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Research Article

IMPACT OF CLIMATE CHANGE ON THE TREES OF GUJARAT, INDIA: PHENOLOGICAL PERSPECTIVE

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ABSTRACT
Phenology refers to the study of seasonal appearances and periodicity of life-cycle events. It involves study of living organism's responses to seasonal and climatic changes (e.g. temperature and precipitation) of the environment in which they live. Over the last century, the global temperature has increased by 0.7°C as a result of increasing anthropogenic carbon emission into the atmosphere. Climatic condition determines the reproductive behaviour of any individual species. Several studies have shown that the flowering and fruiting dates have of some tree species show significant variation (advanced or delayed) as a result of climatic change.
The present work focuses on studying the relationship between the flowering time of the trees of Gujarat and correlating it with the inter-annual variation of the temperature and precipitation patterns since 1978. Phenological patterns of tree of Gujarat as recorded by Shah, 1978 were compared to the recent survey of the trees of Gujarat. Owing to an increase in the annual mean maximum temperature of Gujarat by 1°C, of the 255 tree species reported by Shah, 1978; 55 tree species represented by 28 families and 45 genera have changed their trends in the time of flowering and fruiting (advanced or delayed). The change in the phenological pattern of some of the tree species can be taken as an indicator of the climate change as some plants are highly sensitive to even a slight change in their normal climate pattern especially with respect to the temperature and precipitation pattern. Hence, phenological variation in plants may act as a tool in predicting the impacts of climate change on plants.

Keywords: *Climate Change, Climatic Variability, Plant Phenology*

INTRODUCTION
Phenology refers to the study of seasonal appearances and periodicity of life-cycle events. It involves study of living organism's responses to seasonal and climatic changes (e.g. temperature and precipitation) of the environment in which they live (Moza and Bhatnagar, 2005). Phenological patterns may be influenced by abundance of pollinators, seed dispersers, seed predators, or herbivores (Curran and Leighton, 2000); or by variations in rainfall (Singh and Kushwaha, 2005; Sakai *et al.*, 2006; Ragusa-Netto and Silva, 2007); temperature (Chmielewski and Rotzer, 2001; Sparks and Menzel, 2002; Matsumoto *et al.*, 2003; Badeck *et al.*, 2004; Moriondo and Bindi, 2007; Aitken *et al.*, 2008; Thakur *et al.,* 2008; Nord and Lynch, 2009), radiation, photoperiod (Yadav and Yadav, 2008) and drought (Borchert *et al.,* 2002; Anderson *et al.,* 2005; Singh and Kushwaha, 2005, 2006; Yadav and Yadav, 2008; Nord and Lynch, 2009) from which temperature and moisture variables are of principle importance.
Over the last century, the global temperature has increased by 0.7°C (Smith *et al.*, 2007) as a result of increasing anthropogenic carbon emission into the atmosphere. Climatic condition determines the reproductive behaviour of any individual species. The appearance of the buds, leaves, bloom, pollination, fertilization and seed dispersal are all correlated with the weather patterns (Anonymous, 2009 (NBRI)). Recent climate change in terms of increasing temperature has notable effects on the timing of phenological pattern of plants which are however variable across space and between species (Stirnemann *et al.*, 2008). Several studies have shown that the flowering and fruiting dates of some tree species show significant variation (advanced or delayed) as a result of climatic change (Fitter and Fitter, 2002; Singh and Kushwaha, 2006). Climate change may also lead to changes in critical daylength for plants (Van Dijk and Hautekeete, 2007) or changes in geographic distribution (Walther *et al.,* 2002). Phenological changes

due to climate change may inevitably effect crop production, human health and species distribution, their composition and life cycles (Sparks and Menzel, 2002; Badeck *et al.*, 2004; Singh and Kushwaha, 2006; Yadav and Yadav, 2008). Tree phenological observations have proved to be most effective impact indicators of climate change **(**Kushwaha and Singh, 2008) as many species are highly sensitive even to the smallest change in the long prevailing climate of any ecosystem (Anonymous, 2009 (NBRI)).
The present work focuses on studying the relationship between the flowering time of the trees of Gujarat and correlating it with the inter-annual variation of the temperature and precipitation patterns since 1978. Phenological patterns of tree of Gujarat as recorded by Shah, 1978 were compared to the recent survey of the trees of Gujarat. Owing to an increase in the annual mean maximum temperature of Gujarat by 1°C, of the 255 tree species reported by Shah, 1978; 55 tree species represented by 28 families and 45 genera have changed their trends in the time of flowering and fruiting.

