciduous tree species in the traditional homegardens of Meitei community, (2) to assess the impact of climatic factors on phenophases of the tree species.

MATERIALS AND METHODS

Study area

The study was conducted in the village Bantarapur (24º 38′35" N, 92º 54′65" E) of Cachar district, southern Assam; inhabited by the Meitei community on bank of the River Sonai. Agriculture is the main occupation of the villagers. The mean annual rainfall recorded in the study area was 2193.9 mm and the average monthly maximum and minimum temperature was 30.8ºC and 20ºC respectively. Climatic diagram of the study site from 2011 to 2012 is shown in figure 1.

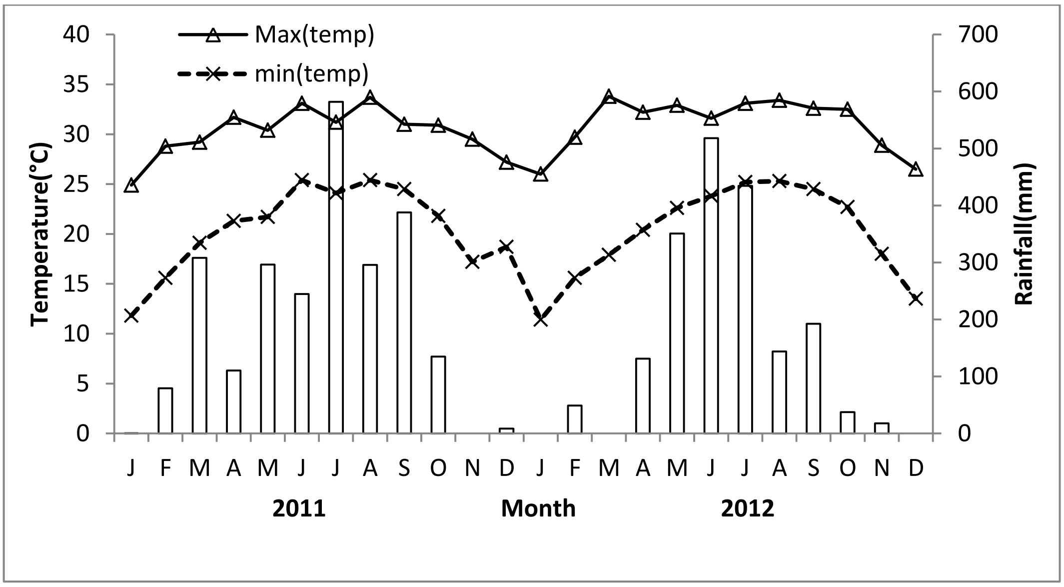

Figure 1. Climatic data of the study site from January 2011 to December 2012.

Phenological data collection

For the present study fifty homegardens with the average size of 0.35 ha were selected. For the phenological study, 10 dominant deciduous tree species having multipurpose uses for the villagers were selected. The tree species were *Albizia lebbeck* (L.) Benth., *Bombax ceiba* L., *Cordia grandis* Roxb., *Erythrina stricta* Roxb., *Gmelina arborea* Roxb., *Lagerstroemia speciosa* (L.) Pers., *Parkia timoriana* (DC.) Merr., *Premna bengalensis* C.B.Clarke, *Spondias pinnata* (L.f.) Kurz and *Toona ciliata* M.Roem. Twenty individuals each with CBH≥15cm for every species were selected for phenological monitoring. Phenological changes were recorded at 15 days interval of every month in the selected individuals on leaf initiation, leaf fall, flowering and fruiting. Vegetative and reproductive phenology was observed on the basis of phenological score. Leaf cover was scored using a four-point scale denoting the proportion of the canopy bearing leaves as follows- 0 (absent), 1 (low), 2 (intermediate), 3 (high) (Broadhead *et al*. 2003). Detailed observation was recorded for a period of two years from January 2011 – December 2012. The phenological activity for each tree species was evaluated as the sum of species with different phenological stages every month. The phenophases of a species was determined by considering the status of the majority of individuals. The duration of a phenological event in a species was computed by obtaining the number of days required for the completion of an event from the date of the fortnightly visit when the event was first observed. A synchrony index for leaf flush and leaf fall phenophases of each tree species was calculated as the ratio between the individuals mean period of a phenological phase and the overall periods of the phase in all conspecific trees (Devineau 1999). The higher the ratio, the greater the coincidence between different individuals of a species (*i.e.* at ratio 1.0 perfect synchrony will occur and as the ratio decrease from 1.0 asynchrony will increase) (Kushwaha & Singh 2005).

Data analysis

Statistical analysis was done using SPSS 16.0. Relationships between duration of deciduousness, leaf strategy index, of different species were examined by computing correlation coefficients using species mean values. Regression and Pearson correlations were performed to investigate correlation between monthly phenophase activity and environmental variables such as temperature and rainfall. Aridity index was estimated by the following formula (Ewer & Hall 1978):

$$\text{Aridity index} = 12P/T + 10$$

Where, P = mean monthly rainfall (mm) and T = mean monthly temperature (°C)

RESULTS

Phenological observation

Table 1. Phenological pattern of selected tree species in Meitei homegardens of Barak Valley, Assam, Northeast India.

