STUDIES ON REPRODUCTIVE PHENOLOGY OF *Hopea parviflora* Bedd. AND *Kingiodendron pinnatum* (DC) Harms. IN WESTERN GHATS

SANJAY, G. R.

MF3TBZ072

DEPARTMENT OF SILVICULTURE AND AGROFORESTRY

COLLEGE OF FORESTRY, PONNAMPET

KELADI SHIVAPPA NAYAKA UNIVERSITY OF AGRICULTURAL AND HORTICULTURAL SCIENCES, SHIVAMOGGA

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COLLEGE OF FORESTRY, PONNAMPET
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CERTIFICATE

This is to certify that the thesis entitled '**Studies on reproductive phenology of *Hopea parviflora* Bedd. and *Kingiodendron pinnatum* (DC.) Harms. in Western Ghats**' submitted in partial fulfillment of the requirement for the degree of **MASTER OF SCIENCE (FORESTRY)** in **SILVICULTURE AND AGROFORESTRY** to the College of Forestry, Ponnampet. Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga, is a bonafide record of research work carried out by **Mr. Sanjay G.R, ID No. MF3TBZ072** (sanjaynayaka098@gmail.com) during the period of study in this university under my guidance and supervision and no part of the thesis has previously formed the basis for the award of any other degree, diploma, fellowship or other similar titles.

Ponnampet
July, 2023

(MAHESWARAPPA V.)
MAJOR ADVISOR

APPROVED BY:

Chairman: **(MAHESWARAPPA V.)**

Members: **(RAMAKRISHNA HEGDE)**

(M. JADEYEGOWDA)

(B.G. NAYAK)

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(Sanjay, G. R.)

Studies on Reproductive Phenology of *Hopea parviflora* Bedd. and *Kingiodendron pinnatum* (DC.) Harms. in Western Ghats

(Sanjay G. R.)

Abstract

Western Ghats are considered as one of the biodiversity hotspots of the world and harbours many endangered and threatened species. Among many of the rare and endangered tree species listed by IUCN, *Hopea parviflora* Bedd. and *Kingiodendron pinnatum* (DC.) Harms. are the two important tree species considered. Reproductive phenology of any tree species renders the events that occurs in time and provide useful information on the periodicity and seasonality of growth and dynamics of flowering and fruiting characters. In this context, the present study was carried out in Makutta territorial range of Kodagu, Karnataka to understand the reproductive phenology, different stages of fruit and seed development, phenological variation in relation to environmental factor. Ten matured trees of both *Hopea parviflora* and *Kingiodendron pinnatum* were selected and tagged to observe the reproductive phenological events once in 15 days. The observation on *Hopea parviflora* and *Kingiodendron pinnatum* indicated that flowering and fruiting periods were from January to July and February to July, respectively which found shift in days for the phenophases. Fruit and seed maturity of the selected species profoundly increases with period of the growth. The fruit length and breadth of *Hopea parviflora* and increased from 5.83 mm to 12.54 mm and 2.84 mm to 7.98 mm, respectively indicating maturity. Observed fruit length and breadth of *Kingiodendron pinnatum* increased from 17.35 mm to 36.41 mm and 12.45 mm to 26.93 mm, from fruit initiation respectively and found increased in seed length and breadth from 11.02 mm to 32.43 mm and 8.10 mm to 25.93 mm. Due to global climate change, the changes in flowering, fruiting, maturity of fruits and seeds, seed germination are found to be strongly influenced by environmental factors such as temperature, precipitation and relative humidity.

Department of Silviculture and Agroforestry

College of Forestry, Ponnampet

KSNUAHS, Shivamogga

July, 2023

Sanjay G. R.

(sanjaynayaka098@gmail.com)

Dr. Maheswarappa V.

(maheswarappav@uahs.edu.in)

ಪಶ್ಚಿಮ ಘಟ್ಟಗಳಲ್ಲಿ ಹೋಪಿಯ ಪಾರ್ವಿಫ್ಲೋರಾ ಬೆಡ್ ಮತ್ತು ಕಿಂಜಿಯೋಡೆಂಡ್ರಾನ್ ಪಿನ್ನಾಟಿಮ್ (ಡಿಸಿ.) ಹಾರ್ಮ್ಸ್ ಸಂತಾನೋತ್ಪತ್ತಿ ಋತುಧರ್ಮಶಾಸ್ತ್ರದ ಅಧ್ಯಯನಗಳು

(ಸಂಜಯ್ ಜಿ.ಆರ್.)

ಸಾರಾಂಶ

ಪಶ್ಚಿಮ ಘಟ್ಟಗಳನ್ನು ವಿಶ್ವದ ಜೀವವೈವಿಧ್ಯತೆಯ ತಾಣಗಳಲ್ಲಿ ಒಂದೆಂದು ಪರಿಗಣಿಸಲಾಗಿದೆ ಮತ್ತು ಅಳಿವಿನಂಚಿನಲ್ಲಿರುವ ಅನೇಕ ಪ್ರಭೇದಗಳಿಗೆ ನೆಲೆಯಾಗಿದೆ. ಐಯುಸಿಎನ್ ಪಟ್ಟಿ ಮಾಡಿದ ಅನೇಕ ಅಪರೂಪದ ಮತ್ತು ಅಳಿವಿನಂಚಿನಲ್ಲಿರುವ ಮರ ಪ್ರಭೇದಗಳಲ್ಲಿ, ಹೋಪಿಯ ಪಾರ್ವಿಫ್ಲೋರಾ ಬೆಡ್ ಮತ್ತು ಕಿಂಜಿಯೋಡೆಂಡ್ರಾನ್ ಪಿನ್ನಾಟಿಮ್ (ಡಿಸಿ.) ಹಾರ್ಮ್ಸ್. ಪ್ರಮುಖ ಮರ ಪ್ರಭೇದಗಳೆಂದು ಪರಿಗಣಿಸಲಾಗಿದೆ. ಯಾವುದೇ ಮರ ಪ್ರಭೇದದ ಸಂತಾನೋತ್ಪತ್ತಿ ಋತುಧರ್ಮಶಾಸ್ತ್ರದ ಅಧ್ಯಯನಗಳು ಸಮಯಕ್ಕೆ ಸಂಭವಿಸುವ ಘಟನೆಗಳನ್ನು ನಿರೂಪಿಸುತ್ತದೆ ಮತ್ತು ಬೆಳವಣಿಗೆಯ ಆವರ್ತಕತೆ ಮತ್ತು ಕಾಲೋಚಿತತೆ ಮತ್ತು ಹೂಬಿಡುವ ಮತ್ತು ಹಣ್ಣು ಬಿಡುವ ಗುಣಲಕ್ಷಣಗಳ ಚಲನಶಾಸ್ತ್ರದ ಬಗ್ಗೆ ಉಪಯುಕ್ತ ಮಾಹಿತಿಯನ್ನು ಒದಗಿಸುತ್ತದೆ. ಈ ಹಿನ್ನೆಲೆಯಲ್ಲಿ, ಪ್ರಸ್ತುತ ಅಧ್ಯಯನವನ್ನು ಕರ್ನಾಟಕದ ಕೊಡಗಿನ ಮಾಕುಟ್ಟ ಪ್ರಾದೇಶಿಕ ವಲಯದ ವ್ಯಾಪ್ತಿಯಲ್ಲಿ ಹೋಪಿಯ ಪಾರ್ವಿಫ್ಲೋರಾ ಮತ್ತು ಕಿಂಜಿಯೋಡೆಂಡ್ರಾನ್ ಪಿನ್ನಾಟಮ್ನ ಸಂತಾನೋತ್ಪತ್ತಿ ಋತುಧರ್ಮಶಾಸ್ತ್ರ, ಹಣ್ಣು ಮತ್ತು ಬೀಜ ಅಭಿವೃದ್ಧಿಯ ವಿವಿಧ ಹಂತಗಳು, ಪರಿಸರ ಅಂಶಕ್ಕೆ ಸಂಬಂಧಿಸಿದಂತೆ ಋತುಧರ್ಮಶಾಸ್ತ್ರದ ವ್ಯತ್ಯಾಸವನ್ನು ಅರ್ಥಮಾಡಿಕೊಳ್ಳಲು ನಡೆಸಲಾಯಿತು. ಹೋಪಿಯ ಪಾರ್ವಿಫ್ಲೋರಾ ಮತ್ತು ಕಿಂಜಿಯೋಡೆಂಡ್ರಾನ್ ಪಿನ್ನಾಟಿಮ್ ಎರಡರ ಹತ್ತತ್ತು ಪಕ್ವಗೊಂಡ ಮರಗಳನ್ನು ಆಯ್ಕೆ ಮಾಡಲಾಯಿತು ಮತ್ತು 15 ದಿನಗಳಿಗೊಮ್ಮೆ ಸಂತಾನೋತ್ಪತ್ತಿ ಋತುಧರ್ಮಶಾಸ್ತ್ರದ ಘಟನೆಗಳನ್ನು ವೀಕ್ಷಿಸಲು ಟ್ಯಾಗ್ ಮಾಡಲಾಯಿತು. ಹೋಪಿಯ ಪಾರ್ವಿಫ್ಲೋರಾ ಮತ್ತು ಕಿಂಜಿಯೋಡೆಂಡ್ರಾನ್ ಪಿನ್ನಾಟಮ್ನ ಮೇಲಿನ ಅವಲೋಕನವು ಹೂಬಿಡುವ ಮತ್ತು ಹಣ್ಣು ಬಿಡುವ ಅವಧಿಗಳು ಕ್ರಮವಾಗಿ ಜನವರಿಯಿಂದ ಜುಲೈ ಮತ್ತು ಫೆಬ್ರವರಿಯಿಂದ ಜುಲೈವರೆಗೆ ಎಂದು ತೋರಿಸಿದೆ, ಋತುಧರ್ಮಶಾಸ್ತ್ರ ಹಂತದ ದಿನಗಳಲ್ಲಿ ಬದಲಾವಣೆಯನ್ನು ಕಂಡುಕೊಂಡಿದೆ. ಆಯ್ದ ಪ್ರಭೇದಗಳ ಹಣ್ಣು ಮತ್ತು ಬೀಜ ಪಕ್ವತೆಯು ಬೆಳವಣಿಗೆಯ ಅವಧಿಯೊಂದಿಗೆ ತೀವ್ರವಾಗಿ ಹೆಚ್ಚಾಗುತ್ತದೆ. ಹೋಪಿಯ ಪಾರ್ವಿಫ್ಲೋರಾದ ಹಣ್ಣಿನ ಉದ್ದ ಮತ್ತು ಅಗಲವು ಕ್ರಮವಾಗಿ 5.83 ಮಿಮೀ ನಿಂದ 12.54 ಮಿಮೀ ಮತ್ತು 2.84 ಮಿಮೀ ನಿಂದ 7.98 ಮಿಮೀ ಗೆ ಏರಿದೆ, ಇದು ಪಕ್ವತೆಯನ್ನು ಸೂಚಿಸುತ್ತದೆ. ಗಮನಿಸಿದ ಕಿಂಜಿಯೋಡೆಂಡ್ರಾನ್ ಪಿನ್ನಾಟಮ್ನ ಹಣ್ಣಿನ ಉದ್ದ ಮತ್ತು ಅಗಲವು ಹಣ್ಣಿನ ಪ್ರಾರಂಭದಿಂದ ಕ್ರಮವಾಗಿ 17.35 ಮಿಮೀ ನಿಂದ 36.41 ಮಿಮೀ ಮತ್ತು 12.45 ಮಿಮೀ ನಿಂದ 26.93 ಮಿಮೀಗೆ ಏರಿದೆ ಮತ್ತು ಬೀಜದ ಉದ್ದ ಮತ್ತು ಅಗಲವು 11.02 ಮಿಮೀ ನಿಂದ 32.43 ಮಿಮೀ ಮತ್ತು 8.10 ಮಿಮೀ ನಿಂದ 25.93 ಮಿಮೀಗೆ ಹೆಚ್ಚಳ ಕಂಡುಬಂದಿದೆ. ಜಾಗತಿಕ ಹವಾಮಾನ ಬದಲಾವಣೆಯಿಂದಾಗಿ ಹೂಬಿಡುವಿಕೆ, ಹಣ್ಣು ಮತ್ತು ಬೀಜಗಳ ಪಕ್ವತೆ, ಬೀಜ ಮೊಳಕೆಯೊಡೆಯುವಿಕೆಯಲ್ಲಿನ ಬದಲಾವಣೆಗಳು ತಾಪಮಾನ, ಮಳೆ ಮತ್ತು ಸಾಪೇಕ್ಷ ತೇವಾಂಶದಂತಹ ಪರಿಸರ ಅಂಶಗಳಿಂದ ಬಲವಾಗಿ ಪ್ರಭಾವಿತವಾಗಿವೆ.

ಅರಣ್ಯ ಕೃಷಿ ಮತ್ತು ಕೃಷಿ ಅರಣ್ಯ ಇಲಾಖೆ

ಅರಣ್ಯ ಮಹಾವಿದ್ಯಾಲಯ, ಪೊನ್ನಂಪೇಟೆ

KSNUAHS, ಶಿವಮೊಗ್ಗ

ಜುಲೈ, 2023

ಸಂಜಯ್ ಜಿ.ಆರ್.

(sanjaynayaka098@gmail.com)

ಮಹೇಶ್ವರಪ್ಪ ವಿ.