MATERIALS AND METHODS

Study Area

Gujarat is in the extreme West part of India (Figure-2). It has tropical climate, namely sub-humid, arid and semi-arid spread over different regions of the state. North Gujarat region comprising of Kutch, part of Banaskantha, Mehsana and North Western part of Saurashtra have arid climate while the South Gujarat have sub-humid climate and in the rest of the state, semi-arid climate. Temperature varies from 6 to 45°C. Annual rainfall varies from 250 mm in the North-West and to more than 1500 mm in South Gujarat.

Figure 1: Showing trees from among the 54 tree species of Gujarat with phenological variation in the time of flowering and fruiting. A: Butea monosperma var lutea (Lam) Taub. B: Salvodora oleoides Decne. C: Tamarix indica Willd. D: Miliusa tomentosa (Roxb) Sinclair. E: Wrightia tinctoria R Br. F: Syzygium cumini (L) Skeel. G: Albizia lebbeck (L) Bth. H: Sterblus asper Lour. I: Capparis decidua (Forsk) Edgew. J: Samanea saman (Jacq) Merill. K: Aegle marmelos (L) Correa. L: Parkinsonia aculeata L. M: Tectona grandis L.f. N: Sterculia ureans Roxb. O: Ixora brachiata Roxb

Climatic Data

In order to establish the relationships between climatic variability and plant development, data for climate indicators such as maximum and minimum monthly temperatures and annual rainfall for the past 50 years

(1957–2007) were collected and obtained from the Indian Meteorological Department (IMD), Pune. Altogether 13 stations were considered which are well distributed across Gujarat (Figure 2). The station data of maximum and minimum monthly temperatures and rainfall were used to calculate the average air temperature and total rainfall respectively for Gujarat from 1957 to 2007 which covered the entire period of our phenological data set.

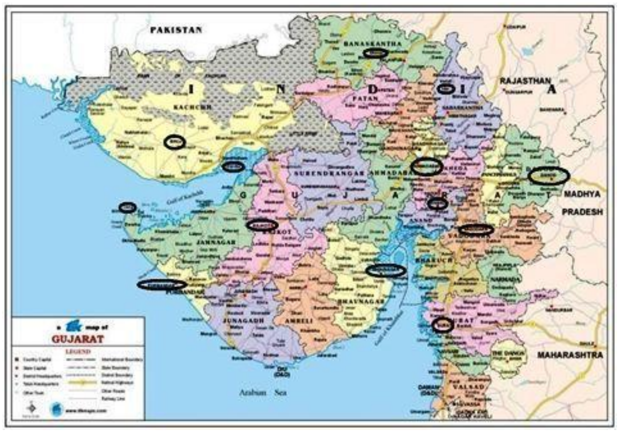

Figure 2: The state of Gujarat as study area showing the marked areas as the meteorological stations for which climatic data was analysed from 1957-2007

Method

Phenological observations with respect to the flowering and fruiting time were done on 255 tree species of Gujarat representing 56 families and 151 genera, as reported by Shah (1978). Phenological patterns of tree of Gujarat as recorded by Shah (1978) were compared to the recent survey of the trees of Gujarat as done by Oza and Rajput (2006) and Singh (2008) and necessary conclusions were made.

RESULT AND DISCUSSION

Climatic Variability

The annual mean maximum temperature of Gujarat has increased by 1°C (Figure-3,4), the annual mean summer temperature by 0.1°C (Figure-5) and the mean winter temperature by 0.4°C (Figure-6) for the past 50 years (1957-2007) (Rathore, 2013; Rathore & Jasrai, 2013) along with increase in the extremities of weather like heavy rainfall, accompanied by sudden burst and episodes of droughts and floods. All these factors have resulted in shifting in the time period of flowering and fruiting pattern in 55 tree species of Gujarat (Table-1).