Name of species	Events & Behavioural patterns			
	Leaf fall	**Leaf flushing**	**Flowering**	**Fruiting**
Albizia lebbeck (L.) Benth.	PD	Pe	PeA	PeL
Bombax ceiba L.	PD	Pb	PbS	Pbr
Cordia grandis Roxb.	PD	Pb	PbS	Pbr
Erythrina stricta Roxb.	PD	Pb	PbS	Pbr
Gmelina arborea Roxb.	PD	Pb	PbS	Pbr
Lagerstroemia speciosa (L.) Pers	PD	Pb	PbA	PeL
Parkia timoriana (DC.) Merr.	PD	Pe	PbS	PbL
Premna bengalensis C.B.Clarke	PD	Pb	PbS	Pbr
Spondias pinnata (L.f.) Kurz	PD	Pb	PbA	PeL
Toona ciliata M.Roem	PD	Pb	PbA	PeL

Note: 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, r= Rapid fruit maturation, less than a month, L= Lengthy fruit maturation

Table 2. Synchrony index and Leaf strategy index of trees in Meitei homegardens of Barak Valley, Assam, Northeast India.

Species	Synchrony index of leaf flush	Leaf strategy index	Leafless duration (days)	
			Average	**Range**
Albizia lebbeck (L.) Benth.	0.76	0.67	68.92	65-71
Bombax ceiba L.	0.94	0.85	96.07	76-114
Cordia grandis Roxb.	0.82	0.70	53.02	50-58
Erythrina stricta Roxb.	0.68	0.71	62.59	61-64
Gmelina arborea Roxb.	0.88	0.61	56.02	54-58
Lagerstroemia speciosa (L.)Pers	0.95	0.79	76.42	74-79
Parkia timoriana (DC.) Merr.	0.84	0.61	45.88	43-49
Premna bengalensis C.B.Clarke	0.78	0.88	112.60	105-121
Spondias pinnata(L.f.) Kurz	0.79	0.99	102.65	96-108
Toona ciliata M.Roem	0.80	0.67	54.27	46-59

The selected tree species with respect to the timing of leaf flushing and leaf fall, showing widely varying timing and duration of deciduousness. The general phenological stages of all species have been presented in table 1. In this study, tree species exhibited maximum leaf production in the warmer dry season just before the onset of monsoon. The tree species exhibited varied (10–30 days) leaf flush initiation between the first year and second year of observation (Fig. 2). Phenological periodicity, scores ascribed for selected tree species is shown in figure 3. A single leaf flushing peak was observed during the months of March to June (Fig. 4A). *Toona ciliata* M.Roem is the only tree species in which the leaf initiation starts in the dry month of December and maintained full leaf cover in the early stages of rainfall. *Parkia timoriana* (DC.) Merr. initiated leaf flush during pre monsoon period and maximum leaf flushing occurred during the rainy season (April–June) which continued throughout the favorable season. The leaf initiation of tree species was strongly influenced by temperature and precipitation. The leaf flush of the tree species showed positive correlation with rainfall and temperature during the 1st and 2nd year of study (Table 2). The Aridity index indicated strong correlations with leaf flush (Table 3). Regression analysis showed significant impact of minimum temperature during first ($r=0.864$, $F=29.52$, $P<0.0001$) and second year ($r=0.907$, $F=46,144$, $P<0.0001$) of the study on leaf flush. The regression analysis of leaf flush and temperature also proves the positive influences of temperature in triggering the species to flush.

