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Climate-Driven Phenological Changes in Butea monosperma: Implications for Conservation and Management from Bhadra Tiger Reserve

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Abstract

Climate change significantly impacts plant phenology, altering key life cycle stages like flowering and fruiting. This study synthesizes research to examine how rising temperatures and changing rainfall patterns affect Butea monosperma in Bhadra Tiger Reserve, Chikmagalur. Observational data collected over several years reveal that warmer spring temperatures have advanced flowering times, aligning with findings from Hu et al. (2005) and Menzel et al. (2006). These changes hold implications for both agriculture and natural ecosystems. However, the study also highlights the complex interplay between climate factors and plant physiology, as evidenced by the variable phenological responses (Meier et al., 2021; Kanwar & Sharma, 2023). By identifying natural adaptation strategies, this research provides valuable insights for ecological restoration and conservation under changing climatic conditions. While the study demonstrates a clear link between rainfall, temperature, and Butea monosperma flowering in 2021, this relationship weakens in subsequent years. To better predict and mitigate climate change impacts on vegetation and ecosystems, the authors emphasize the need for long-term monitoring.

Keywords: Climate change, phenology, flowering time, *Butea monosperma*, ecological adaptation

1. Introduction

Phenology, the study of recurring biological events in plants and animals, acts as nature's internal calendar. From the blossoming of flowers to the migration of birds, these timed events are intricately linked to environmental cues, particularly temperature and rainfall. Climate change, however, is disrupting this delicate balance.

Rising global temperatures are causing a shift in flowering times, with some plants in temperate as well as equatorial regions blooming earlier. This can lead to mismatches in plant growth and development, as crucial events like pollinator availability might not coincide with peak flowering. The situation is particularly concerning in the tropics, where ecosystems are less accustomed to dramatic seasonal changes. Even slight variations in temperature and CO_2 levels can significantly impact flowering time and disrupt the synchronized dance of plant growth and development in these regions. A disrupted growing period due to climate change can have cascading effects on entire ecosystems, potentially leading to habitat loss and food shortages.

Climate change is disrupting flowering times in most plant species, according to Craufurd and Wheeler (2009). This disruption has a cascading effect:
Reduced Crop Yields and Seed Quality: Earlier or later flowering, depending on the species, can lead to decreased yields and compromised seed quality in some crops.
Pollinator Mismatches: Altered flowering times throw off the delicate timing of plant-pollinator interactions. Plants may flower before their pollinators emerge, or vice versa, reducing the chances of successful reproduction (Kudo et al., 2004).

Changes in Floral Traits: Climate change can also influence the development of flowers themselves, altering their fragrance, color, and the structure of floral organs. This can further disrupt the attraction of pollinators (Kehrberger& Holzschuh, 2019).A study by Kehrberger and Holzschuh (2019) found a positive correlation between increased bee visitation and seed set in *Phaseolus vulgaris* (common bean). This highlights the importance of synchronized flowering times for successful plant reproduction.The case of *Corydalis ambigua* (a bumblebee-pollinated species) and *Gagea lutea* (a bee-pollinated species) exemplifies the negative consequences of phenological mismatch. A study by Kudo et al. (2004) found that earlier flowering due to a warm spring (by 7-17 days) resulted in reduced seed set in both species, likely due to a mismatch with pollinator activityUnderstanding these phenological shifts is vital for predicting the future of our planet's flora and fauna. By studying the intricate relationship between phenology and climate change, we can develop strategies to mitigate its impact and ensure the continued sustainable health of our natural world.

Seasonal variations in rainfall trigger phenological changes in tropical dry forests (Daubenmire 1972; Borchert 1994a; Bullock and Solis-Magallanes 1990; Eamus and Prior 2001). Stem water status, influenced by soil water availability, also plays a role in the phenological events (Borchert 1994b, 1998). Endogenous factors like leaf age and area, root size and distribution, and stem wood density all contribute for the timely occurring of various phenological events (Borchert 1994b, 1998). Photoperiod (Bullock and Solis-Magallanes 1990; Borchert et al. 2004; Rivera et al. 2002; Elliot et al. 2006), temperature changes (Ashton et al. 1988; Williams-Linera 1997), and irradiance (Wright and van Schaik 1994) are additional environmental factors influencing phenology.

