CHANGES IN PHENOLOGICAL PATTERNS OF *ERYTHRINA* SPECIES IN TWO DIFFERENT PRECIPITATION REGIMES IN TROPICAL FORESTS OF MIZORAM

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By

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DECLARATION

I, Ms. J. Vanlalremkimi, hereby declare that the subject matter of this thesis entitled "**Changes in Phenological Patterns of *Erythrina* Species in two Different Precipitation Regimes in Tropical Forests of Mizoram**" is the record of work done by me, that the content of the thesis did not form basis for the award of any previous degree or to anybody else, and that I have not submitted the thesis in any other University / Institute for any other degree.

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Chapter 1

Introduction

1.1 Phenology

Phenology is derived from the Greek word *Phiano* meaning to show or to appear. Hence, phenology is the science that measures the timing of life cycle events in plants, animals, microbes and detects how the environment influences the timing of those events. In the case of plants, phenological events involve flowering, fruiting, leaf flushing and germination (Leith, 1974). Phenology involves study of the response of living organisms to seasonal and climatic changes of the environment in which they live. Phenological patterns are basic for understanding biological processes and functioning of tropical trees and ecosystems (Tesfaye et al., 2011). Seasonal duration of leafing, flowering and fruiting mainly determines the phenological behaviour of tropical trees and directly or indirectly their population dynamics. Pattern of phenological events are variously used for characterization of vegetation type (Opler et al., 1980).

Phenology is a key component of life on earth. It is also concerned with the relationships among the phenophases of individuals of the same or different species. The life cycle of an organism is the period of time involving a single generation through reproduction and the period of time; it takes to reproduce a generation in which the organism go through different phenophases. The timing of phenological events can be quite sensitive to environmental conditions. Phenological observations are therefore integrative measures of the condition of the physical, chemical and biological environment (Haggerty and Mazer, 2008). From the historical records and observations, phenological events can vary from year to year. Ecosystems recover from variation between years, but when these changes happen consistently over many years, the timing of events such as flowering, leafing, migration and insect emergence can impact how plants and animals are able to thrive in their environments (Lechowicz, 2001)

One of the important purposes of phenological observations is to improve understanding of the relationships between meteorological variables and associated biological responses. Plant growth is the process of a series of phenophases (visible stages of development) that a plant must pass through if it is to grow (and reproduce) successfully. Understanding these relationships is crucial, not only for predicting ecosystem responses to climate change but also in identifying the C-uptake period (of forest stands); and for examining the seasonal exchanges of water and energy between the land surface and the atmosphere (Chen and Xu, 2012).

The role of phenology in the structure and function of ecological systems is often underappreciated, but its importance is magnified by climate change. Today, this well established science is used to track the effect of global warming and climate change on organisms and to make predictions about the future health of the environment. Shifts in phenology are among the most sensitive biological responses to climate change (Parmesan, 2007). They occur across trophic levels and are observable at local to global scales. This environmental sensitivity means that phenological studies are simple and cost-effective ways to measure environmental changes, including climate change, over the long-term.

Changes in phenological events like flowering and birds’ migrations are among the most sensitive biological responses to climate change. A phenological study records the dates on which seasonal phenomena occur which provides important information on how climate change affects ecosystems over time. Plant phenology has been proposed as an indicator of climatic difference and global change by the European Environmental Agency and the Intergovernmental Panel on Climate Change (IPCC, 2007).

1.2 Why phenological research is important

The phenological study helps to understand the adaptive strategies of the plant species in a particular kind of ecosystems and its management. Therefore, it is important to study the phenological patterns of different taxa for critical analysis of reproductive biology and its implications on scientific study. Phenological study is important in plant management and combating afforestation, honey analysis, floral biology, estimation of reproduction and regeneration (Mulik and Bhosale, 1989). The study of phenology deals not only the vegetative and reproductive phase corresponding to the climate and seasonal changes of a particular area but also determines the degree of reproductive synchrony with other plant species (Rathcke, 1988). Plant phenological study has great significance because it not only provides knowledge about the plant growth pattern but it also provides the idea on the effect of environment and selective pressure on flowering and fruiting behavior (Zhang et al., 2006).

Phenological observation provide information on the status and development of forest trees over the course of the year, it determines the course of the annual development stages of forest trees and their dependence on local (e.g., meteorological and site) conditions including damaging events; and document and explain possible changes in the timing of these stages in relation to environmental factors of natural and/or anthropogenic origin such as air pollution and climate change (Chen and Xu, 2012). Phenological information is important in monitoring all aspects of ecosystems (Lechowicz, 2001) and is essential to understand the dynamics of plant communities, which of course impact animal populations as well.

Different forest types are considered to be indicators of the amount and annual distribution of rainfall because seasonal variation in tree water status constitutes a major determinant of tropical tree phenology (Borchert, 1994). The flowering phenology differs from species to species in accordance with the ecosystems, they associates and this suggest that specific patterns of flowering phenology may be a characteristic of specific ecosystem types (Heinrich, 1976). Flowering phenology can affect the ecology of a plant at multiple levels, including individual plant reproductive success, interactions of the plant with other organisms, plant population dynamics and ecosystem functioning (e.g., the plant-pollinator landscape) (Bronstein, 1995). Flowering phenologies of tree species have ecological significance which provides the platform for natural selection by encouraging genotypic variation in a population (Bronstein, 1995). The particular phenological pattern that an individual exhibits (e.g., the date of germination; the onset and duration of flowering; the average number of flowers open per day during the flowering season; and the time of seed dispersal) is usually due to both genetic and environmental influences.

Singh and Kushwaha (2005) suggested that climate change forced deviations in the length of growing period and competition among species may change the resource use patterns in different species. Kramer (1997) concludes that differences in tree species phenological responses to temperature changes can have long-term consequences on their geographic distribution. He further suggested that phenology and climate relationship can also reveal the potential impacts of future climate changes. The initiation of growth in plants and changes in phenology are governed by various environmental factors and the influence of temperature and moisture has been studied by several workers (Dewald and Steiner, 1986). Hamann (2004) suggested that climatic factors are not directly responsible for triggering and synchronization of phenological events.

Seasonal changes include variations in the duration of sunlight, precipitation, temperature and other life-controlling factors. There has been a significantly increased interest in phenology primarily due to shifts in the timing of different phenological phases in plants, insects, birds and amphibians connected to climate change (Menzel and Fabian, 1999; Sparks et al., 2000). Studies have shown experimentally that plant phenology and more particularly reproductive phenology is an important determinant of fitness (Rathcke and Lacey, 1985). Phenology determines the ability to capture variable resources and it defines the season and duration of growth and reproduction (Schwartz, 2003).

In other animals, phenology is still essential to the reproductive success and survival of the individuals (Post et al., 2008; Sparks et al., 2000). The many applications for phenology data and models include agriculture, drought monitoring, wildfire risk assessment and the management of wildlife, invasive species, agricultural pests and other risks to human health and welfare, including allergies, asthma and vector-borne diseases. It contributes many scientific disciplines from biodiversity, agriculture and forestry to human health. It provides valuable data for land-use planning and crop zonation, control of agricultural, forestry and domestic pest species, protection of species of conservation interest and information on pollen release and its implications for human health (Ruml and Vulic, 2005).

One reason phenology is gaining importance is due to the fact that it is proving to be an independent record on global warming and global change. It is becoming widely documented that spring is occurring earlier and at many locations across the globe due to global warming (Menzel, 2002; Menzel, 2006). Although global climate change is predicted to have large impacts on biological systems and processes in the future (IPCC, 2007), there is mounting evidence across ecosystems and taxa that climate change is already affecting critical aspects of biological systems, including phenology (the timing of biological events) and reproduction (Aerts et al., 2006; Cleland et al., 2006; IPCC, 2007) with biotic interactions exacerbating the effects of climate change on reproductive phenology and success (Hughes, 2000). Changes in phenology and reproduction, in turn, have important implications for plant demography and community interactions, trophic dynamics, ecosystem energy balance and human livelihoods (IPCC, 2007).

1.3 Tropical and temperate phenology

It has long been recognized that seasonal changes in the physiognomy of tropical forests are caused primarily by seasonal variation in rainfall (Schimper, 1898), which in conjunction with soil moisture availability is the principal determinant of tree water status (Doley, 1981). Thus, the seasonal variation in water availability should determine the seasonal development in tropical trees, just as the phenology of deciduous temperate trees is determined primarily by seasonal changes in temperature and photoperiod. Also, tropical tree development should be arrested during drought and proceed actively during periods of adequate rainfall. In many tropical deciduous forests, the major phenological events conform to these expectations (Frankie et al., 1974); usually, leaves are shed during the early dry season and new shoots emerge after the onset of the wet season.

However, many developmental events do not correlate with seasonal precipitation patterns: (i) tropical trees frequently flower during the early dry season after leaffall; (ii) bud break may occur during the dry season; (iii) usually, shoot elongation and leaf expansion are limited to a few weeks during the early wet season and cease under conditions apparently favourable for growth and (iv) trunks often shrink temporarily during the wet season and expand during continuing drought (Daubenmire, 1972; Borchert, 1980; Reich and Borchert, 1982). Thus, several authors have warned against the attempt to infer causal relations from correlations between tree development and rainfall. In stead, variations in temperature and photoperiod were considered to trigger various phases of tree development (Njoku, 1963; Frankie et al., 1974). Daubenmire's (1972) records of seasonal variation in girth of tropical trees imply that changes in tree water status are not always correlated with, and hence not directly caused by variations in water availability.

Detailed analyses of the interrelations between environmental conditions, water status and phenology of the tropical deciduous trees *Erythrina poeppigiana* (Borchert, 1980) and *Tabebuia neochrysantha* (Reich and Borchert, 1982) showed that their water balance depended on soil moisture availability, atmospheric evaporative demand and the transpirational capacity of the tree. The resemblance between the seasonal changes in the physiognomy of tropical and temperate deciduous forests has been long noted by temperate zone botanists visiting the tropics, but relatively detailed phenological studies of tropical deciduous trees have been carried out only recently (Njoku, 1963; Hopkins, 1970; Daubenmire, 1972; Frankie et al., 1974).

Seasonal duration of leafing, flowering and fruiting mainly determine phenological behaviour in tropical trees. These phenological events are not mutually independent in woody species and flowering may be partly or wholly dependent on leafing activity (van Schaik et al., 1993). Nevertheless, tree species with similar leaf phenology often differ in the timing of their flowering and fruiting (Seghieri et al., 1995). Many deciduous tree species show flowering and fruiting during the leafless period, exhibiting wide separation between leafing and flowering phenophases. In many evergreens and in some deciduous species leaf flush and flowering occur close in time on the same new shoot.

Plant phenological studies are fundamental to understand the forest as a resource base for other dependent populations or communities. Tropical plant communities display conspicuous seasonal pattern in vegetative and reproductive phenologies at both community and species levels (Frankie et al., 1974; Chapman et al., 1999; Williams, 2003). Species in the tropics can potentially flower any time of the year, yet coexisting species vary considerably with respect to timing of flowering (Janzen, 1967; Bawa, 1983). Similarly, the frequency of flowering ranges from several times a year to once in several years (Frankie et al., 1974; Bullock et al., 1983; Appanah, 1993). Tropical species in the same community also vary enormously in duration of flowering from a few days to the whole year (Gentry, 1974; Opler et al., 1980).

Seasonality in phenological events has been reported to influence faunal diversity. More recently, efforts have been made to discern the importance of general community patterns in leafing, flowering and fruiting for many species of which particular forest types are composed (Frankie et al., 1974; Reich, 1995). Seasonal peaks for leaf flush and leaf fall are quite common in tropical rainforest pronounced by dry periods (Hladik, 1978). The search for correlations between tree phenology and environmental changes in evergreen forests was even less successful (Alvim, 1964). The lack of direct correlations between climatic variation and certain phases of tree development, as observed in temperate as well as tropical trees can be explained by the assumption that the behavior of trees as large, complex and long-lived systems is determined by the interaction between internal, correlative controls and environmental inputs (Borchert, 1983).

As environmental constraints affecting tree growth are less severe in the tropics than in the temperate zone, one should expect that growth patterns of tropical trees are determined more by internal correlations and less by environmental parameters than temperate trees (Janzen, 1974). One principal characteristic of phenology in tropical forests may be high diversity, partly because of the weaker physical constraints on schedules of biological activities (Gentry, 1974; Janzen, 1974; Sarmiento and Monasterio, 1983; Newstrom et al., 1994). This study showed the great potential of tropical phenological studies to explore selective pressures on phenology. In temperate ecosystems throughout the world, the timing of phenological events is shifting and these shift have been linked to recent global warming (Parmesan and Yohe, 2003; Root et al., 2003; Menzel, 2006). Changes in phenology could have substantial repercussions for conservation of natural systems, potentially creating ecological mismatches between interacting species (Both et al., 2006; Post et al., 2008) or between species and their abiotic environment (Inouye, 2008; Inouye et al., 2002).

In contrast to temperate forests, periodic change in rainfall caused by movements of the inter-tropical convergence zone often plays an important role as proximate and ultimate factors for tropical plant phenology (van Schaik et al., 1993). Dry seasons within an annual cycle occur in most tropical regions and many studies have shown a correlation between tropical plant phenology and rainfall (Augspurger, 1981; Borchert, 1983; Reich and Borchert, 1984) demonstrating existence of annual patterns of plant reproduction even in the tropics. Studies from tropical forests and other regions also showed that flowering phenology is a conservative trait within evolutionary lineages (Kochmer and Handel, 1986; Johnson, 1992; Ollerton and Lack, 1992; Wright and Calderon, 1995).

1.4 Global climate change and phenology

Climate change is a shift in the “average weather” that a given region experiences. The changes in the climate of the earth as a whole would mean “global climate change”. The earth’s natural climate has always been and still is constantly changing. These changes are measured by the change in all the features we associate with weather, such a temperature, wind patterns, precipitation and storms. The climate change seeing today different form previous climate change in both its rate and magnitude (Seth, 1980). With increasing warming, species and ecosystems are likely to shift from lower to higher altitudes and latitudes. Due to this the species would need to migrate upwards to survive. However the upward movement of alpine species occurring near the mountain peaks is likely to be restricted by the lack of space and soil.

In temperate ecosystems throughout the world, the timing of phenological events is shifting, and these shifts have been linked to recent global warming (Parmesan and Yohe, 2003; Root et al., 2003). Changes in phenology could have substantial repercussions for conservation of natural systems, potentially creating ecological mismatches between interacting species (Both et al., 2006) or between species and their abiotic environment (Inouye, 2008). Plants are especially appropriate organisms to study climate effects in phenology because they are sessile and must endure all weather conditions occurring where they are located. Such sessile life style has led plants to show an especially high plasticity in their phenotypes, such as phenology, to deal with environmental variability (Swamy et al., 2000; Singh et al., 2015). Plants exist in their current locations as a consequence of habitat selection and incremental adaptation to environmental conditions best suited to their requirements for survival (Wu and Zhang, 2012).

Phenology has received much attention during the last decade because many organisms are changing their life cycles in response to ongoing climate change (Parmesan and Yohe, 2003; Menzel, 2006). The timing of biological events (especially in regions with a marked seasonality) is strongly controlled by climate and consequently, this response was expected

(Leith, 1974). However, under rapid climate change, the suitability of these habitats inevitably changes. This manifests as a local species response, such as a change in range, abundance or in the timing of life cycle events (Parmesan and Yohe, 2003; Primack, 1985; Odum, 1970). Such changes are potentially problematic economically in terms of agricultural production and other ecosystem services; and ecologically through disrupted ecosystem functioning with the potential for large numbers of species mismatches and extirpations (Huhges, 2000; Primack, 1985; Visser and Hollerman, 2001).

The knowledge of timing of phenological events and their variability can help to get more stable crop yields and quality through improved and sustainable crop management providing dates for timely irrigation, fertilizing and crop protection. Phenology offers evidence of climate change happening now and helps in assessment of the significant effect on plants in future. Erratic weather patterns will have long-term effects on life-cycle stages and phenological patterns of almost all plant species (Reeves and Coupland, 2000). Phenological analysis of trees provides a potential tool to address critical questions related to modeling and monitoring of climate change (Schwartz, 1999).

Climate change will affect many aspects of the biology of tropical trees and its effect on plant phenology would be of immense significance (Corlett and Lafrankie, 1998). Much of the available phenological information on tropical trees is inadequate partly because of lack of standardized terminology, and also because most studies have been for a short term and have focused on community level patterns only (Newstrom et al., 1994). Phenology variables are indicated as some of the most sensitive data to climate conditions and therefore, were proposed by the European Environmental Agency as climate difference and global change indicators (Menzel, 2003). Global climate change is in extricably linked with sustainable development.

Global climate change is of prime concern at global scale in present era of Anthropocene (Zhang and Liu, 2012). In the present era of science and technology, due to the rapid pace of industrialization and urbanization, quantity of natural resources as well as quality of global environment has been altered seriously (Rai and Tripathi, 2009; Zhang and Chen, 2011;Wu and Zhang, 2012). First elucidated the role of climatic thresholds in constraining the geographic boundaries of many species followed by major works were done by MacArthur (1972). The temperature led to fever of earth by 0.6^0 C during the two phases i.e. between 1910 and 1945,1976 onwards, the rate of second being just double of the first (Holttum, 1953).

Plant growth requires sufficient light, water, oxygen, mineral nutrients and suitable temperature. These apparently simple demands actually involve a large number of environmental factors and physiological processes, such as meteorological factors (light, photoperiod, temperature, precipitation, humidity, wind, as well as gases), edaphic factors (topography, slope and exposure and soil properties) as well as biotic factors (such as pests, diseases and competition). Phenological onset of spring correlates very well with air temperature of the preceding months (Menzel, 2002). Phenology is perhaps the simplest way to track changes in the behaviour of species. Various indications of shifts in plant and animal phenology have already been reported for the boreal and temperate zones of the northern hemisphere (Menzel, 2002). There is growing evidence that the global climate is changing (Inouye et al., 2002).

Although evidence is accumulating for biological responses to the changing climate (Hughes, 2000; Inouye et al., 2002) the response of many species to variation in climate remains largely unpredictable. Inouye et al., (2002) observed multifaceted factors altering the timing of flowering in relation to climate change. Climate warming has advanced the biological spring and delayed the arrival of biological winter. These changes in the annual cycle of plants and the lengthening of the green cover season have many consequences for ecological processes, agriculture, forestry, human health and the global economy (Pilson, 2000).

A longer growing season as a result of climate change will in turn affects climate through biogeochemical and biophysical effects (Pilson, 2000). Global climate change could significantly alter plant phenology because temperature influences the timing of development, both alone and through interactions with other cues, such as photoperiod (Cleland et al., 2007). It is certainly conceivable that the schedule of these events has important effects on survival or reproductive success.

1.5 Factors which control phenological events

Plant phenology is strongly controlled by climate and has consequently become one of the most reliable bioindicators of ongoing climate change. This strong dependence on climate explains why, of all taxonomic groups, plants have the highest portion of species shifting their phenology in the predicted direction under current climate change (Parmesan and Yohe, 2003). Since few studies have assessed the effect of other environmental factors such as precipitation, photoperiod, availability of soil nutrients or soil physical properties and consequently evidence for their impact on phenology remains scarce (Badeck et al., 2004). Photoperiod is an important trigger of plant phenology, but regrettably the relative importance of this environmental cue with respect to temperature has been established in only a few wild species (Hunter and Lechowicz, 1992).

The balance between rainfall and evaporation plays a key role in ecosystem functioning in many regions of the planet (e.g. in Mediterranean biomes). Not only abiotic environmental conditions, such as temperature and humidity, but also biotic factors including intraspecific and interspecific competition for various resources, i.e., interactions with other organisms such as herbivores, pollinators and seed dispersers can be selective agents for plant phenology. Some studies have showed experimentally that germination, flowering and leaf production out of season caused low survivorship of seedlings (Tevis, 1958), low seed production (Augspurger, 1981) and a high predation rate (Aide, 1992) respectively.

Plant phenology can greatly affect animals that use young leaves, flowers, mature and immature fruits through temporal changes in plant resource availability (van Schaik et al., 1993). The focus of phenological studies has shifted to questions of how phenology will be affected by climatic factors and what consequences any climatic change may have for species distribution and ecosystem function. Seasonality in phenological events has been reported to influence faunal diversity. The plant-animal interactions in the community are based on the knowledge of seasonal production of plant parts. Mostly in the temperate region (Newstrom et al., 1994) comparison among communities under different climates is useful to consider effects of climate (van Schaik et al., 1993). Temporal variation in availability of pollinators, seed dispersers and herbivores may be strong selection pressures on flowering phenology (Augspurger, 1981). Also variation in flowering patterns among individuals within populations will affect their visitation by both pollinators and seed dispersers; and this will affect the way that natural selection acts to favour particular phenophases.

The phenology of leaf is controlled by a number of factors such as rainfall, temperature, light and relative humidity (Singh and Singh, 1992; Borchert, 1998; van Schaik et al., 1993; Wright and van Schaik, 1994). Although, it is now widely acknowledged that biological interactions and phylogenetic relations can shape phenological patterns (van Schaik et al., 1993; Wright and Calderon, 1995). In broadleaved trees, flowers may open either during or shortly after seasonal shoot growth or, as in the majority of deciduous tropical and temperate trees, after a period of flower bud dormancy, when trees are leafless (Janzen, 1967).

In tropical deciduous forests, flowering occurs commonly during the dry season. In the case of flowering, insect-pollinated species were better modelled by climate than wind-pollinated species (Janzen, 1967; Frankie et al., 1974). Differences in temporal responses of plant phenology to recent climate change are due to differences in the sensitivity to climate among events and species. Environmental factors influencing flowering time may thus contribute to spatial variation in plant– pollinator, plant–seed disperser and plant–seed predator interactions. The onset of flowering was synchronous at each altitude, reflecting a similar response to a uniform and unambiguous environmental cue (Rathcke and Lacey, 1985).

Rusch (1993) also reported that at higher elevation leaf budding was delayed and leaf potential productivity and leaf size decreases as elevation increases. The shortening of the vegetative growth period with altitude is a well known phenomenon (Njoku, 1963). Variation in flowering patterns has been observed in populations (Primack, 1980; Bullock and Bawa, 1981) and in species and communities (Opler et al., 1976; Primack, 1985). The phenological characteristics of flowering (intensity, duration, overlap) are important aspects of the reproductive effort of the plant (Richards, 1986).

The most important proximal environmental cues determining flowering time are considered to be temperature and day length (Reeves and Coupland, 2000). Flowering time distribution in plant populations can be shaped by numerous biotic and abiotic factors, such as pollinator activity (Lack, 1982; Rathcke and Lacey, 1985; Freeman et al., 2003), selection for synchrony with members of same species and/or other species (Rathcke and Lacey, 1985), herbivory (Walther, 2002; Pilson, 2000; Freeman et al., 2003), temperature and drought. The final distribution of flowering time is a result of many factors acting together in a frame set by underlying genetic architecture (Coupland, 1995).

1.6 Phenological studies in North-east India

The phenology of subtropical forest of North eastern region was studied by few authors (Tiwari and Chauhan, 2006). The analyse of the phenological pattern in tree species in the subtropical forests of north east India along disturbance gradient is to understand the response of tree species to climatic factors and the periodicity of seasons. The numbers of evergreen tree species were greater than that of deciduous tree species in all the forest sites (Kikim and Yadava, 2001).

Leaf fall of most of the tree species coincided with the dry season. Flushing started towards the end of the dry season for a majority of the tree species, the degree and period of leaflessness varying with the species. Leaf production in the overstorey species extended over a longer period compared to the understorey species. For most of the species, flowering coincided with leaflessness. Proportionately more overstorey species flowered during the dry season and wet season flowering was more characteristic of understorey species. A majority of the species produced freshly fruits during the wet season. Fruit produced during the dry seaon, were mostly dry (Shukla and Ramakrishnan, 1982). Leaf flush and flowering were simultaneous in both over and understorey tree species whereas the fruiting of understorey tree species is one month earlier than that of overstorey tree species (Kikim and Yadava, 2001).

There is a strong seasonality in phenological pattern of tree species in the sub-tropical forest of north east India. The phenological timing of most of the species seems to be set during the transition of winter and spring seasons so that summer rainfall facilitates recruitment of plants through germination. Seasonal variations in environmental factors and the dissemination of the propagules by birds and animals have a vital role to regulate the phenological pattern of tree species in the sub-tropical forest ecosystems. The spatial and temporal variations in the phenology of the tree species maintain a highly dynamic and productive forest ecosystem. The forest of north east India is sub tropical and the soil of all the forest sites is blackish brown in colour and clay loam texture. The soil is alluvial and acidic in nature (Kikim and Yadava, 2001).

Erythrina species are an important, dominant and primitive group of flowering plants with considerable ecological and economical importance in Mizoram. The knowledge about the location of these species in Mizoram is often constrained by limited field surveys owing to rugged terrain and low population sizes with widely dispersed individuals. Knowledge about distribution, phenological pattern, reproduction system of growth pattern of these species can help in understanding the evolution of life history traits. These may provide background information on functional rhythms of plants and plants communities. Besides, various selective pressures in the environment may influence the living of flowering and fruiting, pollinator activity and diversity of pollinators resulting into their bearing on seed production and ultimately on maintaining viable population of these important species.

The genus *Erythrina* forms a very important and dominant combination of forest types in cool climate high altitudes in Mizoram. It supports a wide range of biodiversity, if disturbed, can degrade habitats that threaten associated biodiversity. In order to bring out sustainable conservation and management of *Erythrina*, the first and foremost requirement is to study the detail about the *Erythrina* population, all ecological processes that maintain their population such as pollination, seed dispersal, involving complex interaction between several species of *Erythrina* and humans, however, adequate data on *Erythrina* population, location and extent of habit, floral phenology and the changes in all these aspects over time are not available for the state of Mizoram. Few efforts have although been made elsewhere such as in Sikkim Himalaya (Tiwari and Chauhan, 2006), Kumaun Himalaya (Singh et al., 2015), Central Himalaya (Gaira et al., 2014).

1.7 Objectives

This study has been focused on the evaluation of the patterns of phenology in two species of *Erythrina* (i.e., *Erythrina subumbrans* and *Erythrina variegata*) growing at two distinct locations that vary in rainfall, temperature and altitude to establish the relative importance of different hypotheses to explain phenological patterns of plants of the same taxa over different geographic locations with the following broad objectives:

(i) To determine intra-specific variation in phenological pattern between sites with different precipitation regimes.

(ii) To compare inter-specific phenological patterns within sites during two successive years.

(iii) To document seasonal pollinator use of floral resources in relation to the flowering phenology of these species.

References:

Aerts, R., Cornelissen J.H.C., Dorrepaal, E. (2006). Plant performance in a warmer world: General responses of plants from cold, northern biomes and the importance of winter and spring events. *Plant Ecology*, 182:63–77.

Aide, T.M. (1992). Dry season leaf production an escape from herbivory. *Biotropica*, 24**:**532–537.

Alvim de, T. (1964). Tree growth and periodicity in tropical climates; in *The formation of wood in tropical trees* (ed.) M. H. Zimmermann (New York: Academic press) pp 475-495.

Appanah, S. (1993). Mass flowering of dipterocarp forests in the aseasonal tropics. *J Biosci.* 18:457–474.

Augspurger, C.K. (1981). Reproductive synchrony of a tropical shrub: experimental studies on effects of pollinator and seed predators on *Hybanthus prunifolius* (Vioraceae). *Ecology* 62:775–788.

Bawa, K. S. (1983). Patterns of flowering in tropical plants. In: Jones C. E, Little R. J (Eds.) *Handbook of experimental pollination biology*. Van Nostrand Reinhold, New York. pp 394–410

Badeck, F.W., Bondeau, A and Bottcher, K. (2004). Responses of spring phenology to climate change. *New Phytol*. 162:295–309.

Borchert, R. (1980). Phenology and ecophysiology of tropical trees: Erythrina poeppigiana *0. F. Cook. Ecology,* 61:1065-1074.

Borchert, R. (1983). Phenology and control of flowering in tropical trees. *Biotropica* 15:81–89.

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

Borchert, R. (1998). Responses of tropical trees to rainfall seasonality and its long-term changes. *Climate Change* 39:381–393.

Both, C., Bouwhuis, S., Lessells, C., M and Visser M.E. (2006). Climate change and population declines in a long-distance migratory bird. *Nature* 441(7089):81–83.

Bronstein, J.L. (1995). The plant-pollinator landscape. In: Hansson L., Fahrig L. and Merriam G. (eds), *Mosaic Landscapes and Ecological Processes*. Chapman and Hall, London, pp. 256–288.

Bullock, S.H and Bawa, K.S. (1981). Sexual dimorphism and the annual flowering pattern in *Jacarantia dolichanla* (D smith) Woodson (Caricaceae) in Costa Rican rain forest; *Ecology* 62:1494-1504.

Bullock, S. H., Beach, J.H and Bawa, K S. (1983). Episodic flowering and sexual dimorphism in *Guarea rhopalocarpa* Radlk. (Meliaceae) in a Costa Rican rain forest. *Ecology* 64: 851–862.

Chapman, C.A., Wrangham, R.W., Chapman, L.J., Kennard, D.K and Zanne, A.E. (1999). Fruit and flower phenology at two sites in Kibale, National park, Uganda. *Journal of Tropical Ecology* 15: 189-211.

Chen, X and Xu, L. (2012). Temperature controls on the spatial pattern of tree phenology in China's temperate zone. *Agr. Forest. Meteorol*. 154(155):195–202.

Cleland, E.E., Chuine, I., Menzel, A., Mooney, H. A and Schwartz, M.D. (2006). Diverse responses of phenology to global changes in a grassland ecosystem. *Proc. Natl. Acad. Sci.* U. S. A. 103:13740–13744.