(maheswarappav@uahs.edu.in)

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LIST OF ACRONYMS

Acronyms/ symbols	**Word/ units**
%	Per cent
m	Meter
cm	Centimeters
mm	Millimeters
Max.	Maximum
Min.	Minimum
km	Kilometer
Sq. km	Square kilometer
º	Degree
'	Minute
"	Second
ºC	Degree Celsius
g	Gram

INTRODUCTION

I INTRODUCTION

India is one of the world's 'Mega diversity' countries, out of the 18 global biodiversity hotspots India has four of them namely the Eastern Himalaya, Western Ghats, Indo-Burma region, and Sundaland (Reddy *et al*., 2020). The Western Ghats biogeographic region in Southern India runs along the West coast extending from 08° 19' 08"– 21° 6' 24" N to 72° 56' 24" – 78° 19' 40" E with a North to South distance of 1,490 km, minimum width of 48 km and maximum width of 210 km, covering a total area of 1,36,800 km^2. The Western Ghats mountain range traverse in the states of Gujarat, Maharashtra, Goa, Karnataka, Kerala and Tamil Nadu interrupted only once by a 30 km break called the Palghat Gap in Northern Kerala (IUCN, 2011).

The Western Ghats are a treasure house of plants and animals next only to Himalayan tracts in terms of its diversity of unique species. This land mass characterized by one of the most varied tropical climates, altitudinal ranges and edaphic features is unique in its forest composition which ranges from tropical wet evergreen to tropical dry deciduous type as well as montane wet temperate forests (Bawa *et al*., 2007). The Western Ghats have over 4,500 species of flowering plants (38 % endemics), 330 butterflies (11 % endemics), 156 reptiles (62 % endemics), 508 species of birds (4 % endemics), 150 mammals (12 % endemics), 289 fishes (41 % endemics) and 135 amphibians (75 % endemics) are among the known biodiversity of Western Ghats (Prajapati, 2010).

The Western Ghats of Karnataka represent 171 (49 %) of the 353 endemic tree species recorded in Western Ghats. Species such as *Hopea canarensis*, *Hopea jacobi*, *Bauhinia foveolate* are endemic to the region. Due to a long dry period, the Karnataka part of the Western Ghats is relatively less diverse in terms of species richness when compared to the Southern region of the Western Ghats. Despite the low diversity, Poeciloneuron forests, Memecylon forests, *Corypha umbraculifera*, Myristica swamps, Kan forests and pockets of *Saraca asoca* and *Mammea suriga* are unique formations in the area (Reddy, 2007).

Phenology is the calendar of events in the life history of plants. It is generally described as the art of observing the phase of the life cycle through the year. Plant phenological study has great significance because it not only provides knowledge about plant growth patterns but also provides the idea of the effect of the selective pressure of the environment on flowering and fruiting behaviour (Arunkumar *et al*., 2020).

The phenological study is essential, as it has many applications such as in regeneration, afforestation, plant management, floral biology and the estimation of reproductive ability (Mulik and Bhosale, 1990; Bajpai *et al.,* 2017). Phenological data are of great importance for the correct use and protection of ecosystems

(Machado *et al.,* 1997). These data may also contribute to the recuperation of disturbed areas, allowing the planning of the collection of seeds of species that will be used for restoration projects (Knowles and Parrota, 1997).

Reproductive phenological studies help in developing strategies to preserve the genetic potential of rare species which are crucial for restoration programs. As the most apparent indicators of global warming and climate change, phenological studies offer very new avenues for understanding the impact of climate change on the biological world **(**Kallarackal and Renuka, 2015).

Global climate change is a reality and a continuous process that needs to be taken seriously, even though there are large uncertainties in its spatial and temporal phenological response of all ecosystems (Nanda *et al*., 2014). The influence of climate on seed or fruit production and tree growth is a central question in forest ecology, with a key role in forest dynamics. However, the mechanisms linking inter- and intra-annual climate variability, fruiting and growth remain poorly understood, although they seem to be largely species-specific (Barreda *et al*., 2021)

Global climate change may force variations in the timing, duration and synchronization of phenological events in tropical forests (Reich, 1995). Tropical trees are expected to respond variously to changes in rainfall and temperature because they differ widely with respect to adaptations to seasonal drought and cues for bud break of vegetative and flower buds. The wide diversity of seasonal flowering and fruiting with linkages to leaf flush time and leafless period reflect the fact that variable reproductive and survival strategies evolved in tree species under a monsoon bio-climate. Flowering periodicity has evolved as an adaptation to an annual leafless period and the time required for the fruit to develop. The direct relationship between the leafless period (inverse of the growing period) and the time lag between the onset of vegetative and reproductive phases reflects the partitioning of resource use for supporting these phases. The predominance of summer flowering coupled with summer leaf flushing seems to be a unique adaptation in trees to survive under a strongly seasonal tropical climate (Singh and Kushwaha, 2006).

The vegetative and flowering phenology of trees is primarily affected by the periodicity of rainfall, soil water availability, duration and intensity of light, temperature and also topographical factors like elevation and altitude (Kumar *et al*., 2014). Therefore the present study was undertaken to investigate the reproductive phenology, seed maturity, seed germination and phenological variation in relation to environmental factors. Studies on the reproductive phenology of these selected RET tree species will provide useful information on the periodicity and seasonality of growth and dynamics of flowering and fruiting characters. Fruits maturity and storage studies on these tree species will provide information on the storage and seed germination characteristics of these species. In this context the present study was carried out with the following objectives:-

1. To study the reproductive phenology of *Hopea parviflora* Bedd. and *Kingiodendron pinnatum* (DC.) Harms.
2. To understand the different stages of fruit and seed development
3. To understand the phenological variation in relation to environmental factors

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

A review of literature provides a basis for preparing the research and conceptualization of different ideas given by different researchers. A brief review of the work done on different aspects of the present investigation is given in this chapter.

2.1 Phenology

The term Phenology is derived from the Greek word "Phaino", meaning to show or to appear is the science concerned with periodic biological events in the animal and plant world as they are influenced by climate and weather (Kumar *et al*., 2014). Phenology is defined as "the study of seasonal timings of life cycle events". It is also defined as the study of recurring biological events in plants and their timing in response to various biotic as well as abiotic forces with the interrelation among phases of the same or different species. The different phases of the plant's life cycle which changes with time are known as phenophases. The event of a phenophase is determined by the biotic appearances of the plant species, and by native climatic characteristics. It includes leaf emergence, leaf expansion, senescence, flowering, fruiting, etc. which are directly affected by temperature, rainfall and day length. These factors change throughout the year because of seasonal variation. Hence, phenological changes in the plant are easily noticed and suggested as a sensitive indicator of climate change (Chhetri *et al*., 2020).

Plant phenological studies are fundamental to understanding the forest as a resource base for other dependent populations or communities. Tropical plant communities display conspicuous seasonal patterns in vegetative and reproductive phenology at both community and species levels. 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. Information on phenological patterns of natural forest vegetation in tropical forests of the Western Ghats is limited (Sundarapandian *et al*., 2005).

Floral phenology and reproductive biology are the base for breeding programs and regulate the genetic structure (Kukade and Tidke, 2013). Reproductive phenology has a great role in the design of successful *In-situ* conservation management plans for any plant population particularly endangered plant populations. The timing of an organism's phenophases can change dramatically as a direct response to environmental conditions, and this can have larger effects on the community. Secondly, any conservation approach is based on a study of plant reproductive phenology and reproductive biology. Reproductive characteristics such as seed dispersal, germination capacity, the survival rate of seedlings and adults, flowering, reproductive life span and the number of flowers and seeds refer to a set of responses that allow a species to adapt to a particular environment. Besides these, the process of gamete development, pollination, endosperm and embryo development and other reproductive features can provide important clues regarding the reproductive constraints of plants (Kallarackal and Renuka, 2015).

2.2 Species description

2.2.1 *Hopea parviflora* Bedd.

Western Ghats are among the major tropical evergreen forest regions in India that are characterized by the presence of many economically important plants. These plants are being used as timber, medicines, fodder, food and other purposes. Dipterocarp forests are the dominant and major source of timber in the tropical forests of South East Asia.

Hopea genus is represented by timber yielding large trees, present in evergreen and semi-evergreen forests. *Hopea parviflora* Bedd. belongs to the family Dipterocarpaceae, the trade name is Hopea and the common names are Irumbangan, Thambagam, Kamagam and indigenous to the evergreen forests of the Western Ghats from North Canara to Kerala.

It is a large, elegant, evergreen tree reaching a height of 30-40 m with a clean cylindrical bole of 20 m and girth of 4-5 m. Bark light brown, mottled with white, smooth in young trees, changes to rusty brown and rough as the tree grows old. The tree is well-known for its timber value as well as its medicinal importance. The silviculture and regeneration of this species are difficult and the complexity of maintaining regeneration in the absence of regular good seed years, further aggravates their sustainability (Kamarudeen *et al*., 2017).

Hopea parviflora, along with its timber value, the bark is a good candidate for tanning material, mainly for heavy leather. The bark possesses 70% tannin and 22.6% non-tannin, used as an astringent (Kamarudeen, 2003) and stilbenoids have effective biological properties produced by Dipterocarpaceous plants (Rose, 2013).

Most of the Dipterocarps are only known from limited localities and their high degree of habitat specificity makes them rare. Fragmentation of habitat, land cover change and overexploitation are the major driving factors responsible for the severe decline in their natural population. To devise strategies for the effective conservation of *Hopea parviflora*, information on its distribution, phenology, and ecology is very much essential.

2.2.2 *Kingiodendron pinnatum* (DC) Harms.

Kingiodendron pinnatum (DC.) Harms belong to the family Caesalpiniaceae (Fabaceae), a vulnerable and endangered medicinal plant. *K. pinnatum* is known as Malabar Mahogany. *K. pinnatum* is an evergreen tree and endemic to the South

Western Ghats of India. Leaves are alternate, ovate-lanceolate or oblong, apex acuminate, entire margin, minute stipules. Flowers are bisexual, 2-3 mm, white in axillary and terminal panicle raceme. Calyx tube with five lobes, broadly ovate, imbricate. Petals are absent. It has 10 stamens filiform filaments, a versatile anther. It has half an inferior ovary, two ovules, and a minute stigma. The flowering and fruiting season is from February-December (Meha and Kevin, 2022).

The leaf extract of *K. pinnatum* contains biologically active compounds like saponins, tannins, terpenoids, steroids, phenols, flavonoids etc. Phenols and flavonoids are potent antioxidants and have strong anticancer activity. The leaf extract of *K. pinnatum* possesses anti-tubular and anti-microbial activity. The oleo-gum-resin of this plant species is used in gonorrhea, catarrhal conditions of genito-urinary and respiratory tracts and it is also used in curing sores of elephants. The population of this species has declined considerably because of unscientific overexploitation of the oleo resin and timber and habitat degradation.

In this context, the present study felt the necessity to understand the phenology and ecological aspects of the *Hopea parviflora* Bedd. and *Kingiodendron pinnatum* (DC) Harms.

2.3 Phenology of Tree Species

Kamarudeen *et al.* (2017) conducted a study on the phenology of *Hopea parviflora* Bedd. The results revealed that the leaf flushing occurred between October to November, flowering extended from January to March and peak in the mid-wet season of February and fruits from June to July.

Shivaprasad *et al.* (2017) studied the phenology and flower morphology of *Dipterocarpus indicus* Bedd. in Agumbe, Western Ghats of Karnataka. The results revealed that the leaf sprouting and development starts in the last week of November and flowering and anthesis. The first floral buds were observed at the end of the December and flower initiation starts at the last week of December. Then the fruit initiation starts from the last week of January and continued till February. The maturation of fruits started in March.

Nadarajan and Pujari (2018) worked on phenological patterns in S*yzygium caryophyllatum* in the Western Ghats. To understand the vegetative and reproductive phenological behaviour of *Syzygium caryophyllatum*, the knowledge of the factor influencing leaf flushing, maturation, leaf fall, flowering and fruiting of this tree species is required. They used field observations collected over 3 years (2012 -2015) at Neeli-yarkottam sacred grove, Kannur district, Western Ghats of Kerala, India, to characterize the relationship between phenological patterns and biotic and abiotic (climatic) factors. The relationship between the phenological pattern of the selected species and abiotic variables such as precipitation and temperature exhibited significant variation among the species. Flowering begins from the second week of March to till May with a peak in April followed by the fruiting.

Somasundaram and Vijayan (2010) worked on plant diversity and phenological patterns of the trees monitored in a montane wet temperate forest (shola) in the Kukkal Forest, Palni hills of the southern Western Ghats, India. Twelve random plots were selected for sampling the vegetation. For phenological studies, twenty-three fleshy fruit trees were identified in the study area and 10 individuals of each species were selected to record the phenological events fortnightly between April 2002 and April 2004. The phenological events were divided into vegetative and reproductive phases. A total of 2279 individuals were inventoried which belong to 83 species, 68 genera and 40 families. About 30% of the species were endemic to the Western Ghats. The fruiting peak occurred in July 2003 and least in June 2002. During the peak period, the fruits of 85 individuals of six species were observed. The results indicate that the montane wet temperate forest is unique in its diversity and a conspicuous display in phenology.

Chhetri *et al*. (2020) carried out a study to know the phenological trend of tree species at the Forest Research Institute, Dehradun, India. The diversity of phenophases patterns among 11 different plant species was recorded for one year (December 2017-November 2018) which included all four seasons. The timing of leaf budding and leaf emergence was observed from February to April whereas the leaf senescence initiated after June. The peak period for flowering and leaf emergence was in March. After the flowering period, the fruit development was noted i.e. budding and fruit emergence in the months of April and May. Among all the studied species first fruit ripping took place in the month of May in *Litsea chinensis* and continued in June *in Shorea robusta, Mangnifera indica*, and *Syzygium cumini* whereas*, Acacia catechu* and *Dalbergia sissoo* in October.