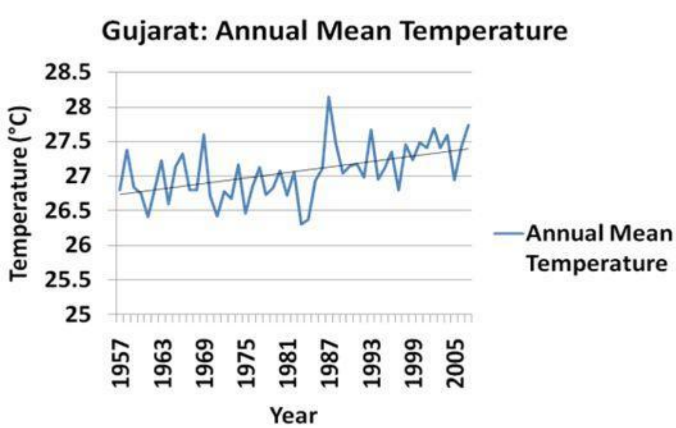

Figure 3: Increasing trend in the annual mean temperature of Gujarat (Rathore, 2013)

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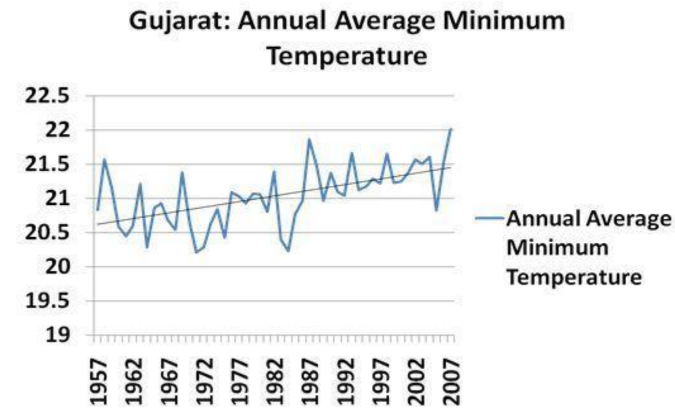

Figure 4: Showing annual average minimum temperature of Gujarat (Rathore, 2013)

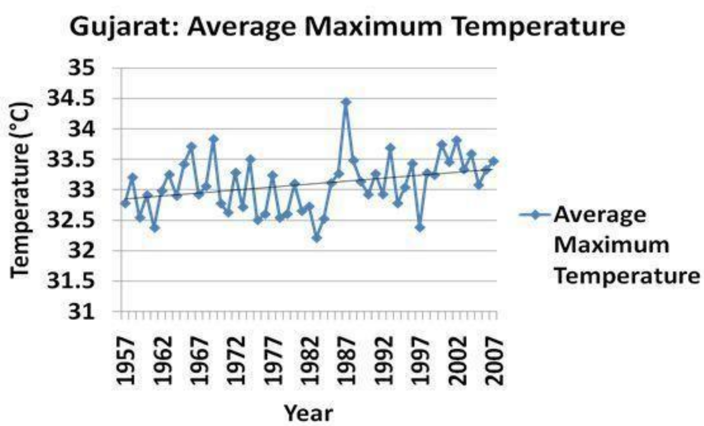

Figure 5: Showing average maximum temperature of Gujarat (Rathore, 2013)

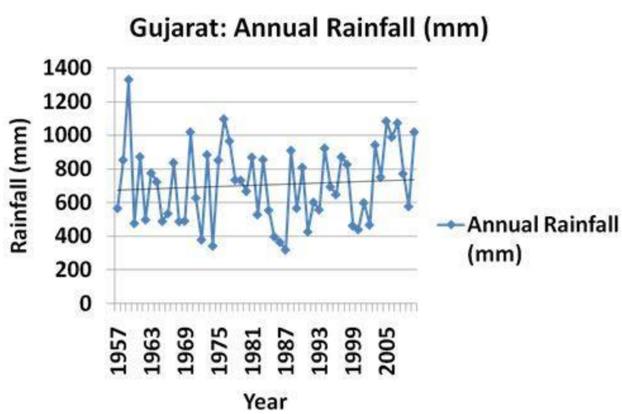

Figure 6: Showing annual rainfall in Gujarat for past 50 years (Rathore, 2013)

According to Houghton *et al.*, 2001 changes in spring phenology correlates with the global warming trend with a period of warming from the end of the 19th century through to the 1950s, followed by a period of stabilization and then a second phase of accelerated warming from the late 1970s onward. The most noticeable climate warming started in 1976 globally (Houghton *et al.*, 2001; Walther *et al.*, 2002; Luo *et al.*, 2007). Therefore, it can be assumed that global climate change has caused phenological changes since the 1970s (Matsumoto *et al.*, 2003).