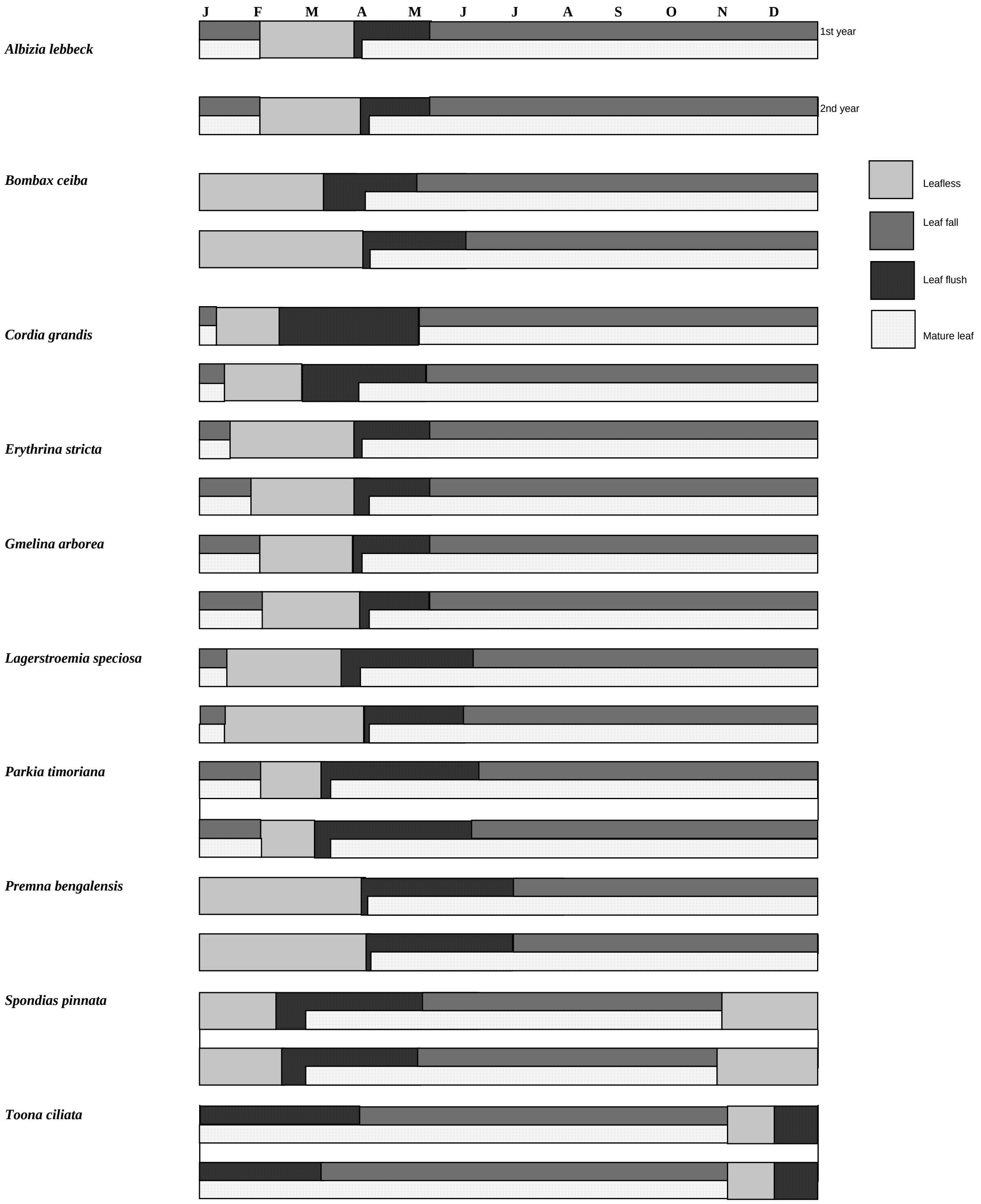

Figure 2. Vegetative phenological characters (leaf flush, leaf mature, leaf fall and leafless) of deciduous trees in Meitei homegardens of Barak valley, Assam, Northeast India

The peak leaf fall for the majority of the species was observed during the months of November–January (Fig. 4B). The selected tree species exhibited variation in the initiation of leaf fall from the first year to the second year of observation. In certain species such as *Bombax ceiba* L., *Spondias pinnata* (L.f.) Kurz, *Erythrina stricta* Roxb. and *Parkia timoriana* (DC.) Merr. variation (10–20 days) was seen in the initiation of leaffall from the first year to the second year of observation.

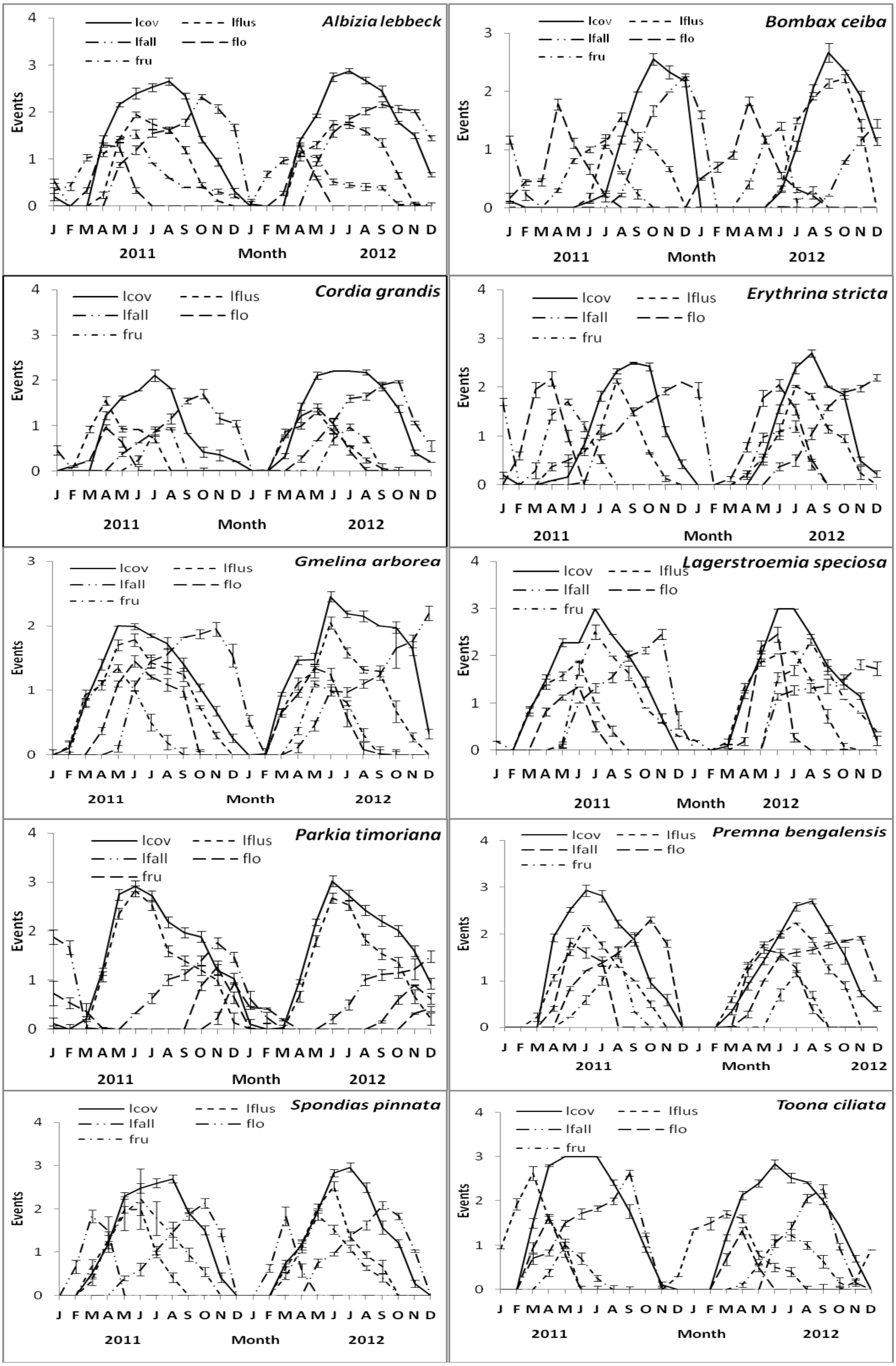

Figure 3. Leaf cover, leaf flushing, leaf fall, flowering and fruiting periods of ten selected species in Meitei homegardens of Barak Valley, Assam, Northeast India. Scores ascribed for all variables were: (0) absent, (1) low, (2) intermediate, (3) high.