Nanda *et al*. (2014) studied the leafing, flowering and fruiting phenology of canopy trees in the dry deciduous forest of Bhadra wildlife sanctuary from June 2004 to May 2006. Leaf fall starts in September with a peak in December and January. Leaf initiation begins in February, with a peak in April before the monsoon. Leaf expansion starts in February from pre-monsoon with a peak in May and July during the monsoon. Leaf senescence begins in September to November and peaks in January to March. Flower bud initiates in January with a peak in April and May, and pollination begins in April with a peak in May and July before the monsoon to the onset of monsoon. Fruit bud initiates in May with a peak in September and October. Unripened fruit was observed in May with a peak in September and November. Fruit fall begins in November with a peak in March.

Padmavathi *et al*. (2012) carried out a study to understand the flowering phenology and reproductive biology of *Rhynchosia beddomei*, an endemic medicinal plant of Tirumala. The results of the study revealed that flowering was initiated in December 1st week and continued up to the end of March. Peak flowering was observed in the 4th week of December and another small peak was also observed in February 2nd week. The flowers are yellow in colour and are arranged in axillary or terminal racemes.

Singh and Kushwaha (2006) documented the phenological diversity of flowering and fruiting with reference to leafing events in Indian dry-tropical tree species in the Hathinala Forest which is spread over the Vindhyan plateau, in the Sonbhadra district of Uttar Pradesh. The results showed that species flowering in different seasons exhibited varying fruiting durations. Formation of fruits continued through 2–3 months following the peak flowering time in different species. However, the time required for fruit maturation varied considerably with species. Fruit fall occurred in most species during the last 2 to 3 months of the fruiting phenophase. Generally, fruit fall was completed in the April to June period, 2 months before the rains began.

Sundarapandian *et al*., 2005 carried out a study on the vegetative and reproductive phenology of 42 tree species of tropical forests at Kodayar in the Western Ghats of Tamil Nadu and they monitored through fortnightly visits for two years. They found a considerable variation in leaf flushing, leaf fall, flowering and fruiting behaviour that could be partly attributed to abiotic factors. Peak activity of leaf fall and leaf emergence that occurred in the early dry period, could be to take full advantage of the first rainy season for vegetative growth and reproduction. Peak flowering activity coincided with leaf fall/leaf flushing, possibly to attract pollinators. The activity of fruit ripening and fruit fall was at its peak in the first rainy season in order to utilize the available soil moisture for seed germination and seedling establishment. The phenological behaviour displayed by the trees is an adaptation to the surrounding abiotic and biotic environment.

Upadhaya *et al*., 2017 carried out a study in the Meghalaya to assess the reproductive phenology and germination behavior of 15 endemic tree species *Acer laevigatum*, *Adinandra griffithii*, *Citrus latipes*, *Elaeocarpus prunifolius*, *Engelhardtia spicata*, *Ilex embelioides*, *Ilex khasiana, Ilex venulosa, Illicium griffithii, Magnolia lanuginosa, Magnolia punduana, Photinia cuspidata, Photinia integrifolia, Quercus glauca and Schima khasiana* were monitored at monthly intervals for two calendar years in subtropical broad-leaved humid forests of Northeast India. The investigated species showed peak flowering during the spring, while the fruiting peak was observed in the autumn season. The majority of the species adopted a zoochoric mode of dispersal. The germination phenology revealed that most of the species *Acer laevigatum, Elaeocarpus prunifolius, Illicium griffithii, Magnolia lanuginosa, Magnolia punduana and Quercus glauca* undergo a period of dormancy during the winter season (December–February) and germination collides with the onset of rain indicating that moisture aids in germination.

Ranganathan *et al*., 2021 reviewed the status of research and conservation of Myristica swamps, a threatened freshwater swamp of the Western Ghats. The species *Myristica malabarica* showed flowering in the month of November to May and fruiting in the month of July to August. In the case of *Myristica fatua,* the flowering was observed in the month of May to November and fruiting in the month of October to March. In the species, *Myristica beddomei,* the flowering and fruiting was observed in the month of October to April and May to July. *Semecarpus kathalekanensis* showed flowering in the month of December to February and fruiting in the month of April to May.

2.4 Studies on fruit and seed maturity

Bhat *et al*., 2017 carried out a study to know the exact time of seed maturity in *Pinus wallichiana* under temperate conditions of Kashmir Himalayas, India at different altitudes. The results revealed that seed collection clearly showed wide variation in the maturity of cones. Cone colour served as an indicator of maturity and it changed from light green to green and green with brown patches at maturity. The seed colour changed from whitish to light brown and dark brown at maturity. The mean cone weight (118.67- 88.17 g) and specific gravity (1.13-0.90) decreased as the cones proceeded towards maturity. The mean seed weight of 21.79 to 57.13 g increased at all altitudes as the cones advanced towards maturity. Cone length, cone diameter and germination per cent differed ($p \leq 0.05$) significantly between altitudes and increased when the cones advanced towards maturity. The germination per cent was recorded more at the altitudinal range of 1,600-2,400 MSL (67.25-70.26 %) at maturity, while as it was recorded lower at higher altitudes (42.12 - 47.25 %). It is concluded that the altitudinal range of 1,600 - 2,400 MSL is the best site for the collection of phenotypically superior seeds in terms of maximum cone length (18.18 cm), diameter (5.23 mm) and weight (108.94 g), the number of seeds per cone (117.72), seed weight (79.99 g) and germinability (68.75 %).

Ghate *et al*., 2021 carried out a study in the Amboli forests of the Northern Western Ghats of Maharashtra to assess the fruit and seed traits as well as germination patterns in *Syzygium caryophyllatum*. Reproductive phenology observations revealed that the flowering period of *S. caryophyllatum* spread over four months from March to June; while the overall fruiting period ranged between May to July. Individual fresh fruit weight ranged from 0.74 to 3.45 g with a highly positively skewed distribution. Seed weight varied from 0.04 to 0.59 g with 83 per cent of seeds being represented in seed weight class of 0.04 to 0.34 g. Seed germination was initiated after the 13th day of sowing and overall germination success was 90 per cent in the germination chamber at 28-35°C temperature and 70-75 % relative humidity.

Majeed *et al*., 2010 studied the maturity indices of Indian horse-chestnut (*Aesculus indica* Colebr.) seeds under temperate Kashmir conditions in 2006. Seed collection was started from 15 July and continued until the maturation of seeds in December. The seeds were harvested fortnightly from identified trees and on each collection date maturity indices, viz. seed colour, seed weight, moisture content, seed dimension, specific gravity and germination percentage were recorded. The study revealed that at the time of maturity (Nov–Dec) the seed colour was a shiny chocolate brown, with a moisture content of 58.37 % and a specific gravity of 0.82. Germination was maximum (80%) at its maturity with a maximum seed weight of 52.03 g per seed.

Tewari *et al*., 2010 carried out a study on seed maturity indices in *Aisandra butyracea* which is a multipurpose tree species of the lower Himalayas. Fruits of *A. butyracea* were collected from five average-sized healthy trees each located at Syat (380 m) and Dhuhani (1300 m) in the Nainital district of Kumaun Himalaya. The mean seed size (length × width) across the collection dates varied between 186.44 ± 0.05 and 238.17 ± 0.5 mm^2 across both elevations. The fruit colour changed from dark green in the beginning to pale yellow on the maturity. The range of seed moisture content (62.83 ± 1.33 to 63.46 ± 0.89 %) coincided with maximum germination.

Sekaran *et al*. (2017) studied on development and maturation of the seeds and morphometric changes that happened during seed storage of medicinally important endangered and threatened tree species *Vateria indica* (Dipterocarpaceae). In this species, the harvestable maturity was determined to be fixed on the 10^{th} week (70 days) after anthesis as the highest dry weight (9.23 g/seed) coupled with the lower fresh weight of seeds (18.56 g/seed). The germination rate of the seeds was also higher (90 %) during that period. For seed germination, the sand medium was determined to be suitable. To know the suitable storage condition for the maximum longevity of seeds, experiments on storage of seeds under three different storage temperatures such as room temperature (28 ± 2°C), fridge (5°C) and deep fridge (-5°C) conditions were conducted. Storage of *V. indica* seeds under fridge conditions was found to be suitable for maintaining viability for up to 1 month.

Singh and Saralch (2012) studied the maturity indices for seed collection of *Gmelina arborea* under Punjab conditions. It was observed that the species started flowering from mid-March to the end of May and fruits started maturing from April onwards which continued well up to the end of June. During the study period colour of fruits changed from green to black at various developmental stages. The fruits remained green till the 10^{th} week after flowering and turned yellowish green, yellow and yellowish brown in the 11^{th} and 12^{th}, 13^{th} and 14^{th} weeks respectively. Maximum values for fruits static as well as for per cent germination were also observed during the 11^{th} and 12^{th}, 13^{th} and 14^{th} weeks of fruit collection. It was observed from studies that fruits of *Gmelina arborea* should be collected when their colour range is in between yellowish green to yellowish brown instead of taking time as a fixed parameter since the time of season may vary from year to year.

Tewari *et al*. (2020) assessed the exact time of seed and fruit maturation and germination of *Ficus semicordata* in the Nainital district of Kumaon Himalaya across 3 sites during two consecutive years 2017 and 2018. Fruits of *Ficus semicordata* were collected from the marked trees from all the sites till the availability of the fruits. Across all the sites the mean fruit size varied between 190.24 ± 0.46 and 395.14 ± 3.56 mm² in first year and 135.56 ± 3.69 to 516.86 ± 1.26 mm² in second year. Across both the sites the colour change from green to pinkish brown appears as one of the indicators of maturity. In addition to the colour fruit moisture content between 50.25 ± 0.58 % and 62.73 ± 2.30 % coincided with maximum germination (48.0 ± 0.06 % and 85 ± 4.61 %).

Vinayachandra and Chandrashekar (2011) performed desiccation and storage trials to better understand the storage behaviour of *Knema attenuata* seeds. Mature seeds with a moisture content (MC) of 31 % exhibited 73 % germination. During the period of desiccation (open lab condition) seeds with MC 23 % showed 40% germination. After further drying to MC 21 % germination was reduced to 16 %. Complete loss in viability resulted when seed moisture was reduced to 18 %. The seeds stored at -10°C, 0°C, 10°C and 28 ± 2°C (open lab condition) lost their viability within 10 days. Seeds stored in sealed polythene bags and moist sand retained viability for more days than seeds stored under all other storage conditions. The sensitivity of seeds to lower temperature and desiccation suggests that the storage behaviour of *Knema attenuata* seeds is recalcitrant. Seeds stored in moist conditions can, at best, be stored for a period of two months.

2.5 Impact of Environment on phenology

Singh and Kushwaha (2006) reported that there are five different flowering types depending on when leaves flush (which happens just before or during a hot, dry summer): summer flowering (on foliated shoots), rainy season flowering (on foliated shoots after significant rains), autumn flowering (on shoots with mature leaves), winter flowering (on shoots undergoing leaf fall), and dry season flowering (on leafless shoots). In dry-season and winter-flowering species, the duration of the fruiting phenophase was the smallest (3–4 months), while it lasted the longest (6–9 months) in rainy and autumn-flowering species and the longest (11 months) in summer-flowering species.

Wadymar *et al.* (2018) combine data from a 3-year snow manipulation experiment on the perennial forb *Boechera stricta* (Brassicaceae) from the same site with a 43-year record of first flowering for six species in subalpine Colorado meadows. The time of snowmelt, the accumulation of growing degree days, and photoperiod, three environmental factors known to affect phenology, are examined in relation to changes at the beginning of blooming. According to their findings, species responses to climate change varied depending on when they flowered, with early-flowering species having higher reproduction rates, lower heat sums, and increasingly variable photoperiods than later-flowering species.

Ramasubbu and Kasi (2021) carried out studies on the observation of phenological patterns, fruit predation, and seed dispersal behaviour of *Elaeocarpus gaussenii* and *Elaeocarpus recurvatus* was carried out at the Megamalai wildlife sanctuary and Kodaikanal wildlife sanctuary, Southern Western Ghats of Tamil Nadu, India. The phenoevents of vegetative and reproductive phases of both trees mainly depended on climatic factors such as temperature and rainfall. The leaf flushing period of two species of Elaeocarpus was observed during the pre-summer season and the leaf initiation was recorded from the end of November or December. The observation of flowering phenology of two species of Elaeocarpus indicated that mass flowering has been observed as regular phenological events, whereas flowering intensity has varied from year to year. However, in both species, the flowering period was influenced by the temperature of the study site.

Nunes *et al*. (2012) showed that different reproductive and vegetative phenological patterns exist among tropical dry forest tree species. Flowering and fruiting occurred in the wet season, whereas leaf fall was concentrated in the dry season. Nevertheless, fruiting seemed to be associated with the dispersal guilds of the different species. Temperature and precipitation were correlated with all phenophases analyzed, and the correlations were more robust with vegetative phenology. Species occurring in the same site showed phenological patterns that were more similar than species from different sites. Climate and soil conditions may influence the occurrence of adaptations that result in similar Phenological patterns among different species.

2.6 Floristic diversity studies in Evergreen Forest

Maheswarappa and Vasudev (2018) carried out a study to assess the structural and floristic diversity in selected landscape elements of Kodagu district which lies in Western Ghats, Karnataka. The species richness of 49, Shannon’s diversity index of 3.51, Simpson’s index of the dominance of 0.038 and a species evenness of 0.687 was reported in the evergreen forest of Kodagu.