In contrast to these environmental factors, competition for pollinators or their attraction (Robertson 1895; Janzen 1967; Gentry 1974; Stiles 1975; Augspurger 1981; Appanah 1985; Murray et al. 1987; Sakai et al. 1999), competition for seed dispersers (Snow 1965), and avoidance of herbivory (Marquis 1988; Aide 1993; van Schaik et al. 1993; Coley and Barone 1996) are considered the ultimate causes shaping phenological patterns in tropical species.Spatial and temporal variations in leaf phenology significantly affect the growth and reproduction of plant species (Suresh and Sukumar 2011). Studies quantifying phenology and elucidating the degree of asynchrony among individuals and between species are crucial for understanding the impact of climate change on tropical trees and the potential consequences for the entire ecological community (Singh and Kushwaha 2005).The seasonality of tropical tree phenology is primarily determined by the duration and intensity of seasonal droughts (Mooney et al. 1995) which is again influenced by the climate change. Even trees of the same species can experience varying degrees of drought stress (Singh and Kushwaha 2005), affecting resource availability for consumer animals (Morellato et al. 2000).While few reports exist on seasonality studies in India (Singh and Singh 1992; Murali and Sukumar 1993, 1994; Bhat 1992; Prasad and Hegde 1986), with the exception of dry forests, studies have focused on montane forests in the Nilgiris (Suresh and Sukumar 2011).

This paper analyses phenological patterns in relation to rainfall, temperature, and circular statistics using various phenophases and observation dates to address four main questions: a) Phenology and Climate change in Tropics b) Effect of Elevated CO_2 on Plant Growth and Development c) Climate change and its impact on flower growth and development d) Seasonality of various phenophases. Predicting the Future Shifts in Phenology at Bhadra Tiger Reserve.

2. History of Phenology

Phenology, the science of cyclical biological phenomena, boasts a rich history dating back centuries.
1736: Swedish naturalist Carl Linnaeus lays the foundation for phenology by establishing a network of observers to document plant flowering times across Europe. This marked the beginning of systematic phenological observations.

18th Century: Phenology gains momentum in Europe and North America as scientists recognize its value in agriculture and forestry. Farmers started using phenological observations to predict crop yields and manage planting schedules.

Late 19th Century: The science of phenology matured with the development of standardized recording methods and the establishment of phenological societies.

19th &Early 20th Century: Phenological networks expanded globally, encompassing observations in Asia and other regions.

Mid-20th Century: The study of phenology experiences a decline due to the rise of instrumental climate monitoring techniques. However, concerns about climate change rekindled interest in phenology in the latter half of the 20th century.

Late 20th & Early 21st Century: Phenology underwent resurgence with the development of remote sensing technologies like satellite imagery. These advancements allowed for large-scale monitoring of vegetation phenology.
Present Day: Phenology is a vital tool in climate change research, helping scientists understand the impacts of rising temperatures on plant life cycles, species distribution, and ecosystem health. Citizen science programs actively engage the public in phenological observations, contributing valuable data to long-term monitoring efforts.Phenology continues to evolve, embracing new technologies and citizen science initiatives to monitor the ever-changing dance between nature and climate.

3. History of Phenology in Indian Context:

Ancient India: Agricultural practices in ancient India relied heavily on observing natural signs for planting, harvesting, and predicting weather patterns. Festivals and rituals often coincided with specific phenophases (stages) of plant growth and animal behavior. For example, the flowering of specific trees might signal the start of the monsoon season.

Mughal Era: The Mughal emperors, known for their love of gardens, documented detailed observations on plant phenology. These records included information on flowering times, fruit production, and bird migration patterns.

Colonial Period: During British rule, the colonial government established formal phenological networks to monitor crop health and predict famines. These networks collected data on plant development stages, insect outbreaks, and weather conditions.

Post-Independence India: Following independence, India continued to utilize phenological observations for agricultural planning. Research institutions like the Indian Institute of Tropical Meteorology (IITM) have played a key role in integrating traditional knowledge with modern scientific methods.