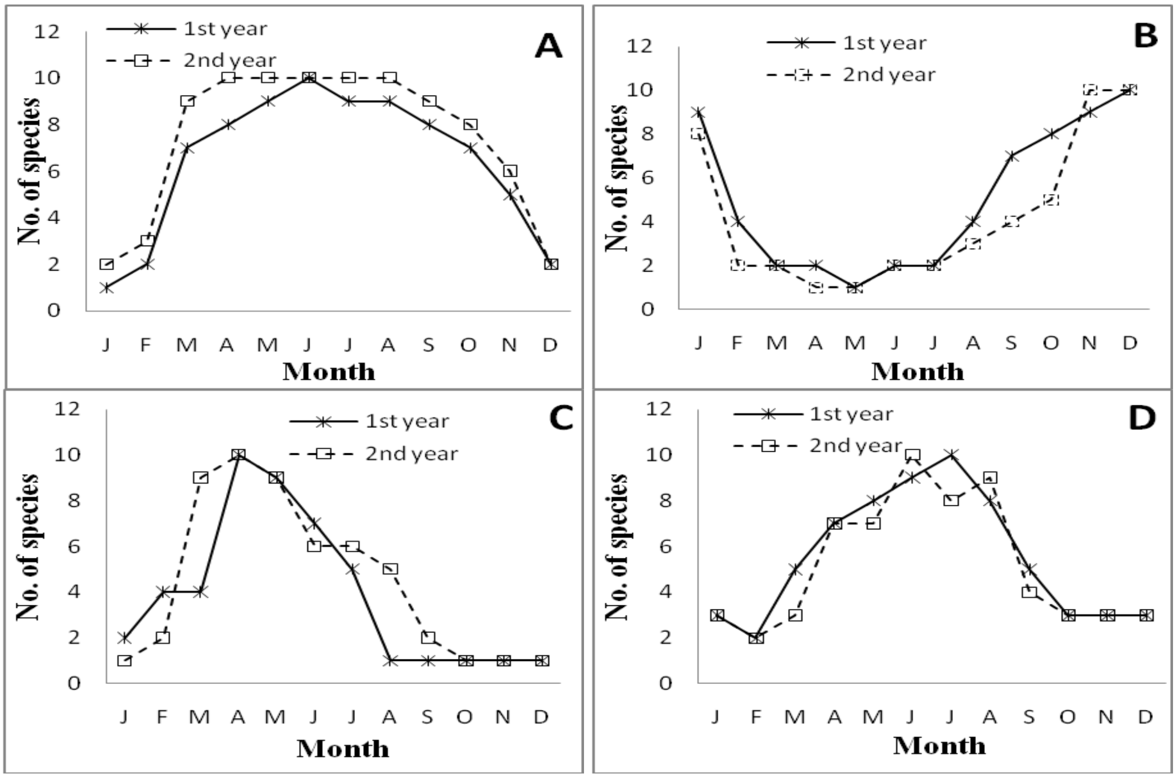

Figure 4. Phenological periodicity of selected tree species in Meitei homegardens of Barak Valley, Assam, Northeast India: **A**, Number of species in leaf flushing; **B**, in leaf fall; **C**, in flowering; **D**, in fruiting.

Table 3. Phenological patterns of tree species in relation to Aridity Index in Meitei homegardens of Barak valley, Assam, Northeast India.

	Aridity index	
Phenophases	2011	2012
Leaf flush	0.80**	0.94**
Leaf fall	-0.61*	-0.69*
Flower	0.58NS	0.49 NS
Fruit	0.86**	0.65*

Note: Pearson correlation**p<0.01, *p<0.05, NS-not significant

Varied duration of the leafless period in tree species growing in the homegarden was observed between the first and second year of observation (Fig. 2). A negative correlation was observed between leaf fall and rainfall in the first year of study while in the second year, no significant relation was recorded. Leaf fall was significantly (–ve) correlated with maximum temperature during second year but insignificant in the first year (Table 2).The relation of leaf fall and the aridity index was observed to be negatively significant (Table 3). Regression analysis showed significant influence of rainfall in the first year (r=0.601, F=5.563, P<0.039) and maximum temperature during the second year (r=0.98, F=1.496, P<0.002) on the leaf fall.

The seasonal patterns of flowering in the present study exhibit two peaks- one major peak during March-April and another minor one in October-November (Fig. 3C). *Albizia lebbeck* (L.) Benth. flowers twice in a year (Fig. 4C). The flowering did not show any significant relation with rainfall and temperature in the first year of study, but positively significant relation with maximum temperature was recorded during the second year (Table 2). The flowering in the tree species showed no significant relation with the aridity index during the study period (Table 3). Regression study showed no significant influence of rainfall and temperature in first year, but in the second year positive influence was recorded (r=0.649, F=7.280, P<0.022) on flowering. The selected tree species in the present study exhibited four basic patterns of flowering in relation to leaf flushing as described by Kikim & Yadava (2001)- a) Flowering before leaf flush and during leafless period, e.g. *Spondias pinnata* (L.f.) Kurz, *Erythrina stricta* Roxb. and *Gmelina arborea* Roxb. b) Flowering long before leaf flush and during leafless period e.g. *Bombax ceiba* L. c) Flowering soon after leaf flushes e.g. *Albizia lebbeck* (L.) Benth and *Toona ciliata* M.Roem d) Flowering later, after leaf flushes e.g. *Lagerstroemea speciosa* (L.) Pers. and *Parkia timoriana* (DC.) Merr.