Cleland, E.E., Chuine, I., Menzel, A., Mooney, H. A and Schwartz, M.D. (2007). Shifting plant phenology in response to global change. *Trends in Ecology & Evolution* 22:357–365.

Corlett, R.T and Lafrankie, J.V. (1998). Potential impacts of climatic change on tropical Asian forests through an influence on phenology. *Climate change* 39:439-453.

Coupland, G. (1995). Genetic and environmental control of flowering time in *Arabidopsis*. *Tends in Genetics* 11(10): 393-397.

Daubenmire, R. (1972). Phenology and other characteristics of tropical semi-deciduous forest in North-western Costa Rica. *J. Ecol.* 60:147-70.

Dewald, L. E and Steiner, K.C. (1986). Phenology, height increment and cold tolerance of Alnus glutinosa population in a common environment. *Silvae Genetica* 35:205-211.

Doley, D. (1981). Tropical and subtropical forests and woodlands. Water Deficits and Plant Growth. Vol VI, pp. 209-323. Academic Press, New York.

Frankie, G.W., Baker, H.G and Opler, P.A. (1974). Comparative phenological studies of trees in tropical wet and dry forests in the lowlands of Costa Rica. *Journal of Ecology* 62:881-899.

Freeman, R.S., Brody, A.K and Neefus, C.D. (2003). Flowering phenology and compensation for herbivory in *Ipomopsis aggregate*. *Oecologia* 136:394-401.

Gaira, K.S., Rawal, R.S., Rawat, B and Bhat, I.D. (2014). Impact of climate change as the flowering of *Rhododendron arboreum* in Central Himalaya, India. *Current Science*, 106(12): 1735-1738.

Gentry, A.H. (1974). Flowering phenology and diversity in tropical bignoniaceae. *Biotropica* 6:64–68

Haggerty, B.P and Mazar, S.J. (2008). The Phenology Handbook: A guide to phenological monitoring for students, teachers, families, and nature enthusiasts. UCSB Phenology Stewardship Program.University of California, Santa Barbara. 41-43 pp.

Hamann, A. (2004). Flowering and fruiting phenology of Philippine sub-montane rain forest climatic factors as proximate and ultimate causes. *Journal of Ecology* 92:24-31.

Heinrich, B. (1976). Flowering phenologies: bog, woodland and disturbed habitats. *Ecology* 57:890-899.

Hladik, A. (1978). Phenology of leaf production in rain forest of Gabon. *The Ecology of Arboreal Folivores;* pp. 51–77.

Hopkins, B. (1970). Vegetation of the Olokemeji Forest Reserve, Nigeria. VII. The plants on the savanna site with special reference to their seasonal growth. *J. Ecol*. 58:795-825.

Holttum, R. E. (1953). Evolutionary trends in an equatorial climate. *Soc. exp. Biol. Symp*. 7:159-73.

Hughes, L. (2000). Biological consequences of global warming: Trends in *Ecology and Evolution* 15: 56-61.

Hunter, A .F and Lechowicz, M .J. (1992). Predicting the timing of bud-burst in temperate trees. J. *Appl Ecol* 29:597-604.

Inouye, D.W., Morales, M.A and Dodge, G.J. (2002). Variation in timing and abundance of flowering by *Delphinium barbeyi* Huth. (Ranunculaceae): the roles of snowpack, frost and La Nina, in the context of climate change. *Oecologia* 130:543-550

Inouye, D.W. (2008). Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. *Ecology* 89:353–362.

IPCC, (2007). *Climate Change 2007: The Physical Science Basis: Summary for Policymakers*. Intergovernmental Panel on Climate Change, Geneva, Switzerland. 1-18 pp.

Janzen, D. H. (1967). Synchronization of sexual reproduction of trees within dry season in Central America. *Ecology* 21:620–637.

Janzen, D. H. (1974). Tropical black water rivers, animals and mast flowering by the dipterocarpaceae. *Biotropica* 6:69–103.

Johnson, S .D. (1992). Climatic and phylogenetic determinants of flowering seasonality in the Cape flora. *J Ecol* 81:567–572.

Kikim, A and Yadava, P. S. (2001). Phenology of tree species in subtropical forests of Manipur in north eastern India. *Trop. Ecol*. 42:269-276.

Kochmer, J. P and Handel, S. N. (1986). Constraints and competition of flowering phenology. *Ecol Monogr* 56:303–325.

Kramer, K. (1997). Phenology and growth of European trees in relation to climate change. In *Phenology of Seasonal Climates I* (Eds.) pp. 39–50.

Lack, A. J. (1982). Competition for pollinators in the ecology of *Centaurea scabiosa* L. and *Centaurea nigra* L. variation in flowering time. *New Phytologist* 91:297–308.

Lieth, H. (1974). Purposes of a phenology book. pp 3-19. In: (H. Lieth, ed.) Phenology and Seasonality Modeling. New York: *Springer*-Verlag. 444 pp.

Lechowicz, M. J. (2001). Phenology Encyclopedia of Global Environmental Change, Volume 2. The Earth System: biological and ecological dimensions of global environmental change. Wiley, London

MacArthur, R. M. (1972). Geographical Ecology. Harper and Row, New York, USA. 129 p.

Menzel, A and Fabian, P. (1999). Growing season extended in Europe. *Nature* 397:659

Menzel, A. (2002). Phenology: Its importance to the global change community. *Climate Change*, 54:379–385.

Menzel, A. (2003). Plant phenological anomalies in Germany and their relation to air temperature and NAO. *Climatic Change* 57:243-263.

Menzel, A. (2006). European phenological response to climate change matches the warming pattern. *Global Change Biol*. 12:1969–1976

Mulik, N .G and Bhosale, L. J. (1989). Flowering phenology of the west coasts of Maharastra India. *J Bombay Nat Hist Soc* 86:355-359.

Newstrom, L E., Frankie, G. W and Baker, H .G. (1994). A new classification for plant phenology based on flowering patterns in lowland tropical rain forest trees at La Selva, Costa Rica. *Biotropica* 26:141–159.

Njoku, E. (1963). Seasonal periodicity in the growth and development of some forest trees in Nigeria. I. Observations on mature trees. *Journal of Ecology* 51:617-624.

Odum, H. T. (1970). *The El Verde study area and the rain forest systems of Puerto Rico.* A Tropical Rain Forest. Tennessee. pp. B3-B32.

Ollerton, J and Lack, A.J. (1992). Flowering phenology: an example of relaxation of natural selection. *Trends Ecol Evol* 7:274–276.

Opler, P .A., Frankie, G. W and Baker, H,G. (1976). Rainfall as a factor in the release, timing and synchronization of anthesis by tropical trees and shrubs. *Journal of Biogeography*, 3: 231-236.

Opler, P.A, Frankie, G. W and Baker, H .G. (1980). Comparative phenological studies of shrubs and treelets in wet and dry forests in the low lands of Costa Rica; *J. Ecol.* 68**:**167-186.

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

Parmesan, C. (2007). Influences of species, latitudes and methodologies on estimates of phenological response to global warming. *Global Change Biology* 13 (9):1860–1872.

Pilson, D. (2000). Herbivory and natural selection on flowering phenology in wild sunflower, *Helianthus annus*. *Oecologia* 122: 72-82.

Post, E.S., Pedersen, C., Wilmers, C.C and Forchhammer, M.C. (2008). Phenological sequences reveal aggregate life history response to climate warming. *Ecology* 89:363–370.

Primack, R.B. (1980). Phenological variation within natural populations: flowering in New Zealand montane shrubs. *J Ecol* 68:849–862.

Primack, R.B. (1985). Longevity of individual flowers. *Annual Review of Ecology and Systematics* 16: 15–38.

Rai, P.K and Tripathi, B.D. (2009). Comparative assessment of *Azollapinnata* and *Vallisneriaspiralis* in Hg removal from G.B. Pant Sagar of Singrauli Industrial region, India. *Environmental Monitoring and Assessment* 148:75-84.

Rathcke, B and Lacey, E. P. (1985). Phenological patterns of terrestrial plants. *Annu Rev Ecol Syst* 16:179–214.

Rathcke, B .J. (1988). Flowering phonologies in a shrub community: Competition and constraint. *Journal of Ecology:* 76:975-994.

Reeves, P.H and Coupland, G. (2000). Response of plant development to environment: control of flowering by day length and temperature. *Current Opinions in Plant Biology* 3:37-42.

Reich, P. B and Borchert, R. (1982). Phenology and ecophysiology of the tropical tree, Tabebuia neochrysantha (Bignoniaceae). *Ecology*, 63:294-299.

Reich, P. B and Borchert ,R. (1984). Water stress and phenology in a tropical dry forest in the lowlands of Costa Rica. *J Ecol* 72:61–71.

Reich, P. B. (1995). Phenology of tropical forests: Patterns, causes and consequences. *Can. J. Bot. 73: 164–174.*

Richards, A. J. (1986). *Plant breeding systems.* Allen & Un-win, London. 1- 529 pp

Root, T.L., Price, J.T., Hall, K.R., Schneider, S.H., Rosenzweig, C and Pounds, J.A. (2003). Fingerprints of global warming on wild animals and plants. *Nature* 241:57–60.

Ruml, M and Vulic, T. (2005). Importance of Phenological Observations and Predictions In Agriculture. *Journal of Agricultural Sciences*, 50(2), 217-225.

Rusch, E. (1993). Altitudinal variation in the phenology of *Nothofagus pumilio* in Argentina, *Revista Chilena de Historia Natural*, 66: 131 – 141.

Sarmiento, G and Monasterio, M. (1983). Life forms and phenology. In: Boulière F (Ed.) *Ecosystems of the world.* Vol 14B: Tropical savannas. Elsevier, Amsterdam. pp 219–240

Schimper, A. F. W. (1898). *Pflanzengeographie auf Physiologischer Grundlage*. Fischer, Jena

Schwartz, M. D. (1999). Advancing to full bloom: Planning phenological research for the 21st century. *International Journal of Biometeorol*. 42:113-118.

Schwartz, M. D. (2003). Phenoclimatic measures. In Phenology: *An Integrative Environmental Science*. pp. 331– 343

Seth, S. K. (1980) Forest and forestry in Himalayan region. Proceedings of national Seminar on resource development and environment in the Himalayan region. pp. 70 – 97.

Seghieri, J., Floret. Ch., Pontanier, R. (1995). Plant phenology in relation to water availability: herbaceous and woody species in the savannas of northern Cameroon. *Journal of Tropical Ecology* 11: 237–254.

Shukla, R. P and Ramakrishnan, P. S. (1982). Phenology of trees in a sub tropical humid forest in north Eastern India. *Vegetatio* 49**:**103-109.

Singh, J. S and Singh, V. K. (1992). Phenology of seasonality dry tropical forest. *Current Science*, 63: 683 - 689.

Singh, K. P and Kushwaha, C. P. (2005). Paradox of leaf phenology. *Shorea robusta* is a semi-evergreen species in tropical dry deciduous forests in India. *Curr. Sci*. 88:1820–1824.

Singh, N., Ram, J., Tewari, A and Yadav, R. P. (2015). Phenological events along the Elevation gradient and effect of climate change on *Rhododendron arboreum* Sm. in Kumaun Himalaya. *Current Science*, 108(1):106-110.

Sparks, T. H., Jeffree, E. P and Jeffree, C. E. (2000). An examination of the relationship between flowering times and temperature at the national scale using long-term phonological records from the UK. *International Journal of Biometeorology* 44(2): 82–87.

Swamy, P.S., Sundarapandian, S.M., Chandrasekar, P and Chandrasekaran, S. (2000). Plant species diversity and tree population structure in a humid tropical forests of Tamil Nadu, India. *Biodiver. Conserv.* 9:1643-1669.

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

Tevis, L. (1958) Germination and growth of ephemerals induced by sprinkling a sandy desert. *Ecology,* 39:681–688.

Tiwari, O .N and Chauhan, U .K. (2006). Rhododendron conservation in Sikkim Himalaya. *Current Science* 90 (4):532-541.

van Schaik, C. P., Terborgh, J. W and Wright, S. J, (1993) The phenology of tropical forests: adaptive significance and consequences for primary consumers. *Annu Rev Ecol Syst* 24:353–377.

Visser, M. E and Holleman, J. M. (2001). Warmer springs disrupt the synchrony of oak and winter moth phenology. *Proceedings of the Royal Society of London B* 268:289-294

Walther, G. R. (2002). Ecological responses to recent climate change. *Nature* 416:389–395

Williams, L. G. (2003). Temporal and special phenological variation of understory shrubs in a tropical Montana cloud forest. *Biotropica* 35:28-36.

Wright, S.J and van Schaik, C.P. (1994). Light and the phenology of tropical trees. *American Naturalist, 143: 192-199.*

Wright, S. J and Calderon, O. (1995). Phylogenetic patterns among tropical flowering phenologies. *J. Ecology* 83:937–948.

Wu, S.H and Zhang, W. J. (2012). Current status, crisis and conservation of coral reef ecosystems in China. *Proceedings of the International Academy of Ecology and Environmental Sciences* 2(1):1-11.

Zhang, X., Roman, M., Kimmel, D., McGilliard, C and Boicourt, W. (2006). Spatial variability in plankton biomass and hydrographic variables along an axial transect in Chesapeake Bay. *J. Geophys. Res.* 111:C05S11, doi:10.1029/2005JC003085.

Zhang, W. J and Chen, B. (2011). Environment patterns and influential factors of biological invasions: a worldwide survey. *Proceedings of the International Academy of Ecology and Environmental Sciences* 1(1): 1-14.

Zhang, W. J and Liu, C.H. (2012). Some thoughts on global climate change: will it get warmer and warmer. *Environmental Skeptics and Critics* 1(1):1-7.

Chapter 2

Review of Literature

2.1 Historical perspective

Phenology is one of the oldest branches of environmental science dating back thousands of years. Phenology observations have a history extending back for thousands of years in assisting farmers for predicting the optimum timing of cultivation practices. Since the late 1990s, phenology has been widely recognized as one of the simplest and most effective indicators of climate change, which is and continues to be a major threat to our living environment. Thus, phenology monitoring and modeling have received steadily increasing research attention over the last decade. While field observations record the timing of the seasonal development for specific animal or plant species, remote sensing is concerned with observing the phenology of whole ecosystems and stands of vegetation on regional and global scales. Such phenology data have been applied in the areas of regional and global environmental modeling, ecological monitoring, and climate change (Xiaoyang Zhang, 2012).

The wealth of historical phenological records allows scientists to examine trends from the past and make cautious predictions about what may happen to species in the future. Climate warming is expected to change seasonal biological phenomena such as plant growth and flowering, which is driven by environmental factors. The phenological changes from year to year may be a sensitive and easily observable indicator of environmental changes, and have a wide range of consequences for ecological processes, agriculture, forestry, human health, and the global economy (Geber and Dawson, 1993).

The history of observations of phenology dates to at least the 11th Century, BCE (Chen, 2003) when phenological events (commonly the flowering of woody plants) were recorded together with descriptions of weather and farming events. The principle objective of these early unsystematic observations was to improve agriculture. This general objective continued into the 13th Century when it became accepted that repeated observations could provide insight into natural processes (Demaree and Rutishauser, 2011). In the 18th Century, Carl Linnaeus made special note of anomalous phenological events and inter-species synchrony. The principle objective remained the improvement of agriculture, and phenological calendars were compiled for individual regions in recognition that phenology varied geographically. Phenological calendars of the modern era include attempts to predict phenology based on longitude, latitude and elevation (Chen, 2003).

Hopkins "Bioclimatic Law" (Hopkins, 1938) predicts the progression of spring phenological events based on these three geographic coordinates. Despite the long history of phenological observations, it was not until 1849 that the term "phenology" first appeared in print (Demaree and Rutishauser, 2011) in an article by Charles- François-Antoine Morren (1807–1858). The modern roots of phenology as a science are in the careful observations of naturalists in the 18th and 19th Centuries, Gilbert White and Henry David Thoreau being perhaps the best known among them. In these times, in fact, many people engaged in regular observation of phenological events. The daily records of the Marsham family, noting the seasonal activity of birds and plants in central England (Sparks and Carey, 1995), span the period between 1736 and 1925. Thomas Mikesell, a farmer in Ohio, made meticulous, twice-daily records of weather and phenology between 1883 and 1912 (Lechowicz, 1995). Long-term data sets of this sort exist in moderate amounts, usually for only single localities. Naturalists have continued a tradition of phenological observation into this Century (Fitter et al., 1995; Bradley et al., 1999), and their efforts have been augmented by the collection of phenological data in various scientific and government networks with greater spatial coverage (Ahas, 1999; Bruns, 1996). For example, the Royal Meteorological Society UK published phenology data regularly for at least 75 years, terminating about 1945.

Numerous studies examining long-term phenological records from the past 50 to 100 years have demonstrated clear changes in the timing of phenological events in taxa including birds, plants, butterflies and mammals (Inouye, 2000; Penuelas et al., 2002; Root et al., 2003; Stinson, 2004). These studies have primarily documented advances in spring plant and animal activity, though changes in summer and autumn events have also been documented (Vitasse et al., 2009; Crimmins et al., 2011; Fridley, 2012). Together, these analyses underscore the value of phenology data as an indicator of plant, animal and ecosystem response to climate change (IPCC, 2007).

Phenological studies have traditionally examined the timing of key life history events relative to calendar dates (Lieth, 1974; Schwartz, 2003). More recently, however, a growing number of studies have begun to consider changes in the timing of life history events for one species relative to those of an interacting species (Durant et al., 2005; Visser and Both, 2005). At a mechanistic level, climatic change may drive phenological shifts by accelerating or decelerating the developmental rates of species (Van Nouhuys and Lei, 2004), or by altering the timing of environmental cues that affect a species appearance in the community (Kemp and Bosch, 2005; Tottrup et al., 2008).

The phenological change is very limited relative to their potential impact on ecology and biophysical systems worldwide (Forrest and Miller-Rushing, 2010). Phenological dynamics is determined by complex interactions between genetic and environmental factors. Phenological observations provide background information on functional rhythms of plants and plants communities (Cruden et al., 1977). It is advantageous to observe the phenology of a species at different microclimate to understand its complete phenological behavior in nature as abiotic factors especially temperature, relative humidity and precipitation have specific roles in regulating phenological events (Wagner et al., 2012). Flowering phenology is often strongly constrained by phylogenetic history, many closely-related plants have very similar phenologies. On the other hand, divergent flowering phenologies can function as isolating mechanisms, which may be reinforced if related plants occur sympatrically (McIntosh, 2002).

By comparison, climatic changes can affect environmental cues that determine a species appearance in the community through processes such as migration (Tottrup et al., 2008), germination, hatching (Dunn and Winkler, 1999; Visser and Holleman, 2001) or emergence from dormancy (Kemp and Bosch, 2005). Importantly, both types of changes are likely to affect the entire phenology of a species life-history, not just the timing of specific life history events. As a result, understanding the consequences of many phenological shifts will require an understanding of stage structured species interactions.

2.2 At Global level

Researchers have used numerous techniques to observe how phenology has shifted in recent decades, including species-level observations (Spark et al., 1995; Parmesan and Yohe, 2003; Root et al., 2003) satellite remote-sensing of ecosystem production (Myneni, 1997) and atmospheric monitoring of carbon dioxide (CO2) concentrations as an indication of the timing of carbon uptake through photosynthesis (Keeling et al., 1996). Many of these studies have documented a correlation between earlier spring phenology and rising temperatures in recent years, but have found differing effects on the end of the growing season (Estrella and

Menzel, 2006; Menzel, 2003). Global change experiments have also documented the influence of increasing temperature, shifting precipitation and other aspects of global change, such as rising CO2 concentrations on the timing of species and ecosystem level phenology (Cleland et al., 2006 Dunne et al., 2003).

Although global climate change is predicted to have large impacts on biological systems and processes in the future (IPCC, 2007), there is mounting evidence across ecosystems and taxa that climate change is already affecting critical aspects of biological systems, including phenology (the timing of biological events) and reproduction (Cleland et al., 2006; IPCC, 2007). Changes in phenology and reproduction, in turn, have important implications for plant demography and community interactions, trophic dynamics, ecosystem energy balance and human livelihoods (IPCC, 2007). Changes in phenology, reproductive effort (number of flowers produced by each individual) and success (proportion of flowers on each individual plant that successfully produce fruits/seeds) may be especially prominent in alpine and arctic ecosystems because they are experiencing higher than average rates of temperature increase under global climate change (Root et al., 2003; IPCC, 2007).

Most studies on plant phenology in tropical forests have been conducted to describe community level patterns of leafing, flowering and fruiting, often for purposes of studying resource availability for consumer animals (Frankie et al., 1974; Putz, 1979; Foster, 1982; Koptur et al., 1988; Murali and Sukumar, 1994; Justiniano and Fredericksen, 2000). From a botanical perspective, individual level behavior has been analyzed in more detail in population level studies for rather short time periods, focusing on physiological releasing mechanisms (Augspurger, 1981; Reich and Borchert, 1982) and degree or effects of synchronization within a population (Augspurger, 1980, 1983; Primack, 1980). It is advantageous to observe the phenology of a species at different microclimates to understand its complete phenological behavior in nature as abiotic factors especially temperature, relative humidity and precipitation have specific roles in regulating phenological events (Kudo and Hirao, 2006).

Among the plant phenological phases, the flowering time is the most often considered, because it is one of the simplest to record and one of the easiest to interprete. Several studies in topics have reported that flowering phenology is a conservative trait within evolutionary lineages (Kochmer and Handel, 1986; Ollerton and Lack, 1992; Wright and Calderon, 1995). Much phenological research has been concerned with the influence of climatic variables upon plants. Air temperature found to be a dominant factor controlling the timing of flowering and other phenological phases (Hunter and Lechowitz, 1992). But, temperature alone cannot explain all the variation in plants development related to their environment. Some researchers stress the importance of photoperiod as well as rainfall and solar radiation (Friedel et al., 1993). Although the influence of soil on plant development is usually smaller than the influence of climate (Weilgolaski, 2001), sometimes the impact of soil temperature, water content, soil type and nutrient supply could be significant (Wielogalski, 1999).

Temperature has been demonstrated as one of the most important factors for plant phenology (Fitter et al., 1995; Sparks et al., 2000; Penuelas et al., 2002; Matsumoto, 2003; Menzel, 2003). Furthermore, precipitation effect in plant phenology is complex and difficult to forecast due to its close relationship with soil moisture. Phenological patterns may be influenced by the temporal abundance of pollinators, seed dispersers, seed predators or herbivores (Frankie et al., 1974; Rathcke and Lacey, 1985; Aide, 1992; Murali and Sukumar, 1993; Curran and Leighton, 2000) or by predictable temporal variations in rainfall, temperature and photoperiod (Opler et al., 1976; Heidi, 1997; Borchert et al., 2002; Williamson, 2002). Most of the studies on plant phenology have been carried out in tropical forests to describe community level pattern of leafing, flowering and fruiting. Some evidence has also indicated a later onset of autumnal phenological events. In Europe and Japan, leaf color changes have shown a delay of 0.3–1.6 days per decade, whereas the length of growing season has increased by up to 3.6 days per decade over the past 50 years (Menzel and Fabian, 1999; Matsumoto, 2003). All these plant phenological changes are highly correlated with temperature changes.

Temperature as well as phenology changed most noticeably after the 1970s. The available data and current knowledge of plant phenology including numerous experimental studies (Menzel and Fabian, 1999; Larcher and Bauer, 1981; Keeling et al., 1996; Price and Waser, 1998; Dunne et al., 2003; Aerts et al., 2004) indicated that the observed changes are mostly due to increased temperature. Climate change impacts on flowering phenology will not only directly affect particular plant species but can alter broader community structure and ecosystem functioning (Hughes, 2000; McCarty, 2001; Parmesan and Yohe, 2003). Most neo-tropical forest communities studied show flowering and fruiting peaks near the end of the dry season (Janzen, 1967; Foster, 1982; Hilty, 1980; Bullock and Solis- Magallanes, 1990; Justiniano and Fredericksen, 2000). The pattern may be caused by high insolation and photosynthesis in dry seasons or by enhancement of germination and seedling survival by adjusting fruiting to precede the beginning of the wet season (van Schaik et al., 1993).

Although many studies have suggested a correlation between rainfall and flowering or leaf flushing, external cues have been experimentally demonstrated in only some plant species. At higher elevations prevailing strong winds may increase bud damage, resulting in more profuse branching. Tree form is a result of a complex interaction between the genetic plan of the species (deterministic architecture) and responses to environmental events (opportunistic architecture) (Hatta et al., 1999). The timing of leaf flushing and flowering in species showing rain-induced bud break will vary greatly according to the onset of rainy season (earlier or delayed); this will affect the length of their growing season and the reproductive success (Menzel and Fabian, 1999). With respect to leaf exchanging species, deviations in summer and/or winter rains may affect the timings of leaf exchange and flowering through drought induced leaf fall and depletion of sub-soil water reserves (Menzel et al., 2006). Any marked delay in the onset of rains will expose relatively young leaves to prolonged severe drought, which in turn, may strongly reduce the leaf activity period (Matsumoto, 2003).

In extra tropical mountains, the timing of pollination may be important because the growing season gets shorter with altitude and time for seed formation may be crucial (Wagner and Mitterhofer, 1998). The increase in flower longevity and the constancy of proportional floral display demonstrate that the overall effort to attract pollinators is larger in high altitude species than in lowland species (Fabbro and Korner, 2004). The rates of visitation to flowers decline with elevation (Arroyo et al., 1985). Phenological studies in seasonal dry forest may affect the pattern of leafing phenology through differing water use and rooting depths and explain both inter and intra specific synchrony in the timing of leaf flush (Sayer and Newbery, 2003).

In temperate zones leaf development starts only after air and soil temperatures are higher than a threshold value following winter rest (Estrella and Menzel, 2006). Tropical plant communities display conspicuous seasonal pattern in vegetative and reproductive phenologies at both community and species levels (Frankie et al., 1974). Bliss (1956) reported that there was a slight delay in phenological events with increasing altitude. The reduction in overall plant size is the most conspicuous structural alteration in plants observed along elevation gradients (Estrella and Menzel, 2006). High altitude species allocated three times more of above ground biomass to floral structures than lowland species (Fabbro and Korner, 2004). Floral size traits do not seem to change with altitude, several studies show that the longevity of individual flowers increases with altitude (Primack, 1985; Billings, 1987).

Human induced climate change is one of the most influential drivers of changes in the distribution of biodiversity and the timing of biological events (Wada, 1983; Parmesan and Yohe, 2003; Root et al., 2003). High elevation environments are characterized by limited photosynthetic activity and a very short growing season, which may be associated with snow or ice (Inouye, 2000; Kikim and Yadava, 2001; Blionis et al., 2001; Bliss, 1956; Ashton and Berlyn, 1994). Differences in phenological responses of tree species to temperature change can have long term consequences on their geographic distribution (Kramer, 1997). Temperature may act directly on flowering and fruiting (Chapman et al., 1994), or as an environmental cue that induces community wide phenological events (Ashton and Berlyn, 1994).

From comparing different habitats, Primack (1985) concluded that flower longevity generally increased with cooler temperatures. The effect of climate factors *viz*., air temperature, relative humidity, light intensity and wind on five grass species *Alopecurus, Dactylis, Festuca, Lolium and Phleum* were carried out (Root et al., 2003) and reported that anthesis was positively related to temperature and light by which it was activated. Relative air humidity did not have any significant direct effect, but it casually inhibited anthesis through reducing light intensity or through precipitation (Root et al., 2003). The climatic factors were related to anthesis in *Holcus and Festuca* both the species showed a diurnal periodicity which were connected to air temperature, relative humidity and light intensity (Root et al., 2003). The reproductive phenology of plants is expected to be influenced by climatic factors and by the phylogenetic history of the species. Flowering and fruiting are important stages of the life history of plants with both ecological and evolutionary consequences (Rathcke and Lacey, 1985). Flowering phenology is particularly important because it determines reproductive synchrony with potential mates (Augspurger, 1981; Marquis, 1988), synchrony with or attractiveness to pollinators (Schemske, 1977; Augspurger, 1981; Galan and Gregory, 1989) and utilization of seasonally available resources such as light or water (Schemske, 1977, Schmitt, 1983; Marquis, 1988; Galen and Stanton, 1991; Walker et al., 1995).

Much of the available phenological information on tropical trees is inadequate partly because of lack of standardized terminology, and also because most studies have been for a short term and have focused on community level patterns only (Newstrom et al., 1994). Flowering phenology has attracted considerable attention in recent years (Rathcke and Lacey, 1985; Kochmer and Handel, 1986). Variation in flowering patterns has been observed in populations (Primack, 1980) and in species and communities (Opler et al., 1976; Primack, 1985). Flowering time may also strongly affect reproductive success by determining synchrony with and thus vulnerability to floral herbivores and seed predators (Breedlove and Ehrlich, 1968, 1972; Augspurger, 1981).

Fenner (1998) suggested that fruit production is largely controlled by the accumulation of enough photosynthetates which can only occur toward the end of growing season. In individual cases, flowering time may set restricted due to fruiting calendar slot. The extent to which flowering times of sympetric species are influenced by competition for pollinators have been much debated over the years. It is hypothesized that competition could be reduced by avoiding overlap in growing times. A number of studies indicate that inter-specific exploitative competition for pollinators does occur (Rathcke and Lacey, 1985). Another form of competition between plants sharing pollinators is the interference which occurs when pollen from one species is deposited on the stigma of another.