Neikha and Nagaraj (2019) carried out a study in the Brahmagiri wildlife sanctuary, Kodagu, Karnataka and they reported that Shannon’s diversity index was 3.86 and Simpson’s index of dominance was 0.97. Similarly, they also reported that the family Anacardiaceae and Dipterocarpaceae dominated the forest canopy cover followed by Calophyllaceae, Fabaceae, Lauraceae, Phyllanthaceae and Meliaceae in the evergreen forest of Kodagu.

Karthik and Viswanath (2012) carried out a study in the evergreen forests of Karnataka and reported that in the permanently marked plots, *Dipterocarpus indicus, Vateria indica and Kingiodendron pinnatum* were the main associated tree species present.

Mohanan *et al.* (1997) carried out a study in the Agasthyamala hills, Southern Western Ghats of Kerala and reported that the Dipterocarpaceae, Myristicaceae and Anacardiaceae were the dominant families in this region.

MATERIAL AND METHODS

III MATERIAL AND METHODS

The present study entitled **"Studies on reproductive phenology of *Hopea parviflora* Bedd. and *Kingiodendron pinnatum* (DC.) Harms. in Western Ghats"** was carried out in the Makutta territorial range forest of Kodagu during the year 2021-2022. Details of the study sites, materials used and methodology adopted during the study are presented in this chapter.

3.1 Study area

The study was carried out in the Makutta territorial range of Virajpet division in Kodagu district, Karnataka which lies between latitudes 12° 3' 16" N and longitudes 75° 42' 56.88" E (Fig 3.1). The terrain was undulating with an elevation ranging up to 600 m to 700 m above MSL (Mean Sea Level). The vegetation varied from evergreen to semi evergreen forests. The vegetation in the sites mainly consists of *Hopea parviflora, Dipterocarpus indicus, Knema attenuata, Syzigium cumini and Kingiodendron pinnatum, Vateria indica, Artocarpus hirsutus, Myristica fatua, etc.*

3.2 Climate of the study area

Makutta territorial Forest range receives rainfall mainly from the South-West monsoon, which commences from the first week of June and continues up to the last week of September. It receives nearly a mean annual rainfall of 2718 mm (10 years average) (Fig 3.2). During the study period, the total rainfall was highest during July *i.e.*, 776.6 mm with a mean maximum temperature of 34°C and a mean minimum temperature of 24°C (Fig 3.3).

3.3 Instruments used in the study

Instruments used in the field and lab include GPS, Measuring tapes, Girth tapes, Ravi altimeter, Magnetic compass, Field scopes, Binoculars, Weighing balance, Hot air oven and Digital vernier callipers.

3.4 Methodology

For the present study field inventory was done and periodic observations were taken. The methodology followed in the study is detailed below.

3.4.1 Laying out sample plot and data collection

Based on the species distribution of principal species, plots of size 20m × 20m were laid (Fig 3.4). For each species 10 plots were laid and trees were marked using tags for reproductive phenological observations. Ten matured trees of both *Hopea parviflora* and *Kingiodendron pinnatum* (Plate 3.1 and Plate 3.2) were selected and tagged for the study of reproductive phenological events. The Geo-coordinates of the marked trees were recorded (Table 3.1). The observations on tree

Table 3.1: Geo-coordinates of the selected and marked tree species in the study area

Kingiodendron pinnatum plots				*Hopea parviflora* plots			
Tree No.	**Latitude(°N)**	**Longitude (°E)**	**Altitude(m)**	**Tree No.**	**Latitude (°N)**	**Longitude(°E)**	**Altitude (m)**
1	12 °4'53.22"	75°43'54.44"	141	1	12 °5'38.94"	75°42'52.74"	132
2	12°4'52.53"	75°43'54.40"	141	2	12 °5'44.7"	75°42'53.21"	138
3	12°4'51.78"	75°43'55.41"	145	3	12 °5'45.2"	75°42'52.52"	143
4	12 °4'54.76"	75°43'54.41"	145	4	12 °5'45.92"	75°42'52.38"	142
5	12 °2'30.84"	75°26'20.44"	160	5	12 °5'46.39"	75°42'51.59"	132
6	12 °2'57.8"	75°26'20.33"	173	6	12 °5'46.96"	75°42'52.13"	163
7	12 °2'57.76"	75°26'19.82"	125	7	12 °5'47.07"	75°42'52.81"	122
8	12 °5'46.14"	75°42'52.56"	153	8	12 °5'46.14"	75°42'52.56"	139
9	12 °2'58.7"	75°26'20.04"	138	9	12 °5'45.55"	75°42'53.20"	138
10	12 °2'58.56"	75°26'19.43"	130	10	12 °5'46.86"	75°42'53.39"	149

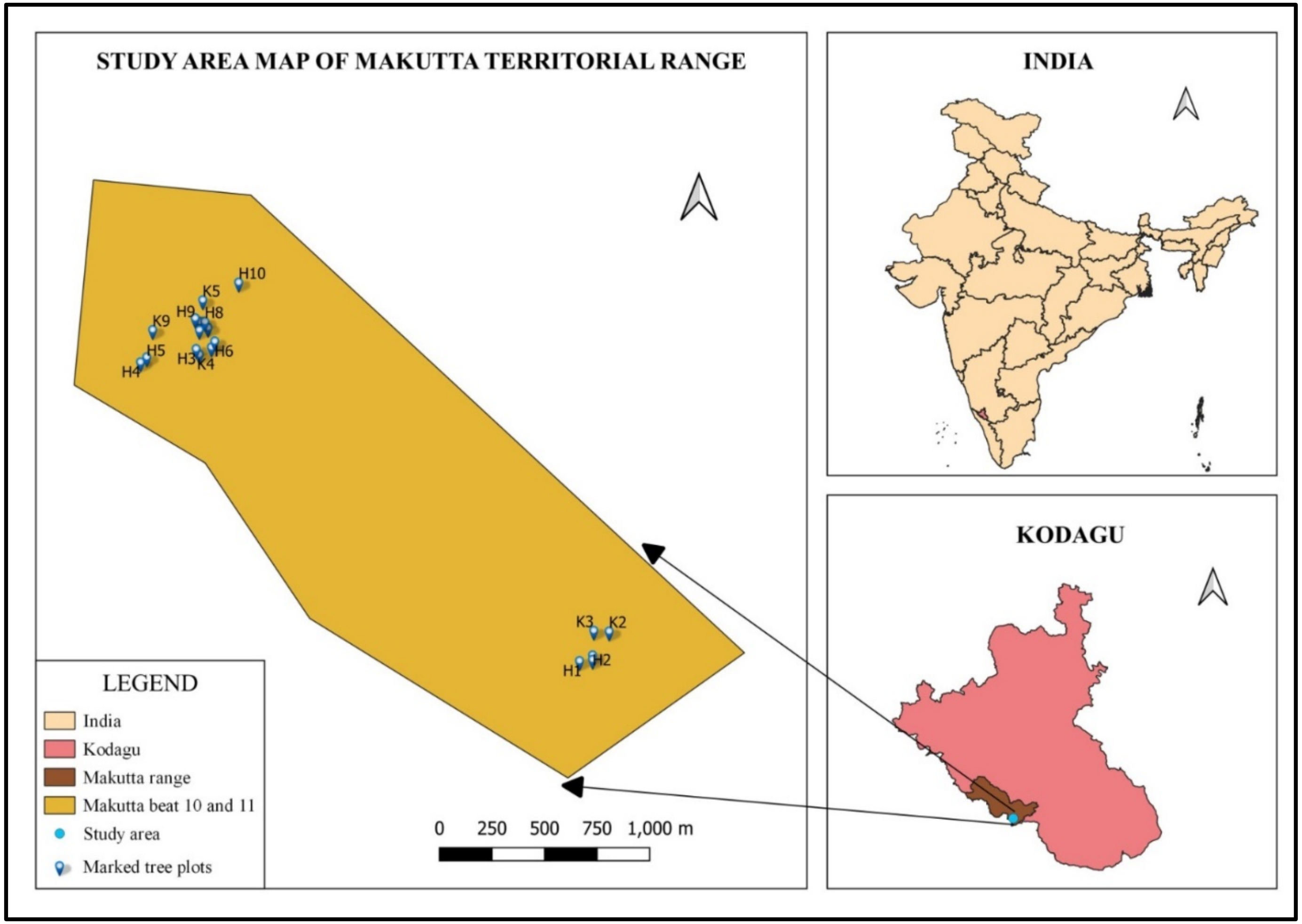


Fig. 3.1: Study area map of the Makutta territorial Forest range

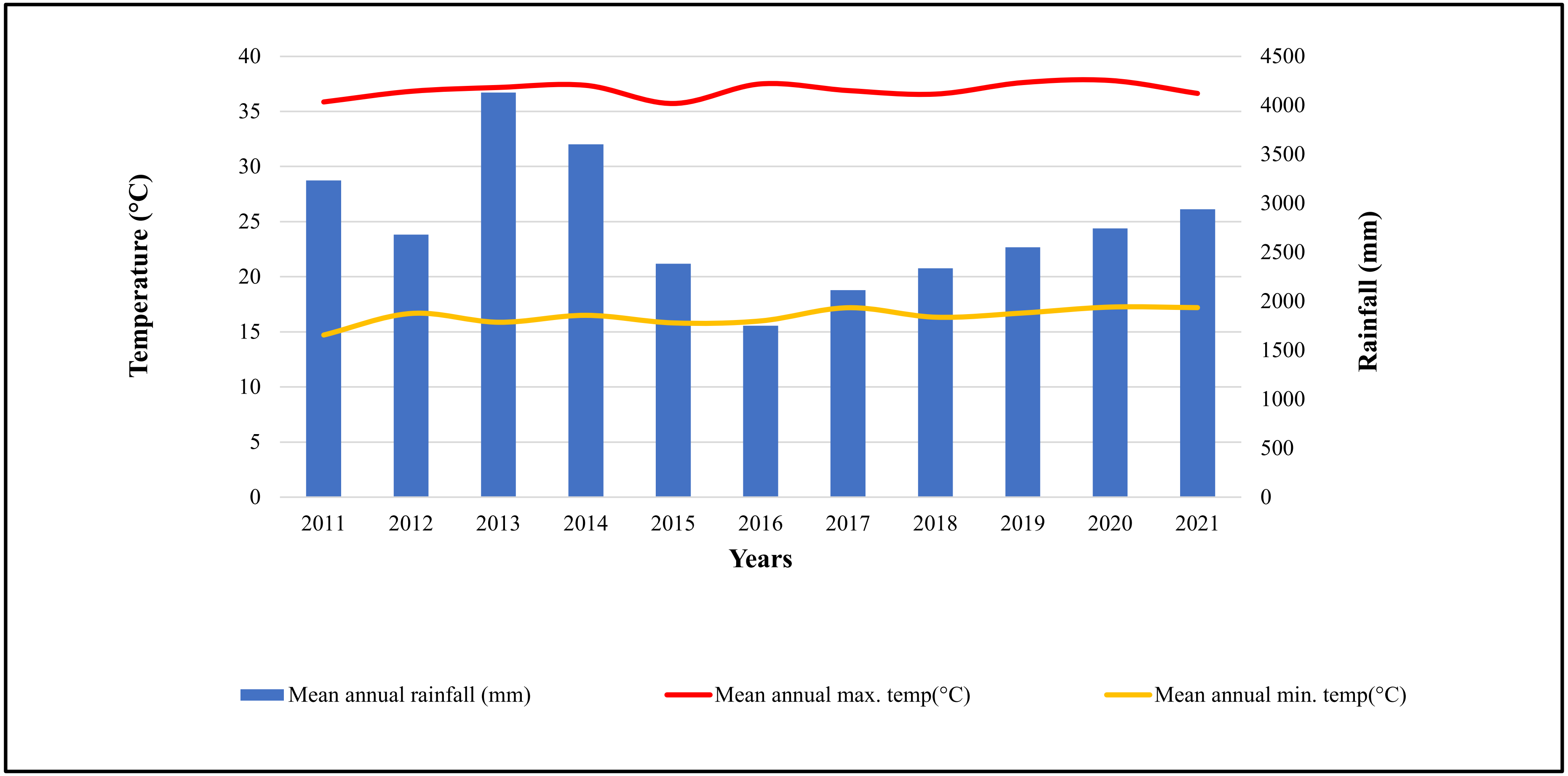


Fig. 3.2: Mean annual distribution of rainfall, maximum and minimum temperature of the study area from 2011 to 2021