In this study, two peak periods of fruit maturation were observed, a major peak during the month of June–July and a minor one in October–November (Fig. 4D). The major peak period of fruit maturation included

Bombax ceiba (L.), *Gmelina arborea* Roxb and *Toona ciliata* M.Roem while species included in the minor peak were *Parkia timoriana* (DC.) Merr. and *Spondias pinnata* (L.f.) Kurz. Majority of the species started fruit maturation during the month of May. During the 1st year of study fruiting is significantly related with rainfall, maximum and minimum temperature but during 2nd year the relation is significant only for rainfall and minimum temperature (Table 2). Aridity index also showed positive correlation with fruiting (Table 3). Regression analysis showed positive influence of rainfall and temperature during the first and second year (r=0.860, F=29.29, P<0.0001) on fruiting.

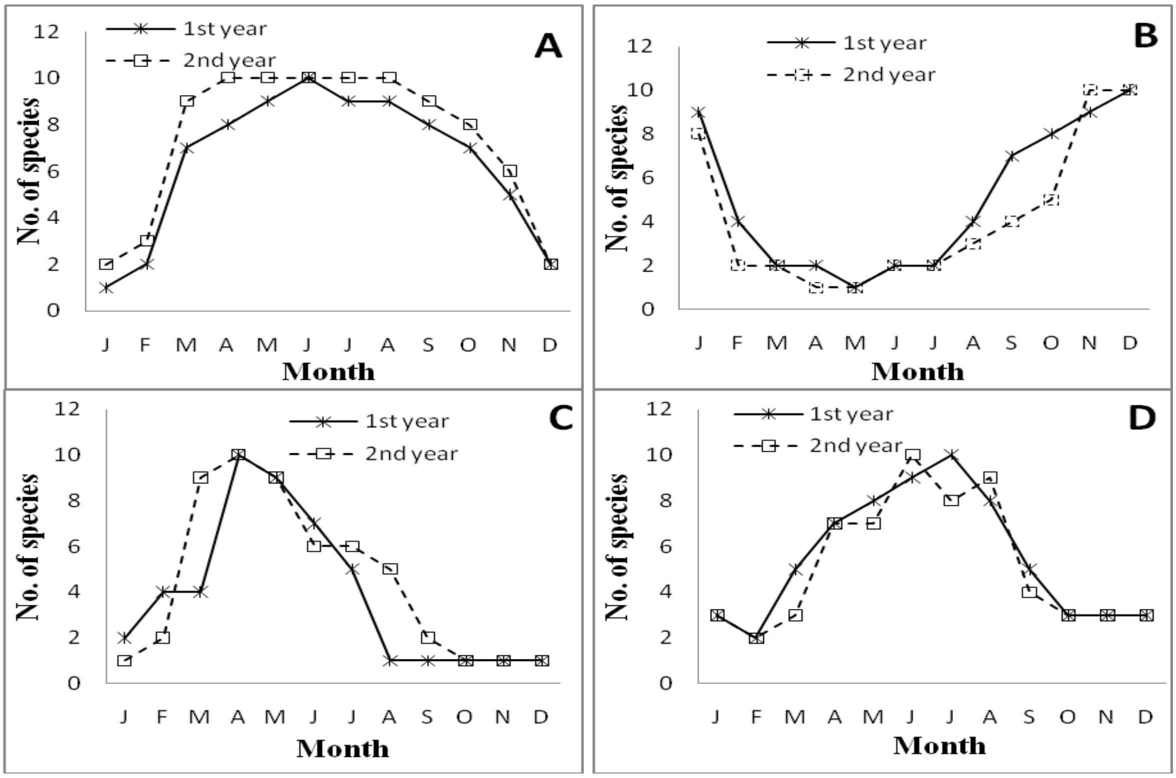

Figure 4. Phenological periodicity of selected tree species in Meitei homegardens of Barak Valley, Assam, Northeast India: **A**, Number of species in leaf flushing; **B**, in leaf fall; **C**, in flowering; **D**, in fruiting.

Table 4. Phenological patterns of tree species in relation to rainfall and temperature of Meitei homegardens of Barak Valley, Assam, Northeast India.

	2011			2012		
Phenophases	**Rainfall (mm)**	**Max Temp (°C)**	**Min Temp (°C)**	**Rainfall (mm)**	**Max Temp (°C)**	**Min Temp (°C)**
Leaf flush	0.80**	0.85**	0.86**	0.84**	0.89**	0.91**
Leaf fall	-0.60*	-0.47NS	-0.03NS	-0.59*	-0.79**	-0.59*
Flower	0.55NS	0.29NS	0.20NS	0.39NS	0.65*	0.38NS
Fruit	0.86**	0.69*	0.75**	0.84**	0.50NS	0.70*

Note: Pearson correlation**p<0.01, *p<0.05, NS-not significant.