The size of the floral display can affect the behavior of pollinators (Klinkhamer et al, 1989). This influences not only the quantity of pollinating visits, but also the quality of the pollination service received. The production of many flowers can increase pollinator visitation (Augspurger, 1980; Bronstein, 1995), which may result in increased reproductive success. Plants from different elevations seem to follow different growth patterns. Anthesis is considered one of the many phenomena under control of endogenous rhythms (Hillman, 1962). Differences among population in the spatial separation of stigmas and anthers during anther dehiscence (herkogamy) might potentially cause variation. Self-polination is promoted by the close proximity of anthers and stigmas (Eckert and Schaefer, 1998).

Although automatic self-pollination is often interpreted as an adaptation for reproductive assurance (Eckert and Schaefer, 1998) is likely to make the mating system sensitive to variation in ecological factors like population size that might influence the level of cross-pollination. It has been suggested that competition through pollination may lead to the staggering of flowering phenologies in a given plant assemblage through either the evolutionary displacement of blooming times; or through an ecological sorting process that eliminates inferior competitors from communities leading to the coexistence of plant species that minimize flowering overlap. However, the influence of this type of competition on community patterns of flowering phenology and the appropriate methods to detect these patterns remain controversial (Stiles, 1977; Pleasants, 1990).

Flowering phenology may also be molded by abiotic environmental factors such as climate, probably the most important factor affecting flowering times (Rathcke and

Lacey 1985). The timing, duration and frequency of flowering define flowering patterns. Plants display a wide variety of patterns, particularly in a seasonal tropic, where favorable conditions for flowering throughout the year result in a broad range of variation in timing, frequency and duration of flowering (Bawa, 1983). Temporal distribution of flowers is a balance between positive and negative density effects, but it is also determined by seasonal position and trade offs with other plant traits, including other phenophases (Both et al., 2009).

The prevalence of phenotypic and genetic correlation between flowering phenology traits and other life history events (Blionis et al., 2001) and other quantitative traits such as plant size or environmental conditions (Dieringer, 1991; Ollerton and Lack, 1998) makes it difficult to predict how populations might respond to selection acting on flowering phenology (O 'Neil, 1997). The diversity and complexity of phenological patterns is greater in tropical than in temperate forest ecosystems (Borchert, 1983; Rathcke and Lacey, 1985). The timing of flowering is most essential for species survival, and is shown in many studies to be highly correlated with plant fecundity (O’Neil, 1997, Stinson, 2004). It can strongly influence the reproductive success of a plant in several ways (Rathcke and Lacey, 1985).

2.3 At National level

The annual initiation of phenological events is driven predominantly by climatic shifts associated with the change of seasons rather than by intrinsic controls (Badeck et al., 2004). Periodic behaviour of plants in tropical environments has received much attention in recent years. The knowledge of phenology of plants has helped to understand the influence of phenological events on feeding, movement patterns, and sociality of insects, birds and mammals (Foster, 1982; Wada, 1983; Appanah, 1985; Croat, 1975). More recently, efforts have been made to discern the importance of general community patterns in leafing, flowering and fruiting for many species, of which particular forest types are composed (Frankie et al., 1974; Lieth, 1974; Opler et al., 1980). A considerable amount of information is available on the major phenological events of plant species from different parts of tropical south-east Asia including continental India (Santapau, 1962; Malaisse, 1974; Monasterio and Sarmeinto, 1976; Liberman, 1982; Rai and Proctor, 1986; Steven et al., 1987; Bullock and Solis-Magallanes, 1990).

Hamann (2004) suggested that climatic factors are not directly responsible for triggering and synchronization of phenological events. Wright (1991) has also suggested that water stress could affect the timing of growth without reducing total annual growth. The leaf initiation during dry season and after the dry season for few tropical tree species is also reported from Western Ghats, India (Sundarapandian et al., 2005). Many researchers (Frankie et al., 1974; Shukla and Ramakrishnan, 1982; Singh and Kushwaha, 2006; Singh and Singh, 1992) have reported leaf initiation during dry season before rains. But a few cases of leaf initiation during wet season have also been observed in many studies (Bullock and Solis-Magallenus, 1990; Lieberman and Lieberman, 1984).

In dry deciduous forests flowering and fruiting pattern are mostly influenced by soil moisture and rainfall pattern (Singh and Kushwaha, 2006). Leaf flushing is mainly coincided with early rainy season might be due to pre rain flash and increasing temperature, such a pattern has also been reported from other seasonal tropical forests (Frankie et al., 1974). Water is an essential component for leaf initiation and those species, which can produce new leaves during the dry season, depend on water stored in the tree stem or water remaining in the subsoil (Sayer and Newbery, 2003). Moreover, deep rooting canopy trees do not experience a water deficit condition during dry season and can continue leaf flushing activity (Santapau, 1962). In most ecosystems, variation in the timing of flowering was associated with the variation in climate (Walker et al., 1995). The differences in leaf fall of different species may be due to micro-environmental factors as also has been reported (Boojh and Ramakrishnan, 1981).

The rate of leaf fall during the dry season was strongly correlated with the decline in soil moisture and increasing water stress of the tree (Reich and Borchert, 1982). The timing of leaves fall and bud break was generally determined by tree water status of the environment and the structural and functional state of the tree (Reich and Borchert, 1984). In the absence of transpiration during leafless phase, trees are able to store some amount of water in their conductive tissues for subsequent use during the early leaf flushing phase (Singh and Singh, 1992).

Plant species' flowering phenologies have ecological relevance at a range of scales–from individual genotypic variation in flowering time within a population (the raw material of natural selection) to interspecific, landscape-wide patterns which may support flower visitor diversity within that landscape (Bronstein, 1995). Consequently, studies of flowering phenology have been used to address ecological and evolutionary questions concerning intra- and interspecific competition, community structure, keystone relationships, coevolution, animal foraging behaviour, phylogenetic constraints and continent-wide patterns (Kochmer and Handel 1986; Bronstein, 1995).

Rathcke and Lacey (1985) and Primack (1985) reviewed many of the studies on flowering time of individual species and supported and developed explanations for how particular flowering patterns might evolve via selection. The synchronization of flowering with leaf flushing is related to moisture, temperature and photo period (Boojh and Ramakrishna, 1981; Murali and Sukumar, 1994*)*. Levesque and Svoboda (1992) make assumptions that a delay in phenology is associated with altitude, plant performance (i.e. number of flowers/plant and biomass/plant) also decrease with altitude, fewer plants flower as they are colder and nutritionally poorer and plants at the highest and therefore most stressful sites may not produce flowers or complete flowering in cold years. In high mountain regions, flowering phenology changes along elevation gradients, with plants at lower elevations typically flowering earlier than plants of the same species that grow at higher elevations (Bertiller et al., 1990; Ziello et al., 2009).

The review of literature reveal that among the various flowering phenology, the timing of flowering is the most widely investigated event in the plant life cycles and has been studied on every scale from the level of community (Murali and Sukumar, 1994) to that of the individual flower (Herrera, 1995) . In plant communities, although at least some species will be in flower throughout the growing season, there is a tendency for peaks of flowering to occur. Many factors have been attributed to peak flowering. For example, in wet tropical forest flowering production may coincide with peaks of radiance (Wright and van Schaik, 1994) while in seasonally dry tropical forest flowering is often concentrated in the transition from the late dry to the early wet season (Murali and Sukumar, 1994).

In some species, it is staggered over a long period, in others there is a much more pronounced peak with relatively few individuals occurring in the early and late parts of flowering period (Proenca and Gibbs, 1994). Various types of flowering (mass flowering, flush flowering and steady state flowering) are nevertheless results of response to different set of selective pressures. A strong peak of flowering suggests a disadvantage to out of season individuals, possibly due to pollination reduction in an out crossing species. In the mass flowering, the properties of flowers that set fruit has been positively correlated with flower abundance in shrub *Befaria resinosa* (Melampy, 1987).

Variation in weather from year to year or changes in pollinator or seed predator abundance may also result in selective pressure on flowering times, favouring early, average or late individuals in different years. Brody (1997) also point out that the net effect of pollinator and seed predator varies both in time and space. Rathcke and Lacey (1985) point out that at least some degree of asynchronous flowering in population would have the benefit of promoting out crossing by forcing pollinator to move between individuals. The highest level of out crossing of mass flowering species probably occurs at the beginning and end of blooming season (Carpenter, 1976). In cross-pollinated species, selection is generally expected to favor synchrony of flowering among individuals, though asynchrony may be favored in populations with intense within-species competition for pollinators (Bawa, 1983).

In closely related sympatric species, differences in flowering phenology may not only reduce competition for pollinators (Waser, 1978), but also help to ensure genetic isolation (Gentry, 1974). Any analysis of the selective pressures acting on flowering patterns requires a clear understanding of interannual variation in population level flowering duration (Bawa, 1983). In some habitats, where seasonal changes in climate are important, abiotic variables are important in determining phenological patterns regardless of the effect these patterns have on the reproductive success of each plant (Inouye and McGuire, 1991). For most species, the time of flowering may be constrained by the living of other phenophases such as growth, seed dispersal and seed desimination (Johnson, 1993). An important constrain on the flowering phenology of a species may also be its taxonomic affinities. Related plants share similar inherent design constraints which would limit their potential evolutionary response to selection (Kochmer and Handel, 1986).

Synchrony type of flowering was quite common in woody species. As majority of species produced flowers during leaf-less phase, which favours wind pollination as well as floral display to attract pollinators (Singh and Singh, 1992). Synchronization of flowering and leaf flushing seems to be related to moisture, temperature and day length, which is in conformity with observations made by other workers (Boojh and Ramakrishnan, 1981; Murali and Sukumar, 1994). In plant communities, although at least some species will be in flower throughout the growing season, there is a tendency for peaks of flowering to occur.

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Rathcke and Lacey (1985) point out that at least some degree of asynchronous flowering in population would have the benefit of promoting out crossing by forcing pollinator to move between individuals. The highest level of out crossing of mass flowering species probably occurs at the beginning and end of blooming season (Fogden, 1972). Sequence often appears to be non random (Schmitt, 1983). Pre-dispersal seed predation could be yet another important biotic influence on flowering time, which may provide a selective pressure if it is concentrated at a particular time within the flowering period (Ziello et al., 2009). Similarly, each life history stages of a plant are to some extent dependent upon or constraint by the preceding and succeeding stages. Borchert (1994) also suggested that the stored water buffers has the impact of seasonal drought and enables flowering and flushing during the dry season.

Flowering during the dry season reflects the availability of water by different sources, for example, through sporadic winter rains, absorption from soil and water stored in stem (Singh and Kushwaha, 2006). Some other workers also reported peak flowering period before rainy season (Boojh and Ramakrishnan, 1981; Kikim and Yadava, 2001; Singh and Singh, 1992), and it has been argued that moisture, temperature and photoperiod seem to be responsible for flowering (Frankie et al., 1974; Lawton and Akpan, 1968; Murali and Sukumar, 1993; Pandey et al., 2002; Wright and van Schaik, 1994; Yadav and Yadav, 2008). Initiation of fruiting mostly depends upon the timing and period of flowering rather than climatic parameters like rainfall and temperature. But fruit ripening and the length of fruiting period are dependent on temperature and photo-period (Pandey et al., 2002). In dry tropical trees, the duration of fruiting phenophase depends at least to some extent on the time of flowering and the leafless period during the annual cycle (Singh and Kushwaha, 2006).

2.4 At Regional level

In India, the phenology of tree species has been studied in the subtropical forests in north-eastern region (Boojh and Ramakrishnan, 1981; Kikim and Yadava, 2001; Shukla and Ramakrishnan, 1982) and in western Himalayas (Ralhan et al., 1985; Sundriyal, 1990). However, few attempts have been made to evaluate the phenology of tree species in the tropical dry deciduous forests (Khan, 1999; Singh and Singh, 1992). Environmental factors other than temperature also modify plant phenology. The second most important trigger of spring phenological phases is photoperiod length. This has been shown in experimental studies (Badeck et al., 2004). The weight of this factor is species-specific. This has also been concluded from fits of phenological models to large data sets of phenological observations (Badeck et al., 2004). Global influences include ongoing changes in temperature and precipitation regimes, with high-altitude environments warming and receiving more precipitation as rain instead of snow (Inouye, 2008). Borchert (1994) also suggested that the stored water buffers the impact of seasonal drought and enables flowering and flushing during the dry season. Tropical species in the same community also vary enormously in duration of flowering, from a few days to the whole year (Gentry, 1974; Opler et al., 1980).

In out crossing plants, flowering patterns determine the outcome of selection by influencing the amount of out crossing (Myneni et al., 1997), number of mates (Bawa, 1983), near-neighbour mating, and reproductive output (Janzen, 1974). Yet little is known about constraints on the timing, duration or frequency of flowering and the selective forces that shape the evolution of various patterns. One possible reason for this neglect is that the diversity of flowering patterns is greatest in a seasonal tropic, where patterns have not been fully described. The extensive literature on flowering phenology of tropical plants is largely focused on the timing or seasonality of flowering at the community level (Janzen, 1967; Frankie et al., 1974; Opler et al., 1980; Wright and Calderon, 1995).

The differences in leaf fall of different species may be due to micro-environmental factors (Boojh and Ramakrishnan, 1981). The rate of leaf fall during the dry season was strongly correlated with the decline in soil moisture and increasing water stress of the tree (Reich and Borchert, 1982). Reproduction in the dry season allows temporal separation of reproductive activity and vegetative growth. Janzen (1967) also attributed a major role to pollinators as selective agents. Most dry-forest trees are pollinated by a diverse range of bees that are seasonally abundant; the lack of leaves in the dry season may increase the visibility of flowers to pollinators (Janzen, 1967; Daubenmire, 1972).

Water stress is a major impetus for flowering during the dry season (Borchert, 1980; 1983). In a seasonal tropic, there is no pronounced dry season. Nevertheless, if the factors postulated by Janzen (1967) and Borchert (1983) are operating, one should expect more species to flower during the periods of low rainfall than during the wet season. With respect to interaction among timing, duration, and frequency of flowering, supra-annual species should flower for a shorter period and in the dry season. Such species, during their flowering, attract pollinators from other species or assist in building up pollinator faunas in those cases where many species in the community participate in supra-annual flowering (Ashton and Berlyn, 1994; Appanah, 1993).

To attract or build up pollinators, massive floral displays over a short period are required. Environmental cues are required to trigger supra-annual flowering (Ashton and Berlyn, 1994). Such cues may be more effective in the dry than in the wet season because relatively abundant moisture in the wet season diminishes environmental fluctuation in temperature as well as water stress. Most species in a tropical dry forest flower in the dry season because leaf fall in the dry season reduces water stress (Borchert, 1983) or because pollinators are most abundant in the dry season (Janzen, 1967).

Although studies pertaining to phenological pattern in plant community have been largely studied and efforts have been made on various tree species by several workers (Primack, 1985; Haase, 1986; Galen and Gregory, 1989; Murali and Sukumar, 1993; Proenca and Gibbs, 1994; Herrera, 1995). In tropical trees, leaf phenology is important because it reflects the influence of evolution and environment on plant characteristics and in turn has substantial implications for plant functioning such as leaf and shoot growth (Reich et al., 2004). Different patterns of leaf emergence are associated with particular patterns of leaf survival and shoot growth (Kikuzawa, 1989; Kikuzawa et al., 1996).

In most of the sub tropical forest of north east India, deciduous species may or may not initiate growth before evergreen species, but they complete it before the evergreens (Dhaila et al., 1995). The shoot extension and leaf growth of both evergreen and deciduous plants are influenced by similar climatic conditions, however, deciduous species shed their leaves soon after the rainy season or before the onset of dry season, while the evergreens retain them throughout the winter and leaves are shed during the dry summer at the time of new shoot growth (Ralhan et al., 1985). In same forest community, some species expand their leaves simultaneously as a flush in the growing season with shoot elongation within a short period, and some others unfold leaves sequentially over a longer period with shoot growth over an extended period (Kikuzawa and Lechowicz, 2011).

Most of the deciduous species in the region initiate growth before the evergreen species and show a rapid shoot growth, leaf recruitment and leaf expansion which may be a significant adaptation attribute that enable deciduous species to accomplish greater growth earlier in the season compared to evergreen species (Mooney and Dunn, 1970; Gray, 1982). Early accomplishment of growth in deciduous species may have competitive advantages over evergreen species to exploit forest resources.

The phenology of *Erythrina* a long an altitudinal gradient of increasing atmospheric water stress showed a transition from an evergreen to a deciduous habit. At permanently humid sites, all phenological phases occurred simultaneously on the same tree. With increasing drought, consecutive developmental stages tended to be more separate in time and more synchronized. In humid tropical climates, characterized by the absence of significant environmental stress, the periodic development of *Erythrina* is thus primarily determined by variables such as leaf age and tree size, which affect the trees' internal functional balance. Increasing environmental stress, in tropical environments most likely drought, may secondarily synchronize certain phases of the basic endogenous rhythmicity with seasonal climatic changes (Borchert, 1980). The tendency of *Erythrina* and many other tropical trees to leaf out soon after leaf shedding, even under continued drought, clearly indicates that trees are not in a state of drought dormancy. Leaf abscission is the consequence of drought-induced tree water deficits and not as expressed in many discussions of the adaptive value of deciduousness in tropical trees (Richards, 1952), an anticipatory reaction "to reduce further loss of water."

The research works on *Erythrina* species are relatively few and far between in Indian states and completely lacking in Mizoram. It is expected therefore that the present study will behave along altitudes as far as their floral phenology and to other influences such as pollinators, predators etc. These species had a low population density and produced fewer flowers per day, but flowered over a longer duration than species flowering massively (Augspurger, 1983). Extended flowering in species that are restricted in space apparently increases mating opportunities over time. Continuous growth during the wet season may also provide resources for extended flowering.

References

Aerts, R., Cornelissen, J.H.C., Dorrepaal, E and Van Logtestijn, R.S.P. (2004). Effects of experimentally imposed climate scenarios on flowering phenology and flower production of subarctic bog species. *Glob Chang Biol.* 10(9):1599–1607.

Aide, T. M. (1992). Dry season leaf production: an escape from herbivory. *Biotropica* 24:532–537.

Ahas, R. (1999). Long-Term Phyto-, Ornitho- and Ichtyophenological Time-Series Analyses in Estonia, *Int. J. Biometeorol.,* 42:119–123.

Appanah, S. (1985). General flowering in the climax rain forest of Southeast Asia. *J Trop Ecol* 1:225–240.

Appanah, S. (1993). Mass flowering of dipterocarp forests in the aseasonal tropics. *J Biosci* 18:457–474.

Arroyo, M. T. K., Armesto, J and Primack, R. (1985). Community studies in the high Temperate Andes of Central Chile. II. Effects of temperature on visitation rates and pollination possibilities. *Plant Systemics and Evolution* 149**:**187 – 203.

Ashton, P.M.S and Berlyn, G.P. (1994). A comparison of leaf physiology and analysis of *Quercus* (section *Erythrobalanus*-Fagaceae) species in different light environments. *Am. J. Bot.* 81:589-597.

Augspurger,C. K. (1980). Mass-flowering of a tropical shrub (*Hybanthus pruniformis*): influence on pollinator attraction and movement. *Evolution* 34:475–488.

Augspurger, C. K. (1981). Reproductive synchrony of a tropical shrub: experimental studies on effects of pollinator and seed predators on *Hybanthus prunifolius* (Vioraceae). *Ecology* 62:775–788.

Augspurger. C.K. (1983). Phenology, flowering synchrony, and fruit set of six Neotropical shrubs. *Biotropica* 15:257–267.

Badeck, F.W., Bondeau, A and Bottcher, K. (2004). Responses of spring phenology to climate change. *New Phytol*. 162:295–309.

Bawa, K. S. (1983). Patterns of flowering in tropical plants. In: Jones C. E, Little R. J (Eds.) *Handbook of experimental pollination biology*. Van Nostrand Reinhold, New York. pp 394–410

Bertiller, M. B., Irisarri, M. P and Ares, J.O. (1990). Phenology of *Festuca pallescens* in relation to topography in North-western Patagonia. *J Veg Sci* 1:579–584.

Billings, W. D. (1987). Constraints to plant growth, reproduction, and establishment in Arctic environments. *Arctic and Alpine Research* 19:357–365.

Blionis, G. J., Halley, J. M and Vokou, D. (2001). Flowering phenology of *Campanula* on Mt Olympos, Greece. *Ecography* 24:696–706.

Bliss, L.C. (1956). A comparison of plant development in microenvironments of Arctic and Alpine Tundras. *Ecological Monographs* 26:303–337.

Boojh, R and Ramakrishnan, P. S. (1981). Phenology of trees in a sub-tropical evergreen mountain forest in north-east India. *Geo-Eco. Trop*. 5:189-209.

Borchert , R. (1980). Phenology and ecophysiology of tropical trees: *Erythrina poeppigiana* of Cook. *Ecology* 6(1):1065-1074.

Borchert, R. (1983). Phenology and control of flowering in tropical trees. *Biotropica* 15:81–89

Borchert, R. (1994). Soil and stem water storage determine phenology and distribution of tropical dry forest trees. *Ecology* 75:1437–1449.

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

Both, C., Van Asch, M., Bijlsma, R. G., Burg Van Den, A.B and Visser, M. E. (2009). Climate change and unequal phonological changes across four trophic levels. *Journal of Animal Ecology* 78: 73-83.

Bradley, N. L., Leopold, A. C., Ross, J and Huffaker, W. (1999). Phenological Changes Reflect Climate Change in Wisconsin, *Proc. Nat. Acad. Sci. USA*, 96:9701–9704.

Breedlove, D. E and Ehrlich, P. R. (1968). Plant–herbivore co-evolution: *Lupines and Lycaenids. Science* 162:671–672.

Breedlove, D. E and Ehrlich, P. R. (1972). Co-evolution: Patterns of legume predation by a *Lycaenid* butterfly. *Oecologia* 10:99–104.

Brody, A. K. (1997). Effects of pollinators, herbivores and seed predators on Flowering phenology. *Ecology*,78 : 1624-1631.

Bronstein, J. L. (1995). The plant-pollinator landscape. In (Eds.) Hansson L, Fahrig L and Merriam G. *Mosaic Landscapes and Ecological Processes*. Chapman & Hall, London. 256–288 pp.

Bruns, E. (1996). Observation Program of the International Phenological Network (Ipn) – Prepared by the Deutscher Wetterdienst (DWD), *Phenol. Seasonality*, 1:25–31.

Bullock, S.H and Solis-Magallanes, J.A. (1990). Phenology of canopy trees of a tropical deciduous forest in Mexico. *Biotropica* 22:22–35.

Carpenter, F.L. (1976). Plant-pollinator interaction in Hawaii: Pollination energetic of Metrosideros collina (Myrtaceae). *Ecology*, 57:1125-1144.

Chapman, C. A., Wangham R and Chapman, L.A. (1994). Indices of habitat wide fruit abundance in tropical forest trees. *Biotropica* 26:160–171.

Chen, X. (2003). Phenological data, networks, and research: East Asia. In: *Phenology: an integrative environmental science*. M.D. Schwartz. pp. 11–25, Kluwer Academic Publishers, ISBN 1-4020-1580-1, London, UK

Cleland, E E., Chiariello, N.R., Loarie, S.R., Mooney, H.A., Field, C.B. (2006). Diverse responses of phenology to global changes in a grassland ecosystem. Proceedings of the National Academy of Sciences, 103, 13740.

Criminis, E. M., Hayward, M.D., Hagedorn, A and Saito, Y. (2011). Change in disabitlity free life expectancy for America 70 yrs old and older. *Demography* 46(3):627-646.

Croat, T. B. (1975). Phenological behavior of habit and habitat classes on Barro Colorado Island (Panama canal zone). *Biotropica* 7:270-277.

Cruden, R. W. (1977). Pollen-ovule ratios: A conservative indicator of breeding systems in flowering plants. *Evolution*. 31: 32 – 46.

Curran, L.M and Leighton, M. (2000). Vertebrate responses to spatiotemporal variation in seed production of mast-fruiting dipterocarpaceae. *Ecol. Monogr*. 70:101–128.

Daubenmire, R. (1972). Phenology and other characteristicso f tropical semi-deciduousf orest in north-western Costa Rica. *J. Ecol.* 60:147-70.

Demaree, G.R and Rutishauser, T. (2011). From "Periodical Observations" to" Anthochronology" and "Phenology" - the scientific debate between Adolphe Quetelet and Charles Morren on the origin of the word "Phenology". *International Journal of Biometeorology*. Vol. pp. 1–9

Dhaila, S., Singh, SP., Negi, G.C.S., Rawat, Y.S. (1995). Shoot growth phenology of co-existing evergreen and deciduous species in an oak forest. *Ecol Res* 10:151–159

Dieringer, G. (1991). Variation in individual flowering time and reproductive success of *Agalinis strictifolia* (Scrophulariaceae). *American Journal of Botany* 78:497-503.

Dunn, P.O and Winkler, D.W. (1999). Climate change has affected the breeding date of Tree Swallows throughout North America. *Proc. R. Soc. B Biol. Sci*. 266:2487–2490.

Dunne, J.A., Harte, J and Taylor. K. J. (2003). Subalpine Meadow Flowering Responses to Climate Change: Integrating Experimental and Gradient Methods. *Ecological Monographs* 73:69–86.

Durant, J.M., Hjermann, D.O and Anker Nilssen, T. (2005). Timing and abundance as key mechanisms affecting trophic interactions in variable environments. *Ecol. Lett.* 8:952–958.

Eckert, C.G and Schaefer, A. (1998). Does self-pollination provide reproductive assurance in wild columbine*, Aquilegia Canadensis (Ranunculaceae).? American Journal of Botany,* 85: 919 – 924.

Estrella, N and Menzel, A. (2006). Responses of leaf colouring in four deciduous tree species to climate and weather in Germany. *Clim. Res.* 32:253-267.

Fabbro, T and Korner, C. (2004). Altitudinal differences in flower traits and Reproductive allocation. *Flora* 199:70 -81.

Fenner, M. (1998). The phenology of growth and reproduction in plants. Perspectives in Plant Ecology. *Evolution and Systematics* 1:78-91.

Fitter, A. H., Fitter, R.S. R., Harris, I.T.B and Williamson, M.H. (1995). Relationships between first flowering date and temperature in the flora of a locality in central England. *Functional Ecology* 9: 55-60.

Frankie, G.W., Baker H.G and Opler, P.A. (1974). Comparative phonological studies of trees in tropical wet and dry forests in the lowlands of Costa Rica. *J Ecol* 62:881–919.

Fridley, J. D. (2012). Extended leaf phenology and the autumn niche in deciduous forest invasions. *Nature* 485(7398):359–362.

Friedel, M. H., Nelson, D. J., Sparrows, A. D., Kinloch, J. E and Maconochie, J. R. (1993). What induced central Austrian trees and shrubs to flower and fruit. *Aus. J. Bot*. 41:307-319.

Fogden, M. P. L. (1972). The seasonality and population dynamics of equatorial forest birds in Sarawak. *Ibis* 114**:**307-342.

Forrest, J and Miller Rushing, A.J. (2010). Toward a synthetic understanding of the role of Phenology in ecology and evolution. Philosophical Transactions of the Royal Society B – *Biological Sciences* 365: 3101-3112.

Foster, R.B. (1982). A seasonal rhythm of fruit fall on Barro Colorado Island. In: Leigh E.G, Rand A.S and Windsor D.M (Eds.) *The ecology of a tropical forest, seasonal rhythms and long-term changes.* Smithsonian Institution Press, Washington. 151-172 pp.

Galen, C and Gregory, T. (1989). Inter-specific pollen transfer as a mechanism for competition: consequences of foreign pollen contamination for seed set in an alpine wildflower, *Polemonicum viscosum*. *Oecologia* 81:120-123.

Galenc and Stantonn, L. (1991). Consequences of emergence phenology for reproductive success in *Ranunculus adoneus* (Ranunculaceae). *Am. J. Bot*. 78:978-988.

Geber, M.A and Dawson, T. E. (1993) Evolutionary responses of plants to global change. In Kareiva PM, Kingsolver JG, Huey RB (eds) Biotic interaction and global change. Sinauer, USA, pp 179–197

Gentry, A. H. (1974). Flowering phenology and diversity in tropical Bignoniaceae. *Biotropica* 6:64-68.

Gray, J .T. (1982). Community structure and productivity in Coenothus chaparral and coastal sage scrub of southern California. *Ecol Monogr* 52:415–435

Haase, P. (1986). Flowering records of some subalpine trees and shrubs at Arthur's pass, New Zealand. *New Zealand Journal of Ecology* 9:19-23.

Hamann, A. (2004). Flowering and fruiting phenology of a Philippine sub-montane rain forest: climatic factors as proximate and ultimate causes. *Journal of Ecology* 92:24-31.

Hatta, H., Honda, H and Fishe, J. B. (1999). Branching principles governing the Architecture of *Cornus kousa* (Cornaceae). *Annals of Botany* 84**:** 183–93.

Heide, O. M. (1997). Environmental control of flowering in some northern *Carex* species. *Annals of Botany* 79:319–327.

Herrera, C.M. (1995). Floral biology, microclimate and pollination by ectothermic bees in an early blooming herb. *Ecology* 76:218-228.

Hillman, W. S. (1962). The physiology of flowering. Holt, Rinehart and Winston, New York.

Hilty, S. L. (1980). Flowering and fruiting periodicity in a premontane rain forest in Pacific Colombia. *Biotropica* 12:298-306.

Hopkins, A.D. (1938). Bioclimatics - a science of life and climate relations. Miscellaneous Publication 280. United States Department of Agriculture, US Forest Service, Washington, DC, USA. p. 188.

Hughes, L. (2000). Biological consequences of global warming. Trends inEcology and *Evolution* 15:56-61

Hunter, A. F and Lechowicz, M. J. (1992): Predicting the timing of bud-burst in Temperate trees. J. *Appl Ecol* 29:597-604.