Modern Phenology: Today, India actively participates in global phenological research initiatives. Remote sensing technologies and citizen science programs are being employed to monitor large-scale changes in vegetation phenology across the diverse Indian landscape.

4. Importance of Phenology and Climate Change Studies:

Shifts in Species Composition and Population Density: Climate change disrupts established ecological relationships. Phenology helps us track changes in species composition and population density as some plants and animals struggle to adapt to altered conditions.

Range Shifts Towards Polar Regions and Higher Altitudes: Rising temperatures force species to adjust their geographical distribution. Phenological observations reveal these range shifts, with plants and animals migrating towards cooler regions or higher elevations.

Earlier Blooming, Breeding, and Egg-laying: A hallmark consequence of climate change is the advancement of phenophases. Plants flower earlier, animals breed sooner, and birds lay eggs at an earlier time in response to warmer temperatures.
Extended Growing Seasons: Warmer temperatures can lead to longer growing seasons for some plants. Phenology allows us to monitor these changes and understand their implications for ecosystem productivity.

Temporal Disruptions in Phenophases: Climate change throws off the delicate timing of biological events. Phenological studies reveal these disruptions, highlighting potential mismatches between plant growth and pollinator availability or disruptions in predator-prey interactions.

Phenology's strength lies in its simplicity and affordability. By observing the timing of natural events, scientists can gain valuable insights into the ecological consequences of climate change. This information is crucial for developing strategies to mitigate climate change impacts, conserve biodiversity, and ensure the health and resilience of our ecosystems

Variations in Flowering due to Phenological Events

The timing of reproduction, or phenology, plays a critical role in an organism's fitness and continuity of its spices. Altered timing of reproduction, either before or after the ideal season, can lead to a cascade of problems. Organisms may struggle to find mates, fail to food for their offspring during crucial food shortages, or experience mismatches with pollinators – flowers blooming before pollinators emerge or vice versa.Given these potentially devastating consequences, it's no surprise that many species have evolved to rely on dependable environmental cues for their reproductive timing. However, climate change presents a significant ecological and evolutionary challenge. Can organisms adapt their reproductive behavior to keep pace with ongoing environmental changes? Can they adjust their reliance on previously reliable cues to ensure successful reproduction?Answering these questions requires long-term observations and experiments to understand how species are responding to a rapidly changing climate.

Phenology and Climate change in Tropics:

Temperature may not be as influential on tropical plant phenology as seasonal or inter-annual variations in precipitation (Corlett & Lafrankie, Jr., 1998). Unlike temperate regions, the factors driving plant phenology in the tropics remain poorly understood, making it even harder to predict how climate change will impact it (Richardson et al., 2013).

Variability is the name of the game: Responses to seasonal abiotic factors are highly diverse across the tropics, with no clear trends in phenological responses to temperature and precipitation variations (Corlett & Lafrankie, Jr., 1998).

Landscape-level changes: A 14-year study in Ethiopia using remote sensing data observed a similar trend to temperate regions – a longer overall growing season with an earlier start (Workie & Debella, 2018). Interestingly, this change was linked to increasing variability in the high-rainfall season's onset, and unlike temperate regions, greening vegetation showed an inverse correlation with rising temperatures across the country.

Regional variations: A study in Xishuangbanna, China, examined 21 species over 27 years. It found delays in budburst for 7 species, extended growing seasons for 4 species, and shortened flowering periods for 5 species (Zhao et al., 2013). Here, vegetative phenology trends correlated with increasing temperatures, while changes in flowering phenology aligned with decreased sunshine duration during the rainy season.

El Niño Southern Oscillation (ENSO) plays a role: This global weather phenomenon, characterized by warming eastern Pacific Ocean sea surfaces, impacts tropical climates. Plant phenology responds to ENSO-driven weather events. For example, a Ugandan study found a positive correlation between fruit production and prior ENSO events (Chapman et al., 2018). In Panama, ENSO shifted seed-fall phenology to coincide with peak water deficit, suggesting an adaptation to high light and low water availability (Detto et al., 2018).

Extreme ENSO events and their consequences: These events can trigger extreme local weather patterns like floods and droughts. Plants respond accordingly. An ENSO-driven drought in Costa Rica led to irregular phenology, with water-stressed trees retaining leaves and deciduous trees flushing leaves during the dry season (Borchert et al., 2002).