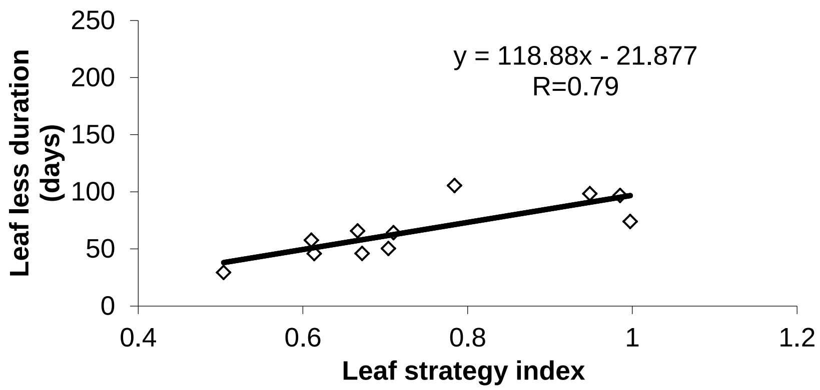

Figure 5. Relationship between leafless duration and leaf strategy index in Meitei homegardens of Barak valley, Assam, Northeast India

Deciduous and leaf Strategy index

Synchrony indices for leaf flush phenophase of different tree species ranged from 0.68–0.95. Maximum leaf flush Synchrony occurred in *Lagerstroemia speciosa* (L.) Pers. and minimum in *Erythrina stricta* Roxb. The selected tree species differed considerably in terms of leafless period. The leaf strategy index increased as a function of deciduousness duration and ranged from 0.61 to 0.99 for the tree species (Table 4). The leaf strategy index for <2 month deciduous tree ranged from 0.61 to 0.67 and 0.67 to 0.99 for 2–3 months deciduous. Relationships between leafless period and leaf strategy index were examined across different species (Fig. 5).

DISCUSSION

The flushing and leaf production towards the end of the dry season and just before the rains has also been reported from other parts of India (Singh & Kushwaha 2005, Nath *et al.* 2016, Bajpai *et al.* 2017). It is found that the leaf flush advanced by 2 to 13 days during 2nd year of study, whereas, Thakur *et al.* (2008) reported a leaf flush advancement of 5 to 40 days. Increased rainfall in March–April months during 2nd year compared to that of the 1st year might result in the advancement in leaf flush of tree species. The leaf initiation of tree species was strongly influenced by temperature and precipitation (moisture) (Bajpai *et al.* 2012, 2017, Chaturvedi & Raghubanshi 2016).

Leaf fall during the dry-cold period is largely due to the effect of water stress on the morpho-physiological activities of the plants. Water stress can induce leaf fall by decreasing the water potential of leaf during the dry season and leaf fall is an adaptation to reduce the effect of water shortage (Borchert *et al.* 2002, Tesfaye *et al.* 2011). As a defense mechanism to tolerate the dry conditions, the species shed leaves and recover during the rainy seasons, this leaf fall may be induced by microenvironment factors as reported by other studies (Kikuzawa & Lechowicz 2011, Chaturvedi & Raghubanshi 2016, Omondi *et al.* 2016). In the present study negative correlation was observed between temperature and leaf fall in tree species. The findings of the present study resembles the vegetative leaf phenology of trees from Northeast India (Nath *et al.* 2016). Negative correlations between leaf fall and environmental variables indicate that this phenophase is associated with a reduction in temperature and precipitation (Nunes *et al.* 2005).

In the present study area variation of flowering and fruiting was recorded that will facilitate in seed germination during favourable conditions. The tree species *Gmelina arborea* Roxb. and *Toona ciliata* M.Roem. flower during the monsoon, which reflects the importance of high water availability for reproductive success as also reported by other studies (Das & Das 2013, Bajpai *et al.* 2017).

The initiation of flowering by the end of winter, during high temperature and increasing day length has also been reported from other tropical areas (Yadav & Yadav 2008, Kushwaha *et al.* 2011, Gritto *et al.* 2015, Bajpai *et al.* 2017, Mohandass *et al*. 2018). The selected tree species in the present study exhibited four basic patterns of flowering in relation to leaf flushing as described by (Kikim & Yadava 2001), a) Flowering before leaf flush and during leafless period, e.g. *Spondias pinnata* (L.f.) Kurz, *Erythrina stricta* Roxb. and *Gmelina arborea* Roxb. b) Flowering long before leaf flush and during leafless period e.g. *Bombax ceiba* L. c) Flowering soon after leaf flushes e.g. *Albizia lebbeck* (L.) Benth., *Toona ciliata* M.Roem. d) Flowering later, after leaf flushes e.g. *Lagerstroemea speciosa* (L.) Pers., *Parkia timoriana* (DC.) Merr. whereas five flowering types in 119 tropical tree species was recorded by Singh & Kushwaha (2006). The tree species produced flowers during leafless phase, favored wind pollination as well as a floral display to attract pollinators. Such tree species which flower in leafless conditions could act as 'keystone species' which provide food for birds when food availability is low during the dry season (Murali & Sukumar 1994, Das & Das 2013, Bajpai *et al.* 2015b)

In the majority of species fruit maturation started from the month of May. The fruiting peak and ripening of fruits in the latter part of pre-monsoon dry period or close to rainfall recorded in our study was similar to that in subtropical forests of Manipur (Kikim & Yadava 2001). Fruit ripening of majority of tree species close to the rainy season could help in fruit dispersal and also to regenerate during the rainy season. Fruiting during the rainy season may have evolved to ensure dispersal of seeds when soil moisture conditions are favorable for seed germination, seedling growth and survival (Singh & Kushwaha 2006, Bajpai *et al.* 2017). Selected species in the present study included explosive, dispersal by birds and wind. This was also observed in other parts of India (Murali & Sukumar 1994, Yadav & Yadav 2008, Borah & Devi 2014). The difference in the pattern of fruiting activity and the period of ripening of fruits maintains the availability of fruits throughout the year. Flowering and fruiting pattern of this study is similar to that found in other tropical seasonal environments. The findings also reveal that flowering and fruiting were significantly associated with rainfall and temperature and this pattern is similar to that described in many previous studies (Yadav & Yadav 2008, Mohandass *et al*. 2018).