IPCC (2007). *Climate Change 2007: The Physical Science Basis: Summary for Policymakers*. Intergovernmental Panel on Climate Change, Geneva, Switzerland. 1-18 pp.

Inouye, D.W and Mc Guire, A.D. (1991). Effects of snowpack on timing and abundance of flowering in Delphinium nelsonii (Ranunculaceae): implications for climate change. *American Journal of Botany* 78: 997-1001.

Inouye, D.W. (2000). The ecological and evolutionary significance of frost in the context of climate change. *Ecology Letters* 3:457–463.

Inouye D. W (2008). Effects of climate change on phenology, frost damage, and floral abundance ofmontane wildflowers. *Ecology* 89:353–362.

Janzen, D.H. (1967). Synchronization of sexual reproduction of trees within dry season in Central America. *Ecology* 21:620–637.

Janzen, D.H. (1974). Tropical blackwater rivers, animals and mast flowering by the dipterocarpaceae. *Biotropica* 6:69–103.

Johnson, S.D. (1993). Climatic and phylogenetics determinants of ectothermic bees in an early blooming herbs. Ecology, 76: 218-228.

Justiniano, M. J and Fredericksen, T. S. (2000). Phenology of tree species in Bolivian dry forests. *Biotropica* 32:276–281.

Kemp,W.P and Bosch, J (2005). *Alfalfa* leaf cutting bee population dynamics, flower availability and population rates in two Oregon alfalfa fields. *J. con. Entomol.* 98(4): 1077-1087.

Keeling, C.D., Chin, J. F. S and Whorf, T.P. (1996). Increased activity of northern vegetation inferred from atmospheric CO_2 measurements. *Nature* 382:146–149.

Khan, J. A. (1999). Periodicity of major phenophages in woody species in dry deciduous forests of Gir, India. *Tropical Ecology* 40:299-303.

Kikim, A and Yadava, P.S. (2001). Phenology of tree species in subtropical forests of Manipur in north eastern India. *Trop. Ecol*. 42:269-276.

Kikuzawa, K. (1989). Ecology and evolution of phenological pattern, leaf longevity and leaf habit. *Evol Trend Plant* 3:105–110

Kikuzawa, K., Koyoma, H., Umeki, K., Lechowicz, M. J. (1996). Some evidence for an adaptive linkage between leaf phenology and shoot architecture in sampling trees. *Ecol* 10:252–257

Kikuzawa, K and Lechowicz, M. J. (2011). Ecology of leaf longevity. *Ecol Res Monogr*. Springer, Berlin

Klinkhamer, P. G. L., De Jong, T. J and De Bruyn, G.-J. (1989). Plant size and pollinator visitation in *Cynoglossum officinale*. *Oikos* 54: 201-204.

Kochmer, J. P and Handel, S. N. (1986). Constraints and competition of flowering phenology. *Ecol Monogr* 56:303–325

Koptur , S., Haber, W. A., Frankie, G. W and Baker, H. G. (1988). Phenological studies of shrub and treelet species in tropical cloud forests of Costa Rica. *Journal of Tropical Ecology* 4:323–346.

Kramer, K. (1997). Phenology and growth of European trees in relation to climate change. In *Phenology of Seasonal Climates*. Backhuys, The Neatherlands. 39-59 pp.

Kudo, G and Hirao, A. S. (2006). Habitat-specific responses in the flowering phenology and seed set of alpine plants to climate variation: implications for global-change impacts. *Population Ecology* 48:49–58.

Larcher, W and Bauer, H. (1981). *Ecological significance of resistance to low Temperatures* Springer-Verlag, Berlin 403–438 pp.

Lawton, J. R. S and Akpan, E. E. J. (1968). Periodicity in *Plumeria*. *Nature* 218:384-386.

Lechowicz, M. J. (1995). Seasonality of Flowering and Fruiting in Temperate Forest Trees. *Can. J. Bot.*, 73:175–183.

Levesque, E and Svoboda, J. (1992). Growth of Arctic poppy in contrasting habitats of a polar oasis and a polar desert. *Musk–Ox* 39**:**148–156.

Liberman, D. (1982). Seasonality and phenology in a dry tropical forest in Ghana. *J. Ecol* 70:791-806.

Lieberman, D and Lieberman, M. (1984). The causes and consequences of synchronous flushing in a dry tropical forest. *Biotropica* 16:193-201.

Lieth, H. (1974). Purposes of a phenology book. In: H. Lieth (Ed.) *Phenology and Seasonality Modeling*. New York: Springer-Verlag. 444 pp.

Malaisse, F. (1974). Phenology of the Zambesian wood land area with emphasis on the miombo ecosystem. In Lieth H (Ed.) *Phenology and seasonality modeling.* Berlin: Springer-Verlag 269-286 pp.

Marquis, R. J. (1988). Phenological variation in the neotropical understory shrub *Piper arieianum:* causes and consequences. *Ecology* 69:1552-1565.

Matsumoto K (2003). Climate change and extension of the *Ginkgo biloba* L. growing season in Japan. *Global Change Biol*. 9:1634–1642.

McCarty, J. P. (2001). Ecological consequences of recent climate change. *Conserv Biol* 15(2): 320–331

Mcintosh, M. E. (2002). Flowering phenology and reproductive output in two sister species of Ferocactus (Cactaceae). *Plant Ecology*,15 9:1 -13.

Melampy, M.N. (1987). Flowering phenology , pollen flow and fruit production in the Andean shrub *Befaria resinosa. Oecologia*, 73:293-300.

Menzel, A and Fabian, P. (1999). Growing season extended in Europe. *Nature* 397: 659.

Menzel, A. (2003). Plant phenological anomalies in Germany and their relation to air temperature and NAO. *Climatic Change* 57:243-263.

Menzel, A. (2006). European phenological response to climate change matches the warming pattern. *Glob Change Biol* 12(10):1969–1976.

Monasterio, M and Sarmiento, G. (1976). Phenological strategies of plant species in the tropical savanna and the semideciduous forest of the Venezuelan llanos. *J. Biogeogr*. 3**:**325-356.

Mooney, H.A and Dunn, D. L. (1970). Convergent evolution of Mediterranean climate evergreen sclerophyll shrubs. *Evolution* 24:292–303

Murali, K. S and Sukumar, R. (1993). Leaf flushing phenology and herbivory in a tropical dry deciduous forest, southern India. *Oecologia* 94:114-119.

Murali, K.S and Sukumar, R. (1994). Reproductive phenology of a tropical dry forest in Mudumalai, southern India. *J Ecol* 82:759–767.

Myneni, R. B., Keeling, C. D., Tucker, C. J., Asrar, G and Nemani, R. R. (1997). Increased plant growth in the northern high latitudes from 1981 to 1991. *Nature* 386:698–702.

Newstrom, L. E., Frankie, G. W and Baker, H.G. (1994). A new classification for plant phenology based on flowering patterns in lowland tropical rain forest trees at La Selva, Costa Rica. *Biotropica* 26:141–159.

Ollerton, J and Lack, A. J. (1992). Flowering phenology: an example of relaxation of natural selection. *Trends Ecol Evol* 7:274–276.

Ollerton, J and Lack, A. J. (1998). Relationships between flowering phenology, plant size and reproductive success in *Lotus corniculatus* (Fabaceae). *Plant Ecol*. 139:35–47.

O'Neil, P. (1997). Natural selection on genetically correlated phonological characters in *Lythrum salicaria* L. (Lythraceae). *Evolution* 51:267–274.

Opler, P. A., Frankie, G.W and Baker, H.G. (1976). Rainfall as a factor in the release timing and synchronization of anthesis by tropical trees and shrubs. *Journal of Biogeography* 3: 231-236.

Opler, P. A., Frankie, G. W and Baker, H. G. (1980). Comparative phonological studies of treelet and shrub species in tropical wet and dry forests in the lowlands of Costa Rica. *J Ecol* 68:1167–1188.

Pandey, A. K., Solanki, K. R and Gupta, V. K. (2002). Periodical growth and phenology of 4-year-old Neem in semi-arid region. *Range Management and Agro-forestry* 23:122-126.

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

Penuelas, J., Filella, I and Comas, P. (2002). Changed plant and animal life cycles from 1952 to 2000 in the Mediterranean region. *Global Change Biol.* 8:531–544.

Pleasants, J. M. (1990). Null model tests for competitive displacement: the fallacy of not focusing on the whole community. *Ecology* 71: 1078-1084.

Price, M.V and Waser, N. M. (1998). Effects of experimental warming on plant reproductive phenology in a subal pine meadow. *Ecology* 79:1261–1271.

Primack, R. B. (1980). Phenological variation within natural populations: flowering in New Zealand montane shrubs. *J Ecol* 68:849–862.

Primack, R. B. (1985). Longevity of individual flowers. *Annual Review of Ecology and Systematics* 16:15–38.

Proenca, C. E. B and Gibbs, P. E. (1994). Reproductive biology of eight sympatric Myrtyaceae from Central Brazil. *New Phytologist* 126:343-354.

Putz, F. E. (1979). A seasonality in Malaysian tree phenology. *Malay For* 42:1–24.

Rai, S. N and Proctor, J. (1986). Ecological studies on four rainforests in Karnataka, India, II. Litterfall. *J Ecol.* 74:455-463

Ralhan, P. K., Khanna, R. K., Singh, S. P and Singh, J. S. (1985). Phenological characters of the tree layer of Kumaun Himalayan forests. *Vegetatio* 60:91–101.

Rathcke, B and Lacey, E. P. (1985). Phenological patterns of terrestrial plants. *Annu Rev Ecol* Syst 16:179–214.

Reich, P.B and Borchert, R. (1982). Phenology and ecophysiology of the tropical tree, *Tabebuia neochrysantha* (Bignoniaceae). *Ecology* 63: 294-299.

Reich, P. B and Borchert, R. (1984). Water stress and phenology in a tropical dry forest in the lowlands of Costa Rica. *J Ecol* 72:61–71.

Reich, P B., Uhl, C., Walters, M.B., Prugh, L and Ellsworth, D. S. (2004). Leaf demography and phenology in Amazonian rain forest: *Ecol Monogr* 74:3–23

Richards, P. W. (1952). The tropical rain forest. An ecological study. Cambridge University Press, Cambridge, Massachusetts, USA.

Root, T.L., Price, J.T., Hall, K. R., Schneider, S. H., Rosenzweig, C and Pounds, J.A. (2003) Fingerprints of global warming on wild animals and plants. *Nature* 241:57–60.

Santapau, J. (1962). Gregarious flowering of *Strobilanthes* and bamboos; *J. Bombay Nat. Hist. Soc.* 59:688 695.

Sayer, E. J and Newbery, D. M. (2003). The role of tree size in the leafing phenology of a seasonally dry tropical forest in Belize, Central America. *J. Trop. Ecol*. 19:539–548.

Schemske, D.W. (1977). Flowering phenology and seed set in *Claytonia virginiana* (Portulacaceae). *Bull. Torrey Bot. Club* 104:254-263.

Schmitt, J. (1983). Density dependent pollinator foraging, flowering phenology and temporal pollen dispersal patterns in *Linanthus bicolor*. *Evolution* 37(6):1247-1257.

Schwartz, M. D. (2003). *Phenology: An Integrative Environmental Science*. Kluwer Academic Publishers, Dordrecht, Netherlands. 467 – 485 pp.

Shukla, R. P and Ramakrishnan, P. S. (1982). Phenology of trees in a sub tropical humid forest in north Eastern India. *Vegetatio* 49**:**103-109.

Singh, J.S and Singh, V.K. (1992). Phenology of seasonality dry tropical forest., *Current Science*, 63: 683 - 689.

Singh, K. P and Kushwaha, C.P. (2006). Diversity of flowering and fruiting phenology of trees in tropical deciduous forest in India. *Annals of Botany* 97:265-276.

Sparks, T. H and Carey, P .D. (1995). The Responses of Species to Climate Over Two Centuries: an Analysis of the Marsham. Phenological Record, 1736–1947, *J. Ecol.*, 83:321–329.

Sparks, T. H., Jeffree, E.P and Jeefree, C .E. (2000. An examination of relationships between flowering times and temperature at the national scale using long-term phenological record from the UK. *Int. J. Biometeorological*. 44:82-87.

Steven, D. De., Windsor, D. M and Putz, F. E. (1987). Vegatative and reproductive phenologies of a palm assemblage in Panama. *Biotropica* 19**:**342-356.

Stiles, F. G. (1977). Coadapted competitors: the flowering seasons of hummingbird-pollinated plants in a tropical forest. *Science* 198: 1177-1178.

Stinson, C. (2004). Natural selection favours rapid reproductive phenology in *Potentilla pulcherrima* (Rosaceae) at opposite ends of a subalpine snowmelt gradient. *American Journal of Botany* 91:531–539.

Sundrapandian, S. M., Chandrasekaran, S and Swamy, P. S. (2005). Phenological behaviour of selected tree species in tropical forests at Kodayar in the Western Gats, Tamil Nadu, *India. Curr. Sci.* 88:805-810.

Sundriyal, R. C. (1990). Phenology of some temperate woody species of the Garhwal Himalaya. *Int. J. Ecol. Environ. Sci*. 6:107-117.

Tottrup, A. P. K., Thorup, K., Raino R and Yosef, E. (2008). Avian migrates adjust migration in response to environmental conditions enroute. *Biology letters* 4:685-688.

Van nouhuys , S and Lei, G. C. (2004). Parasitoid-host metapopulation dynamics: the causes and consequences of phenological asynchrony. *J Anim Ecol* 73:526-535.

Van Schaik, C. P., Terborgh, J. W and Wright, S. J. (1993). The phenology of tropical forests: adaptive significance and consequences for primary consumers. *Annu Rev Ecol Syst* 24:353–377.

Visser, M. E and Holleman, J.M (2001). Warmer springs disrupt the synchrony of oak and winter moth phenology. *Proceedings of the Royal Society of London B* 268:289-294.

Visser, M. E and Both, C. (2005). Shifts in phenology due to global climate change: the need for a yardstick. Proceedings of the Royal Society B: *Biological Sciences* 272:2561-2569.

Vitasse, Y., Porte, A. J., Kremer, A., Michalet, R and Delzon, S. (2009). Responses of canopy duration to temperature changes in four temperate tree species: relative contributions of spring and autumn leaf phenology. *Oecologia* 161(1):187–198.

Wada, K. (1983). Ecological adaptations in Rhesus monkeys at the Kumaun Himalaya. *J. Bombay. Nat Hist. Soc.* 59:469-498.

Wagner, J and Mitterhofer, E. (1998). Phenology, seed development, and reproductive success of an alpine population of Gentianella germanica in climatically varying years. *Acta Botanica*, 111:159–166.

Wagner, J., Steinacher, G and Larl, I. (2012). From the Flower Bud to the Mature Seed: Timing and Dynamics of Flower and Seed Development in High-Mountain Plants. In: C. Leutz, (Ed.) *Plants in Alpine Regions.* Springer -Verlag/Wien, 135 – 152 pp.

Walker, M. D., Ingersoll, R.C and Webber, P. J. (1995). Effects of interannual climate variation on phenology and growth of two alpine forbs. *Ecology* 76:1067–1083.

Waser, N. M. (1978). Competition for hummingbird pollination and sequential flowering in two Colorado wildflowers. *Ecology* 59:934 - 944.

Wielgolaski, F. E. (1999). Starting dates and basic temperatures in phonological observations of plants. *Int. J. Biometeorol* 42:158–168.

Wielgolaski, F. E. (2001). Phenological modifications in plants by various edaphic factors. *Int. J. Biometeorol* 45:196–202.

Williamson, G. B. (2002). Mast fruiting and ENSO cycles—does the cue betray the cause. *Oikos 97:*459–461.

Wright, S. J. (1991). Seasonal drought and the phenology of understory shrubs in a tropical moist forest. *Ecology* 72:1643-1657.

Wright, S. J and van Schaik, C. P. (1994). Light and the phenology of tropical trees. *Am. Nat*. 143:192-199.

Wright, S.J and Calderon, O. (1995). Phylogenetic patterns among tropical flowering phenologies. *J Ecology* 83:937–948.

Xiaoyang Zhang. (2012). Phenology and climate change. pp 1-297.

Yadav, R. K and Yadav, A. S. (2008). Phenology of selected woody species in a tropical dry deciduous forest in Rajasthan, India. *Tropical Ecology* 49**:**25-34.

Ziello, C., Estrella, N and Kostova, M. (2009). Influence of altitude on phenology of selected plant species in the alpine region (1971– 2000). *Climate Research* 39:227–234.

Chapter 3

Materials and Methods

3.1 Geographical location of Mizoram

Mizoram is located in the north eastern part of India, and is bounded on the north side by Cachar district of Assam and Manipur state; on the east and south by Chin Hills of Myanmar; on the west by Chittagong hill tracts of Bangladesh and Tripura. The state is divided into eight administrative districts, *viz*., Aizawl, Champhai, Kolasib, Mamit, Lunglei, Serchhip, Lawngtlai and Saiha. About 57.8 percent of the population depends on agricultural products and practice jhum cultivation (Anonymous, 2004).

Mizoram lies between **21^{0}30’N – 23^{0}15’N** latitudes and **92^{0}16’E – 93^{0}26’E** longitudes (Rintluanga, 1994). With a geographical area of over 21,087 Sq km and perched on the high hills of the north eastern part of India. Mizoram possibly has the most difficult terrain over 80% of the total geographical area being hilly and with steep hills separated by rivers flowing north to south, thus, creating innumerable hurdles in intra- state as well as inter-state communication (Rintluanga, 1994).

The topography of Mizoram is, by and large mountainous with precipitous slopes forming deep gorges culminating into several streams and rivers. Almost all the hill ranges traverse in the north–south direction. The eastern part of Mizoram is at a higher elevation compared to the western part. The average height of the hill ranges is around 920 m, although the highest peak, the Blue Mountain (Phawngpui) goes up to 2165 m (Anonymous, 2004).

3.2 Climate and weather

Mizoram enjoys a moderate and pleasant climate. The temperature varies from 9^0C to 24^0C during winter and 24^0C to 32^0C during summer. The climate is pleasant in the months of October and November (19^0C to 25^0C). The upper parts of the hills are predictably cool, during the summer, while the lower reaches are relatively warm and humid. Storms break out during March to April, just before or around the summer. The entire Mizoram comes under the direct influence of the south west monsoon receiving an annual average rainfall of 2095 mm in the year 2009. The rainy season normally starts from June and continues up to September and the rainfall is more or less evenly distributed throughout the state excepting the south-western parts that generally receives slightly higher rainfall (Anonymous, 2011).

3.3 Forest and Agriculture

The state of Mizoram falls under the tropical semi-evergreen belt. However, due to reduced jhum cycles it is replaced by bamboo interspersed with secondary forests. The state is divided into 12 forest divisions falling under three territorial circles. The forest of Mizoram is governed by the Mizoram Forest Act, 1955. Commercial utilization of the forests is prohibited but small felling is permitted for the use of *bona fide* locals to meet their needs (Anonymous, 2006).

The forests are divided into Protected areas, reserve forest and unclassified forests. According to State of Forest Report, open forest occupies 61.18%, scrub 0.01%, moderately dense 28.87%, very dense 0.64% and non-forest 9.3% to the total geographical area of the state. Area under recorded forest is 16,717 $km^{2.}$ The reserved - forest covers 6465 km^2 and the protected forest coves 941 km^2. The practice of shifting cultivation, uncontrolled fire, felling of trees, agricultural expansion and road building have resulted in deforestation (Anonymous, 2008a).

Various authors have classified the vegetation of the state. Based on Champion and Seth's classification (1968) the following types of forest are found to be present in the state:

(a) Tropical wet-evergreen forests (up to 900 m)

(b) Tropical semi-evergreen forests (900 to 1500 m)

(c) Montane sub-tropical pine forests (1500 to 2158 m)

Tropical wet -evergreen forests are found in the southern and western parts of Mizoram. The common timber species found in these areas are *Dipterocarpus turbinatus*, *Artocarpus chaplasa*, *Terminalia myriocarpa*, *Duabanga sonneratoides*, *Michelia champaca* growing in association with undergrowth (Anonymous, 2003).

Tropical semi-evergreen covers the central bio-geographic zone and the coverage is approximately 50 percent of the total geographic area. The common tree species are *Michelia champaca, Schima wallichi, Gmelina arborea, Catanopsis tribuloidies* etc. Bamboo species like *Melocanna baccifera* and *Dendrocalamus* species and canes are abundant, especially in shady and low lying areas (Anonymous, 2003).

The Montane sub-tropical pine forest occurs in the eastern fringes bordering Myanmar and constitutes about 24 per cent of the total geographical area. The common tree species are *Pinus kesiya, Rhododendron arboretum, Quercus serrata, Quercus griffithii*, etc. (Anonymous, 2003).

3.4 Study sites

This study was conducted in two tropical forests in the Aizawl district of Mizoram, which differ in precipitation regime and average temperature.

The first site is selected as Neihbawi, located in the northern part of Aizawl, with an altitude of 1300 m asl. The area of Neihbawi lies between geographical location of **23° 53' 5" N** latitude and **92° 43' 29" E** longitude [Figure 1].

The average annual rainfall during the past six years was 4198.5 ± 211.87mm, which ranged between 3571 in 2005 and 4859 mm in 2007 (Anonymous, 2008b), with a dry season from November to March. The climate is humid-sub tropical and characterized by long winter. In summer, the temperature ranges from 13^{o}C to 31^{o}C and in winter 8^{o}C to 24^{o}C. The area receives maximum rainfall between May and August. This site will be referred to hereafter as cooler site with heavier rainfall.

The second site, i.e. Sairang is located in the western part of Aizawl with 200m altitude. The area of Sairang lies between geographical location of **23° 48' 0" N** latitude and **92° 40' 0" E** longitude. Sairang is 28 km from Aizawl [Figure 1].

This site receives 2211.17 ± 127.74 mm average annual rainfall for past six years, which oscillated between 1661 in 2008 and 2489 mm in 2007 (Anonymous, 2008b). The majority of the tree species are deciduous, abscising their leaves during the dry season and producing flowers. The temperature ranges from 17^{o}C to 33^{o}C in summer and in winter 10^{o}C to 26^{o}C. The area receives maximum rainfall between June and August. This site will be referred as warmer site with less rainfall.

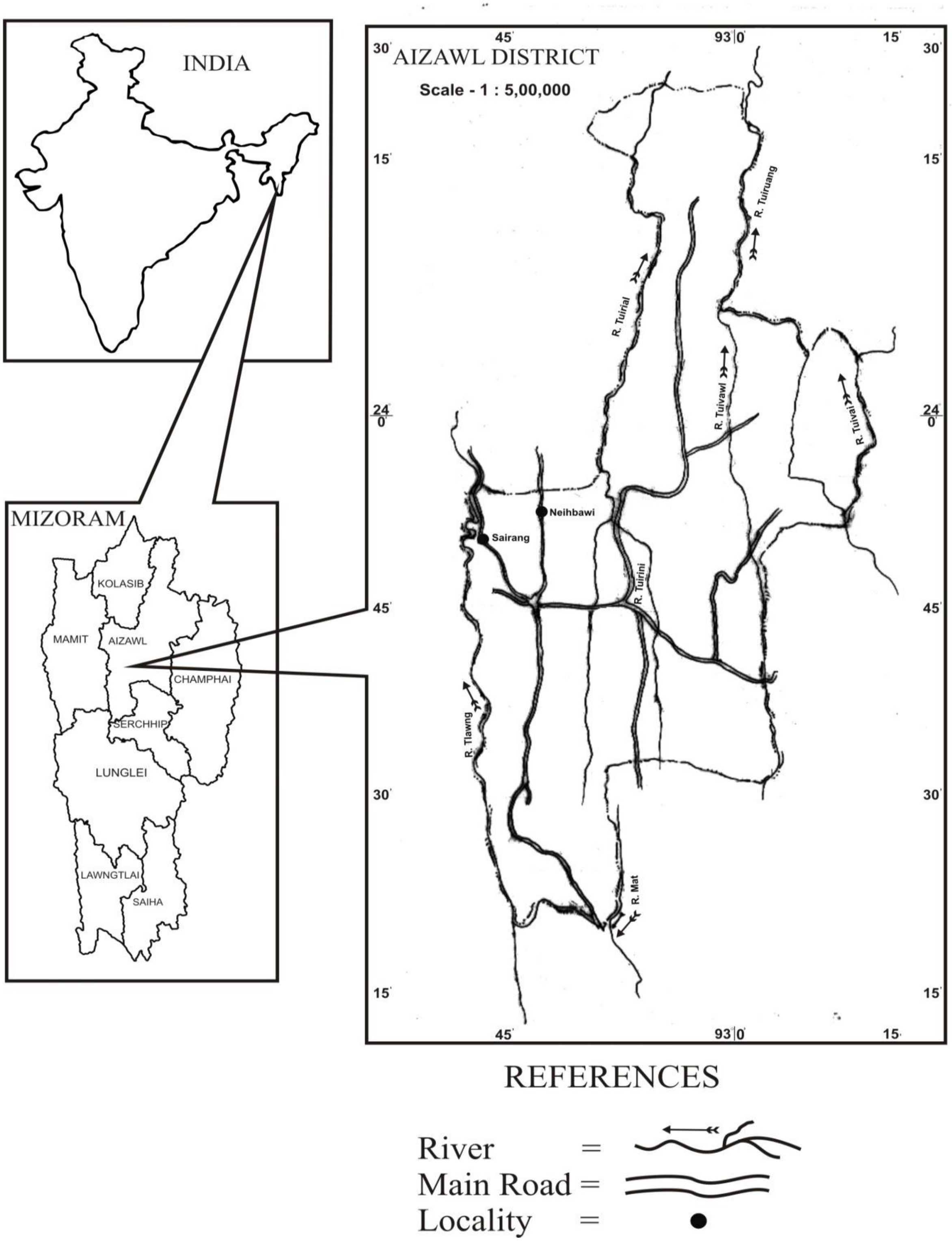

Figure: 1. Topographical map of study sites

3.5 Study species

Erythrina is a genus of tropical and subtropical flowering trees in the Family Fabaceae sub group Papilionaceae and distributed in tropical and subtropical regions worldwide. There are about 130 species in the genus *Erythrina*. In Mizoram four species viz. *Erythrina aborescens*, *Erythrina stricta*, *Erythrina variegata* and *Erythrina subumbrans* has been reported (Sawmliana, 2003). This study focuses on *Erythrina variegata* and *Erythrina subumbrans* to study the phenological events in relation to varying precipitation regime.

3.5.1 ***Erythrina variegata***

3.5.1.1 Taxonomy

Kingdom : Plantae – plants

Sub kingdom : Viridiplantae

Division : Tracheophyta – vascular plants, tracheophytes

Sub division : Spermatophytina – spermatophytes, seed plants

Class : Magnoliopsida – dicotyledons

Order : Fabales

Family : Fabaceae – peas, legumes

Genus : *Erythrina* L.

Species : *E. variegata* L. – tiger's claw

3.5.1.2 Morphology

Size: The tree grows up to 20 m in height with a spreading crown (except in the cultivar "Tropic Coral"). The dense, oblong to rounded crown is low-branching with many ascending branches.

Flowers: Inflorescence of many-flowered fascicles occurs in terminal or axillary racemes up to 20cm (8 in) or more long. Calyx is top-shaped, deeply split along one side, 1–1.8cm (0.4–0.7 in) long, on a pedicel 2–5mm (0.1–0.2 in) long. Corolla is papilionaceous; standard is short-clawed, ovate to subelliptic, 3–4cm (1.2–1.6 in) long, red-orange with longitudinal white lines; wings are about half as long as the standard, greenish to pale red; keel is as long as the wings, greenish to pale red. Ovary is superior, stamens 10, diadelphous, with 9 fused together at the base, enclosed within the keel.

Leaves: Leaves are trifoliate, alternate; rachis is mostly 10–20 cm (4–8 in) long; blades are ovate to rhomboid, 8–18 cm (3.2–7.2 in) long; lateral ones are smaller than the terminal one, petiolules 6–13 mm long, with vegetative parts finely pubescent. They are deciduous just before and during the flowering season. Low temperatures, powdery mildew, and/or drought combined with very windy conditions will accelerate leaf drop and retard the development of new leaves.

Fruits: Fruit a compressed, narrowly oblong pod 10–14 cm (4–5.6 in) long, sterile in the basal portion, and not constricted between the 5–10 dark brown seeds. The fruits are ripe from April to June; they often remain on the tree for several months longer.

Seeds: Seeds are kidney-shaped, dark purple to red, and 1–1.5 cm (0.4–0.6 in) in length. These simply fall to the ground and may be washed away (they have been seawater-dispersed over their native range).

3.5.1.3 Ecology

Erythrina variegata is well adapted to the humid and semi-arid and tropics and subtropics, occurring in zones with annual rainfall of 800 to 1500 mm distributed over a five to six month rainy season. The species is most commonly found in warm coastal areas up to an elevation of 1500 m. The trees prefer a deep, well drained sandy loam, but they tolerate a wide range of soil condition from sands to clays of pH 4.5 to 8.0. They can withstand water logging for up to two weeks and are fairly tolerant of fire. *Erythrina variegata* is bird pollinated, outcrossed and sometimes genetically incompatible.

3.5.1.4 Agroforestry uses

Erythina variegata has highly valued ornamental and has been described as one of the gems of the floral world. It has also proven valuable for agroforestry uses.

Support for vine: Farmer in India use *Erythrina variegata* to support climbing plants such as betel (*piper betle*), black pepper (*piper nigrum*), Vanilla (*Vanilla planifolia*) and yam (*Dioscorea spp*.) (Hedge, 1993). Trees established to support vines are usually planted at a spacing of 2X2 to 2X3 m. Vines are planted three to four months after establishment of the tree seedlings or during the following rainy season. During the hottest months, foliage from the closely spaced trees shades the vines and keeps them moist. When the day become cooler, the leaves fall and the vines receives more direct sun light which matches their requirements at this time.