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Phenological Variability

The results so obtained are the comparison of phenological status of tree species in 1976, 2006 and 2008 and impact of changing climate on phenophases in the past 33 years. Of the 259 species of trees belonging to 39 families reported by Shah (1976) 55 tree species represented by 28 families and 45 genera have changed their trends in the time of flowering and fruiting (Figure-1). The flowering and fruiting time has been observed at present to be either advanced or delayed by a period of one to three months in comparison to the 33 year old data of Shah (1976) (Table-1). The rise in annual mean maximum temperature of Gujarat by 1°C, 0.1°C rise in the summer temperature and 0.4°C rise in the winter temperature for the past 50 years (1957-2007) has resulted in shifting in the time period of flowering and fruiting pattern in 55 tree species of Gujarat. The flowering and fruiting time has been delayed in 24 tree species of 20 genera belonging to 16 families and has advanced in 31 tree species of 28 genera belonging to 19 families, by a period of one to three months (Table-1).

Table 1: Showing the variation in the time of flowering (advanced/delayed) of tree species of Gujarat

Sr No	Family	Tree species	G. L. Shah (1976) Flowering time	G.M. Oza and K. S. Rajput (2006) Flowering time	H. S. Singh *et al.*, (2008) Flowering time	Remark
1	Annonaceae	*Miliusa tomentosa* (Roxb) Sinclair	Mar-June	Apr-June	Apr-June	D
2	Capparaceae	*Capparis decidua* (Forsk) Edgew	Feb-Sept	Feb-Sep	Nov-June	A
3	Capparaceae	*Crateva adansonii* DC subsp. *odora* (Buch Ham) Jacobs	Apr-May	-	Mar-Sep	A
4	Flacortiaceae	*Casearia championii* Thwaites	May	-	Mar	A
5	Flacortiaceae	*Casearia tomentosa* Roxb ex Hook	Feb-June	Feb-June	Jan-Apr	A
6	Flacortiaceae	*Flacourtia montana* Grah	Feb-Apr	Feb-Apr	Jan-May	A
7	Tamaricaceae	*Tamarix aphylla* (L) Karst	Aug-Sept	July-Nov	July-Nov	A
8	Tamaricaceae	*Tamarix indica* Willd	Aug-Mar	Aug-Mar	Oct-Mar	D
9	Bombacaceae	*Adansonia digitata* L	Apr-Dec	May-Dec	May-Dec	D
10	Sterculiaceae	*Sterculia foetida* L	Dec-June	Feb-Aug	Feb-Aug	D
11	Sterculiaceae	*Sterculia urens* Roxb	Nov-May	Dec-May	Dec-May	D
12	Tiliaceae	*Grewia disperma* Rottl	Oct	Aug-Nov	-	A
13	Rutaceae	*Aegle marmelos* (L) Correa	Jan-July	Mar-July	Mar-July	D
14	Burseraceae	*Commiphora wightii* (Arn) Bhandari	Jan-May	-	Mar-Sep	D
15	Burseraceae	*Garuga pinnata* Roxb	Dec-May	Jan-May	Jan-May	D
16	Meliaceae	*Melia composita* Willd	Jan-Mar	Jan-May	Mar-June	D
17	Meliaceae	*Soymida febrifuga* (Roxb) A Juss	Feb-June	Jan-Aug	Jan-Aug	A
18	Rhamnaceae	*Zizyphus glabrata* Heyne ex Roxb	Aug-Apr	June-Apr	June-Apr	A
19	Rhamnaceae	*Zizyphus mauritiana* Lam	Sep-Feb	July-Jan	July-Jan	A
20	Sapindaceae	*Sapindus emarginatus* Vahl	Sep-Dec	Sep-May	Oct-Apr	D
21	Sapindaceae	*Sapindus laurifolius* Vahl	Sep-Mar	Sep-Apr	Oct-Apr	D
22	Anacardiaceae	*Anacardium occidentale* L	Sep-Apr	Dec-June	Jan-Apr	D
23	Anacardiaceae	*Buchnania lanzan* Spreng	Dec-Apr	Jan-May	Jan-May	D
24	Anacardiaceae	*Lannea coromandelica* (Houtt) Merill	Jan-July	Dec-July	Dec-July	A
25	Moringaceae	*Moringa concanensis* Nimmo	Oct-Mar	Nov-Apr	Nov-Apr	D