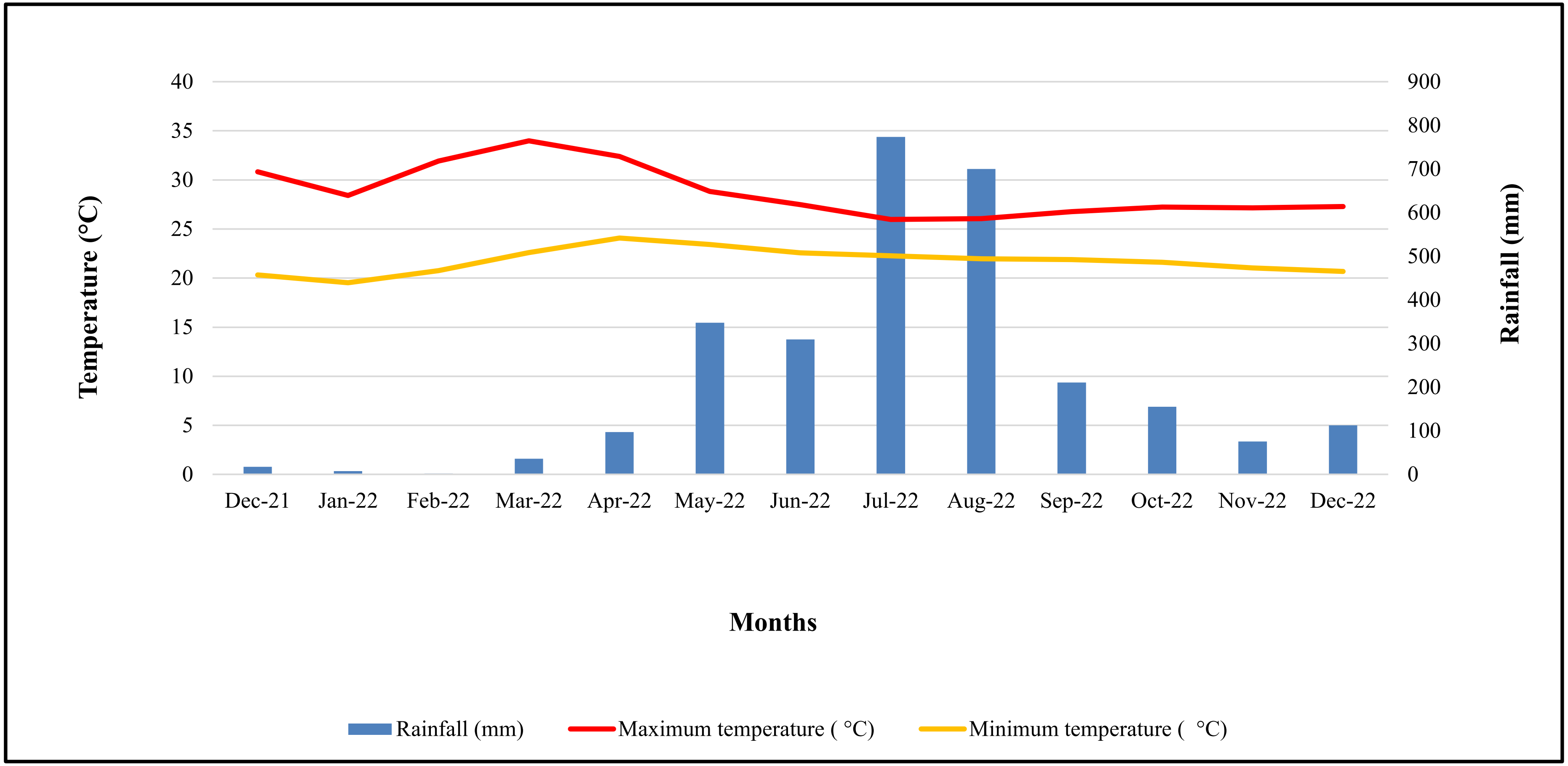


Fig. 3.3: Monthly average rainfall, maximum and minimum temperature during the study period from December 2021 to December 2022

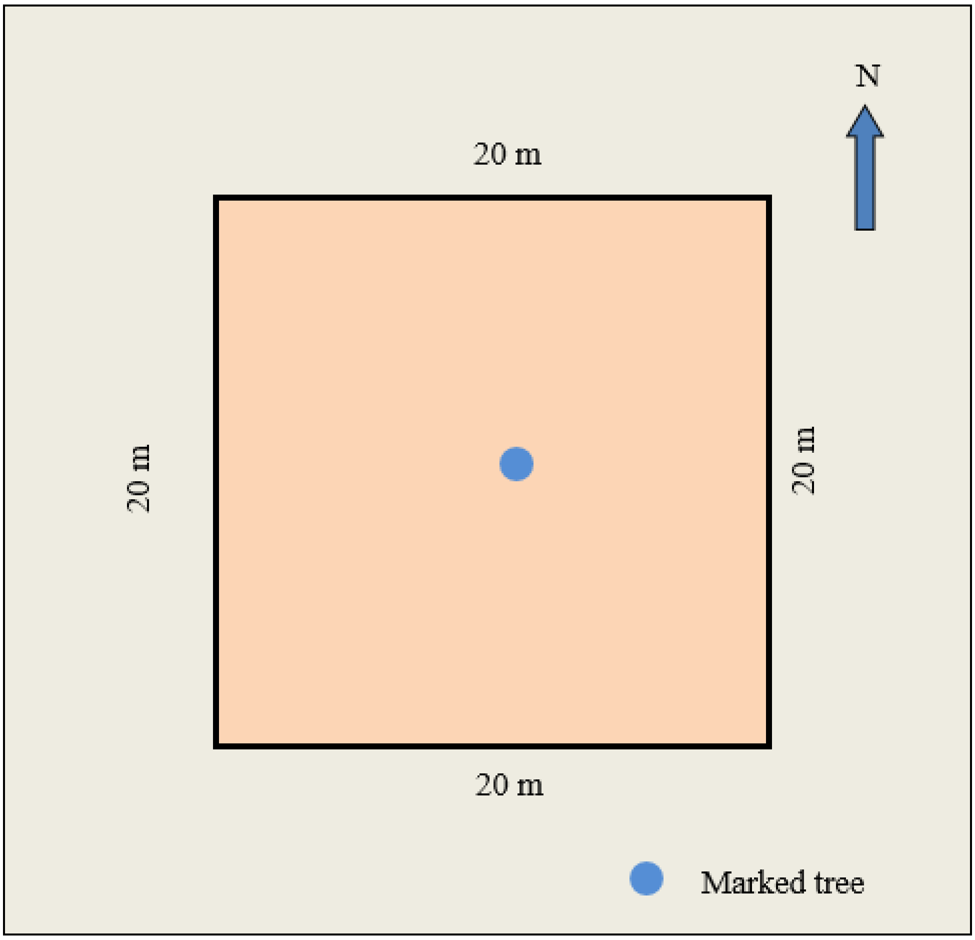
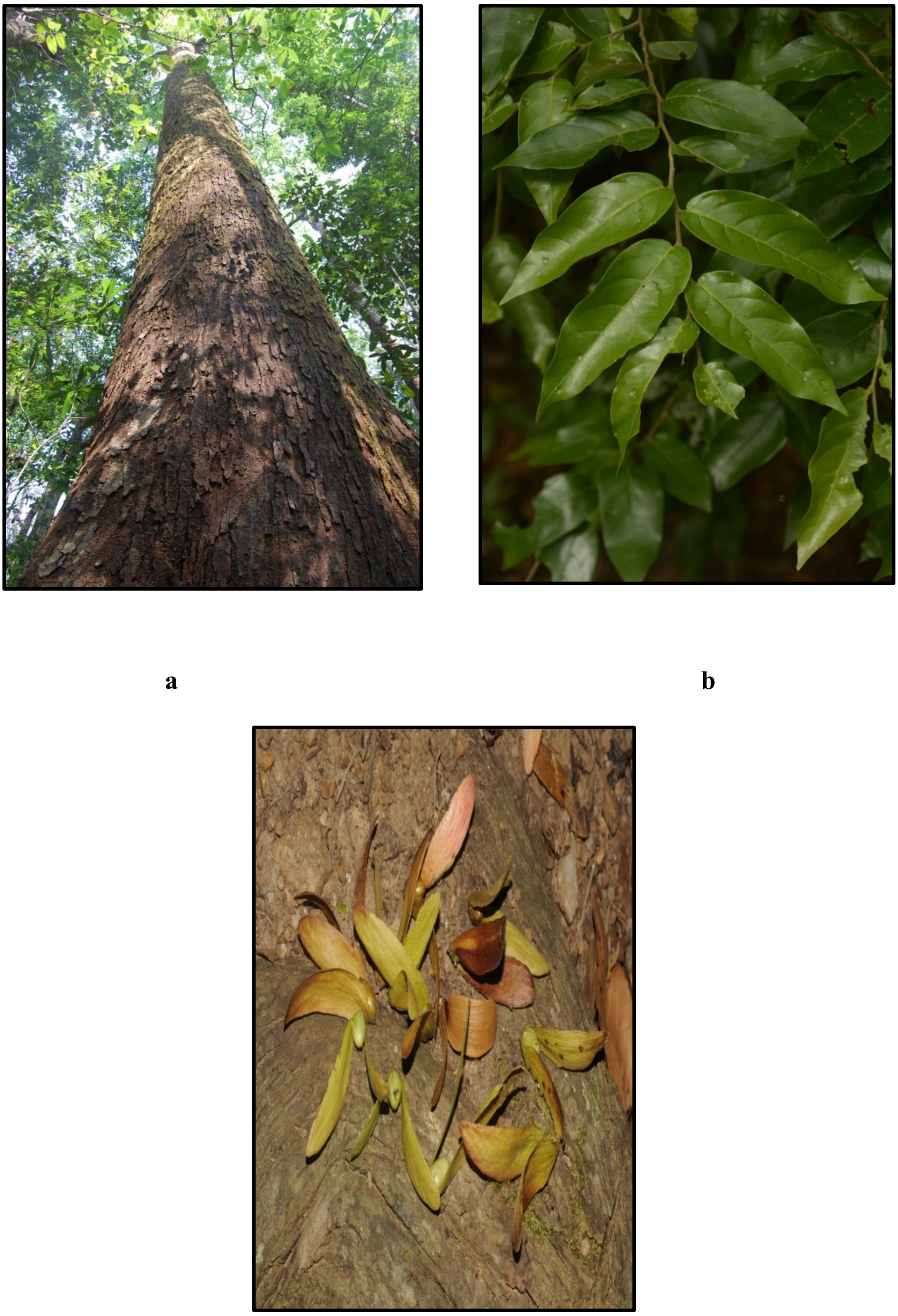


Fig. 3.4: Sample plot design of the experiment



a b

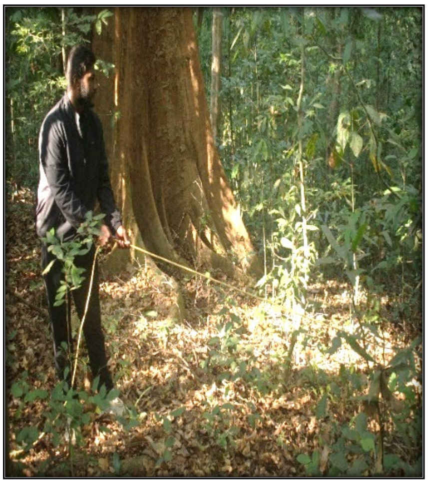
c

Plate 3.1: ***Hopea parviflora*** **Bedd. in the natural forest; a- tree with bark, b- leaves, c – fruit**

a b

c d

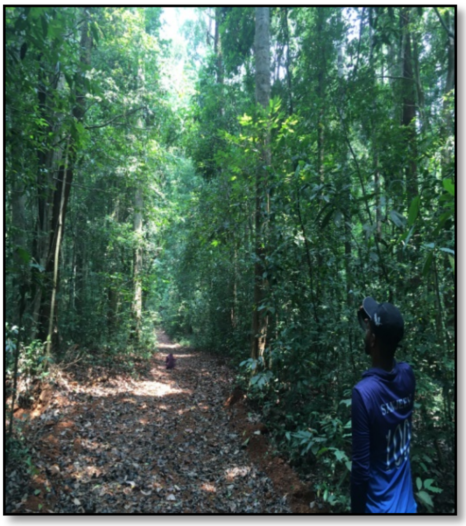
Plate 3.2: ***Kingiodendron pinnatum*** **(DC.) Harms. in the natural forest; a- tree, b- bark, c- leaves, d- fruit**



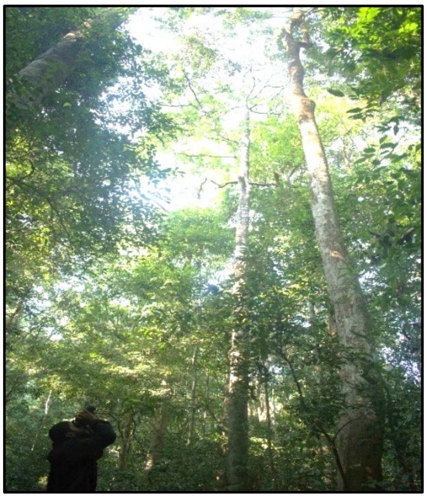
a

b

c



d



e

Plate 3.3: Methods of data collection in the study area; a- Laying of plot, b- Tagging a tree, c- Girth measurement, d- Height measurement, e- Phenological observation recording

parameters like height and GBH were taken by using Ravi altimeter and measuring tape respectively for both principal and other associated species for the analysis (Plate 3.3).

3.4.2 Reproductive phenological events

The tree crown area of the marked trees was divided into four parts and the observations of various reproductive phenological events were done in the lower branches of the marked trees on all four sides. The observations on different phenophases of the marked trees were taken once in a 15 days interval using a field scope and binoculars. The following phenophases were recorded for assessment (Plate 3.3).

I. Flowering phenology

a) Flower initiation

b) Flowering duration

c) Peak flowering initiation

d) Peak flowering duration

II. Fruiting phenology

a) Fruit initiation

b) Fruiting duration

c) Mature fruit fall

3.4.3 Floristic diversity studies

The data collected on principal species and associated species were used to compute the following parameters. Floristic diversity indices were calculated to know the species composition and association in the study area.