Shade: Coffee and cacao growers establish *Erythrina variegata* shade trees from large cuttings (2 to 3 m long and 2 to 5 cm in diameter) at a spacing of 8X10m. The trees are pollarded once a year to a height of 2 to 3 m to produce spreading crown. The pruned leaves are usually spread in the plantations as mulch.

Windbreaks: *Erythrina variegata*, particularly the columnar variety, is widely used as a windbreak for soil and water conservation. The trees have a strong vertical root system that does not seem to compete too severly with adjacent crops (Rotar et al., 1986). Windbreaks are normally established from large cuttings planted in lines at a spacing of about 2 m.

Live fenceposts: *Erythrina variegata* makes excellent live fenceposts. Farmers commonly establish fenceposts from 3 years old upright branches about 15 cm in diameter and 2.5 m long. These are normally stacked in the shade in an upright position and left to cure for one week before planting.

Silvopasture: Live fenceposts can be used as support for fencing suitable for containing cattle or horses. The periodic pruning of these fenceposts yields excellent fodder. Trees are also grown inside paddocks to provide some shade, wind protection and as a potential source of off-season fodder.

Crop/tree interaction: *Erythrina variegata* produces soil nitrogen from the roots and green mulch from the falling leaves.

Soil improver: The leaves are used as green manure. *Erythrina variegata* forms root nodules and fixes atmospheric nitrogen in symbiosis with rhizobia. *Erythrina variegata* is a useful species for soil enrichment because it modulates readily and prolifically in both acid and alkaline soils.

Waterlogging: *Erythrina variegata* is resistant to periodic water logging for up to 2 weeks, but it prefers well drained sandy loams.

Salt spray: *Erythrina variegata* is moderately tolerant of salt spray, as it is a littoral tree.

3.5.1.5 Commercial products

Fodder: The foliage of *Erythrina variegata* makes an excellent feed for most livestock. Leaves normally contain 16 to 18% crude protein and have an invitro dry matter digestibility of 50%. A tree of average size, pruned 3 or 4 times a year produces from 15 to 50kg of green fodder annually depending on growing conditions. Trees maintained in coffee plantations benefit from associated cultivation practices they can produce up to 100kg of fodder from one annual harvest. The leaves have no known toxicity to cattle.

Fibre: The wood has been tested as a source of pulp for the paper industry. The fibre is acceptable for pulping, having good length and high flexibility.

Wood: The wood of *Erythrina variegata* is light and soft with a specific gravity of 0.2 to 0.3. Each shade tree in a coffee plantation can yield from 25 to 40kg of wood from annual pollarding. The wood is used to construct floats, packing boxes, picture frames, toys and in India, it is increasingly used for pulp production.

Essential oils: In New Britain, blackened dried leaves are worn for their scent.

Medicinal: *Erythrina variegata* has a reputation for medicinal properties in India, China and south-east Asia. The bark and leaves are used in many traditional medicines. Juice from the leaves is mixed with honey and injested to kill tapeworm, roundworm and threadworm (Hedge, 1993). Women take this juice to stimulate lactation and menstruation. It is also commonly mixed with caster oil to cure dysentery. A warm poultice of the leaves is applied externally to relieve rheumatic joints. The bark is used as a laxative, diuretic and expectorant.

3.5.2 *Erythrina subumbrans*

3.5.2.1 Taxonomy

Kingdom : Plantae – plants

Sub kingdom: Viridiplantae

Division : Tracheophyta – vascular plants, tracheophytes

Sub division : Spermatophytina – spermatophytes, seed plants

Class : Magnoliopsida – dicotyledons

Order : Fabales

Family : Fabaceae – peas, legumes

Genus : *Erythrina* L.

Species : *E. subumbrans* L. (Hassk.) Merr.

3.5.2.2 Morphology

Size: *Erythrina subumbrans* is a medium-sized tree which can reach 5-25 m tall, while its trunk can reach upto 60 cm in diameter. The crown spreads and the bark is whitish. The trunk and branches are armed with stout prickles while in cultivation.

Flowers: The inflorescence is recemose at the upper leaf axils. It is 5-23 cm long and brownish hairy. There are many flowers arranged in groups of 3. The peduncle is cylindrical, robust, measures 3-15 cm long and pubescent. The pedicel is 2-3 mm long, where in fruit it is upto 6 mm long. The sepal is bell-shaped measures 1-1.5 cm long, splits open halfway down, hairy and yellow green. The 5 petals are red where the upper part is broadly elliptical, shortly clawed measuring 2.5-4 cm x 2-3 cm, scarlet and with numerous white stripes at the base inside. The wings are as long as the keel or slightly longer. There are about 1.5 cm long, and pale red with a blackish at the upper margin. There are 10 stamens which are 3-3.5 cm long. The pistil is with a hairy ovary.

Leaves: The leaves are arranged alternate with three leaflets. The stipules are orbicular. The rachis is 10-21 cm long and inclusive of the petiole which is 8-16 cm long anf thickened at the base. There are two stipels below the lateral leaflets. They are cup-like, grandular and measure 2mm long. The leaflets are ovate-triangular rhomboid, with terminal one being largest and measuring 8-16 cm x 6-14 cm. The base is rounded, acuminate at apex and hairless.

Fruits: The pod is flat, curved, measures 10-15 cm long and on a slender stalk 3-4.5 cm long. The lower part is seedless and it is 2-2.5 cm wide, while the upper part is thicker, which is 1-1.5 cm wide and 1-4 seeded. It is septate between the seed and dehiscent.

Seeds: The seed is ellipsoid, measuring 7-18 mm x 5-11 mm, smooth and dull black. There are 1-4 seeded per pod. The seeds are dispersed by water and occasionally by birds.

3.5.2.3 Ecology

Erythrina subumbrans occurs at low and medium altitudes from 150m - 1500m, in moist valleys, near streams, in open locations and secondary forests. It requires a high annual rainfall with a maximum of 4 months, with less than 100 mm rainfall and a mean annual temperature above 22^{o}C. It is reported, however to occur in open grasslands, in stony or sandy, occasionally dry places, elsewhere it is widely dispersed.

3.5.2.4 Agroforestry uses

The species of *Erythrina subumbrans* often grown as an ornamental. This species also has a sturdy component of agroforesty uses.

Fire: *Erythrina subumbrans* is somewhat fire resistant.

Boundary makers: It is commonly used for a boundary maker as a living fence.

Windbreaks: It is used extensively in windbreak as an ornamental in parks and gardens.

Shade or shelter: It is one of the best shade and live support trees for a wide range of crops. In sotheast India, it is occasionally grown as shade tree for coffee and other crops. *Erythrina subumbrans* is probably more commonly used for this purpose.

Frost: *Erythrina subumbrans* is intolerant of frost, which limits its natural distribution to the tropics.

Soil enrichment: *Erythrina subumbrans* species has a symbiotic relationship with certain soil bacteria; these bacteria form nodules on the roots and fix atmospheric nitrogen. Some of this nitrogen is utilized by the growing plant, but some can also be used by other plants growing nearby.

Organic matter: With their rapid growth and prolific modulation, all *Erythrinas* are a good source of organic matter for green manure. The nitrogen rich litterfall decomposes rapidly making nutrients available for plant uptake.The dry foliage of *Erythrina* normally contains from 1 to 3% nitrogen. Aqueous leaf extracts of *Erythrina* have also proven highly toxic to certain nematodes (Mohanty and Das, 1988).

3.5.2.5 Commercial products

Timber: The wood is extremely light and porous course textured, durable under water. It is utilized in canoe and raft building (Khanna, 2008).

Edible: Very young leaves are steamed and eaten in salads. Boiled leaves can be eaten as a potherb.

Bark: Bark gives good cordage fibre. Wood bark and ash are used in dyeing.

Medicinal: A decoration of the bark is taken to the treat spleen afflictions. A decoration of the leaves is used as a treatment for coughs. The pounded young leaves are used as a poultice for women soon after giving birth and as a treatment for headache. The juice of the leaves is used as an eye-wash. Several species are used in a variety of traditional medicines, eg: for poulticing wounds, against toothache and relieves fever for children.

3.6 Methodology

The study was conducted during two consecutive years in annual flowering season from 2010 to 2011. The forests stands of *Erythrina* in two different sites ie, Neihbawi and Sairang of Aizawl district, Mizoram in the north-eastern hill region (NEH) of India, were selected for the study.

The first site, ie, Neihbawi was located at 1300m asl and the second site, ie, Sairang was located at 200m asl. The altitudinal difference between both sites is 1100m. The traits selected for this study were Phenological events, Floral phenology and Pollinator frequency. Two sites with different elevation were selected for comparison of variation in between and within species in different parameters. Five trees were selected randomly from the two sites of wild population of *Erythrina* for studying each trait. For population level study, twenty individual trees were considered and compared between the sites. Studies were done in two elevations for each species as follows:

3.6.1 Phenological patterns

To determine the sequence of phenological events in trees of both species of the *Erythrina* across the two study sites, observations on the phenology of marked individuals were done every two weeks intervals annually on each site for both the selected species. Twenty Individuals of each species were marked by a metal tag on both sites. The phenological events were recorded as: (i) production of young leaves (YL), (ii) maturation of leaves (ML), (iii) abscission of leaves (AL), (iv) production of flowers (YF), (v) maturation of flowers (MF), (vi) abscission of flowers (AF), (vii) production of young fruits (YFR), (viii) maturation of fruits (MFR), and (ix) abscission of fruits (AFR).

Each phenological event was recorded for both species on each site by scoring dates of leaf, flower and fruit production. The dates of leaf flush and leaf fall (all leaves dropped) were recorded for all individuals sampled. An individual was considered to be fully leafed between the dates of flower flushing and leaf fall. The dates of flushing of flowers, anthesis period and development of fruits were also recorded on the selected individuals of both *Erythrina* species. Flowering period was divided into (1) onset, <50% of the population blooming (2) Peak, 51-100% of the population blooming; and (3) end, <50% of the population blooming.

3.6.2 Floral Phenology

In order to study the flowering phenology, different phenophases were recorded during visual monitoring of selected individuals. The method used for floral phenology was closely followed as of McIntosh (2002). Different phenological events were observed in 10 days interval during low activity period and at weekly interval at peak activity period for each phenological event. The flowering phenologies were recorded for five variables: a) first flowering date/ floral initiation, b) flowering peak date, c) flowering duration d) flowering amplitude and e) flowering synchrony. Every phenophase were considered to be at peak when 51-100% of the marked trees showed the phenological event. The phenophase were taken to have initiated when less than 50% of the marked trees showed the events.

3.6.2.1 Floral Initiation

For the estimation of the floral initiation (onset) five selected individuals in a site were monitored and the mean values of first flower were marked from the sample trees which were used as the floral initiation for plant, and for the whole population the first flower among population was used.

3.6.2.2 Duration of flowering

Duration of flowering was estimated as the duration of mean values of the first and last flower of selected individual for a plant but for the population it was estimated as the duration between the first flower and the last flower among population.

3.6.2.3 Peak flowering

Peak flowering was estimated as mean flowering date i.e., the average of the census dates during which that individual was flowering, with each census date valued by the number of flowers in that period.

3.6.2.4 Flowering amplitude

Flowering amplitude was estimated as during flowering period a total of ten days was monitored and observed for a selected five individuals in which number of flowers were counted every census dates in each selected individuals.

Amplitude = number of flowers/ no of plants / no of days

3.6.2.5 Synchrony

Flowering synchrony within an individual plant was the degree to which blooming period of the plant overlapped the blooming period of all the other plants within the population. Synchrony was calculated using the method of Augspurger (1983) modified by Primack (1980). For each individual, the number of days when the flowering overlapped that of other individuals was estimated. The index of synchrony (X) for an individual plant (i) was estimated as: Synchrony of a given individual with its conspecifics: X, the index of synchrony for individual i , is defined as

$$Xi = \left(\frac{1}{n-1}\right)\left(\frac{1}{f_i}\right)\sum_{\mathrm{j=i}}^{\mathrm{n}} \mathrm{e}_{\mathrm{j \neq i}}$$

where, e = number of days both individuals i and j are flowering synchronously, j≠i

f = number of days individual i is flowering;

n = number of individuals in population.

When X = 1.0, perfect synchrony occurs, i.e., all flowering days of individual i overlap with all flowering days of each other individual, j ≠ i, in the population.

When X = 0.0, no synchrony occurs, i.e., no overlap occurs among any of the flowering days of individual i and any other individual, j ≠ i, in the population. The amount of overlap of all individuals with each other in the population defines population synchrony (Z), which equals the mean of the values of individual's synchrony. The index includes the entire flowering time, and also considers the temporal overlap between each set of two individuals in the population from the perspective of both individuals which advances Primack's (1980) method that summarizes overlap from the perspective of only one of the two individuals.

To study the effect of climatic condition on flowering, the mean temperature, and rainfall data of study sites were recorded so as to correlate these with various phenological events of both *Erythrina* species.

3.6.3 Flower Production

Flower production was estimated on five individuals trees selected and marked randomly on each location and the same trees have been monitored /sampled for each successive year. For the estimation of production of flowers per tree, first the total number of floral buds (inflorescence) were counted and the number of flowers per bud (inflorescence) were counted on ten different bud (inflorescence) selected randomly on the crown of each individual. The total number of flowers per tree was calculated by multiplying the mean value number of flower per inflorescence by the mean value of number of inflorescence per tree.

Flower per Tree = (No. of flower per inflorescence) X (No. of inflorescence per tree)

The sizes of floral parts were measured varied from year to year. Mature individuals were selected randomly from each population. Four floral traits were measured that is, length of style: distance from the base of the perianth to the distal end of the stigma. Length of filament: distance from the base of the perianth to the anther. Length of flower: distance from the base of the perianth to the distal end of the Corolla. Width of flower: distance between the distal ends of dorsal Corolla.

3.6.4 Fruits setting

For the estimation of fruits setting, first the total number of fruits per bud (inflorescence) were counted and the number of flowers per bud (inflorescence) were counted on ten different bud (inflorescence) selected randomly on the crown of each individual. Fruit set percentage (%) was calculated by dividing the mean value number of fruits per tree by the mean value of number of flower per tree and multiplied by 100.

Fruit set % = (Number of fruits per tree) / (Number of flowers per tree) X 100

3.6.5 Pollinator Frequency

To determine the pollinators and their visitation rates, counting of the visiting insect species and their frequency was done on all the five chosen trees in each site. The study period covered fifteen days of peak flowering season after every three days interval in each location covering five days observation at each sample trees. The observations were made on ten randomly chosen inflorescence per tree and recorded for the number of opened flowers. For each visit the numbers of visited flowers were recorded. The observations were made at six different times each day, each starting at 2 hours interval that is from 0600h to 0800h, 0800h to 1000h, 1000h to 1200 and so forth.

Visitation frequency was calculated as the number of visits per total number of open flower within an observation period. Birds were the main pollinators recorded for both species. Frequency of visit was considered as a measurement of pollination efficiency.

3.6.6 Statistical Analysis

The existence of significant correlations between the phenological patters of leaves, flowers and fruits in relation to rainfall, maximum and minimum temperature was evaluated by means of Spearma's rank correlation.

The ANOVA was performed by using analysis PAST to test the difference in flowering phenology in two studied population. The variation in floral phenology between the years and between the sites (elevation) was analyzed using analysis of variance for a given species at a time.

References:

Anonymous (2003). *Mizoram Forest*. Department of Environment and Forest, Govt. of Mizoram. 1-15 pp.

Anonymous (2004). *Statistical Handbook of Mizoram*. Directorate of Economic and Statistics, Govt. of Mizoram. 1-9 pp.

Anonymous (2006). State of Forest Report, Mizoram; Aizawl. 1-30 pp.

Anonymous (2008) a. *Statistical Hand Book*. Directorate of Economics and Statistics, Mizoram; Aizawl. 145 p.

Anonymous (2008) b. *Daily and monthly rainfall record* (January to December from 2003 to 2008). Directorate of Agriculture (crop husbandry) Mizoram, Aizawl.1-50 pp.

Anonymous (2011). *The Meteorological data of Mizoram for the year 2009*. Department of Economics and Statistics Mizoram : Aizawl. pp 17.

Augspurger, C. K. (1983). Phenology, flowering synchrony, and fruit set of six Neotropical shrubs. *Biotropica* 15:257–267.

Hegde, N. (1993). Cultivation and uses of *Erythrina variegata* in Western India. In (Eds.) Westley S. B and Powell M. H. *Erythrina in the New and Old Worlds*. Paia, HI (USA): NFRA, pp. 77-84.

Khanna, L.S. (2008). Silviculrure of useful trees. pp 198

Mcintosh, M .E. (2002). Flowering phenology and reproductive output in two sister species of *Ferocactus* (Cactaceae). *Plant Ecology* 15(9):1 -13.

Mohanty, K.C and Das, S.N. (1988). Nematicidat properties of *Erythrina indica* against *Meloidogyne* incognita and *Tylenchorhynchus mashhoodi*. Indian Journal of Nematology. 18(1):138.

Primack, R.B. (1980). Phenological variation within natural populations: flowering in New Zealand montane shrubs. *J Ecol* 68:849–862.

Rintluanga, P. (1994). *Geography of Mizoram*; R.T Enterprise, Aizawl, Mizoram, India; pp 1-67.

Rotar, P.P., Joy, R.J and Weissich, P.R. (1986). '*Tropic coral' tall erythrina*. Research extension series 072. University of Hawaii, Honolulu.

Sawmliana, M. (2003). *The book of Mizoram plants* (includes some wild animals and birds of Mizoram). Zakhuma P, Chanmari West, Aizawl, Mizoram. 1 – 472 pp.

Chapter 4

Results and Discussion

4.1 Phenological patterns

The results of the study indicated that leaf fall in both the species of *Erythrina* are mainly coincided with dry season while leaf flush is coincided with early rainy season. Both studied tree species (*Erythrina variegata* and *Erythrina subumbrans*) on two sites with different precipitation regimes abscised their leaves at the beginning of the dry season (December – January) during the two study years, 2010 and 2011. These results indicated that the species of *Erythrina* respond to a general proximate environmental signal associated with the dry season for leaf abscission.

Neihbawi site (high altitude, cooler and heavy rainfall site) had earlier leaf fall of an average of 16 – 18 days as compared to Sairang site (low altitude, warmer and less rainfall). Leaf production/flush in both studied species is coincided with early rainy season, April – May for the two years, 2010 and 2011. Both studied species had earlier leaf flush with the average of 7–8 days in *Erythrina variegata* and 10 days in *Erythrina subumbrans* at Sairang site as compared to Neihbawi. Maturation of leaves in both studied species reached during peak rainy season, last May – first week of June at both studied forest site during the two years of study [Table 1].

Erythrina variegata exhibited peak flowering during very early rainy season (i.e. mid week of February to midweek of March for the two years, 2010 and 2011 while *Erythrina subumbrans* flowered during late rainy season (i.e. mid week of August to midweek of September in both year of study). Fruiting pattern of both studied species varied significantly with season and time. *Erythrina variegata* starts fruiting i.e. production of fruit after a month of abscission of flower and continued for 2–3 months. Fruiting phase is in *Erythrina variegata* coincided with early to peak rainy season (April–June; 2010–2011). While *Erythrina subumbrans* starts fruiting after 2 months of abscission of flower, which continued upto 3 months. On an average fruiting was 8–10 days early in *Erythrina variegata* while it was 4 days prior in *Erythrina subumbrans* at Sairang compared to Neihbawi. Fruiting phase in *Erythrina subumbrans* is coincided with dry season with no rainfall and low temperature (December–February; 2010–2011). Time required for maturation of fruits in *Erythrina variegata* and *Erythrina subumbrans* varied from average 45–51 during the study period with little interannual variability [Table 1].

Total rainfall during 2010 at Neihbawi site was recorded as 4404 mm and at Sairang site it was 2679 mm. During 2011 total rainfall of 3684 mm was recorded at Neihbawi while Sairang received 2137 mm rainfall. The average minimum and maximum temperature of the cooler site, Neihbawi ranges between 14.71 – 27.06^{0}C, whereas the warmer site, Sairang, it ranges between 17.44 – 29.82^{0}C in 2010. In the year of 2011, the average minimum and maximum temperature ranges between 14.6 – 26.49^{0}C and 17.27 – 29.68^{0}C for both the sites, respectively [Figure 2].

The significant correlations was evaluated by means of Spearma’s rank correlation between the phenological patterns (leaves, flowers and fruits) with that of rainfall, maximum and minimum temperature during the two study years. It showed that leaf fall in *Erythrina variegata* and *Erythrina subumbrans* is significantly negatively correlated with the climatic factors viz. rainfall, average minimum and maximum temperature. Fruiting in *Erythrina subumbrans* is again significantly negatively correlated with all the climatic factors for both the years. Leaf flush in *Erythrina subumbrans* is positively correlated with the rainfall in both the study sites while in *Erythrina variegata* is weakly correlated. In flowering there was no significant correlation for both the studied species [Table 2, 3, 4 ,5].

Table: 1. Average scoring date of phenological events for both forest study sites

	2010				2011			
Phenophase	*E. Variegata*		*E. Subumbrans*		*E. Variegata*		*E. Subumbrans*	
	Neihbawi	Sairang	Neihbawi	Sairang	Neihbawi	Sairang	Neihbawi	Sairang
Production of young leaves (YL)	28-Apr	20-Apr	2-May	22-Apr	29-Apr	22-Apr	3-May	23-Apr
Maturation of leaves (ML)	8-Jun	26-May	10-Jun	27-May	8-Jun	27-May	7-Jun	27-May
Abscission of leaves (AL)	5-Dec	22-Dec	6-Dec	23-Dec	7-Dec	24-Dec	8-Dec	24-Dec
Production of young flower (YF)	18-Feb	8-Feb	20-Aug	9-Aug	19-Feb	8-Feb	21-Aug	9-Aug
Maturation of flower (MF)	8-Mar	26-Feb	10-Sep	29-Aug	10-Mar	26-Feb	12-Sep	29-Aug
Abscission of flower (AF)	16-Mar	5-Mar	24-Sep	14-Sep	17-Mar	7-Mar	25-Sep	12-Sep
Production of young fruit (YFR)	14-Apr	5-Apr	6-Dec	2-Dec	16-Apr	8-Apr	9-Dec	5-Dec
Maturation of fruit (MFR)	2-Jun	21-May	26-Jan	20-Jan	6-Jun	25-May	25-Jan	19-Jan
Abscission of fruit (AFR)	28-Jun	15-Jun	14-Feb	10-Feb	29-Jun	18-Jun	17-Feb	12-Feb

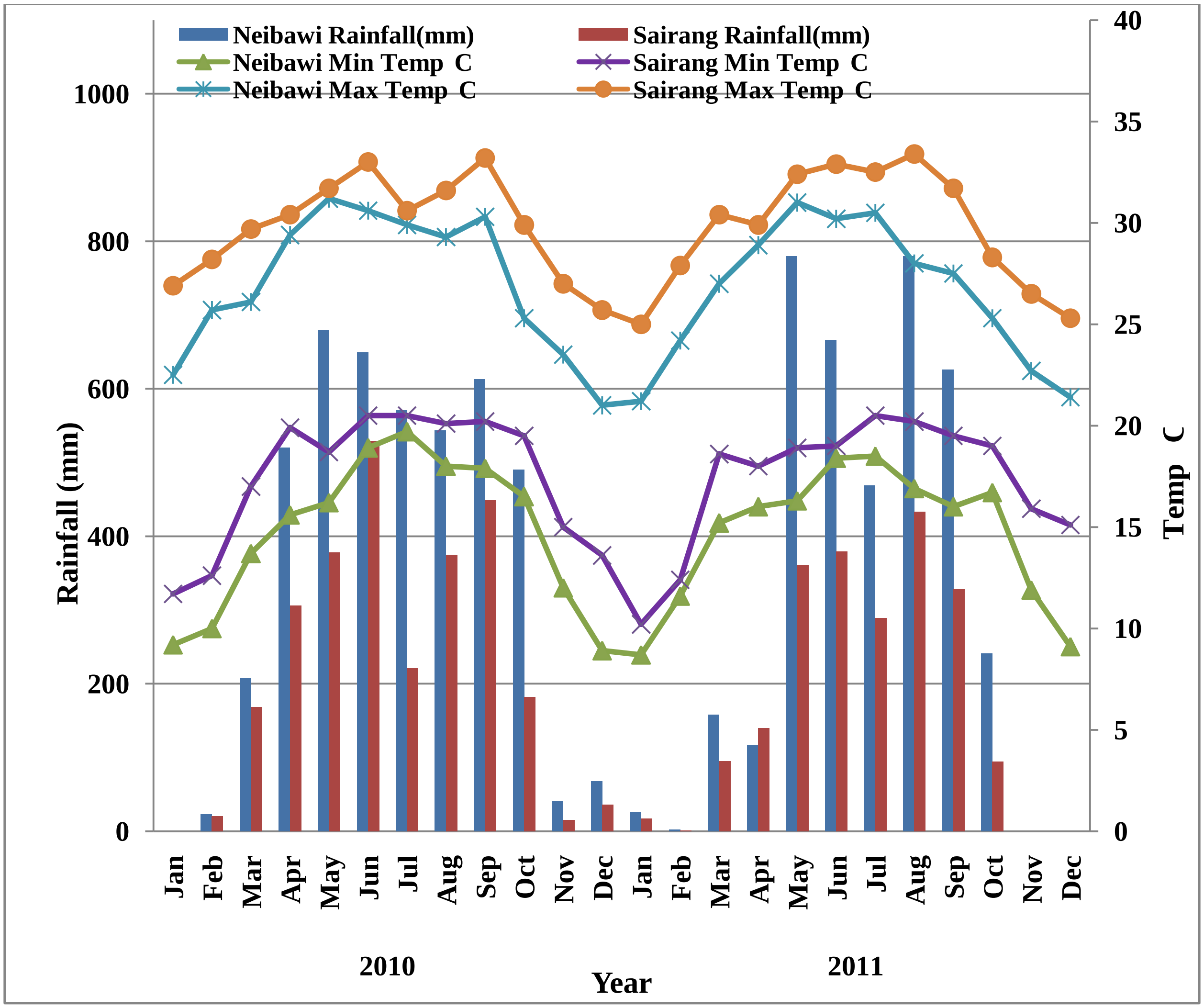

Figure: 2. Mean monthly rainfall, minimum and maximum temperature distribution in study areas during study period 2010-11.

Source: Department of Agriculture and animal husbandry, Aizawl, Mizoram.

Table: 2. Phenological patterns of ***Erythrina variegata*** in relation to rainfall, maximum, temperature and minimum temperature at Neihbawi in two seasonal calendars (2010-11)

Phenophases	Environmental factor Spearman's rank correlation coefficient (r_s) and in bracket probability (p)					
	2010			**2011**		
	Rainfall	Max. Temp	Min. Temp	Rainfall	Max. Temp	Min. Temp
Flowering	r = -0.388	-0.129	-0.323	-0.260	-0.194	-0.324
	p ≤ (0.211)	(0.688)	(0.304)	(0.414)	(0.545)	(0.303)
Fruiting	r = 0.585	0.641	0.250	0.391	0.641	0.335
	p ≤ (0.045)	(0.024)	(0.431)	(0.208)	(0.024)	(0.287)
Leaf Flush	r = 0.388	0.453	0.00	0.227	0.129	0.097
	p ≤ (0.211)	(0.138)	(1.00)	(0.477)	(0.688)	(0.763)
Leaf Fall	r = -0.518	-0.647	-0.647	-0.487	-0.647	-0.648
	p ≤ (0.084)	(0.022)	(0.022)	(0.107)	(0.022)	(0.022)

Table: 3. Phenological patterns of ***Erythrina variegata*** in relation to rainfall, maximum, temperature and minimum temperature at Sairang in two seasonal calendars (2010-11)

Phenophases	Environmental factor Spearman's rank correlation coefficient (r_s) and in bracket probability (p)					
	2010			**2011**		
	Rainfall	Max. Temp	Min. Temp	Rainfall	Max. Temp	Min. Temp
Flowering	r = -0.323	-0.259	-0.389	-0.259	-0.129	-0.324
	p ≤ (0.304)	(0.416)	(0.210)	(0.415)	(0.688)	(0.303)
Fruiting	r = 0.585	0.473	0.335	0.474	0.362	0.055
	p ≤ (0.045)	(0.119)	(0.287)	(0.118)	(0.247)	(0.863)
Leaf Flush	r = 0.00	0.259	0.064	0.00	0.00	-0.129
	p ≤ (1.00)	(0.416)	(0.841)	(1.00)	(1.00)	(0.687)
Leaf Fall	r = -0.518	-0.647	-0.584	-0.486	-0.647	-0.584
	p ≤ (0.084)	(0.022)	(0.046)	(0.108)	(0.022)	(0.046)

Table: 4. Phenological patterns of ***Erythrina subumbrans*** in relation to rainfall, maximum, temperature and minimum temperature at Neihbawi in two seasonal calendars (2010-11)

Phenophases	Environmental factor Spearman's rank correlation coefficient (r_s) and in bracket probability (p)					
	2010			**2011**		
	Rainfall	Max. Temp	Min. Temp	Rainfall	Max. Temp	Min. Temp
Flowering	$r =$ 0.250	0.083	0.418	0.447	0.027	0.335
	$p \leq$ (0.431)	(0.796)	(0.176)	(0.144)	(0.931)	(0.287)
Fruiting	$r =$ - 0.696	-0.641	-0.752	-0.615	-0.696	-0.752
	$p \leq$ (0.011)	(0.024)	(0.004)	(0.033)	(0.011)	(0.004)
Leaf Flush	$r =$ 0.647	0.670	0.323	0.552	0.582	0.389
	$p \leq$ (0.022)	(0.023)	(0.304)	(0.062)	(0.046)	(0.210)
Leaf Fall	$r =$ -0.518	-0.647	-0.647	-0.487	-0.647	-0.648
	$p \leq$ (0.084)	(0.022)	(0.022)	(0.107)	(0.022)	(0.022)

Table: 5. Phenological patterns of ***Erythrina subumbrans*** in relation to rainfall, maximum, temperature and minimum temperature at Sairang in two seasonal calendars (2010-11)

Phenophases	Environmental factor Spearman's rank correlation coefficient (r_s) and in bracket probability (p)					
	2010			**2011**		
	Rainfall	Max. Temp	Min. Temp	Rainfall	Max. Temp	Min. Temp
Flowering	$r =$ 0.362	0.418	0.363	0.363	0.306	0.558
	$p \leq$ (0.247)	(0.176)	(0.246)	(0.243)	(0.332)	(0.059)
Fruiting	$r =$ - 0.641	-0.753	-0.752	-0.614	-0.696	-0.753
	$p \leq$ (0.024)	(0.004)	(0.004)	(0.033)	(0.011)	(0.004)
Leaf Flush	$r =$ 0.582	0.518	0.292	0.519	0.453	0.162
	$p \leq$ (0.046)	(0.084)	(0.357)	(0.083)	(0.138)	(0.614)
Leaf Fall	$r =$ -0.518	-0.647	-0.584	-0.486	-0.647	-0.584
	$p \leq$ (0.084)	(0.022)	(0.046)	(0.106)	(0.022)	(0.046)

4.2 Flowering phenology

During the two studied years, it was observed that some of the flowering phenological events did not show much variation between and within species, though fluctuations between sites were noticed. In *Erythrina variegata* at Neihbawi site flower onset was almost the same during the study years, it occurred between 21st February and 23rd February for the mean plant value. But for the population as a whole it comes under 16th February to 18th February. At Sairang site, the onsets mean plant value for *Erythrina variegata* was the same during two year, it was 15th February, and for the population it was between 9th to 11th February which was earlier than Neihbawi site for both mean plant value and population. *Erythrina variegata* exhibited peak flowering during very early rainy season i.e. in the first of March at Neihbawi site, but in Sairang site, it was mainly in the last of February. Flowering end at Neihbawi site reaches up to 18th March but in Sairang site it attains only 10th March [Table 6].