ENSO and ecosystem impacts: Changes in plant growth phenology due to ENSO can affect ecosystem properties like net primary productivity. Studies in areas impacted by ENSO, like Taiwan, have shown a negative correlation between growing season length and seasonal droughts (Chang et al., 2013). More frequent or intense ENSO-driven droughts could lead to shorter growing seasons and reduced ecosystem productivity.

The challenge of untangling cause and effect: Researchers are working to distinguish natural variability in ENSO events from those potentially driven by climate change. Given the unpredictable nature of future ENSO patterns, the consequences for tropical plant phenology remain uncertain (Collins et al., 2010; Chen et al., 2017).

Effect of Elevated CO_2 on Plant Growth and Development:

The concentration of atmospheric CO_2 has risen dramatically since the pre-industrial era, and this trend is expected to continue. This increase is a key driver of global warming, but it also has a significant impact on plants. Let's delve into the complex ways that rising CO_2 affects plant life.

Boosting Photosynthesis and Growth: For many C3 plants, elevated CO_2 acts like a fertilizer. It directly enhances photosynthesis by increasing the availability of CO_2 at the site of RuBisCO, an enzyme crucial for carbon fixation. Studies on crops like tomatoes and beans have shown that this translates to increased photosynthesis rates, biomass production, and yields (Kaiser et al., 2017; Bajwa et al., 2019). This CO_2 fertilization effect can also lead to more vigorous growth in some C4 plants, like sugarcane (Misra et al., 2019) and foxtail millet (Li et al., 2019a). Researchers have even identified genes activated by elevated CO_2 that contribute to these growth benefits (Li et al., 2019a).

Improved Water Use Efficiency: Elevated CO_2 can also improve water use efficiency in plants. Some studies have shown that plants grown under higher CO_2 levels require less water to maintain the same level of photosynthesis (Pan et al., 2020). This can be a significant advantage in drought-prone areas if harnessed properly.

Enhanced Nutritional Value (for some): Contrary to some concerns, recent research suggests that elevated CO_2 may not universally diminish the nutritional value of C3 plants like beans and wheat (Andrews et al., 2020).

The Dark Side of CO_2 **Enrichment:** While the benefits of CO_2 fertilization are undeniable, there's a flip side to the story. Prolonged exposure to very high CO_2 concentrations can have negative consequences:

a) **Reduced Photosynthesis in the Long Run:** Plants can acclimatise to elevated CO_2 levels by down regulating some photosynthetic processes. This can lead to a decrease in overall photosynthetic activity in the long term (Gamage et al., 2018).
b) **Nutritional Deficiencies:** Elevated CO_2 can dilute the concentration of essential minerals like nitrogen in plants, leading to reduced protein content and potentially impacting nutritional quality (Rosa et al., 2019; Giri et al., 2016). Studies on vegetables like lettuce and spinach have shown decreases in key nutrients like potassium and phosphorus under high CO2 (Giri et al., 2016). The exact mechanisms behind this dilution effect are still being explored.
c) **Stunted Root Growth:** While elevated CO_2 may enhance shoot growth, some studies suggest it can hamper root development in herbaceous plants (Cohen et al., 2018). This could disrupt nutrient uptake and overall plant health.
d) **Altered Plant Defences**: Increased CO_2 may also lead to abrupt changes in the production of secondary metabolites like phenolics, which play a role in plant defense against herbivores. Studies on maize have shown an increase in total phenolics under elevated CO_2 (Miliauskienė et al., 2016). The full implications of these changes for plant-insect interactions are still being investigated.
e) **Impact on Flowering Time:** Rising CO_2 levels can influence flowering time in plants. Some studies suggest that high CO_2 concentrations may delay flowering, possibly due to altered sugar signaling within the plant (Jagadish et al., 2016; Sreeharsha et al., 2015). This could disrupt plant reproductive cycles and interactions with pollinators.

Thus, The impact of rising CO_2 on plants is multifaceted. While it can boost photosynthesis, growth, and water use efficiency in some cases for shorter duration there are also potential downsides like reduced nutrient content, stunted root growth, and altered flowering times. The long-term consequences of chronically elevated CO_2 for plant communities and agricultural systems remain an active area of research.