26	Fabaceae	*Butea monosperma var lutea* (Lam) Taub	Dec-May	-	Nov-June	A
27	Fabaceae	*Erythrina suberosa* Roxb	Apr-Nov	Mar-Oct	Mar-Oct	A
28	Fabaceae	*Sesbania sesban* (L) *var bicolor* W & A	Jan-Mar	Jan-Apr	Oct-Mar	A
29	Fabaceae	*Sesbania sesban* (L) *var sesban* Gillet	Oct-Feb	Aug-Mar	Aug-Mar	A
30	Caesalpiniaceae	*Cassia roxburghii* DC	Mar-Oct	Mar-Oct	Sep-Oct	D
31	Caesalpiniaceae	*Parkinsonia aculeata* L	Jan-May	Dec-May	Dec-May	A
32	Mimosaceae	*Acacia ferruginea* DC	Apr-Oct	Apr-Oct	Mar-Aug	A
33	Mimosaceae	*Acacia planifrons* Koen ex W&A	July	Nov	Sep-May	D
34	Mimosaceae	*Acacia polycantha* Willd	May-Dec	May-Feb	July-Feb	D
35	Mimosaceae	*Albizia lebbeck* (L) Bth	July-Mar	July-Mar	Mar-June	A
36	Mimosaceae	*Samanea saman* (Jacq) Merill	Mar-June	Apr-July	Apr-July	D
37	Myrtaceae	*Syzygium cumini* (L) Skeel	Feb-July	Feb-July	Jan-May	A
38	Rubiaceae	*Adina cordifolia* (Roxb) Bth & Hkf ex Brandis	July-Mar	July-Mar	Apr-May	A
39	Rubiaceae	*Gardenia resinifera* Roth Nov Pl	Oct-Feb	Oct-Feb	Aug-Mar	A
40	Rubiaceae	*Ixora brachiata* Roxb	Feb-June	Nov-June	Nov-May	A
41	Rubiaceae	*Morinda tomentosa* Heyne ex Roth	Mar-Nov	Apr-Nov	Apr-Nov	D
42	Goodeniaceae	*Scaevola taccada* (Gaertn) Roxb	July-Aug	-	June-July	A
43	Salvadoraceae	*Salvadora oleoides* Decne	Nov-Mar	Nov-Apr	Jan-June	D
44	Apocynaceae	*Wrightia tinctoria* R Br	Dec-June	Dec-Aug	Jan-Aug	D
45	Loganiaceae	*Strychnos potatorum* L	May-Nov	Mar-Nov	Mar-Nov	A
46	Ehretiaceae	*Cordia macleodii* Hkf	May	Mar-Apr	Mar-Apr	A
47	Ehretiaceae	*Ehretia aspera* Roxb	Nov	Nov-May	Feb-June	D
48	Ehretiaceae	*Ehretia laevis* Roxb	Dec-May	Jan-Aug	Jan-Aug	D
49	Bignoniaceae	*Millingtonia hortensis* L f	Nov-Feb	Nov-Feb	Oct-Dec	A
50	Bignoniaceae	*Spathodea campanulata* Beauv	Feb-May	Nov-May	Nov-Apr	A
51	Verbenaceae	*Tectona grandis* L	Aug-Dec	June-Dec	June-Dec	A
52	Euphorbiaceae	*Trewia polycarpa* Bth & Hkf	Mar-Apr	Mar-Apr	Dec-July	A
53	Moraceae	*Ficus drupacea* Thunb	Mar-June	Apr-May	Apr-May	D
54	Moraceae	*Ficus nervosa*	Mar	Mar	Feb	A
55	Moraceae	*Streblus asper* Lour	Mar-July	Jan-May	Jan-May	A

In the table above, Thy= timing of flowering and fruiting throughout the year; A= Advanced; D= Delayed timing of flowering and fruiting.