1. Species richness

Species richness indicates the number of different species represented in an ecological community, landscape or region. Species richness is simply a count of species and it does not consider the abundance of the species or their relative abundance distributions (Gotelli *et al*., 2009).

2. Shannon-Wiener index (*H'*)

Shannon -Wiener index is the measure of the average degree of uncertainty in predicting to what species individuals chosen at random from a collection of 'S' species and 'N' individuals will belong (Magurran and Henderson, 2003). This average uncertainty increases as the number of species increases and as the distribution of individuals among the species becomes even. Thus, $H'= 0$ when all species are represented by the same number of individuals. It is estimated by using the formula:

$$H' = -\sum_{i=1}^{S} [\left(\frac{\text{ni}}{\text{N}}\right) \ln \left(\frac{\text{ni}}{\text{N}}\right)]$$

Where,

ni= Number of individuals belonging to the i^{th} species

N= Total number of individuals in the sample

S= No. of species

A community with only one species would have an H' value of 0. If the species are evenly distributed then the H' value would be high. So, the H' value allows us to know not only the number of species but how the abundance of the species is distributed among all the species in the community.

3. Species evenness (E):

It refers to how equally the individuals are represented from each species. Species evenness is calculated using the formula:

$$E = \frac{H'}{\ln \text{S}}$$

Where,

H'= Shannon's diversity index

S= Species richness

4. Simpson’s dominance index (D):

Simpson’s dominance index (D) measures the probability that two individuals randomly selected from a population belong to the same species. It varies from 0-1, if the index is high, then both individuals belong to the same species in turn diversity of the community is low. This index is calculated using the formula:

$$\lambda = \sum_{i=1}^{s} P_i^2$$

Where,

P_i is the proportional abundance of the i^{th} species given by $P_i = \frac{n_i}{N}$

n_i = The number of individuals of the i^{th} species

N = Total number of individuals for all the species in the population

5. Importance value index (IVI)

It gives the total status of the species per community structure. To obtain this value, the percentage value of relative frequency, relative density and relative basal area are summed up and the obtained value is described as the important value index of the species (Curtis and Melntosh, 1950).

$$\text{IVI=Relative density(RD)} + \text{Relative dominance(Rd)} + \text{Relative frequecy(Rf)}$$

$$\text{Relative density(RD)} = \frac{\text{Number of individuals of the species 'A'}}{\text{Total number of individuals of all the species}} \text{x100}$$

$$\text{Relative dominance(Rd)} = \frac{\text{Total basal area of species 'A'}}{\text{Total basal area of all the species}} \text{x100}$$

$$\text{Relative frequency(Rf)} = \frac{\text{Frequency value of species 'A'}}{\text{Sum of frequency value of all species}} \text{x100}$$

6. Family importance value index (FIVI)

The family importance value index (FIVI) for botanical families is calculated by adding the IVI for different species of the same family (Curtis and Melntosh, 1950).

Family Importance Value = Relative density (RD) + Relative dominance (Rd)+ Relative diversity (Family)

$$\text{Relative density(RD)} = \frac{\text{Number of individuals of the species 'A'}}{\text{Total number of individuals of all the sample}} \text{x100}$$

$$\text{Relative dominance(Rd)} = \frac{\text{Total basal area of the family}}{\text{Total basal area of all the sample}} \text{x100}$$

$$\text{Relative diversity} = \frac{\text{Number of species in the family}}{\text{Total number of species in the sample}} \text{x100}$$

3.4.4 Studies on stages of fruit/seed development

Identification of fruit development stages was done at regular monthly intervals and fruit maturity indices were developed. Fruits of all trees at one collection date were mixed and a composite sample was made and the following observations were recorded.

1. Fruit/ seed colour

The colour of the fruit or seed coat was estimated on an ocular basis. From the composite sample, 25 fruits or seeds were taken for determining the fruit or seed colour for each collection.

2. Size of the Fruit/seed

From the composite sample, 25 fruits or seeds were taken to determine the size of the fruits or seeds. The length and width of fruits or seeds were measured by using a digital Vernier calliper and a measuring scale. It is expressed in mm.

3. Fresh weight of the Fruit/seed

From the composite sample, 100 fruits or seeds were taken and the fruits or seeds weight was measured by using an electronic balance (Plate 3.4).

4. Seed germination (%)

The seeds were collected from the marked trees. A total of 100 seeds were taken and sown in the tray filled with potting mixture (soil: sand: FYM- 2:1:1). The observations on the germination were taken daily (Plate 3.5). The seed germination per cent was calculated by using the formula:

$$\text{Germination percent } (\%) = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds}} \times 100$$

5. Seed moisture content (%)

The seed moisture content was calculated for each collection date using 100 seeds that were dried at 103 ± 2 °C for 16 ±1 hours in a hot air oven and then weighed (Jaganathan *et al*., 2022). The seed moisture content was calculated by using the formula:

$$\text{Seed moisture content } (\%) = \frac{\text{Fresh weight } - \text{Dry weight}}{\text{Fresh weight}} \times 100$$

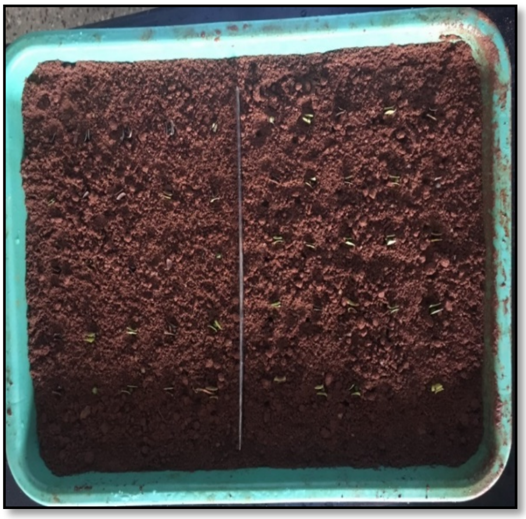
3.4.5 Phenological variation pattern in relation to environmental factors

To understand the phenological variation in relation to environmental factors, the data related to rainfall, temperature and relative humidity of the study area during the study period (December 2021 to December 2022) were obtained from the NASA website (http://power.larc,nasa.gov/data-access...).

Based on the intensity of flowering and fruiting, the scoring was given on ocular estimation with the following criteria as given by Broadhead *et al*. (2003).

Sl. No.	Intensity	Score
1	Absent	0
2	< 30%	1
3	30%- 60%	2
4	60%-100%	3

Plate 3.4: Fruit weight measurement of *Hopea parviflora*



a

b

Plate 3.5: Seed germination test; a- *Hopea parviflora*, b- Germinated seedling of *Hopea parviflora*

3.5 Statistical analysis

The descriptive statistical analysis and Pearson's correlation were used to study the seed maturity indices. The correlation between phenological events and climatic variables such as rainfall, temperature and relative humidity of the study periods was studied with Spearman's rank correlation coefficient (r_s) (Nadarajan and Pujari, 2018).

RESULTS

IV RESULTS

The present study entitled "Studies on reproductive phenology of *Hopea parviflora* Bedd. and *Kingiodendron pinnatum* (DC.) Harms. in Western Ghats" was carried out during 2021-2022 to investigate the reproductive phenology, seed maturity and phenological variation in relation to environmental factors in *Hopea parviflora* and *Kingiodendron pinnatum* in Makutta territorial range, Kodagu district, Karnataka, India. The results of this study have been presented under the following sub-headings.

4.1 Reproductive phenology of *Hopea parviflora* Bedd. and *Kingiodendron pinnatum* (DC.) Harms.

4.1.1 Growth observation of the marked trees

The average height and GBH of the marked *Hopea parviflora* and *Kingiodendron pinnatum* trees in the study area were presented in Table 4.1. The average height of the marked *Hopea parviflora* trees was 31.18 ± 2.34 m with a range of 27.4 m to 34.6 m and the average GBH was 2.28 ± 0.54 m with a range of 1.65 m to 3.34 m respectively.

The average height of the marked *Kingiodendron pinnatum* trees was 29.45 ± 1.64 m with a range of 27.1 m to 32.3 m and the average GBH was 1.92 ± 0.37 m with a range of 1.35 m to 2.62 m respectively.

4.1.2 Floristic diversity studies

Table 4.2 represents the diversity of associated species present in the study area. The species richness of associated species was 22 in *Hopea parviflora* plots and 26 in *Kingiodendron pinnatum* plots respectively.

The highest Shannon-Wiener index (*H'*) of 2.95 was reported in *Kingiodendron pinnatum* plots compared to *Hopea parviflora* plots with 2.72. In *Hopea parviflora* plots, the highest Simpson's dominance index (D) value of 0.083 was observed and the lowest was observed in *Kingiodendron pinnatum* plots (0.06). From the results, it is evident that the *Kingiodendron pinnatum* plots were more diverse than *Hopea parviflora* plots. The species evenness was observed more in *Kingiodendron pinnatum* (0.90) plots than in the *Hopea parviflora* plots (0.88).

4.1.3 Importance value index (IVI)

Importance value index (IVI) indicates the dominant species present in that area, it evaluates the species by its number of individuals (relative density), occurrence (relative frequency) and coverage (relative dominance). In *Hopea parviflora* plots, species such as *Hopea parviflora, Drypetes elata, Dipterocarpus indicus, Holigarna arnottiana, Artocarpus hirsutus, Tectona grandis,*

Table 4.1: Growth observations of selected tree species in the evergreen forest of Makutta

Hopea parviflora			*Kingiodendron pinnatum*		
Tree no	Height (m)	GBH (m)	Tree no	Height (m)	GBH (m)
1	31.5	2.15	1	29.3	1.35
2	32.3	2.72	2	31.1	2.12
3	34.6	3.34	3	29.6	2.62
4	31.6	2.4	4	30.5	1.73
5	30.8	1.85	5	27.1	1.63
6	33.6	2.24	6	29.8	2.1
7	32.6	2.8	7	32.3	2.3
8	27.9	1.77	8	27.9	1.77
9	27.4	1.65	9	27.4	1.65
10	29.5	1.91	10	29.5	1.91
Mean ± SD	31.18 ± 2.34	2.28 ± 0.54	Mean ± SD	29.45 ± 1.64	1.92 ± 0.37
Range	27.4-34.6	1.65-3.34	Range	27.1-32.3	1.35-2.62

Table 4.2: Diversity of associated species of *Hopea parviflora* and *Kingiodendron pinnatum* plots of the study area

Diversity	*Hopea parviflora*	*Kingiodendron pinnatum*
Species richness	22	26
Shannon-Wiener index (H')	2.72	2.95
Simpson's dominance index (D)	0.083	0.06
Species evenness	0.88	0.90

Diospyros nilagirica, Bacaurea cortallensis, Myristica fatua, and *Knema attenuata* were the top ten dominant tree species. Whereas, in *Kingiodendron pinnatum* plots *Dipterocarpus indicus*, *Hopea parviflora, Knema attenuata, Drypetes elata, Artocarpus hirsutus, Kingiodendron pinnatum*, *Vateria indica, Palaquium ellipticum, Pterygota alata* and *Diospyros nilagirica* were the dominant tree species (Table 4.3 and Table 4.4).

The importance value index of *Hopea parviflora* plots (Table 4.3) reports that *Hopea parviflora* (53.39) was found to be the most dominant tree species followed by *Drypetes elata* (29.43) and *Dipterocarpus indicus* (25.56). The importance value index of *Kingiodendron pinnatum* plots (Table 4.4*)* reports that *Dipterocarpus indicus* (35.52) was the dominant tree species followed by *Hopea parviflora* (25.58) and *Knema attenuata* (24.85).

4.1.4 Family importance value index (FIVI)

The family Importance value index (FIVI) indicates the dominant family present in that area. The dominant families of the *Hopea parviflora* plots were Myristicaceae, Lythraceae, Apocynaceae, Lauraceae and Euphorbiaceae. In *Kingiodendron pinnatum* plots, Dipterocarpaceae, Myristicaceae, Euphorbiaceae, Moraceae and Caesalpiniaceae were the dominant families present.