Effect of Elevated Temperature on Plant Growth and Development:

Temperature is a key player in plant growth and development. Each plant species thrives within a specific optimal temperature range, typically around 25-30°C for maximum growth (Hatfield and Prueger, 2015). However, the predicted rise in global mean temperature by 1.2-3.7°C in the next 30-50 years (IPCC, 2014) paints a concerning picture for plant life. Climate change is expected to increase the frequency, duration, and intensity of both extreme low and high temperatures (Yamori et al., 2014).When temperatures climb above the optimal range, plants suffer from heat injury. The summer season's temperature fluctuations can disrupt the delicate intermolecular interactions crucial for normal plant growth, impacting fruit set and development (Bita and Gerats, 2013). Plants grapple with a complex interplay of intensity, duration, and rate of elevated temperatures. Prolonged exposure to high temperatures can severely alter metabolic activities and cause cellular disorganization, ultimately leading to stunted growth and development (Rai et al., 2018).

Germination, the very first stage of plant growth, is particularly susceptible to heat stress. Elevated temperatures decrease germination percentage, viability, plumule, and radicle growth (Rodríguez et al., 2005). This decline can be attributed to cellular water loss, leading to reduced cell size and hampered growth. Dürr et al. (2018) demonstrated a similar effect in wheat (*Triticum aestivum*) and peas (*Pisum sativum*). Exposure to high temperatures decreased germination rates, seed dry weight, and even altered the crops' nutritional value. Laghmouchi et al. (2017) studied the effect of temperature on germination in *Origanum compactum* seeds. They found that germination rates dropped to zero at a high temperature of 25°C.

The link between reduced seed germination and high temperatures is tied to their direct impact on plant metabolism. Specific enzymes function optimally within a certain temperature range. Belmehdi et al. (2018) point out that exceeding this range disrupts metabolism in plants. Srivastava et al. (2012) observed a decrease in sugarcane's relative growth rate under heat stress. This decline was attributed to a reduced net assimilation rate (NAR). In another study, Chalanika De Silva and Asaeda (2017) investigated the effect of heat stress on *the growth of three submerged macrophytes: Elodea nuttallii, Potamogeton crispus, and Vallisneria asiatica*. They found that high temperature decreased the relative growth rate in all three species. This reduction is linked to the accumulation of reactive oxygen species (ROS) under elevated temperature conditions.

Heat stress doesn't just affect plant physiology and metabolism in isolation. Its impact intensifies when combined with other abiotic stresses like drought or salt stress. According to Zinn et al. (2010), high temperatures have a more significant effect on the reproductive stage of crop species compared to the vegetative stage. This results in a sudden yield decline due to pollen infertility. However, the extent of heat stress impact varies across species, affecting both vegetative and reproductive stages (Bita and Gerats, 2013).

Heat stress disrupts cellular structures, destabilizes proteins, disintegrates membranes, and throws plant metabolism into disarray. This leads to excessive ROS production and oxidative stress (Bita and Gerats, 2013; He et al., 2017). Plants have cellular machinery to sense high temperatures and activate specific responses. These responses include stimulation of the lipid signaling pathway, calcium ion influx through calcium-mediated membrane channels, and reorganization of cytoskeletal elements (Carmody et al., 2016). This might be linked to the heat stress-mediated inhibition of RuBisCO and RuBisCOactivase enzymes, further damaging the Calvin-Benson cycle (C3 cycle) responsible for carbon fixation in plants. The decline in carbon fixation generates excessive ROS in the photosystems and hinders repair processes (Apel and Hirt, 2004).

Heat stress significantly disrupts the photosynthetic machinery of plants. Studies have shown a reduction in the level of photosynthetic pigments and activity of antioxidant enzymes (Jajoo and Allakhverdiev, 2017). Chalanika De Silva and Asaeda (2017) observed a decrease in chlorophyll a and b content in *P. crispus* and *V. asiatica* under moderate and high temperature conditions. This reduction is attributed to ROS production causing oxidative stress in plants. Ahammed et al. (2018) investigated the role of the COMT1 gene in tomato (*Solanum lycopersicum*) photosynthesis under heat stress. They found that silencing COMT1 worsened the heat stress-induced reduction in photosynthesis by decreasing photosynthesis.