The flowering was delayed in *Miliusa tomentosa* (Roxb) Sinclair, *Adansonia digitata* L, *Sterculia urens* Roxb, *Garuga pinnata* Roxb, *Sapindus emarginatus* Vahl, *Sapindus laurifolius* Vahl, *Buchnania lanzan* Spreng, *Moringa concanensis* Nimmo, *Cassia roxburghii* DC, *Samanea saman* (Jacq) Merill, *Wrightia tinctoria* R Br, *Ehretia laevis* Roxb, *Ficus drupacea* Thunb and *Morinda tomentosa* Heyne ex Roth by a period of one month; in *Tamarix indica* Willd, *Sterculia foetida* L, *Aegle marmelos* (L) Correa, *Commiphora wightii* (Arn) Bhandari, *Melia composita* Willd, *Acacia planifrons* Koen ex W&A, *Acacia polycantha* Willd and *Salvadora oleoides* Decne by a period of two months; in *Ehretia aspera* Roxb by a period of three months and in *Anacardium occidentale* L by a period of four months
The flowering was advanced in *Crateva adansonii* DC subsp. *odora* (Buch Ham) Jacobs, *Casearia tomentosa* Roxb ex Hook, *Flacourtia montana* Grah, *Tamarix aphylla* (L) Karst, *Soymida febrifuga*

(Roxb) A Juss, *Lannea coromandelica* (Houtt) Merill, *Butea monosperma* var *lutea* (Lam) Taub, *Erythrina suberosa* Roxb, *Parkinsonia aculeata* L, *Acacia ferruginea* DC, *Syzygium cumini* (L) Skeel, *Scaevola taccada* (Gaertn) Roxb, *Millingtonia hortensis* L f and *Ficus nervosa* by a period of one month; in *Capparis decidua* (Forsk) Edgew, *Casearia championii* Thwaites, *Grewia disperma* Rottl, *Zizyphus glabrata* Heyne ex Roxb, *Zizyphus mauritiana* Lam, *Sesbania sesban* (L) var *sesban* Gillet, *Gardenia resinifera* Roth Nov Pl, *Strychnos potatorum* L, *Cordia macleodii* Hkf, *Tectona grandis* L and *Streblus asper* Lour by a period of two months; in *Sesbania sesban* (L) var *bicolor* W & A, *Adina cordifolia* (Roxb) Bth & Hkf ex Brandis, *Ixora brachiata* Roxb, *Spathodea campanulata* Beauv and *Trewia polycarpa* Bth & Hkf by a period of three months and in *Albizia lebbeck* (L) Bth by a period of four months.

Thus, since *Anacardium occidentale* L and *Albizia lebbeck* (L) Bth both show a delay and advance respectively in flowering time by a period of four months, they can be considered as the most sensitive tree species to changes in climate and can be considered as ideal indicators of climate change.

The change in the phenological pattern of some of the tree species can be taken as an indicator of the climate change as some plants are highly sensitive to even a slight change in their normal climate pattern especially with respect to the temperature and precipitation pattern. The flowering is induced by both endogenous (cicardian rhythms and hormones) and exogenous (day length and temperature) factors. The interaction of both these factors enables plants to synchronize their reproductive development with the environment (Taiz and Zeiger, 1998). It is evident that climate change will occur during the long lifespan of tree species and changes in phenology may be the major visible short-term response. In fact, tree phenological observations have proved to be most effective impact indicators of climate change (Chmielewski and Rotzer, 2001; Kushwaha and Singh, 2008).