The higher synchrony ratio (0.68 to 9.5) of leaf flush and leaf fall in the present study indicates that most of the total population of selected tree species shows both the phenophases in the similar time period and this is similar to that reported from tropical dry deciduous forest (Kushwaha & Singh 2005) as well as tropical moist deciduous forest (Bajpai *et al.* 2017). Tree species adjusted to variable micro climatic conditions often show diverse leaf strategies. Leaf strategy primarily denotes adaptation in leaf dynamics controlling the ability of a tree species to utilize resources in relation to its ability to conserve the resources (Kushwaha & Singh 2005). Selected tree species in the present study showing varied leafless period exhibits significant differences in their leafing pattern, as reflected by the leaf strategy index. The higher leaf strategy index (0.61–0.99) recorded in the present study is comparable to that of tropical deciduous forests from other parts of India (Kushwaha & Singh 2005). Greater the value of the leaf strategy index than 0.5, longer is the deciduousness duration (Kushwaha & Singh 2005) and the same pattern is also reflected in our observation.

Most of the studies on the vegetation phenological trends during last few decades commonly assumed the climate change as the key factor for the changes (Zhang *et al.* 2019). Singh & Kushwaha (2005) also suggested that changes in the length of the growing period, and competition among species for the resource use patterns resulted due to climate change. Present findings also indicating the influence of varied climatic parameters (between 1st and 2nd year of study) on the phenology of deciduous trees. Long term phonological study on the same species might clearly exhibit their phonological adaptation to varied climatic condition.

CONCLUSION

From this study, our understanding of the influence of varied climatic parameters e.g. temperature and rainfall on the phenophases of deciduous tree species is significantly improved. Selected deciduous tree species were observed to be sensitive to the variation in rainfall pattern, thereby to the moisture availability. Thus it can be concluded that any sudden change in climatic parameters would have a drastic effect on the plant phenology and so to the sustainability of homegarden resources. However, more detailed and long term observations on the impact of environmental parameters to the species–specific phenology for multipurpose deciduous trees are needed to understand a tree's ability to capture environmental resources successfully in response to changing climatic conditions. This would facilitate the selection of suitable tree species to nurture in the traditional Meitei homegarden and also in managing the trees efficiently to fulfill the needs of the landowner.

ACKNOWLEDGEMENTS

Financial support as the Rajiv Gandhi National fellowship by UGC to the first author is thankfully acknowledged.The authors would like to thank the homegarden owners of Bantarapur for permission to carry out the work in their homegardens and for sharing their experience. Department of Ecology and Environmental Science, Assam University is thankfully acknowledged for providing laboratory facilities.

REFERENCES

Bajpai O, Kumar A, Mishra AK, Sahu N, Behera SK & Chaudhary LB (2012) Phenological study of two dominant tree species in tropical moist deciduous forest from the northern India. *International Journal of Botany* 8(2): 66–72.

Bajpai O, Pandey J & Chaudhary LB (2015a). Consequences of western disturbance-triggered cooling on the tree flowering in Himalayan Terai region. *Current Science* 109(10): 1781–1782.

Bajpai O, Kumar A, Srivastava AK, Kushwaha AK, Pandey J & Chaudhary LB (2015b) Tree species of the Himalayan Terai region of Uttar Pradesh, India: a checklist. *Check List* 11(4): Article no. 1718.

Bajpai O, Pandey J & Chaudhary LB (2017) Periodicity of different phenophases in selected trees from Himalayan Terai of India. *Agroforestry Systems* 91: 363–374.

Benjamin TJ, Montanez PI, Jimenez JJ & Gillespie AR (2001) Carbon, water and nutrient flux in Maya homegardens in the Yucatan peninsula of Mexico. *Agroforestry Systems* 53: 103–111.

Borchert R, Rivera G & Hagnauer W (2002) Modification of vegetative phenology in a tropical semi-deciduous forest by abnormal drought and rain. *Biotropica* 34: 381–393.

Borah M & Devi A (2014) Phenology, growth and survival of *Vatica lanceaefolia* Bl.: A critically endangered tree species in moist tropical forest of Northeast India. *Tropical Plant Research* 1(3): 1–12.

Broadhead JS, Ong CK & Black CR (2003) Tree phenology and water availability in Semi-arid agroforestry systems. *Forest Ecology and Management* 180: 61–73.

Chaturvedi RK & Raghubanshi AS (2016) Leaf life-span dynamics of woody species in tropical dry forests of India. *Tropical Plant Research* 3(1): 199–212.

Cleland EE, Chuine I, Menzel A, Mooney HA & Schwartz MD (2007) Shifting plant phenology in response to global change. *Trends in Ecology & Evolution* 22(7): 357– 365.

Das T & Das AK (2013) Vegetative and reproductive phenology of some multipurpose tree species in the homegardens of Barak Valley, northeast India. *International Journal of Biometeorology* 57: 185–196.

Devi NL & Das AK (2010) Plant species diversity in traditional homegardens of Meitei Community: a case study in Barak Valley, Assam. *Journal of Tropical Agriculture* 48(1-2): 40–43.

Devi NL (2011) Studies on tree diversity, phenology and growth in traditional meitei homegardens of Barak valley, Assam, northeast India. Ph.D thesis submitted to Assam University.

Devineau JL (1999) Seasonal rhythms and phenological plasticity of savanna woody species in a fallow system (South-west Burkino Faso). *Journal of Tropical Ecology* 15: 497–513.

Ernakovich JG, Hopping KA, Berdanier AB, Simpson RT, Kachergis EJ, Steltzer H & Wallenstein MD (2014) Predicted responses of arctic and alpine ecosystems to altered seasonality under climate change. *Global Change Biology* 20(10): 3256–69.