In case of *Erythrina subumbrans*, onset starts on 25th August for the plants and 19th to 20th August for the population at Neihbawi site. At Sairang site, it starts from 15th to 18th August for the plant and 9th August for the population. Peak Flowering occurs on the day of 5th September for the plant and 5th to 7th September for the population at Neihbawi site. For Sairang site it occurs between 23rd to 26th August for the plant and 25th August for the population, showing minimal variation in peak flowering between sites. Flower end in 25th and 11th September for both Neihbawi and Sairang sites, respectively [Table 7].

The timing of flowering is most essential for a species survival, and is shown in many studies to be highly correlated with plant fecundity (O'Neil, 1997; Kelly and Levin, 2000; Stinson, 2004). It can strongly influence the reproductive success of a plant in several ways (Rathcke and Lacey, 1985). From the field observation, evidently flowering took place in lower elevation site earlier than in higher elevation site. With rise in elevation, delay in flower onset timing and contraction in flowering duration has been documented elsewhere as well (Crimmins et al., 2009; Rusch, 1993; Singh, 2014). This study variation showed that at higher altitude sites the onset, peak flowering and end of flowering were late, while at lower altitude sites onset, peak and end of flowering were short and early. This may be because every character of the tree needs a particular set of temperatures for its growth and development. This optimum set of temperatures is met early at low elevation and later as elevation increases.

In high mountainous regions, flowering phenology changes along elevation gradients, with plants at lower elevation typically flowering earlier than those of the same species growing at higher elevations (Bertiller et al., 1990; Ziello et al., 2009; Singh et al., 2015). Generally, air temperature in mountainous regions decreases strongly with increasing elevation at a lapse rate of about 0.6 °C every 100 m (Fang and Yoda, 1988). This temperature gradient is a crucial factor in the timing of biological events. Atmospheric circulation pattern, precipitation and sunshine duration vary strongly in mountainous regions due to variation in aspect and inclination. This creates strongly variable microclimates within mountain regions, which lead to differences between phenology at high altitudes compared to lower sites (Inouye and Wielgolaski, 2003). The most important proximal environmental cues determining flowering time are considered to be temperature and day length (Reeves and Coupland, 2000). Temperature is the strongest driver of phenology (Ranjitkar et al., 2013). Occasional deviation from this pattern along elevation gradients may have been caused by variation in micro - environmental factors (Gimenez-Benavides et al., 2007). In many cases, flowering phenology is largely determined by seasonal changes in resources availability; however, in some other, climatic factors such as heat sum are the best predictors of flowering (White, 1995).

Table: 6. Intraspecific variation of Phenological data of *Erythrina variegata* at the plant and population levels between two forest sites. Dates are given in the calendar date.

Observed Variables		2010		2011	
		Plant	population	Plant	Population
Neihbawi	onset	21-Feb	16-Feb	23-Feb	18-Feb
	peak	1-Mar	2-Mar	3-Mar	4-Mar
	end	11-Mar	17-Mar	12-Mar	18-Mar
Sairang	onset	15-Feb	11-Feb	15-Feb	9-Feb
	peak	22-Feb	24-Feb	22-Feb	22-Feb
	end	1-Mar	10-Mar	1-Mar	8-Mar

Table: 7. Intraspecific variation of Phenological data of *Erythrina subumbrans* at the plant and population levels between two forest sites. Dates are given in the calendar date.

Observed Variables		2010		2011	
		Plant	population	Plant	Population
Neihbawi	onset	25-Aug	20-Aug	25-Aug	19-Aug
	peak	5-Sep	7-Sep	5-Sep	5-Sep
	end	17-Sep	25-Sep	15-Sep	23-Sep
Sairang	onset	15-Aug	9-Aug	18-Aug	9-Aug
	peak	23-Aug	25-Aug	26-Aug	25-Aug
	end	1-Sep	11-Sep	3-Sep	10-Sep

4.3 Duration of flowering

The flowering duration varied from 13 to 18 days at the plant level and 27 to 29 days at population level for *Erythrina variegata* in both studied sites. Flowering occurred in 2nd week of February in *Erythrina variegata* and ended by in the mid of March, with small fluctuations between years and sites. Duration of flowering in *Erythrina variegata* at Neihbawi site is 17 to 18 days at the plant level and 28 to 29 days at the population level. For the second site, Sairang, the flowering duration ranges from 13 to 14 days at the plant level and 27 days for the population level [Table 8].

For the second species, *Erythrina subumbrans*, flowering occurred in the last of August and ended by in the mid of September. During two successive years of study the flowering duration in *Erythrina subumbrans* for the first site, Neihbawi ranges from 21 to 22 days for the plant value and for the population it ranges between 35 to 36 days. For this species at Sairang site it ranges between 16 to 17 days for the plant value and for the population it ranges between 32 to 33 days [Table 9].

In overall the flowering duration was within a month for *Erythrina variegata* for the individuals and for the population it was little over a month by another 5 to 10 days more. But in *Erythrina subumbrans* flowering duration was about one and half month for the individuals and population. Several studies show that the longevity of individual flowers increases with altitude (Primack, 1985; Bingham and Orthner, 1998; Blionis and Vokou, 2001). Our study is in conformity with those reported above.

Intraspecific variation between the individuals located in higher and lower elevation showed that flowering durations, early budding and higher intensity occurred in those growing at lower elevation. It can be suggested that the longer duration of open flower production varies with micro environmental conditions around the individual (Korner, 2003). Extended phase of flowering has several advantages for plant's reproducctive success (Bawa, 1983; Rathcke and Lacey, 1985). A long duration of flowering may result in a lower risk of reproductive failure, as it likely to be affected by bad weather or lack of pollinators at a particular time (Korner, 2003). The species of *Erythrina subumbrans* has a long duration of flowering of population in both sites which sometimes goes to 32 to 36 days and hence reproductive fecundity is also high, i.e. 25.4% to 30% fruit set for the natural pollination. Whereas in *Erythrina variegata* flowering duration in both sites was 27 to 29 days which has lower reproductive fecundity i.e. 21.3% to 27.4% fruit set for natural pollination.

Many studies in which flowering times of a species within communities are recorded show that there is often a temporal sequence of flowering with each species peaking, in turn, making them appear non-random (Fenner, 1998). The time of flowering too could be related to other phenophases such as growth, seed dispersal or seed germination (Johnson, 1993).

Analysis of variation on duration of flowering due to site and due to years showed that there was highly significant variation in the years, but in the sites there was no significant variation [Table 10, 11].

There are reports which suggest that most species react differently to climate change and the climate change has lead to shifts in phenology in many species distributed widely across taxonomy groups. One of the main challenges therefore is to determine the extent of correlation between phenology and temperature (usually the mean temperature over a fixed date period), actually reflects the underlying causal mechanisms. This is crucial because the extrapolations using climate scenario now sometimes predict that the phenology events will occur outside the date period of phenology.

Table: 8. Intraspecific variation on duration of flowering in *Erythrina variegata* population between the two site. For plant data, values shown are the mean of all plant values ± standard Error. For population data, values given represent whole population.

Observed variables			2010	2011
Duration	Neihbawi	plant	18d ± 1	17d ± 1
		population	29d	28d
	Sairang	plant	13d ± 1	14d ± 1
		population	27d	27d

Table: 9. Intraspecific variation on duration of flowering in *Erythrina subumbrans* population between the two site. For plant data, values shown are the mean of all plant values ± standard Error. For population data, values given represent whole population.

Observed variables			2010	2011
Duration	Neihbawi	plant	22d ± 1	21d ± 1
		population	36d	35d
	Sairang	plant	17d ± 2	16d ± 1
		population	33d	32d

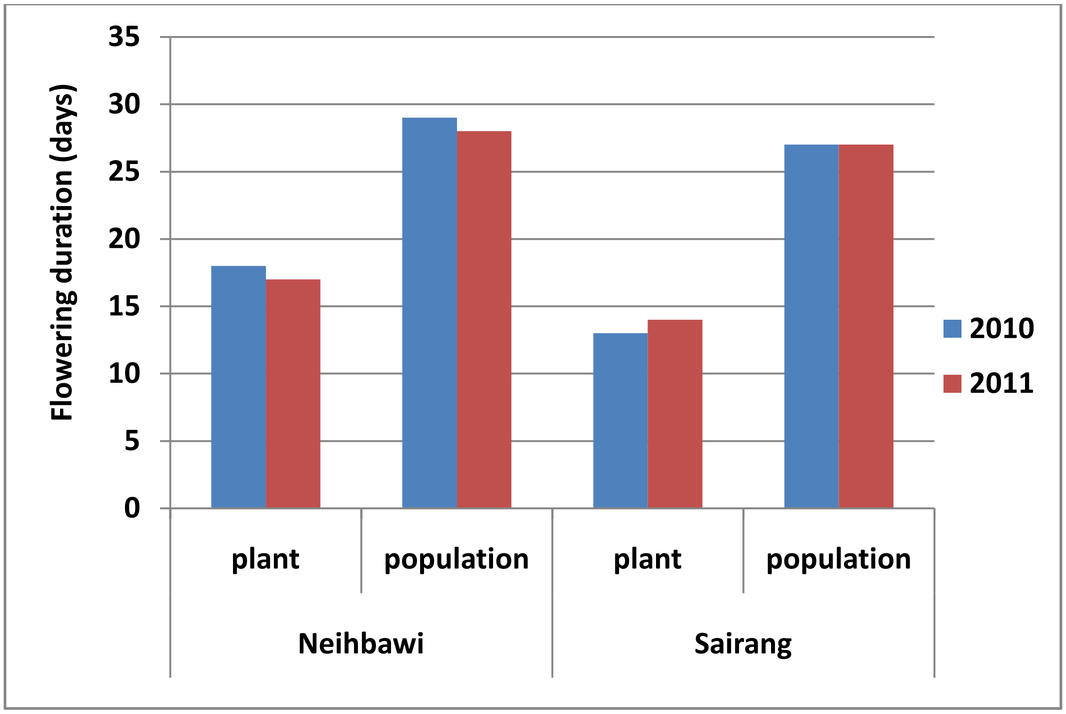

Figure: 3. Variation of flowering duration in *Erythrina variegata* at the two forest sites

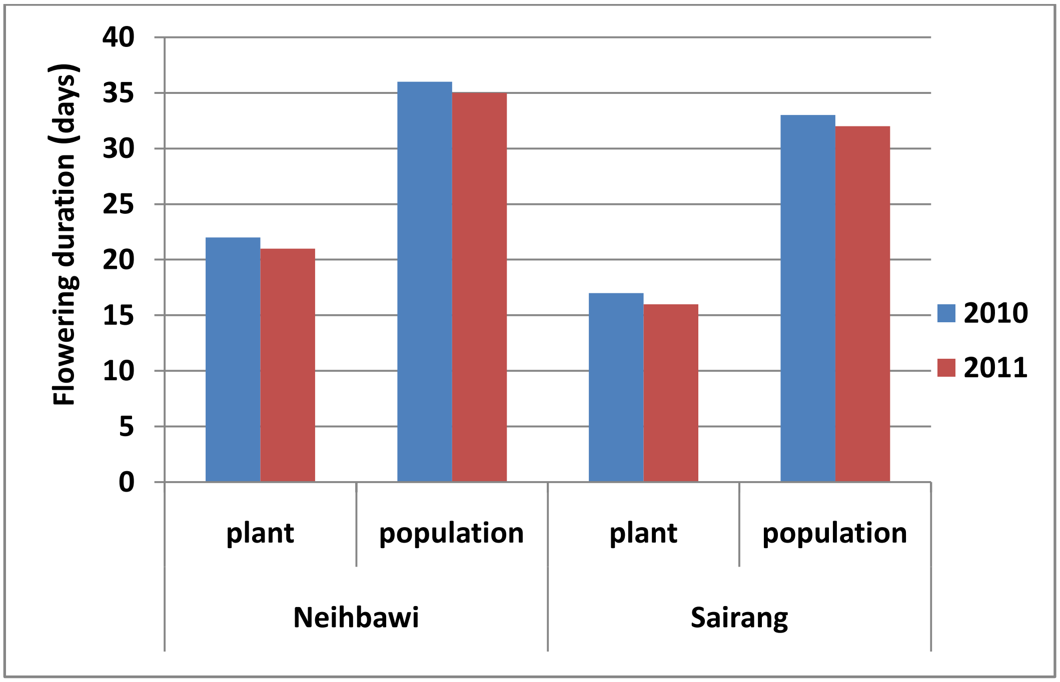

Figure: 4. Variation of flowering duration in *Erythrina subumbrans* at the two forest sites

Table: 10. ANOVA of the effect of site on duration of flowering

Sites	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*
Erythrina variegata (Neihbawi)	Between Groups	1.6	1	1.6	0.477612	0.509059
	Within Groups	26.8	8	3.35		
	Total	28.4	9			
Erythrina variegata (Sairang)	Between Groups	0.1	1	0.1	0.021978	0.885814
	Within Groups	36.4	8	4.55		
	Total	36.5	9			
Erythrina subumbrans (Neihbawi)	Between Groups	4.9	1	4.9	1.053763	0.334677
	Within Groups	37.2	8	4.65		
	Total	42.1	9			
Erythrina subumbrans (Sairang)	Between Groups	1.6	1	1.6	0.166667	0.6938
	Within Groups	76.8	8	9.6		
	Total	78.4	9			

Table: 11. ANOVA of the effect of year on duration of flowering

Years	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*
2010	Between Groups	207.35	3	69.11667	11.61625	0.000272
	Within Groups	95.2	16	5.95		
	Total	302.55	19			
2011	Between Groups	142.95	3	47.65	9.297561	0.000855
	Within Groups	82	16	5.125		
	Total	224.95	19			

4.4 Flowering amplitude

Variation in flowering amplitude between the sites on *Erythrina variegata* and *Erythrina subumbrans* are shown in [Table 12]. Flowering amplitude in *Erythrina variegata* ranged from 0.624 to 0.632 at high elevation (Neihbawi site) and from 0.698 to 0.704 at low elevation (Sairang). On the other hand, flowering amplitude in the second species *Erythrina subumbrans* ranged between 0.629 to 0.638 at Neihbawi site, and at Sairang site it ranged between 0.708 to 0.720 [Table 12). The highest flowering amplitude in all sites for both the species was 0.720 at Sairang site in 2010. The lowest was 0.624 at Neihbawi site in 2011. The rate of flower production rose quickly at low elevation than high elevation.

McIntosh (2001) reported that plant size was found to be positively correlated with mean flowering amplitude. Thus at least for these species, large plants make so many more flowers than small plants, that even though they also flower for a longer period, their mean flowering amplitude is still higher than that of small plant. Therefore the low elevation, Sairang site has higher amplitude than higher elevation, Neihbawi site.

McIntosh (2001) also reported that greater amplitude can also be the result of plant growth. Tree height had significant positive relation with the production of flowers and fruits, which has translated the effect of tree on fecundity. Larger trees produce more fruits and seeds than smaller trees and are at a reproductive advantage in the population. The larger plants in the population are usually the most fecund. Similar other results were also reported for other species like *Lupines Lepidus* and *Ferocactus cylindraceus* and *F. wislizeni* (Bishop and Schemske, 1998; McIntosh, 2002).

Table: 12. Intraspecific and interspecific variation of flowering amplitude in *Erythrina variegata* and *Erythrina subumbrans*. For plant data, values shown are the mean of all plant values ± standard Error.

	Erythrina variegata		*Erythrina subumbrans*	
Year	Neihbawi	Sairang	Neihbawi	Sairang
2010	0.632 ± 0.098	0.704 ± 0.085	0.638 ± 0.094	0.720 ± 0.087
2011	0.624 ± 0.095	0.698 ± 0.085	0.629 ± 0.093	0.708 ± 0.083

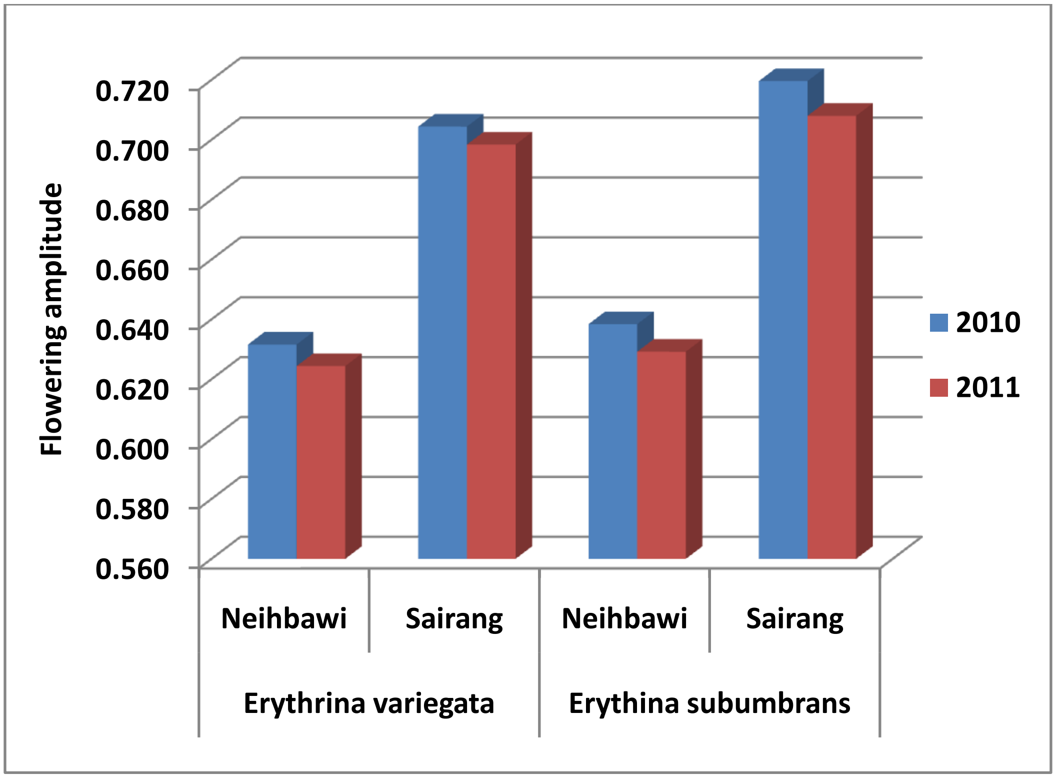

Figure: 5. Intraspecific and interspecific variation of Flowering amplitude

4.5 Synchrony

Mean synchrony is varied from 0.406 to 0.512 for *Erythrina variegata* and *Erythrina subumbrans* during study period (2010 and 2011) with slightly high mean in both studied species. Flowering phenophase was moderately synchronized within a population and was simultaneous within the individual [Table 1, 6, 7, 8, 9].

The Sairang site (low elevation, warm and less rainfall) has higher synchrony than Neihbawi site (high elevation, cooler and high rainfall). Highest synchrony occurs in 2010 at Sairang site while lowest in 2010 at Neihbawi site with a score of 0.512 and 0.406 respectively. In general for both species and sites, the synchrony value was not high [Table 13].

High overlapping in the flower bloom ensured the higher chance of cross-pollination, which is a key to reproductive success in the plants (Ranjitkar et al., 2013). Synchronization in flowering within a population is of prime importance for successful seed setting and maximum outcrossing level, which will determine the partitioning of genetic variation in the population (Medan and Bartoloni, 1998). Synchrony among individuals increases cross-pollination via attraction of pollinators. Population synchrony increased among species as the mean individual flowering duration decreased (Augspurger, 1983). The observations of this study were also in the line with Augspurger (1983). Also high synchrony was occurred where flowering amplitude was high. Several hypotheses exist to explain selection for a high degree of synchrony with conspecifics: such as

a) Increase in the potential for cross-pollination, a requirement if the individual is self incompatible (Holttum, 1953; Baker, 1959; Bawa, 1983).

b) Increase in the efficiency of energetics of pollinators attraction of pollinators (Gentry, 1974; Opler et al., 1976; Bawa, 1983).

c) Escape from flower and later seed predators. High synchrony among a high number of individuals within a given region favors genetic variation by enabling high levels of cross-pollination. This, in turn, should promote genetic diversity and thereby raise the capacity of a species to adapt to the harsh conditions (Stinson, 2004).

Table: 13. Intraspecific and interspecific variation of flowering Synchrony in *Erythrina variegata* and *Erythrina subumbrans* (Neihbawi and Sairang). For plant data, values shown are the mean of all plant values ± standard Error.

Year	*Erythrina variegata*		*Erythrina subumbrans*	
	Neihbawi	Sairang	Neihbawi	Sairang
2010	0.406 ± 0.01	0.512 ± 0.03	0.408 ± 0.01	0.511 ± 0.03
2011	0.41 ± 0.01	0.506 ± 0.03	0.42 ± 0.01	0.507 ± 0.02

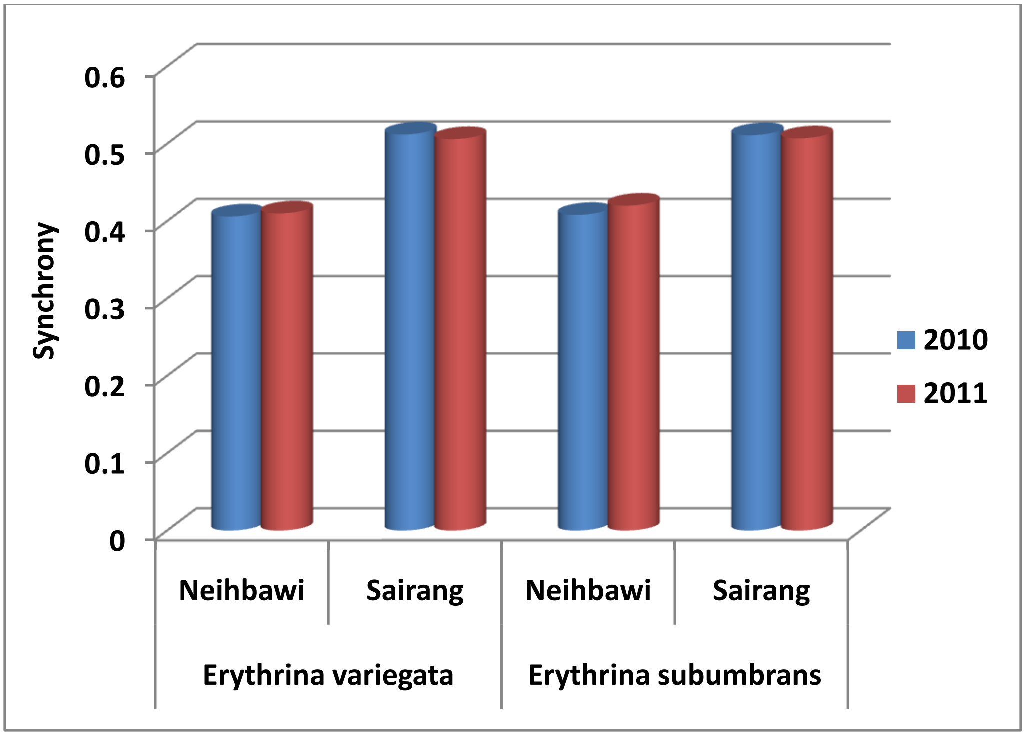

Figure: 6. Intraspecific and interspecific variation of flowering synchrony

4.6 Floral Parts

This study showed that the sizes of floral parts measured were varied from year to year. In case of *Erythrina variegata,* the length of style, length of filament, length of flower and width of flower were longer in the lower elevation in both studied years. The sizes of flower parts were increased in 2010 than the next year 2011 except the length of flower at Neihbawi site in *Erythrina variegata*. The floral sizes were fluctuating both the two studied years for both the two forest sites [Table 14].

In case of *Erythrina subumbrans*, the sizes of floral parts were longer in the lower elevation, ie, Sairang site than higher site, ie, Neihbawi in both studied years. There was a little difference between the two forest sites. In overall, the floral size of *Erythrina subumbrans* is larger than *Erythrina variegata* [Table 15].

Several studies showed that the longetivity of individual flowers increases with altitude whereas floral size traits do not seem to change with altitude (Primack, 1985; Bingham and Orthner 1998; Blionis et al., 2001). The reduction in overall plant size is the most conspicuous structural alteration in plant observed along elevation gradient (Korner and Basler, 2001). The size of the floral display can affect the behavior of pollinators **(**Klinkhamer et al., 1989). This influences not only the quantity of pollinating visits, but also the quality of the pollination service received. A comparison in nine Campanula species along an altitudinal gradient in Greece revealed that massively reduced shoot mass and height of alpine plants, dry weight and mean display area of individual blossoms did not differ from lowland species. Neither corolla width nor corolla depth changed with elevation (Blionis et al., 2001). The overall change in pollinator spectrum with altitude (Arroyo et al., 1985) does not seem to result in a general altitudinal change of blossom size.

In order to study variation between floral parts between sites and years, analysis of variance (ANOVA) was performed and it showed that there was significant variation in sites, ie, length of style, length of filament and width of flower at Sairang and length of flower at Neihbawi in *Erythrina variegata*. The analysis of variance between years and floral parts also revealed that significant variation in length of style in *Erythrina variegata* for the year 2011 and in length of flower in *Erythrina variegata* in both studied years [Table 16, 17].

In case of *Erythrina subumbrans*, there was significant variation in length of style, length of flower and width of flower for both the sites. The variation between years and floral parts was strongly significant in length of style in 2010 and length of flower in 2010 and

2011, showing floral parts sizes were fluctuating year to year. This may be attributed to the micorclimate within the area. There was no significant variation in length of filament due to sites for both the two species [Table 18, 19].

Table: 14. Intraspecific variation of Floral parts of *Erythrina variegata* between the two forest sites.

Year	Length of Style (cm)		Length of filament (cm)		Length of flower (cm)		Width of flower (cm)	
	Neihbawi	Sairang	Neihbawi	Sairang	Neihbawi	Sairang	Neihbawi	Sairang
2010	2.6 ± 0.04	2.7 ± 0.03	1.5 ± 0.04	1.6 ± 0.03	3.2 ± 0.03	3.5 ± 0.05	2.3 ± 0.06	2.6 ± 0.03
2011	2.5 ± 0.04	2.6 ± 0.02	1.4 ± 0.03	1.5 ± 0.04	3.3 ± 0.03	3.3 ± 0.03	2.2 ± 0.02	2.4 ± 0.03

Table: 15. Intraspecific variation of Floral parts of *Erythrina subumbrans* between the two forest sites.