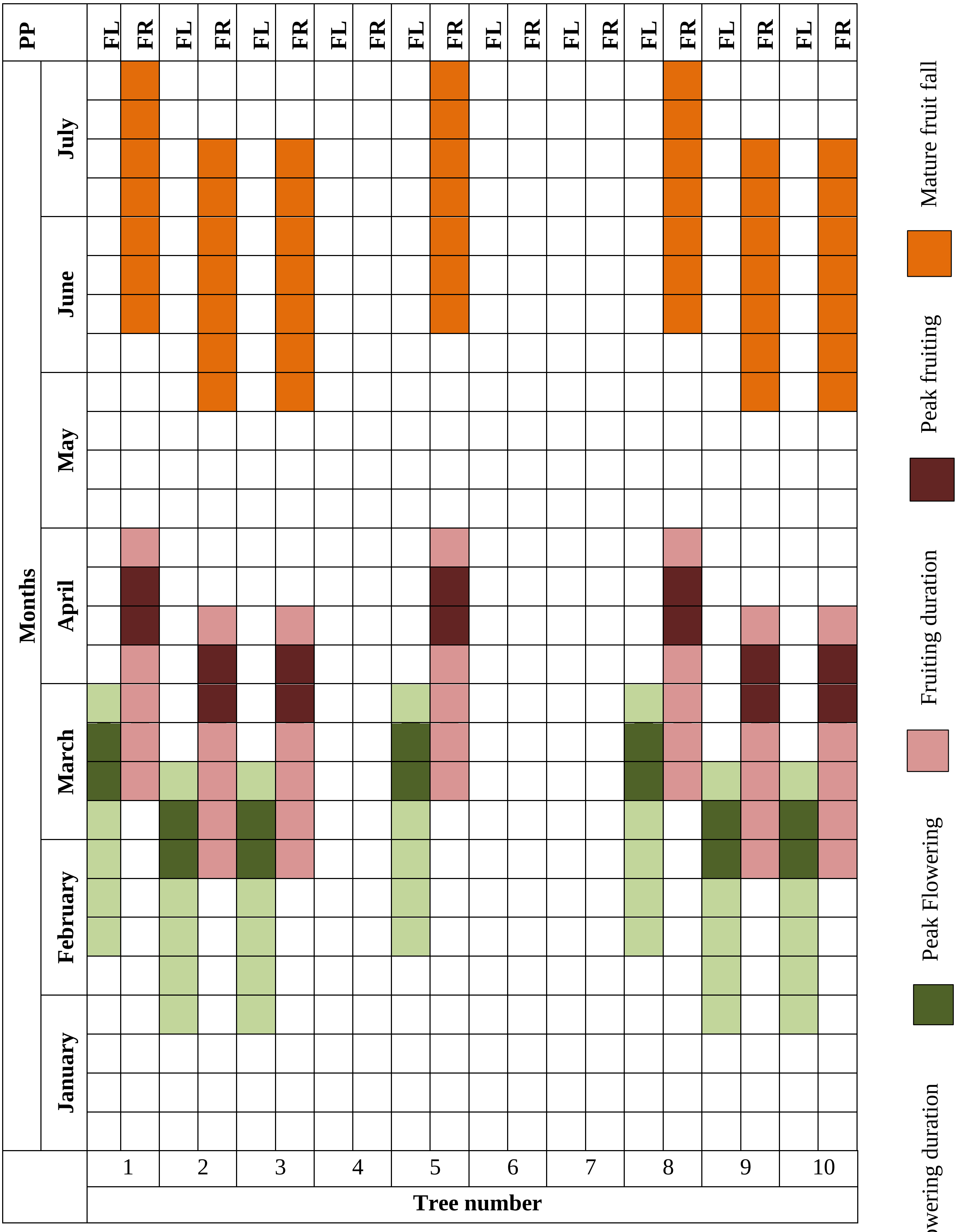
The family importance value index of *Hopea parviflora* plots indicates that Myristicaceae (61.75 %) was found to be the most dominant family with two species followed by Lythraceae (23.14 %) with one species and the least was Malvaceae family (5.73 %) with one species (Table 4.5).

The family importance value index of *Kingiodendron pinnatum* plots indicates that Dipterocarpaceae (70.39 %) was found to be the most dominant family with three species followed by Myristicaceae (29.48 %) with two species and the least was Annonaceae family (4.82 %) with one species (Table 4.6).

4.1.5 Reproductive phenology

Ten matured trees of each species were marked for reproductive phenological observation in the study area. In *Hopea parviflora*, out of ten marked trees, trees 1, 2, 3, 5, 8, 9 and 10 show reproductive phenological events and trees 4, 6 and 7 didn’t show any reproductive phenological events (Fig 4.1).

The flowering in *Hopea parviflora* started from the last week of January and continued till March. Peak flowering was observed during last week of February. The fruit initiation started from February to April. The mature fruit fall was observed from the end of May till July (Fig 4.1).



PP- Phenophases, FL- Flowering phenology, FR- Fruiting phenology

Fig. 4.1: Phenogram of individual marked *Hopea parviflora* trees in the study area

Table 4.3: Top ten dominant tree species based on IVI values found in *Hopea parviflora* plots of the study area

Sl. No.	Tree species	Relative density	Relative frequency	Relative Dominance	IVI
1	*Hopea parviflora*	15.32	8.43	29.63	53.39
2	*Drypetes elata*	16.12	10.84	2.46	29.43
3	*Dipterocarpus indicus*	7.25	7.22	11.07	25.56
4	*Holigarna arnottiana*	5.64	7.22	9.62	22.50
5	*Artocarpus hirsutus*	4.03	3.61	14.50	22.14
6	*Tectona grandis*	6.45	6.02	6.64	19.12
7	*Diospyros nilagirica*	5.64	7.22	3.39	16.27
8	*Bacaurea cortallensis*	7.25	6.02	1.32	14.60
9	*Myristica fatua*	4.83	6.02	3.15	14.02
10	*Knema attenuata*	4.83	4.81	2.86	12.51

Table 4.4: Top ten dominant tree species based on IVI values found in *Kingiodendron pinnatum* plots of the study area

Sl. No.	Tree species	Relative density	Relative frequency	Relative dominance	IVI
1	*Dipterocarpus indicus*	9.30	9.37	16.83	35.51
2	*Hopea parviflora*	6.20	6.25	13.13	25.58
3	*Knema attenuata*	10.85	8.33	5.66	24.85
4	*Drypetes elata*	10.07	9.37	3.07	22.52
5	*Artocarpus hirsutus*	3.87	4.16	14.31	22.34
6	*Kingiodendron pinnatum*	6.97	6.25	7.91	21.14
7	*Vateria indica*	6.20	3.12	8.22	17.55
8	*Palaquium ellipticum*	6.97	5.21	4.76	16.94
9	*Pterygota alata*	5.42	7.29	3.62	16.34
10	*Diospyros nilagirica*	6.20	5.21	3.18	14.59

Table 4.5: Family importance value index of species found in *Hopea parviflora* plots

Sl. No.	Family	FIVI (%)	No. of species
1	Myristicaceae	61.75	2
2	Lythraceae	23.14	1
3	Apocynaceae	23.07	1
4	Lauraceae	22.88	1
5	Euphorbiaceae	21.15	2
6	Moraceae	19.81	1
7	Verbanaceae	17.64	1
8	Myrtaceae	15.64	2
9	Dipterocarpaceae	15.61	2
10	Anacardaceae	15.51	2
11	Ebenaceae	13.12	1
12	Rutaceae	12.64	2
13	Oleaceae	12.54	1
14	Salicaceae	11.42	1
15	Phyllanthaceae	8.27	1
16	Malvaceae	5.73	1

Table 4.6: Family importance value index of species found in *Kingiodendron pinnatum* plots

Sl. No.	Family	FIVI (%)	No. of species
1	Dipterocarpaceae	70.39	3
2	Myristicaceae	29.48	2
3	Euphorbiaceae	24.55	2
4	Moraceae	21.63	1
5	Caesalpiniaceae	18.52	1
6	Sapotaceae	15.45	1
7	Myrtaceae.	13.62	2
8	Ebenaceae	13.15	1
9	Malvaceae.	12.80	1
10	Rutaceae	10.51	2
11	Guttiferae	9.67	1
12	Anacardaceae	9.63	1
13	Meliaceae	9.14	1
14	Lythraceae	8.28	1
15	Oleaceae	6.61	1
16	Phyllanthaceae	5.61	1
17	Lauraceae	5.47	1
18	Rubaceae	5.22	1
19	Fabaceae	4.92	1
20	Annonaceae	4.82	1

In *Kingiodendron pinnatum*, out of 10 marked trees, trees 1, 3, 4, 7, 9 and 10 show reproductive phenological events and trees 2, 5, 6 and 8 didn't show any reproductive phenological events (Fig 4.2).

The flowering in *Kingiodendron pinnatum* was initiated in second week of February and extended up to March and peak flowering was observed during mid-March. The fruit initiation started from the second week of March. The mature fruit fall was observed from the last week of May up to July (Fig 4.2).

4.2 Different stages of fruit and seed development

4.2.1 Fruit or seed colour

The colour of the *Hopea parviflora* fruit changed over the collections at monthly intervals from the initiation of fruit development. The colour was yellowish green in the first collection, then turned to green and changed to brown in the final collection.

The colour of the *Kingiodendron pinnatum* fruit changed from green in the first collection to dark brown in the final collection whereas the colour of the seed was creamy white in the first collection and changed to brown in the final collection from the initiation of the fruit development.

4.2.2 Fruit or seed size

The size of the *Hopea parviflora* fruit increased over the collections at monthly intervals from the initiation of fruit development. The mean length and breadth of the *Hopea parviflora* fruits increased during their development *i.e.,* 5.83 ± 1.32 mm to 12.54 ± 1.46 mm and 2.84 ± 0.74 mm to 7.98 ± 0.67 mm respectively (Table 4.7).

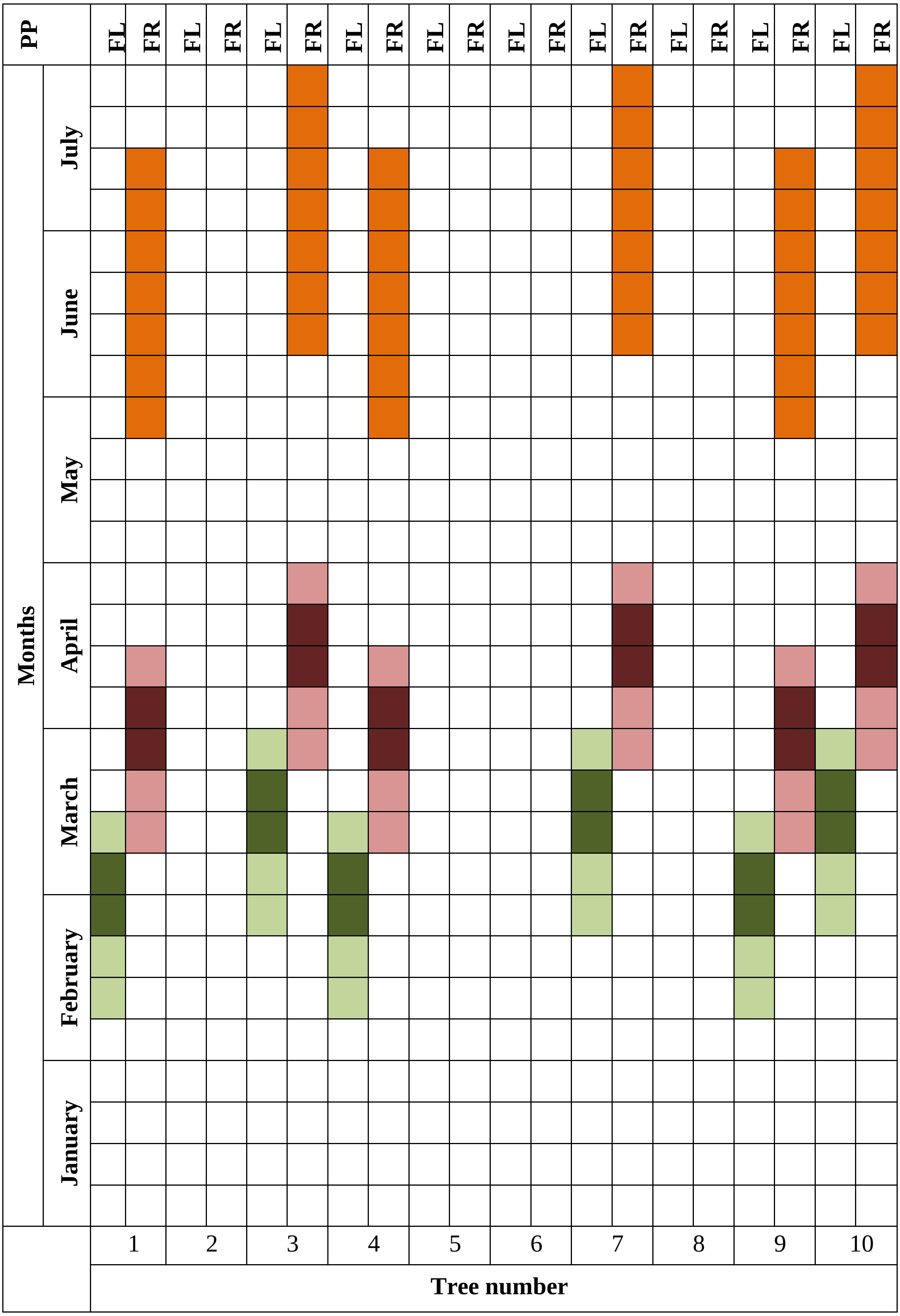
The mean length and breadth of *Kingiodendron pinnatum* fruits increased from 17.35 ± 2.15 mm to 36.41 ± 3.13 mm and 12.45 ± 1.46 mm to 26.93 ± 3.42 mm, respectively. The mean length and breadth of *Kingiodendron pinnatum* seeds increased from 11.02 ± 1.27 mm to 32.43 ± 4.61 mm and 8.1 ± 0.52 mm to 25.93 ± 3.45 mm, respectively (Table 4.8). From the results, it is evident that the fruit and seed size of *Hopea parviflora* and *Kingiodendron pinnatum* increased over the collections.

4.2.3 Fresh weight of the fruit or seed

The fresh weight of the *Hopea parviflora* fruit increased over the collections at monthly intervals from the initiation of fruit development. The fresh weight of the 100 fruits was 15.64 g in the first collection and increased to 38.52 g in the last collection. The fresh weight of 100 *Kingiodendron pinnatum* seeds was 183.54 g in the first collection and increased to 434.25 g in the last collection (Table 4.7 and Table 4.8).