Ewer DW & Hall JB (1978) *The interrelations of organisms*. In: *Ecological Biology*. Longman, London. p. 526.

Fu YH, Piao S, Vitasse Yet al (2015) Increased heat requirement for leaf flushing in temperate woody species over 1980–2012: effects of chilling, precipitation and insolation. *Global Change Biology* 21: 2687– 2697.

Gritto MJ, Nandagopalan V, Doss A & Prabha AL (2015) Phenological behaviour of some tree species of Pachamalai, Tamilnadu, India. *Journal of Advanced Botany and Zoology* 3(4): 1–4.

IPCC (2014) Climate change 2014: *Impacts, adaptation, and vulnerability, part A: Global and sectoral aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA. 1,132 pp.

Kikim A & Yadava PS (2001) Phenology of tree species in subtropical forests of Manipur in North East India. *Tropical Ecology* 42: 269–276.

Kikuzawa K & Lechowicz MJ (2011) *Ecosystem Perspectives on Leaf Longevity*. In: *Ecology of Leaf Longevity*. Ecological Research Monographs. Springer, Tokyo.

Kushwaha CP & Singh KP (2005) Diversity of leaf phenology in a tropical deciduous forest in India. *Journal of Tropical Ecology* 21: 47–56.

Kushwaha CP, Tripathi SK & Singh KP (2011) Tree specific traits affect flowering time in Indian dry tropical forest. *Plant Ecology* 212: 985–998.

Mohandass D, Campbell MJ, Chen X & Li Q (2018) Flowering and fruiting phenology of woody trees in the tropical-seasonal rainforest, Southwestern China. *Current science* 114: 2313–2322.

Morellato LPC, Alberton B, Swanni T, Alvarado ST, Borges B, Buisson E, Camargo MGG,

Cancian LF, Carstensen DW, Escobar DFE, Leite PTP, Mendoza I Rocha NNWB, Soares NC, Silva TSF, Staggemeier VG, Streher AS, Vargas BC & Pere CA (2016) Linking plant phenology to conservation biology. *Biological Conservation* 195: 60–72.

Murali KS & Sukumar R (1994) Reproductive phenology of a tropical dry forest in Mudumalai, Southern India. *Journal of Ecology* 82: 759–767.

Nath S, Nath AJ & Das AK (2016) Vegetative and reproductive phenology of a flood plain tree species *Barringtonia acutangula* from North East India. *Journal of Environmental Biology* 37: 215–220

Nunes YRF, Fagundes M, Santos RM, Domingues EBS, Almeida HS & Gonzaga AP (2005)

Atividades fenológicas de *Guazuma ulmifolia* Lam. (Malvaceae) em uma floresta estacional decidual no norte de Minas Gerais. *Lundiana* 6(2): 99–105.

Parmesan C & Yohe G (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature* 421(6918): 37–42.

Piao S, Tan J, Chen A et al. (2015) Leaf onset in the northern hemisphere triggered by daytime temperature. *Nature communications* 6: 6911. [DOI: 10.1038/ncomms7911]

Post E & Forchhammer MC (2008) Climate change reduces reproductive success of an Arctic herbivore through trophic mismatch. *Philosophical Transactions of the Royal Society B-Biological Sciences* 363(1501): 2369–75.

Richardson AD, Keenan TF, Migliavacca M, Ryu Y, Sonnentag O & Toomey M (2013) Climate change, phenology, and phenological control of vegetation feedbacks to the climate system. *Agricultural and Forest Meteorology* 169: 156–73.

Shen M, Piao S, Chen X, An S, Fu YH, Wang S, Cong N & Janssens IA (2016) Strong impacts of daily minimum temperature on the green-up date and summer greenness of the Tibetan Plateau. *Global Change Biology* 22: 3057–3066.

Singh KP & Kushwaha CP (2005). Emerging paradigms of tree phenology in dry tropics. *Current Science* 89: 964–974.

Singh KP & Kushwaha CP (2006) Diversity of flowering and fruiting phenology of trees in a tropical deciduous forest in India. *Annals of Botany* 97: 265–276.

Sudip KR, Arun KP & Ashok KB (2017) Phenology and floral visitors of *Acer caesium*Wall. ex Brandis (Sapindaceae) – A threatened Himalayan tree. *Pleione* 11(1): 1–9.

Omondi SF, Odee DW, Ongamo GO, James I, Kanya JI & Khasa DP (2016) Synchrony in leafing, flowering, and fruiting phenology of *Senegalia senegal* within Lake Baringo Woodland, Kenya: Implication for Conservation and Tree Improvement. *International Journal of Forestry Research* 6(5): 1–11.

Tesfaye G, Teketay D, Fetene M & Beck E (2011) Phenology of seven indigenous tree species in a dry Afromontane forest, southern Ethiopia. *Tropical Ecology* 52: 229–241.

Thakur PS, Dutt V & Thakur A (2008) Impact of inter-annual climate variability on the phenology of eleven multipurpose tree species. *Current Science* 94(8): 1053–1058.

Yadav RK &Yadav AS (2008) Phenology of selected woody species in a tropical drydeciduous forest in Rajasthan, India. *Tropical Ecology* 41: 25–34.

Zhang G, Song Q & Yang D (2006) Phenology of *Ficus racemosa* in Xishuangbanna, Southwest China. *Biotropica* 38: 334–341.

Zhang X, Liu L & Henebry GM (2019) Impacts of land cover and land use change on long-term trend of land surface phenology: a case study in agricultural ecosystems. *Environmental Research Letters* 14: 1–12.