Flower initiation is an important phenophase, which is the result of cumulative reflection of all the vital physiological processes in any individual tree (Thakur *et al.*, 2008). Reproductive events generally occur during the period of low photosynthetic activity or after the period of high rates of reserve accumulation (Singh and Kushwaha, 2006). Global warming will affect flowering of many plant species as the shoot meristem is sensitive to temperature changes and severe fluctuation will bring a halt in flowering response (Moriondo and Bindi, 2007). Temperature is a main driver of many plant developmental processes, and in many cases higher temperatures have been shown to speed up plant development and lead to earlier switching to the next ontogenetic stage (Badeck *et al.*, 2004).

An increase in the temperature by 1°C has shown to advance flowering which is in accordance with the works of Chmielewski and Rotzer, (2001) as observed in Germany, by Luo *et al.*, (2007) in three woody plant species (*Prunus davidiana*, *Hibiscus syriacus*, and *Cercis chinensis*) in China, by Thakur *et al.*, (2008) during their study in the region of Western Himalayas has shown an advancement in the flower initiation phase of 10 out of 11 multipurpose tree species (*Grewia optiva*, *Morus alba*, *Bauhinia variegata*, *Robinia pseudoacacia*, *Melia azedarach*, *Dalbergia sissoo*, *Toona ciliata*, *Celtis australis*, *Gmelina arborea*, *Sapindus mukurosii* and *Albizia stipulata*), by Menzel and Fabian (1999) and Menzel (2000) in aspen poplar *Populus tremuloides*, by Abu-Asab *et al.*, (2001) in 89 out of 100 plant species in Washington DC. Anderson *et al.*, (2005) in his study on 797 trees in the Tai National Park, Cote d'Ivoire and concluded that deviations from phenology cycles were largely attributable to fluctuations in rainfall and temperature.

Flowering and fruiting pattern are also found to be influenced by rainfall pattern (van Schaik *et al.*, 1993; Ragusa-Netto and Silva, 2007). It has been hypothesize that plants can predict which years will be best for the survival of seedlings, then synchronously flower and produce seeds only in such years. Flower induction is basically the transformation of leaf buds to flower buds. Thus, these results suggest plants initiate buds when dry conditions start and produce either leaves or flowers depending on the severity of the drought (Sakai *et al.*, 2006).

The variability of weather from year to year leads to certain fluctuations in the annual timing of phenophases. The seasonal cycle of plants however is influenced to the greatest extent by temperature, photoperiod and precipitation. Ground observations of phenology not only bear a clear and consistent warming signal, but also indicate parallelism in the phases of warming and advancement of phenology (Badeck *et al.,* 2004). Investigations by Chuine *et al.,* (1999), Kramer *et al.,* (2000) and Linkosalo (2000) showed that the phenological response of trees to an increase in temperature depends on the plant species (Chmielewski and Rötzer, 2001).

Analysis of long-term phenological records can provide an effective means for examination of phenological trends with time (Bradley *et al.,* 1999). An understanding of how vegetation responded to past climate will be helpful for predictions of response of plants to future climate change (Moza and Bhatnagar, 2005; Luo *et al.,* 2007).

Conclusion

An increase in the annual mean maximum temperature of Gujarat by 1°C, the mean summer temperature by 0.1°C and mean winter temperature by 0.4°C for the past 50 years (1957-2007) has resulted in shifting in the time period of flowering and fruiting pattern in 55 tree species of Gujarat in the past 33 years. The fluctuation in the temperature and precipitation may promote the growth of some plants while making some sensitive species vulnerable to the change. Phenological observations are some of the most sensitive data in identifying how plant species respond to regional climate conditions and to climatic changes (Chmielewski and Rotzer, 2001). Extreme sensitivity of life-cycle events to inter-annual variations in meteorological conditions make phenological studies of great importance in addressing critical questions related with global modeling, monitoring and climate change (Kushwaha and Singh, 2008). Phenology and climate relationship can also reveal the potential impacts of future climate changes (Yadav & Yadav, 2008). Phenological changes can be observed visually on field and no specialized techniques or sophisticated equipments are required to monitor how plants respond to climatic variation (Moza and Bhatnagar, 2005). In recent decades, there has been a resurgence of interest in plant phenology, and changes in phenology are extensively utilized as indicators of global change (Fitter and Fitter, 2002; Badeck *et al.,* 2004; Menzel *et al.,* 2006; Kushwaha and Singh, 2008; Nord and Lynch, 2009).

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