Year	Length of style (cm)		Length of filament (cm)		Length of flower (cm)		Width of flower (cm)	
	Neihbawi	Sairang	Neihbawi	Sairang	Neihbawi	Sairang	Neihbawi	Sairang
2010	2.7 ± 0.04	2.7 ± 0.03	1.5 ± 0.03	1.6 ± 0.03	3.2 ± 0.06	3.5 ± 0.04	2.4 ± 0.04	2.6 ± 0.03
2011	2.5 ± 0.02	2.6 ± 0.02	1.5 ± 0.03	1.5 ± 0.04	3.0 ± 0.03	3.3 ± 0.03	2.3 ± 0.04	2.5 ± 0.02

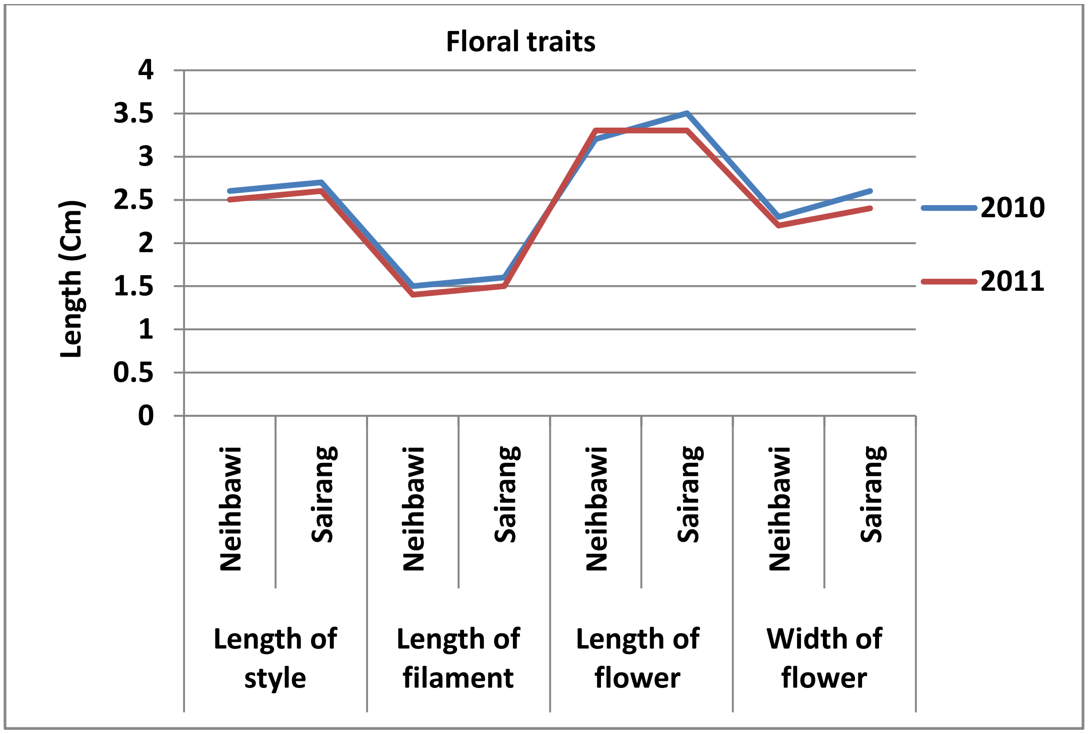

Figure: 7. Intraspecific variation of floral parts in *Erythrina variegata*

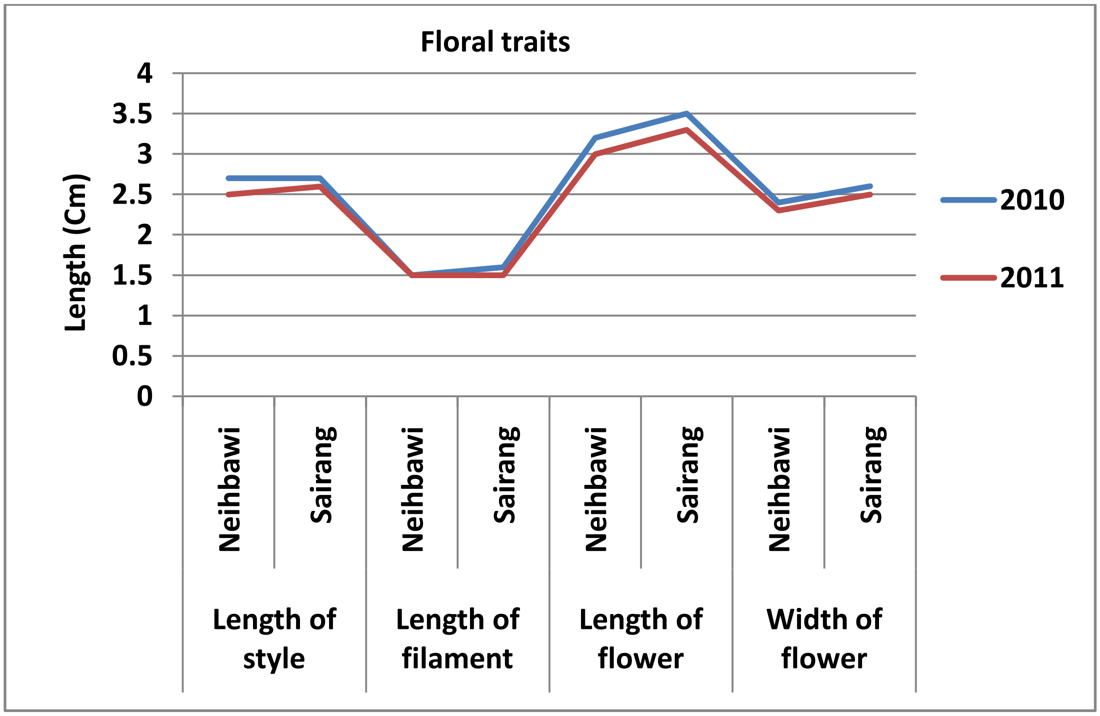

Figure: 8. Intraspecific variation of floral parts in *Erythrina subumbrans*

Table: 16. ANOVA of the effect of site on floral parts of *Erythrina variegata*.

Variables	Sites	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*
Length of style	Neihbawi	Between Groups	0.016	1	0.016	2	0.195016
		Within Groups	0.064	8	0.008		
		Total	0.08	9			
	Sairang	Between Groups	0.064	1	0.064	16	0.00395
		Within Groups	0.032	8	0.004		
		Total	0.096	9			
Length of filament	Neihbawi	Between Groups	0.025	1	0.025	3.3333	0.105322
		Within Groups	0.06	8	0.0075		
		Total	0.085	9			
	Sairang	Between Groups	0.049	1	0.049	7.5384	0.025229
		Within Groups	0.052	8	0.0065		
		Total	0.101	9			
Length of flower	Neihbawi	Between Groups	0.1	1	0.1	20	0.002077
		Within Groups	0.04	8	0.005		
		Total	0.14	9			
	Sairang	Between Groups	0.025	1	0.025	3.3333	0.105322
		Within Groups	0.06	8	0.0075		
		Total	0.085	9			
Width of flower	Neihbawi	Between Groups	0.025	1	0.025	2.3809	0.161397
		Within Groups	0.084	8	0.0105		
		Total	0.109	9			
	Sairang	Between Groups	0.025	1	0.025	5	0.055767
		Within Groups	0.04	8	0.005		
		Total	0.065	9			

Table: 17. ANOVA of the effect of year on floral parts of *Erythrina variegata*.

Variables	Years	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*
Length of style	2010	Between Groups	0.016	1	0.016	2.909091	0.126475
		Within Groups	0.044	8	0.0055		
		Total	0.06	9			
	2011	Between Groups	0.064	1	0.064	9.846154	0.01385
		Within Groups	0.052	8	0.0065		
		Total	0.116	9			
Length of filament	2010	Between Groups	0.009	1	0.009	1.384615	0.273139
		Within Groups	0.052	8	0.0065		
		Total	0.061	9			
	2011	Between Groups	0.025	1	0.025	3.333333	0.105322
		Within Groups	0.06	8	0.0075		
		Total	0.085	9			
Length of flower	2010	Between Groups	0.025	1	0.025	5	0.055767
		Within Groups	0.04	8	0.005		
		Total	0.065	9			
	2011	Between Groups	0.289	1	0.289	32.11111	0.000472
		Within Groups	0.072	8	0.009		
		Total	0.361	9			
Width of flower	2010	Between Groups	0.004	1	0.004	1	0.346594
		Within Groups	0.032	8	0.004		
		Total	0.036	9			
	2011	Between Groups	0.004	1	0.004	0.347826	0.571623
		Within Groups	0.092	8	0.0115		
		Total	0.096	9			

Table: 18. ANOVA of the effect of site on floral parts of *Erythrina subumbrans.*

Variables	Sites	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*
Length of style	Neihbawi	Between Groups	0.049	1	0.049	7.538462	0.025229
		Within Groups	0.052	8	0.0065		
		Total	0.101	9			
	Sairang	Between Groups	0.036	1	0.036	10.28571	0.012478
		Within Groups	0.028	8	0.0035		
		Total	0.064	9			
Length of filament	Neihbawi	Between Groups	0.016	1	0.016	1.882353	0.207305
		Within Groups	0.068	8	0.0085		
		Total	0.084	9			
	Sairang	Between Groups	0.009	1	0.009	1.384615	0.273139
		Within Groups	0.052	8	0.0065		
		Total	0.061	9			
Length of flower	Neihbawi	Between Groups	0.4	1	0.4	26.66667	0.000859
		Within Groups	0.12	8	0.015		
		Total	0.52	9			
	Sairang	Between Groups	0.1	1	0.1	13.33333	0.00648
		Within Groups	0.06	8	0.0075		
		Total	0.16	9			
Width of flower	Neihbawi	Between Groups	0.196	1	0.196	17.81818	0.002911
		Within Groups	0.088	8	0.011		
		Total	0.284	9			
	Sairang	Between Groups	0.081	1	0.081	23.14286	0.001337
		Within Groups	0.028	8	0.0035		
		Total	0.109	9			

Table: 19. ANOVA of the effect of year on floral parts of *Erythrina subumbrans*.

Variables	Years	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*
Length of style	2010	Between Groups	0.036	1	0.036	14.4	0.005276
		Within Groups	0.02	8	0.0025		
		Total	0.056	9			
	2011	Between Groups	0.025	1	0.025	3.333333	0.105322
		Within Groups	0.06	8	0.0075		
		Total	0.085	9			
Length of filament	2010	Between Groups	0.036	1	0.036	4.8	0.059838
		Within Groups	0.06	8	0.0075		
		Total	0.096	9			
	2011	Between Groups	0.025	1	0.025	3.333333	0.105322
		Within Groups	0.06	8	0.0075		
		Total	0.085	9			
Length of flower	2010	Between Groups	0.1	1	0.1	20	0.002077
		Within Groups	0.04	8	0.005		
		Total	0.14	9			
	2011	Between Groups	0.4	1	0.4	22.85714	0.001389
		Within Groups	0.14	8	0.0175		
		Total	0.54	9			
Width of flower	2010	Between Groups	0.025	1	0.025	3.571429	0.095452
		Within Groups	0.056	8	0.007		
		Total	0.081	9			
	2011	Between Groups	0	1	0	0	1
		Within Groups	0.06	8	0.0075		
		Total	0.06	9			

4.7 Flower production and Fruit setting

During the two studied years, flower per inflorescence and the mean flower per tree count were more in the lower site. The more flower per inflorescence ultimately leads to production of more flower per tree. There was little fluctuation in the production of flower and fruit set percentage in each location. The lower site has more fruit set percentage than higher site. In *Erythrina variegata*, mean flower per bud (inflorescence) at Sairang ranges between 21.6 and 22.6 whereas the higher site, Neihbawi, it ranges between 19.6 and 20.4. Flower production per tree was highest at Sairang site in 2010 with 496 flowers, whereas lowest was Neihbawi with 410 flowers in 2011. The highest fruit set occurs in 2010 at Sairang site having 27.4 %, whereas lowest occurs in 2011 at Neibawi site with 21.3% [Table 20].

In case of *Erythrina subumbrans*, the mean flower per bud (inflorescense) was also higher at Sairang site; it ranges between 22.2 and 22.8, whereas Neihbawi site ranges between 19.8 and 21.6. Flower production per tree count ranges from 474 to 505 at Sairang whereas Neihbawi varies from 415 to 461 flowers. Fruit set percentage was highest with 30.0 % at Sairang site, whereas Neihbawi site was recorded with 25.4%. Mostly fruit set percentage were lower in Neihbawi site [Table 20]. The percentage of fruit set was high in *Erythrina subumbrans* than *Erythina variegata* in both studied years.

Dieringer (1991) reported that plants that start flowering early tend to produce more flowers and more fruits. For both studied species, large plants make so many more flowers than small plants, which lead to higher flowering amplitude than that of small plant. The largest plants in the population are usually the most fecund. Similar other results were also reported for other species like *Lupines lepidus* and *Ferocactus cylindraceaus* and *F.wislizeni* (Bishop and Schemke, 1998; McIntosh, 2002). Tree height had significant positive relation with the production of flowers and fruits, which has explained the effect of tree size on fecundity. The commonly accepted hypothesis is that synchronous individuals of a mass–flowering species have a reproductive advantage because of the increased number of pollinators and decreased probability of seed and flower predation (Augspurger, 1981, 1983; Bawa, 1983).

Analysis of variation on fruit setting due to site and due to years showed that there was highly significant variation in the years, but in the sites there was no significant variation [Table 21, 22].

Table: 20. Intraspecific and interspecific variation of flower production and fruit set % of *Erythrina variegata* and *Erythrina subumbrans* for both the two sites. Values shown are the mean of all plant values ± standard Error.

Erythrina variegata	2010		2011	
	Neihbawi	Sairang	Neihbawi	Sairang
Flower/inflorescence	20.4 ± 0.6	22.6 ± 0.2	19.6 ± 0.4	21.6 ± 0.5
Inflorescence/tree	21.2 ± 0.2	22 ± 0.3	21 ± 0.3	21.2 ± 0.2
Flower production/tree	431 ± 12	496 ± 5.0	410 ± 14	456 ± 9.0
Fruit/inflorescence	4.8 ± 0.3	6.2 ± 0.3	4.2 ± 0.2	5.4 ± 0.2
Fruit production/tree	101 ± 8.5	135.5 ± 9.3	88 ± 5.4	114 ± 7.2
Fruit set percentage	23.5 ± 1.3	27.4 ± 1.4	21.3 ± 0.6	25.1 ± 1.6
Erythrina subumbrans				
Flower/inflorescence	21.6 ± 0.5	22.8 ± 0.3	19.8 ± 0.5	22.2 ± 0.2
Inflorescence/tree	21.4 ± 0.2	22.2 ± 0.2	21 ± 0.3	21.4 ± 0.2
Flower production/tree	461 ± 13	505 ± 7.2	415 ± 15	474 ± 7.3
Fruit/inflorescence	5.6 ± 0.2	6.8 ± 0.3	4.8 ± 0.2	6.2 ± 0.2
Fruit production/tree	119 ± 5.6	149.5 ± 5.4	100 ± 5.6	132 ± 5.3
Fruit set percentage	25.4 ± 1.1	30.0 ± 1.1	24.2 ± 0.5	28.1 ± 0.7

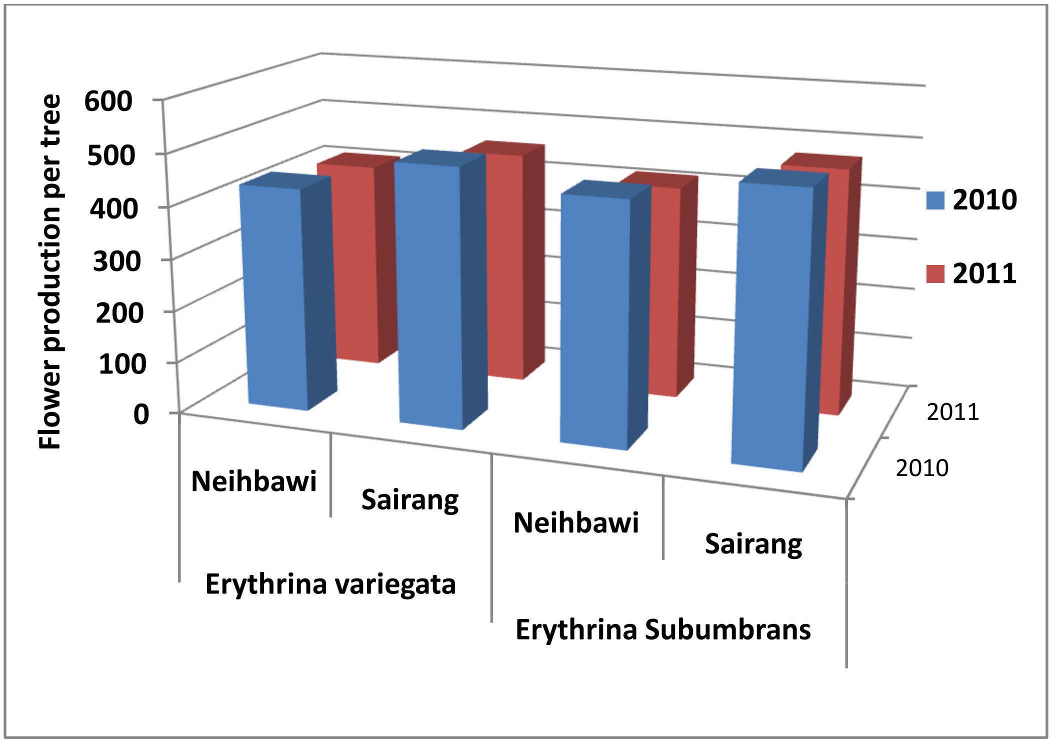

Figure: 9. Intraspecific and interspecific variation of flower production per tree

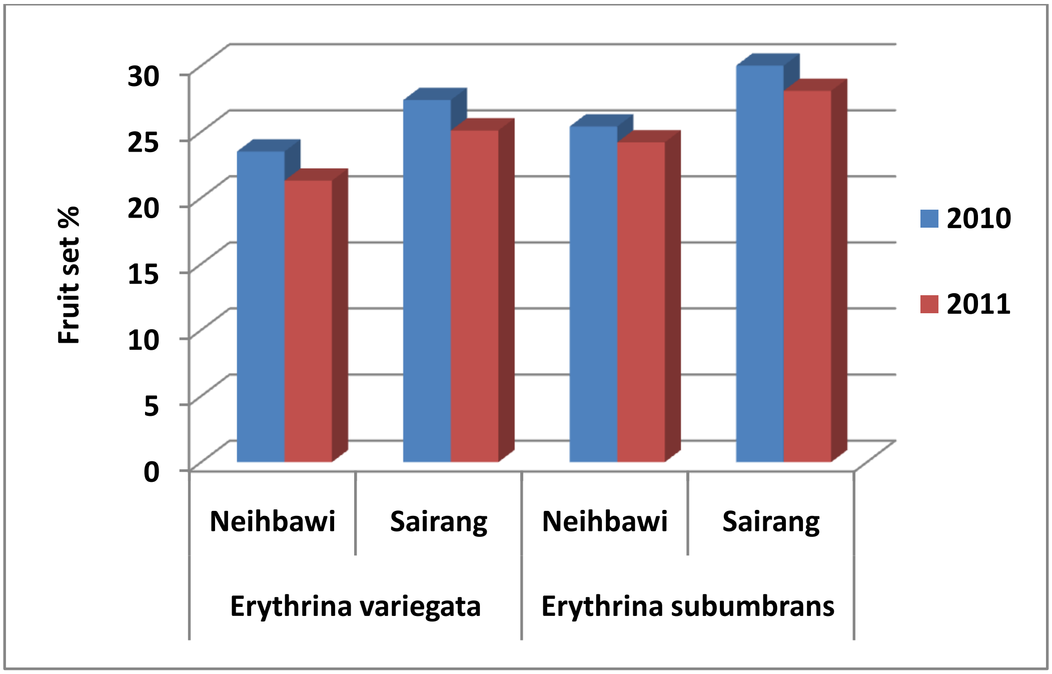

Figure: 10. Intraspecific and interspecific variation of fruit set percentage.

Table: 21. ANOVA of the effect of site on fruit setting.

Sites	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*
Erythrina variegata (Neihbawi)	Between Groups	5.476	1	5.476	0.643635	0.445574
	Within Groups	68.06344	8	8.50793		
	Total	73.53944	9			
Erythrina variegata (Sairang)	Between Groups	3.38724	1	3.38724	0.235832	0.640254
	Within Groups	114.9036	8	14.36295		
	Total	118.2908	9			
Erythrina subumbrans (Neihbawi)	Between Groups	9.90025	1	9.90025	3.239006	0.109599
	Within Groups	24.45256	8	3.05657		
	Total	34.35281	9			
Erythrina subumbrans (Sairang)	Between Groups	0.79524	1	0.79524	0.101442	0.758262
	Within Groups	62.715	8	7.839375		
	Total	63.51024	9			

Table: 22. ANOVA of the effect of year on fruit setting.

Years	*Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*
2010	Between Groups	125.9083	3	41.96944	7.527847	0.002319
	Within Groups	89.2036	16	5.575225		
	Total	215.1119	19			
2011	Between Groups	142.7253	3	47.5751	4.207138	0.022552
	Within Groups	180.931	16	11.30819		
	Total	323.6563	19			

4.8 Pollinator Frequency

Pollinator and their visitation rates were monitored six times a day for each location. The observations were made on ten randomly chosen inflorescences per tree and for each visit the number of visited flowers and interactions with other visitors were recorded. In each population the trees were observed over the course of the whole day length between 0600h and 1800 h in 6 observation blocks, each starting at the 2-hours interval that is, between 0600 to 0800, 0800 to 1000, 1000 to1200 and so forth.

Overall the visitation rates were higher in *Erythrina subumbrans* at the lower site. The visitation rates were highest in the morning between 6:00am to 8:00am while it was lowest in the noon between 10:00am to 2:00pm and again increase rates starts in 4:00pm to 6:00pm. In *Erythrina variegata*, the highest visitation occurs in Red vented bulbul (*Pycnonotus cafer*) at Sairang site (*e.g.* Plate 1), both in the morning between 6am to 8am and late in the evening, 4pm to 6pm. The total number of pollinator visits per day ranges from 11.6 to 37.9 visitors at Neihbawi, whereas at Sairang it ranges from 12.2 to 43.5 visitors [Table 25].

In case of *Erythrina subumbrans,* the overall visitation frequency was higher at Sairang site than Neihbawi site. The total number of visit per day in the first site, Neihbawi ranges from 12.7 to 42.6 visitors whereas the second site, Sairang ranges from 13.8 to 44 visitors [Table 25]. In the early morning between 6:00am to 8:00am pollinator were more and low in noon between 11:00am to 1:00pm, again in the evening visitor were increasing. Overall in the two years (2010 and 2011) of study for both species, the pollinator frequency was higher at Sairang site than Neihbawi site [Table 23, 24]. The pollinators recorded for both the species were common at both studied sites. The recorded pollinators include, *Pycnonotus cafer* (Red vented Bulbul: Plate 1), *Pycnonotus goiavier* (Yellow vented Bulbul: Plate 2), *Turdoides caudata*

(Common Babbler), *Chloropsis aurifrons* (Golden fronted chloropsis: Plate 4), *Zosterops palpebrosus* (Indian White-eye: Plate 5), *Dicrurus macrocercus* (Black Drongo: Plate 6), *Phoebus sennae* (Cloudless Sulphur Butterfly: Plate 7) and *Apis mellifera* (Honey bee: Plate 8)

The frequency of pollinators was assessed in terms of visits/flower/hour. Birds, Honey bees and butterflies were the main pollinators recorded for this species and observations were recorded only on these three types of pollinators. Among the birds *Pycnonocus* sp. was the most effective pollinators for both *Erythrina* species.

The plants with a lower degree of flowering synchrony were visited by a greater number of flower visitors, indicating a constant relationship between pollinator abundance and flowering synchrony. That is, the probability of a plant receiving pollinator visits increases when the total number of plants in flower decreases. This relationship has been observed by other researchers (Zimmerman, 1980; Melampy, 1987; Pettersson, 1991), and may be due to a mechanism of intraspecific competition among plants (Zimmerman, 1980). Pollination of the flowers of individual tree may be influenced by its own pattern of flower production or by its synchronization. The size of the floral display can affect the behavior of pollinators (De Jong and de Bruyn, 1989). This influences not only the quantity of pollinating visits, but also the quality of the pollination service received. The production of many flowers can increase pollinator visitation (Klinkhamer et al., 1989; Stout, 2007; De Jong et al., 1993), which may result in increased reproductive success. In both the species, sites with more flower production had high pollinator visitation. Alternatively, plants with large floral displays may suffer from inbreeding as a result of increased geitonogamy (within plant pollen transfer) (De Jong et al., 1992; Klinkhamer and de Jong, 1993).

Table : 23. Intraspecific variation of the average pollinator frequency in *Erythrina variegata* for the two years 2010 & 2011. Values shown are the mean of all plant values ± standard Error.

Time	6am – 8am		8am – 10am		10am – 12pm		12pm – 2pm		2pm – 4pm		4pm – 6pm	
	Neih bawi	Sai rang	Neih bawi	Sai rang	Neih bawi	Sai rang	Neih bawi	Sai rang	Neih bawi	Sai rang	Neih bawi	Sai rang
Red vented Bulbul	9 ± 0.3	10.2 ± 0.6	8.8 ± 0.5	9.3 ± 0.2	3.9 ± 0.3	4.2 ± 0.5	3.7 ± 0.2	4.5 ± 0.8	5 ± 0.5	7.4 ± 0.8	7.5 ± 0.6	7.6 ± 0.8
Yellow vented Bulbul	8.3 ± 0.5	9.1 ± 0.3	6.7 ± 0.5	8.7 ± 0.4	4.6 ± 0.3	3.7 ± 0.5	2.3 ± 0.3	3.6 ± 0.6	6.5 ± 0.7	7 ± 0.6	6.5 ± 1	7.2 ± 1
Common Babbler	7.8 ± 0.3	9.9 ± 0.4	7.2 ± 0.4	7.7 ± 0.3	3.6 ± 0.4	3.3 ± 0.6	2.8 ± 0.7	2.9 ± 0.5	5.5 ± 0.5	6.5 ± 0.5	5.5 ± 0.6	7.7 ± 0.9
Black Drongo	7.9 ± 0.3	8.5 ± 0.2	7.7 ± 0.6	7.2 ± 0.6	2.2 ± 0.5	2.5 ± 0.5	2.5 ± 0.5	2.6 ± 0.6	3.5 ± 0.8	5.7 ± 0.5	5.3 ± 0.5	6 ± 0.7
Indian white eye	6.7 ± 0.2	8.3 ± 0.3	6.2 ± 0.3	6 ± 0.5	3.8 ± 0.2	3 ± 0.3	2 ± 0.3	2.6 ± 0.6	3.6 ± 0.7	4.9 ± 0.6	5 ± 0.7	5.9 ± 1
Golden fronted chloropsis	5.9 ± 0.3	5.5 ± 0.5	4.9 ± 0.6	5.2 ± 0.7	1.3 ± 0.4	1.5 ± 0.3	1.5 ± 0.4	1.3 ± 0.3	1.9 ± 0.4	3.2 ± 0.4	3.4 ± 0.5	5.1 ± 0.6
Butterfly		1.9 ± 0.3	3.1 ± 0.5	3.7 ± 0.4	4.4 ± 0.4	4.4 ± 0.4	5.2 ± 0.5	5.2 ± 0.5	3.3 ± 0.4	2.6 ± 0.3		
Honey bee			1.7 ± 0.2	2.2 ± 0.2	2.6 ± 0.5	3.9 ± 0.4	4.2 ± 0.5	3.8 ± 0.4	3.1 ± 0.5	2.3 ± 0.5		

Table : 24. Intraspecific variation of the average pollinator frequency in *Erythrina subumbrans* for the two years 2010 & 2011. Values shown are the mean of all plant values ± standard Error.

Time	6am – 8am		8am – 10am		10am – 12pm		12pm – 2pm		2pm – 4pm		4pm – 6pm	
Species	Neih bawi	Sai rang	Neih bawi	Sai rang	Neih bawi	Sai rang	Neih bawi	Sai rang	Neih bawi	Sai rang	Neih bawi	Sai rang
Red vented Bulbul	10.8 ± 0.4	11 ± 0.5	9.7 ± 0.7	9.2 ± 0.4	4.2 ± 0.3	4.5 ± 0.5	4 ± 0.5	4 ± 0.6	6.7 ± 0.7	7.4 ± 0.9	7.2 ± 0.7	7.9 ± 0.6
Yellow vented Bulbul	10.5 ± 0.3	11.4 ± 0.6	8.8 ± 0.6	9.4 ± 0.5	4.9 ± 0.4	4.2 ± 0.6	3.7 ± 0.5	4.5 ± 0.6	6 ± 0.5	6.5 ± 0.5	6.3 ± 0.5	7.4 ± 0.7
Common Babbler	9.6 ± 0.4	10 ± 0.7	7.9 ± 0.4	7.2 ± 0.7	3.4 ± 0.3	3.5 ± 0.5	2.6 ± 0.5	3 ± 0.6	5.7 ± 0.5	6.3 ± 0.5	5.9 ± 0.8	7.5 ± 0.7
Black Drongo	8.5 ± 0.2	10.2 ± 0.4	7.6 ± 0.5	7.7 ± 0.7	2.4 ± 0.5	3.2 ± 0.5	2.9 ± 0.4	2.6 ± 0.5	4.2 ± 0.7	5.5 ± 0.5	5.6 ± 0.3	6.6 ± 0.7
Indian white eye	7.6 ± 0.3	8.8 ± 0.4	6.8 ± 0.6	6.5 ± 0.7	2.2 ± 0.5	2.5 ± 0.2	1.85 ± 0.4	2.2 ± 0.4	3.5 ± 0.6	4.6 ± 0.5	5.1 ± 0.6	5.9 ± 0.9
Golden fronted chloropsis	6.4 ± 0.4	6.5 ± 0.7	4.4 ± 0.7	5.5 ± 0.8	1.4 ± 0.6	1.8 ± 0.5	2.2 ± 0.4	1.7 ± 0.4	2.2 ± 0.6	3.4± 0.4	3.9 ± 0.6	5.3 ± 0.8
Butterfly		2.16 ± 0.3	3 ± 0.4	3.5 ± 0.3	4.5 ± 0.4	5.1 ± 0.6	5.3 ± 0.4	5.6 ± 0.3	3.8 ± 0.2	3.2 ± 0.4		
Honey bee			1.83 ± 0.2	3.1 ± 0.2	3 ± 0.5	4.3 ± 0.4	4.3 ± 0.5	3.9 ± 0.6	3.5 ± 0.4	2.5 ± 0.3		

Table: 25. Intraspecific and interspecific variation of total visited per day in pollinator frequency. Values shown are the mean of all plant values ± standard Error.