Influence of Climate Change on Flowering Time:

Winter temperatures play a crucial role in the physiological processes leading to flowering (Blázquez et al. 2003; Capovilla et al. 2014). Extended exposure to low temperatures, a process called vernalization (Chouard 1960), accelerates flowering initiation in many plant species, including winter wheat (Evans et al. 1975), barley (Fettell et al. 2010), and tulips (Rietveld et al. 2000). The optimal temperature and duration of vernalization vary among plant species (Wiebe 1990; Philips et al. 2020).

Warm Temperatures During the Growing Season:

Rising temperatures over the past century have shifted the flowering times of many plant species (Hu et al., 2005; Menzel et al., 2006). Spring-flowering plants, for instance, have begun blooming earlier (Fitter and Fitter, 2002). In the US, the heading date of winter wheat has been advancing by 0.8-1.8 days per decade, primarily due to warmer spring minimum temperatures (Hu et al., 2005)

An analysis of several hundred wild plant species in the southwestern US (at an elevation of 945-1079 meters) revealed an advancement in flowering dates by 2.5 days per year between 1984 and 2014 (Rafferty et al., 2020). This advancement became less significant at higher elevations. At elevations of 1671-1939 meters, flowering dates advanced by 0.36 days per year during the same period, and no significant change was observed at the highest locations (above 1939 meters). Similarly, between 1975 and 2011, the flowering time of *Boechera stricta* in the Rocky Mountains of Colorado (around 2900 meters) advanced by 0.2-0.5 days per generation (Anderson et al., 2012).

An analysis of 21 short grass species from 1995 to 2014 showed that the first flowering date advanced by 7.5 days for every 1 °C increase (Moore and Lauenroth, 2017; Fox and Jönsson, 2019).
In many plant species, earlier flowering is strongly correlated with spring temperatures (Bustamante and Burquez, 2008). For example, warmer spring temperatures have led to earlier flowering in lilac, hawthorn, elder, and blackthorn (Siegmund et al., 2016). However, the influence of temperatures extends beyond spring. An increase in winter and monsoon temperatures caused a 22-day earlier flowering in three alpine ginger species from 1913 to 2011 (Mohandass et al., 2015). Warmer summer temperatures in the previous year can also induce earlier flowering, as seen in *Erythronium grandiflorum* (Benscoter et al., 2010).

Effect of Climate Change on Growing Period:

Climate change can indirectly affect bioclimatic conditions during the growing period by influencing leaf phenology (Vitasse et al. 2009, Zhao et al. 2020). Shifts in leaf unfolding and colouring can change the days and total number of days included in the growing period. As a result, changes in bioclimatic conditions during the growing period stem from both direct and indirect climate change effects.
Direct climate change can cause alterations in bioclimatic conditions, for example, by increasing temperatures, even if the timing or length of the growing period remains unchanged. Indirectly, climate change can also modify bioclimatic conditions through shifts in the timing and length of the growing period. This can happen by incorporating cooler or warmer days, or wetter or drier days, into the growing season.

Need for Regular Research:
Research on phenology and climate change is crucial because mismatches between flowering times and pollinator activity due to rising temperatures can have cascading effects on ecosystems, potentially leading to reduced crop yields, compromised seed quality, and even habitat loss.

Predicting the Future Shifts in Phenology
The differing phenological responses of species to climate change raise a critical question: how will future climate change scenarios impact the phenology of entire ecosystems? (Houghton et al. 2001).
A major challenge lies in determining the true causal mechanisms behind the reported correlations between phenology and temperature (typically the mean temperature over a fixed date range). This is crucial because climate scenarios often predict phenological events occurring outside the time frame used for temperature data in these predictions. To address this, linking studies on the physiological mechanisms underlying phenology is essential for accurate predictions of future shifts.