	Erythrina variegata		*Erythrina subumbrans*	
Pollinators	Neihbawi	Sairang	Neihbawi	Sairang
Red vented Bulbul (*Pycnonotus cafer*)	37.9 ± 0.4	43.5 ± 0.6	42.6 ± 0.6	44 ± 0.5
Yellow vented Bulbul (*Pycnonotus goiavier*)	34.9 ± 0.5	39.3 ± 1	40.2 ± 0.4	43.4 ± 0.5
Common Babbler (*Turdoides caudata*)	32.4 ± 0.5	38 ± 0.5	35.1 ± 0.4	37.5 ± 0.6
Black Drongo (*Dicrurus macrocercus*)	29.1 ± 0.5	32.5 ± 0.5	31.2 ± 0.4	35.8 ± 0.6
Indian white eye (*Zosterops palpebrosus*)	27.3 ± 0.4	30.7 ± 0.4	26.7 ± 0.5	30.5 ± 0.5
Golden fronted chloropsis (*Chloropsis aurifrons*)	18.9 ± 0.4	21.8 ± 0.5	20.5 ± 0.5	24.2 ± 0.6
Butterfly (*Phoebus sennae*)	16 ± 0.3	18.2 ± 0.3	16.9 ± 0.3	18.9 ± 0.2
Honey bee (*Apis mellifera*)	11.6 ± 0.4	12.2 ± 0.3	12.7 ± 0.3	13.8 ± 0.3

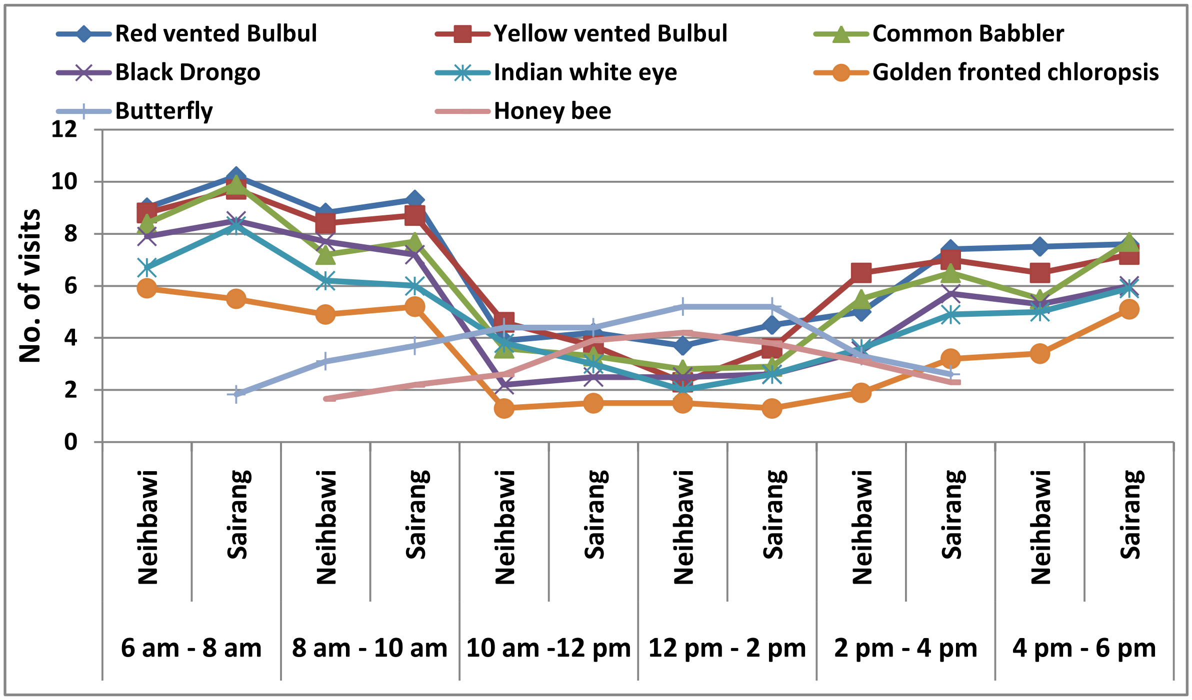

Figure: 11. Intraspecific variation of Pollinator Frequency in *Erythrina variegata*

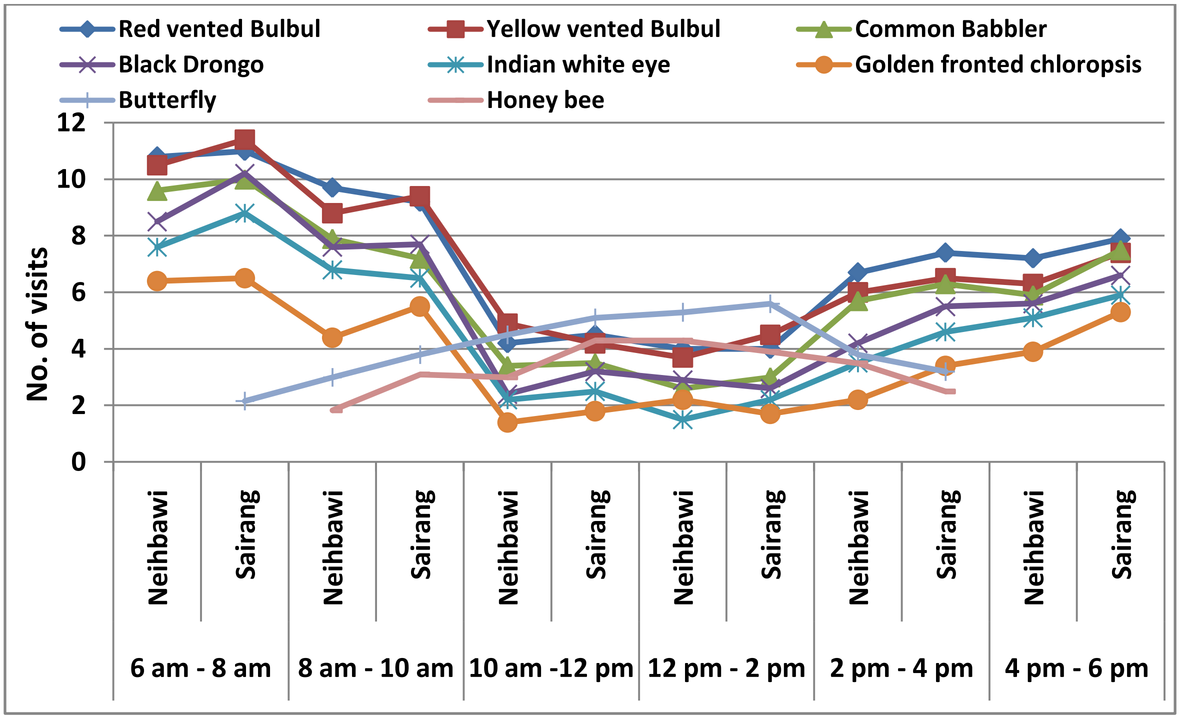

Figure: 12. Intraspecific variation of Pollinator Frequency in *Erythrina subumbrans.*

References:

Arroyo, M. T. K., Armesto, J and Primack, R. (1985). Community studies in the high temperate Andes of Central Chile. II. Effects of temperature on visitation rates and pollination possibilities. *Plant Systemics and Evolution* 149:187–203.

Ausperger, C. K. (1981). Reproductive synchony of a tropical shrub: experimental studies on effects of pollinators and seed predators on *Hybanthus prunifolius* (Violaceae). *Ecology* 62:775-788.

Augspurger, C. K. (1983). Phenology, flowering synchrony, and fruit set of six Neotropical shrubs. *Biotropica* 15:257–267.

Bawa, K. S. (1983). Patterns of flowering in tropical plants. In (Eds.) Jones C. E, Little R. J *Handbook of experimental pollination biology*. Van Nostrand Reinhold, New York. 394–410 pp.

Baker, H. G. (1959). Reproductive methods as factors in speciation in flowering plants. Cold Spr. Harb. Symp. *Quant. Biol*. 24:177-191.

Bertiller, M.B., Irisarri M.P and Ares, J.O. (1990). Phenology of *Festuca pallescens* in relation to topography in North-western Patagonia. *J Veg Sci* 1:579–584.

Bingham, R. A and Orthner, A. R. (1998). Efficient pollination of alpine plants. *Nature* 391:238–239.

Bishop, J. G and Schemske, D.W. (1998). Variation in flowering phenology and its consequences for lupines colonizing Mount St. Helens. *Ecology* 79:534–546.

Blionis, G. J,, Halley J. M and Vokou, D. (2001). Flowering phenology of *Campanula* on Mt Olympos, Greece. *Ecography* 24**:**696–706.

Crimmins, TM., Crimmins, M.A and David Bertelsen, C. (2009). Flowering range changes across an elevation gradient in response to warming summer temperatures. *Glob. Chang. Biol*. 15:1141–1152

De Jong, T.J. and Gerrit-Jan de Bruyn (1989). Plant Size and Pollinator Visitation in Cynoglossum Officinale. *Oikos* 54(2): 201-204.

De Jong, T. J., Klinkhamer, P. G. L and Van Staalduinen, M. J. (1992). The consequences of pollination biology for selection of mass or extended blooming. *Functional Ecology* 6:606-615.

De Jong, T. J., Waser, N.M and Klinkhamer, G.L. (1993). Geitonogamy: The neglected side of selfing. *Trends in Ecology and Evolution* 8:321–325.

Dieringer, G. (1991).Variation in individual flowering time and reproductive success of A galinisst rictifolia(Scrophulariaceae). *American Journal of Botany* 78:497-503.

Fang, J Y and Yoda, K. (1988). Climate and vegetation in China (I) changes in the altitudinal lapse rate of temperature and distribution of sea level temperature. Ecol Res 3:37−51

Fenner, M. (1998). The phenologyo f growtha nd reproduc-tioni n plants. Perspectives in Plant Ecology, *Evolutionan d Systematics* 1:78-91.

Gentry, A. H. (1974). Flowering phenology and diversity in tropical Bignoniaceae. *Biotropica* 6:64–68.

Gimenez-Benavides, L., Escudero, A and Iriondo, J.M. (2007). Reproductive limits of a late-flowering high-mountain Mediterranean plant along an elevational climate gradient. *New Phytol* 173:367–382.

Holttum, R. E. (1953). Evolutionary trends in an equatorial climate. *Soc. exp. Biol. Symp*. 7:159-73.

Inouye, D.W and Wielgolaski, F. E. (2003). High altitude climates. In (Ed.) Schwartz M.D *Phenology: an integrative environmental science*, Kluwer Academic Publishers, Dordrecht, Netherlands. 195-214 pp.

Johnson, S.D. (1993). Climatic and phylogenetic determinants of flowering seasonality in the Cape Flora. *Journal of Ecology* 81:567–572.

Kelly, M.G and Levin, D. A. (2000). Directional selection on initial flowering date in *Phlox drummondii* (Polemoniaceae). *American Journal of Botany* 87:382-391.

McIntosh, M. E. (2001). Plant size, breeding system, and limits to reproductive success in two sister species of *Ferocactus* (Cactaceae). *Plant Ecol.* 162: 273-288

Mcintosh, M. E. (2002). Flowering phenology and reproductive output in two sister species of *Ferocactus* (Cactaceae*). Plant Ecology* 159:1-13.

Klinkhamer, P. G. L., De Jong, T. J and De Bruyn, G.-J (1989). Plant size and pollinator visitation in *Cynoglossum officinale*. *Oikos* 54: 201-204.

Klinkhamer, P.G.L and De Jong, T.J. (1993). Attractiveness to pollinators: a plant's dilemma. *Oikos* 66:180-184.

Korner, C and Basler, D. (2001). Phenology under Global Warming. *Science* 32**7**:1461–1462.

Korner, C. (2003). Alpine plant life: Functional plant ecology of high mountain ecosystems. Germany, Springer, Berlin.

Medan, D and Bartoloni, N. (1998). Fecundity effects of dichogamy in an asynchronically flowering population: a genetic model, *Annals of Botany* 81(3): 373–383.

Melampy, M. N. (1987). Flowering phenology pollen flow and fruit production in the Andean shrub *Befaria resinosa. Oecologia* 73:293-300.

O'Neil, P. (1997). Natural selection on genetically correlated phonological characters in *Lythrum salicaria* L. (Lythraceae). *Evolution* 51:267–274.

Opler, P.A., Frankie, G.W and Baker, H. G. (1976). Rainfall as a factor in the release, timing, and synchronization of anthesis by tropical trees and shrubs. *J Biogeogr* 3:231–236.

Pettersson, M W. (1991). Flower herbivory and seed predation in *Silene vulgaris* (Caryophyllaceae) :Effects of pollination and phenology. *Holarctic Ecology* 14:45–50.

Primack, R.B. (1985). Longevity of individual flowers. *Annual Review of Ecology and Systematics* 16:15–38.

Ranjitkar, S., Luedeling, E., Shrestha, K.K., Guan, K and Xu, J. (2013). Flowering phenology of tree rhododendron along an elevation gradient in two sites in the Eastern Himalayas. *Int. J. Biometeorol.* 57:225–240.

Rathcke, B and Lacey, E.P. (1985). Phenological patterns of terrestrial plants. *Annu Rev Ecol Syst* 16:179–214.

Reeves, P.H and Coupland, G. (2000). Response of plant development to environment: control of flowering by daylength and temperature. *Current Opinions in Plant Biology* 3: 37-42.

Rusch, V.E. (1993). Altitudinal variation in the phenology of Nothopha – guspumilio in Argentina. *Rev Chil Hist Nat* 66:131–141.

Singh, N. (2014). Flowering Phenology Of Tree *Rhododendron Arboreum* *a*long an Elevation gradient In Different Sites Of Kumaun Himalayas. *International Journal of Science and Nature* 5 (3):572-576.

Singh, N., Ram, J., Tewari, A and Yadav, R. P. (2015). Phenological events along the elevation gradient and effect of climate change on *Rhododendron arboreum* Sm. in Kumaun Himalaya. *Current Science,* 108(1):106-110.

Stinson, C. (2004). Natural selection favours rapid reproductive phenology in *Potentilla pulcherrima* (Rosaceae) at opposite ends of a subalpine snowmelt gradient. *American Journal of Botany* 91:531–539.

Stout , J.C. (2007). Reproductive Biology of invasive exotic shrub, *Rhododendron Ponticum* L. (Ericaceae). *Botanical Journal of the Linnean Society*, 155:373- 381.

White, L.M. (1995). Predicting flowering of 130 plants at 8 locations with temperature and daylength. *Journal of Range Management* 48:108-114.

Ziello, C., Estrella, N and Kostova, M. (2009). Influence of altitude on phenology of selected plant species in the alpine region (1971– 2000). *Climate Research* 39:227–234.

Zimmerman, M. (1980). Reproduction in *Polemonium*: pre-dispersal seed predation. *Ecology* 61: 502–506.

Chapter 5

Summary and Conclusion

5.1 Summary

Erythrina reflects importance of rainfall and temperature as a proximate environmental factors regulating leaf phenology. There are studies which reflect that the beginning of winter season initiate leaf fall in the tropics. Major peak of leaf fall is during dry and low temperature in a month December and January for both species. Leaf fall in the tropics may be associated to the onset of cooler environmental periods. In dry deciduous forests flowering and fruiting pattern are mostly influenced by soil moisture and rainfall pattern. During seasonal drought the leafless condition helps in the rehydration of the stem and twigs, pre-requisite for the subsequent flowering or leaf flushing and mechanism of maintaining shoot turgidity.

There was earlier leaf abscission in high altitude site i.e. Neihbawi than low altitude sites this may be due to high sloping topography at Neihbawi that are prone to erosion and draining of soil water due to slope, leading to low soil moisture condition and stress induced by water scarcity which might have an impact on the phenological behavior of tree species. 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.

Study comparing to tropical dry forest sites with different annual rainfall in southern India concluded that phenological patterns depend upon precipitation. Leaf flushing in both species of *Erythrina* is mainly coincided with early rainy season, might be due to pre rain flash and increasing temperature, such a pattern of leaf initiation during dry season before rains has also been reported from other seasonal tropical forests. But a few cases of leaf initiation during wet season have also been observed in some studies. Few species strongly relate with rainfall for their leaf developmental activity.

Water is an essential component for leaf initiation and those species, which can produce new leaves during the dry season, depend on water stored in the tree stem or water remaining in the subsoil. Moreover, deep rooting canopy trees do not experience a water deficit condition during dry season and can continue leaf-flushing activity. Rain induced leafing in a deciduous tree species. The delayed leaf flushing was observed in *Anogeissus pendula*, *Boswellia serrata*, *Bombax cieba*, *Butea monosperma* and *Crataeva nurvala* in response to drought, which confirmed the role of rainfall in their leaf development. The delayed leaf initiation due to drought has also been reported in the woody species of the dry deciduous forests.

Fruiting of *Erythrina variegata* was recorded after completion of flowering phase. Initiation of fruiting mostly depends upon the timing and period of flowering rather than climatic parameters like rainfall and temperature. But fruit ripening and the length of fruiting period are dependent on temperature and photo-period. In dry tropical trees the duration of fruiting phenophase depends at least to some extent on the time of flowering and the leafless period during the annual cycle.

Peak fruiting of *Erythrina variegata* occurred during rainy season, thus it need high moisture level for proper fruit development as compared to that of *Erythrina subumbrans* in which maturation of fruits take place during dry season. This study supports differential flowering and fruiting timing among related genera, which might be important to avoid competition for pollinators and driving factor for high faunal diversity in tropics. Even many of tropical fleshy fruits formed during wet season. This also support differential fruiting in tropics supports high faunal diversity.

Flowering during the dry season reflects the availability of water by different sources, for example, through sporadic winter rains, absorption from soil and water stored in stem. Some other workers also reported peak flowering period before rainy season. It has been shown that the moisture, temperature and photoperiod seem to be responsible for flowering. With rise in elevation, delay in flower onset timing and contraction in flowering duration has been documented as well. Plants belonging to the same population do not always have the same phenological flowering pattern.

Variation among individuals in flowering date determines the degree of flowering synchrony of a plant species, creating a gradient among species with individuals that bloom at the same time (high phenological synchrony) and species with individuals that flower at different times (low phenological synchrony). Intraspecific variation between the individuals located in higher and lower elevation showed that flowering durations, early budding and higher intensity occurred in those growing at lower elevation. It can be suggested that their longer duration of open flower production varies with micro environmental conditions around the individual.

Observation of this study showed that high overlapping in the flower bloom ensures the higher chance of cross-pollination, which is a key to reproductive success in the plants. Tree height had significant positive relation with the production of flowers and fruits, which has decipherd the effect of tree on fecundity. Larger trees produce more fruits and seeds than smaller trees and are at a reproductive advantage in the population. The larger plants in the population are usually the most fecund. The plants that start flowering early tend to produce more flowers and more fruits. The size of the floral display can affect the behavior of pollinators. This influences not only the quantity of pollinating visits, but also the quality of the pollination service received. The production of many flowers can increase pollinator visitation, which may result in increased reproductive success. In both the species of *Erythrina*, the sites which produce more flower also received high pollinator visitation.

Plant size was found to be positively correlated with mean flowering amplitude, thus, for both *Erythrina* species, large plants make so many more flowers than small plants and their mean flowering amplitude is still higher than that of small plant. The rates of visitation to flowers decline with elevation and the probability of a plant receiving pollinator visits increases when the total number of plants in flower decreases. This may be due to a mechanism of intraspecific competition among plants. Both species of *Erythrina* are mainly pollinated by bird of same guilds, henceforth the competition for pollinators might be avoided by the reasons functioning on the time and duration of flowering.

It is very vital to study phenological behaviour of plant species growing in different geographical and climatic conditions to explore ecological and evolutionary adaptation. In global climate regime such study is valuable to know how plant species are going to be affected by climatic changes. A Phenological study records provides important information on how climate change affects ecosystems over time. Phenological observations determines the course of the annual development stages of forest trees and their dependence on local (e.g., meteorological and site) conditions including damaging events, document and explain possible changes in the timing of these stages in relation to environmental factors of natural or anthropogenic origin such as air pollution and climate change.

This study focuses on phenological patterns of two species of *Erythrina* i.e, *Erythrina variegata* and *Erythrina subumbrans* growing at two distinct locations that vary in different climatic conditions ie, rainfall, temperature and altitude. The major findings of this study were as follows:

1. Leaf fall in both the species of *Erythrina* is mainly coincided with dry season while leaf flush is coincided with early rainy season.
2. Both studied tree species of *Erythrina variegata* and *Erythrina subumbrans* observed to have their peak leaf abscission during early dry season (December-January; 2010-2011) in both studied sites. There was earlier leaf fall in both the studied species at high altitude cooler and heavy rainfall site i.e. Neihbawi as compared to low altitude, warmer and less rainfall site i.e. Sairang.
3. Leaf production/flush in both studied species is coincided with early rainy season (April-May; 2010-2011). Both studied species had earlier leaf flush of an average 7-8 days in *Erythrina variegata* and 10 days in *Erythrina subumbrans* in Sairang site as compared to Neihbawi.
4. *Erythrina variegata* exhibited peak flowering during very early rainy season (i.e. mid week February to midweek of March; 2010-2011), while *Erythrina subumbrans* flowered during late rainy season (i.e. mid week August to midweek of September; 2010-2011).
5. Both studied species produced young flower (onset) earlier in warmer and less rainfall i.e. Sairang site than cooler and heavy rainfall site i.e. Neihbawi, during studied period (2010 and 2011)

6. Fruiting pattern of both studied species varied significantly with season and time. Fruiting phase in *Erythrina variegata* was coincided with early to peak rainy season (April-June; 2010-2011). Fruiting phase in *Erythrina subumbrans* was overlapped with dry season with no rainfall and low temperature (December-February; 2010-2011). Time required for maturation of fruits in *Erythrina variegata* and *Erythrina subumbrans* varied from average 45-51 during study period with little interannual variability.
7. The two years field observation on initiation of flower in both Erythrina species *(Erythrina variegata* and *Erythrina subumbrans*) revealed that there were small fluctuations in commencement of flowering between two distinct studied sites. This is true in both the species.
8. Peak flowering of *Erythrina variegata* and *Erythrina subumbrans* was observed earlier by 6 days to 9 days and 13 to 15 days, respectively in lower site than higher site for both plant and population.
9. End of flowering was observed earlier by 7 to 10 days in *Erythrina variegata* in lower site than higher site. However in *Erythrina subumbrans,* 16 to 18 days for both the plant and population.
10. Flowering duration for *Erythrina variegata* varied from 13 to 18 days at the plant level and 27 to 29 days at population level for both studied sites and there was no significant variation between the sites.
11. In *Erythrina subumbrans* flowering duration varied from 16 to 22 days at individual level and 32 to 36 days at population level at both studied sites. There was no

significant variation among the site for the plant. For the whole population it was ranged between 25days to 41days.

12. The analysis of variance (ANOVA) showed that there was highly significant variation in the duration of flowering due to years but not with the sites.
13. Flowering amplitude observation showed that higher the number of flower production higher the flowering amplitude.
14. Flower production per tree was highest in 2010 at the lower site and this site also has highest flowering amplitudes.
15. There was intraspecific and interspecific conspicuous variation of flowering amplitude between site and species.
16. Large individual in the population make more flowers than small individuals, their mean flowering amplitude was higher than that of small individuals. In *Erythrina variegata* and *Erythrina subumbrans,* lower site has higher amplitude than higher site as lower site has larger plant.
17. Intraspecific and interspecific variation in synchrony was very low. High synchrony occurred in the site where flowering amplitude was high.
18. The analysis of variance shows that there was significant variation between floral parts due to sites and due to years. This study showed that the sizes of floral parts measured were varied from site to site and year to year in both the species.
19. *Erythrina subumbrans* has higher significant variation of floral parts due to sites and years than *Erythrina variegata* .
20. There was minimal significant variation between floral parts due to sites for both the species; overall the lower site for both species has longer sizes than higher site.

21. In the two years of study, there was conspicuous variation of flower productions between sites and species. However the conspicuous variation is based on the size of a tree. Larger the tree more production of flower. That leads to production of higher fruit set percentage.
22. In *Erythrina variegata,* lower site has more flower production per tree i. e. 456 to 496 flowers than higher site, 410 to 431 flowers. In *Erythrina subumbrans,* more flower production of 474 to 505 per tree in lower site than higher site 415 to 461.
23. Fruit set percentage was higher in lower site than higher site for both species. As the individuals that start flowering early tend to produce more flowers and more fruits.
24. Overall fruit set percentage in *Erythrina subumbrans* was more than *Erythrina variegata*. Synchronous individuals of a mass-flowering species have a reproductive advantage because of the increased number of pollinators and decreased probability of seed and flower predation.
25. The analysis of variance (ANOVA) showed that there was highly significant variation on fruit setting due to years but not with the sites.
26. Pollinator frequency was highest in the morning between 6am to 8am for both the sites and all the study years for *Erythrina variegata* and *Erythrina subumbrans*.
27. Pollinator visitation was more in lower site at Sairang for both the species of *Erythrina variegata* and *Erythrina subumbrans* than higher sites at Neihbawi.
28. Pollinator frequency was higher in *Erythrina subumbrans* than *Erythrina variegata.* This may attribute to the longer the floral size in *Erythrina subumbrans*. The size of the floral display can affect the behavior of pollinators. This influences not only the quantity of pollinating visits, but also the quality of the pollination service received.

29. The pollinators recorded for both the species were common at both studied sites. The recorded pollinators include, *Pycnonotus cafer* (Red vented Bulbul), *Pycnonotus goiavier* (Yellow vented Bulbul), *Turdoides caudata* (Common Babbler), *Dicrurus macrocercus* (Black Drongo), *Zosterops palpebrosus* (Indian White-eye), *Chloropsis aurifrons* (Golden fronted chloropsis). *Apis mellifera* (Honey bee) and *Phoebus sennae* (Butterfly).
30. Flowering in *Erythrina variegata* is occurred during end of dry season while in *Erythrina subumbrans* in exhibited during peak rainy season. Fruiting in *Erythrina variegata* is coincided with early to peak rainy season while fruiting in *Erythrina subumbrans* is occurred in dry season and cool climatic condition. This study supports differential flowering and fruiting timing among related genera which might be important to avoid competition for pollinators and driving factor for high faunal diversity in tropics.

5.2 Conclusion

Plant phenology has been proposed as an indicator of climatic difference and global change. The phenological studies are important from the point of view of the conservation of genetic resources and forestry management as well as for a better understanding of the ecological adaptations of plant/animal species and their community level interactions.

Seasonal duration of leafing, flowering and fruiting mainly determines the phenological behaviour of tropical trees, and directly or indirectly their population dynamics. Population structure of a species is characterized by the proportion of seedlings, saplings and young trees. Knowledge of population structure and regeneration status of forest communities is important for formulating strategy for the maintenance of forests. Phenology and climate relationship can also reveal the potential impacts of future climate changes. The initiation of growth in plants and changes in phenology are governed by various environmental factors and the influence of temperature and moisture has been studied by several workers. Climatic factors are not directly responsible for triggering and synchronization of phenological events.

Two different species of *Erythrina* distinctly varied in the flowering and fruiting phenological clock reflects that the phylogenetic constraints acting as an ultimate cause of phenological behaviour. Individuals of *Erythrina variegata* and *Erythrina subumbrans* flowered during mostly same period of time in each calendar year with very high interspecies variation and little inter annual variability despite growing in distinct geographical and precipitation regime (i.e. Neihbawi and Sairang), seem to conclude that the phylogenetic constraints are stronger influencing forces than the local selective pressure. This study supports differential flowering and fruiting timing among related genera, which might be important to avoid competition for pollinators and driving factor for high faunal diversity in tropics. Thus, this study is rigging the hypothesis that the evolutionary limitations are more reliant than the local environment and biotic conditions. Thus, the results of the study sustains hypothesis of evolutionary limitations which are highly contingent than the biotic and abiotic factors of locality, and therefore imply that the same species growing at distinct geographical location have comparable patterns of phenology.

Photo plate 1: *Pycnonotus cafer* (Red vented Bulbul) visiting *Erythrina* flower.

Photo plate 2: *Pycnonotus goiavier* (Yellow vented Bulbul) visiting *Erythrina* flower.

Photo plate 3: A flock of *Pycnonotus cafer* (Red vented Bulbul) probing the nectar, showing high frequency of this pollinator.

Photo plate 4: *Chloropsis aurifrons* (Golden-fronted Leafbird) visiting *Erythrina* flower.

Photo plate 5: *Zosterops palpebrosa* (Indian white-eye) ready to probe the flowers.

Photo plate 6: *Dicrurus macrocercus* (Black Drongo) taking rest after probing the nectar.

Photo plate 7. *Phoebus sennae* (Cloudless Sulphur butterfly) feeding on *Erythrina* flower.

Photo plate 8. *Apis mellifera* (Honey bee) visiting *Erythrina* flower.

Photo plate 9: *Erythrina variegata* flower.

Photo plate 10: *Erythrina subumbrans* flower – Few leaves remain during flowering period.

Photo plate 11: *Erythrina variegata* fruits.

Photo plate 12: *Erythrina subumbrans* fruits – Fruits are flat and splitting into two sections.