Observations in the Flowering season:
Researchers defined the flowering season as the period between when petals unfurl and when they senesce (wither and die). We observed and recorded the presence of flowers in each pot twice a week. For each individual plant (in its pot), the first and last day a flower had unfolded petals were designated as the first flowering day and last flowering day, respectively.To determine flowering rate, we calculated the ratio of pots with flowers to the total number of surviving pots under each experimental condition. The flowering period for each individual plant was then calculated as the difference between the last and first flowering day. Additionally, the length of the stem and flowering stalk was measured twice a week.Dry deciduous forest of present study peak month of flowering in dry season during April.Similar patterns of flowering were observed in other tropical forests (Van Schaik et al.,1993; Foster, 1982 and Justiniano and Frederickson, 2000).

5. Discussion:
Phenological Shifts: Rising temperatures often lead to earlier onset of phenological events like flowering and leafing (Menzel et al., 2006; Parmesan, 2007). However, reduced precipitation can counteract this by causing water stress, which can delay these events (Craine et al., 2012).

Temperature Effects: Higher temperatures typically accelerate growth and flowering (Cleland et al., 2007). For Butea monosperma, which flowers in the late winter to early summer, higher temperatures could lead to earlier flowering.
The table presents data on rainfall, temperature, and correlation metrics over three years (2022-2024) that are relevant to understanding how changing climatic conditions might impact the phenological phases (growth, flowering, fruiting, etc.) of Butea monosperma, a species of tree, in the Bhadra Tiger Reserve in Chikmagalur.

In 2022, With high rainfall (142.22 mm) and higher temperatures (27.73°C), one might expect enhanced growth and earlier flowering. However, the negative correlation (-0.473) suggests that increases in temperature might be associated with decreases in rainfall. This could mean that while temperatures are conducive to early phenological events, potential reductions in rainfall might counterbalance this effect, causing variability in phenological phases (Menzel et al., 2006). The R^2 value of 0.224 indicates a moderate level of explanation for phenological variability, though the significance level (0.120) suggests caution in interpretation.

In 2023, The year shows moderate rainfall (67.21 mm) and temperature (21.72°C). The weak negative correlation (-0.149) and low R^2 (0.022) suggest minimal impact of these factors on phenological phases. This indicates other environmental or biological factors might be playing a more significant role this year (Cleland et al., 2007). With the lowest rainfall (39.25 mm) and temperature (14.39°C) in 2024, the positive correlation suggests that as temperatures drop, rainfall also reduces. This scenario could lead to significant water stress, delaying phenological phases like flowering and fruiting (Craine et al., 2012). The R^2 value (0.178) still shows some explanatory power, though the lack of statistical significance (0.172) implies other factors are also important. The data suggests that both temperature and rainfall influence the phenological phases of Butea monosperma, but their impact varies yearly. While higher temperatures generally promote earlier flowering, reduced rainfall can lead to water stress, counteracting temperature effects. The moderate to low R^2 values and lack of statistical significance in correlations indicate that while climatic factors are important, other variables (e.g., soil moisture, tree age, genetic factors) also play crucial roles.

Flowering Pattern of *Butea monosperma* at Bhadra Tiger Reserve area different Locations:
Hebbe Range:

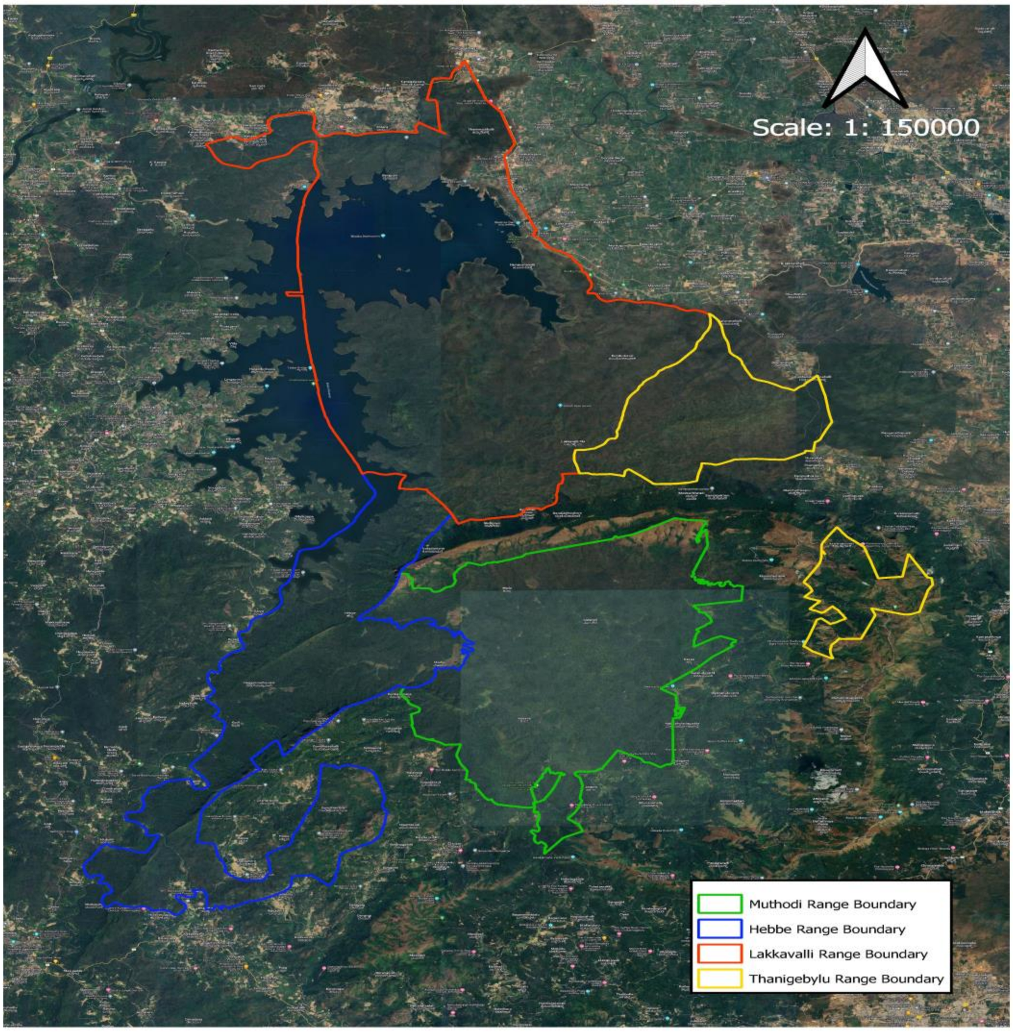
Lakkavalli:

Tannigebailu:

Muthodi:

Geographic Location:

Map Showing Range Boundaries of Bhadra Tiger Reserve, Chikkamagaluru



6. Conclusion:

Rainfall seasonality has been shown to be the major abiotic factor controlling the timing, intensity, and duration of flowering and fruiting periodicities in seasonal tropical forest ecosystems (Singh and Singh, 1992; Newstrom et al., 1994; Sun et al., 1996; Borchert et al., 2004). However, the present study reveals a negative significant influence of rainfall on flowering phenophases.Lieberman (1982) predicted that, for some species, the time-lag between events reflects partitioning of resources for various physiological activities. We observe similar lag periods in the present study.Solar irradiance and rainfall are often investigated as the main seasonal variables influencing the flowering phenology of tropical plants (Wright and Van Schaik, 1994; Wright, 1996). A dry-season flowering period can be seen as a response to a rapid resource-use rate during summer. Water storage in tree trunks may enable these plants to maintain high stem water potential and flower during the dry season (Schongart et al., 2002). Dry season flowering coincides with most trees being in a leafless stage, potentially enhancing advertisement to pollinators.Studies on seasonal trees receiving over 100 cm of rain annually (Koelmeyer, 1959; Janzen, 1967; Daubenmire, 1972; Frankie et al., 1974) have shown a tendency for peak flowering to occur during the dry season.

Based on the findings, while there is evidence of a relationship between rainfall, temperature, and *Butea monosperma* flowering growth in 2021, this relationship becomes less clear in subsequent years. The moderate negative correlation observed in 2021 suggests that high rainfall might inhibit flowering growth, possibly due to environmental factors like waterlogging or nutrient leaching. However, the weaker correlations in 2022 and 2023 indicate that other factors or variations in environmental conditions may also influence flowering patterns.

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