Table 4.7: Fruit development parameters of *Hopea parviflora* at monthly intervals from the initiation of fruit development

Collection No.	Date of collection	Parameters					
		Length with wings (mm) Mean ± SD	Length without wings (mm) Mean ± SD	Breadth (mm) Mean ± SD	100 Seed weight (g)	Seed moisture content (%)	Seed Germination (%)
1	28-04-2022	29.00 ± 6.00	5.83 ± 1.32	2.84 ± 0.74	15.64	52.23	0.00
2	29-05-2022	45.50 ± 4.00	7.56 ± 1.03	4.72 ± 0.94	24.52	60.97	0.00
3	30-06-2022	55.70 ± 4.90	11.27 ± 1.52	7.53 ± 1.07	32.64	51.22	28.00
4	25-07-2022	56.80 ± 4.30	12.54 ± 1.46	7.98 ± 0.67	38.52	45.24	47.00



PP- Phenophases, FL- Flowering phenology, FR- Fruiting phenology

Fig. 4.2: Phenogram of individual marked *Kingiodendron pinnatum* trees in the study area

Table 4.8: The fruit and seed development parameters of *Kingiodendron pinnatum* at monthly intervals from the initiation of fruit development

Collection No.	Date of collection	Parameters						
		Fruit Length (mm) Mean± SD	Fruit breadth (mm) Mean ± SD	Seed length (mm) Mean ± SD	Seed breadth (mm) Mean ± SD	100 Seed weight (g)	Seed moisture content (%)	Seed Germination (%)
1	28-04-2022	17.35 ± 2.15	12.45 ± 1.46	11.02 ± 1.27	8.10 ± 0.52	183.54	54.32	0
2	29-05-2022	29.72 ± 3.22	19.35 ± 2.16	22.13 ± 2.11	14.33 ± 1.55	258.95	57.43	0
3	30-06-2022	32.44 ± 4.51	20.25 ± 3.98	28.32 ± 4.10	21.32 ± 2.93	312.53	47.86	32
4	25-07-2022	36.41 ± 3.13	26.93 ± 3.42	32.43 ± 4.61	25.93 ± 3.45	434.25	42.45	63

4.2.4 Seed germination (%)

The germination percentage in *Hopea parviflora* was highest in the final collection and 47 % of germination was observed. In *Kingiodendron pinnatum* germination percentage of 63 % was recorded in the final collection. From the results, it is evident that the seeds from the final collections showed the highest germination percentage when compared to the previous collections (Table 4.7 and Table 4.8).

4.2.5 Moisture content of the fruit or seed (%)

The moisture content of *Hopea parviflora* fruits recorded in the first collection was 52.23 % and 45.24 % in the last collection. The moisture content of the *Kingiodendron pinnatum* seeds was 54.32 % in the first collection and 42.45 % in the last collection (Table 4.7 and Table 4.8). From the results, it is evident that the moisture content of *Hopea parviflora* fruits and *Kingiodendron pinnatum* seeds decreased over the collections.

4.2.5 Correlation analysis

The result of Pearson's correlation analysis between different parameters of *Hopea parviflora* fruit is presented in Table 4.9. The close perusal of the correlation matrix revealed that these were the association of ranging degrees between different parameters. The fruit length showed a significant positive correlation with fresh weight ($r = 0.986$ at $p < 0.05$) and seed germination ($r = 0.960$ at $p < 0.05$). Fruit length also shows a positive and highly significant correlation with fruit width ($r = 0.992$ at $p < 0.01$). Fresh weight shows a significant positive correlation with fruit breadth.

The fruit length of the *Kingiodendron pinnatum* showed a highly significant positive correlation with seed length ($r = 1$ at $p < 0.01$) and it also exhibit a significant positive correlation with fruit width and seed width. Fruit width showed a highly significant positive correlation with seed width and it also exhibits a positive significant correlation with fresh weight ($r = 0.974$ at $p < 0.05$) and seed length ($r = 0.982$ at $p < 0.05$). Seed germination shows a significant negative correlation with moisture content($r = - 0.978$ at $p < 0.05$) (Table 4.10).

4.3 Phenological variation in relation to environmental factors

4.3.1 Relationship of flowering and fruiting phenology of Hopea parviflora with weather parameters

The Spearman's rank correlation coefficients between the flowering phenology of *Hopea parviflora* and weather parameters are given in Table 4.11. The flowering of *Hopea parviflora* showed a highly significant positive correlation with the maximum temperature ($r_s = 0.533$ at $p < 0.01$) and precipitation ($r_s = 0.699$ at

$p < 0.01$). It also exhibits a highly significant negative correlation with the minimum temperature (r_s= - 0.594 at $p < 0.01$) and relative humidity (r_s= -0.587 at $p < 0.01$).

The fruiting of *Hopea parviflora* exhibits a highly significant positive correlation with maximum temperature (r_s= 0.695 at $p < 0.01$) and it shows a significant negative correlation with relative humidity (r_s= -0.699 at $p < 0.01$) and precipitation (r_s= - 0.508 at $p < 0.05$) (Table 4.12).

4.3.2 Relationship of flowering and fruiting phenology of Kingiodendron pinnatum with weather parameters

The flowering of *Kingiodendron pinnatum* showed a highly significant positive correlation with maximum temperature (r_s= 0.640 at $p < 0.01$). It showed a highly significant negative correlation with the relative humidity (r_s= - 0.647 at $p < 0.01$) and precipitation (r_s= -0.525 at $p < 0.01$) and also did not exhibit any significant correlation with the minimum temperature (Table 4.13).

The fruiting of *Kingiodendron pinnatum* showed a significant positive correlation with maximum temperature (r_s= 0.496 at $p < 0.05$) and shows a significant negative correlation with relative humidity (r_s= -0.477 at $p < 0.05$). It did not exhibit any significance with minimum temperature and precipitation (Table 4.14).

Table 4.9: Pearson's correlation (r) of the fruit and seed maturity parameters of *Hopea parviflora*

Parameters	Fruit length (mm)	Fruit width (mm)	Fresh weight (g)	Moisture content (%)	Seed germination (%)
Fruit length (mm)	1.000				
Fruit width (mm)	0.992**	1.000			
Fresh weight (g)	0.986*	0.984*	1.000		
Moisture content (%)	- 0.655	-0.559	-0.561	1.000	
Seed germination (%)	0.960*	0.916	0.928	-0.829	1.000

* Correlation is significant at the 0 .05 level (2 tailed)

** Correlation is significant at the 0 .01 level (2 tailed)

Table 4.10: Pearson' s correlation coefficient (r) for the fruit and seed maturity of *Kingiodendron pinnatum*

Parameters	Fruit length(mm)	Fruit width(mm)	Seed length(mm)	Seed width (mm)	Fresh weight(g)	Moisture content (%)	Seed germination (%)
Fruit length (mm)	1.000						
Fruit width (mm)	0.984*	1.000					
Seed length (mm)	1.000**	0.982*	1.000				
Seed width (mm)	0.988*	0.994**	0.989*	1.000			
Fresh weight (g)	0.945	0.974*	0.938	0.942	1.000		
Moisture content (%)	-0.763	-0.866	-0.758	-0.835	-0.870	1.000	
Seed germination (%)	0.858	0.935	0.852	0.900	0.953*	-0.978*	1.000

*Correlation is significant at the 0 .05 level (2 tailed)

** Correlation is significant at the 0 .01 level (2 tailed)

Table 4.11: Spearman's rank correlation (r_s) for the flowering of *Hopea parviflora* and different weather parameters

Parameters	Flowering	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Precipitation (mm)
Flowering	1.000				
Maximum temperature (°C)	0.533**	1.000			
Minimum temperature (°C)	-0.594**	0.108	1.000		
Relative humidity (%)	-0.587**	-0.628**	0.470*	1.000	
Precipitation (mm)	0.699**	-0.479*	0.614**	0.805**	1.000

*Correlation is significant at the 0 .05 level (2 tailed)

** Correlation is significant at the 0 .01 level (2 tailed)

Table 4.12: Spearman's rank correlation (r_s) for the fruiting of *Hopea parviflora* and different weather parameters

Parameters	Fruiting	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Precipitation (mm)
Fruiting	1.000				
Maximum temperature (°C)	0.695**	1.000			
Minimum temperature (°C)	-0.100	0.108	1.000		
Relative humidity (%)	-0.699**	-0.628**	0.470*	1.000	
Precipitation (mm)	-0.508*	-0.479*	0.614**	0.805**	1.000

*Correlation is significant at the 0 .05 level (2 tailed)

** Correlation is significant at the 0 .01 level (2 tailed)

Table 4.13: Spearman's rank correlation (r_s) for the flowering of *Kingiodendron pinnatum* and different weather parameters

Parameters	Flowering	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Precipitation (mm)
Flowering	1.000				
Maximum temperature (°C)	0.640**	1.000			
Minimum temperature (°C)	-0.220	0.108	1.000		
Relative humidity (%)	-0.647**	-0.628**	0.470*	1.000	
Precipitation (mm)	-0.525**	-0.479*	0.614**	0.805**	1.000

*Correlation is significant at the 0 .05 level (2 tailed)

** Correlation is significant at the 0 .01 level (2 tailed)

Table 4.14: Spearman's rank correlation (r_s) for the fruiting of *Kingiodendron pinnatum* and different weather parameters

Parameters	Fruiting	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Precipitation (mm)
Fruiting	1.000				
Maximum temperature (°C)	0.496*	1.000			
Minimum temperature (°C)	-0.306	0.108	1.000		
Relative humidity (%)	-0.477*	-0.628**	0.470*	1.000	
Precipitation (mm)	-0.246	-0.479*	0.614**	0.805**	1.000

*Correlation is significant at the 0 .05 level (2 tailed)

** Correlation is significant at the 0 .01 level (2 tailed)

DISCUSSION

V DISCUSSION

The complete information on the phenology and germination requirements of native species along with sound criteria for their proper selection provide strong support to successful ecological restoration projects, *In-situ* and *Ex-situ* gene conservation of RET tree species (Arteaga, 2007).

The study of vegetative and reproductive phases or periodic activities in the life cycle of plants along with their spatial and temporal variations play a significant role in the growth and reproduction of plant species (Nanda *et al*., 2014). Systemic assessment of phenological events enables us to ascertain patterns in the production timing of plant structures. Thus, the information allows the development of fruit-collecting strategies which increase the amount of the quality of seeds or fruits for plant propagation, species diversity, assisted natural regeneration techniques and conservation of very important RET species.

Hence, the present study entitled "Studies on reproductive phenology of *Hopea parviflora* Bedd. and *Kingiodendron pinnatum* (DC.) Harms. in Western Ghats" was carried out during 2021-2022 to investigate the reproductive phenology, seed maturity, phenological variation in relation to environmental factors in *Hopea parviflora* and *Kingiodendron pinnatum* in Makutta territorial range, Kodagu district, Karnataka, India. The results of this study are discussed below.

5.1 Reproductive phenology of *Hopea parviflora* Bedd. and *Kingiodendron pinnatum* (DC.) Harms.

5.1.1 Growth observation of the marked trees

The reproductive phenology of tree species enables the time collection of fruits and seeds for further research. It is evident that the selections of matured trees are important for further reproductive phonological studies. In the study area from the sample plots of ten in the *Hopea parviflora* plots, the mean height of the marked trees was 31.18 m with SD of 2.34 m and Girth at Breast Height (GBH) of 2.28 m with SD of 0.54 m. Similarly, the mean height of *Kingiodendron pinnatum* was 29.45 m with an SD of 1.64 m and Girth at Breast Height (GBH) of 1.92 mm with an SD of 0.37 m from the ten plots sampled.

These observations on the growth characteristics of the two species indicated that the maturity of the tree species and better for the collection of seeds for quality seedling production. In matured trees, prolonged reproductive phonological events will be noticed. Hence recording growth observations with its Geo-coordinates helps the foresters in the collection of fruits and seeds. These growth observations were similar to the studies by Kamarudeen *et al.* (2017), who reported that in evergreen forests, growth characteristics play an important role in attaining the maximum height and girth. These growth characteristics are attributed to the edaphic, climatic and topographic features of the study area.

5.1.2 Floristic diversity studies

Species richness was the simplest way to describe community and regional diversity (Magurran, 1988) and this variable number of species forms the basis of many ecological models of community structure (Macarthur and Wilson, 1967). The species richness of associated species was 22 in *Hopea parviflora* plots and 26 in *Kingiodendron pinnatum* plots respectively.

Similar work was carried out by Maheswarappa and Vasudev (2018) in different landscapes of Kodagu and reported that in evergreen forests the species richness is 49 and which is different from the present study.

Diversity indices were generated to bring the diversity and abundance of species in different habitats to a similar extent for comparison and the higher the value, the greater the species richness, diversity and abundance (Adekunle *et al.,* 2013). The simple measure of species diversity was Shannon's diversity index and it was the most widely used species diversity measure. The highest Shannon-Wiener index (*H'*) of 2.95 was reported in *Kingiodendron pinnatum* plots followed by *Hopea parviflora* plots (2.72). Neikha and Nagaraj (2019) carried out a study in the Brahmagiri wildlife sanctuary, Kodagu, Karnataka. They reported that the Shannon's diversity index is 3.86 which is nearer to the present study.

Maheswarappa and Vasudev (2018) carried out a study in the evergreen forest of Kodagu and reported that the Shannon's diversity index is 3.51 which is similar to the present study.

Simpson's dominance index (D) measures the probability that two individuals randomly selected from a sample will belong to the same species (some category other than species). Simpson's index of dominance the values range between 0 and 1 and the lesser the value more will be the diversity, zero indicates infinite diversity whereas 1 indicates no diversity.

In *Hopea parviflora* plots, the highest Simpson's dominance index (D) value of 0.083 was observed and the lowest was observed in *Kingiodendron pinnatum* plots (0.06). From the results, it is evident that the *Kingiodendron pinnatum* plots were more diverse than the *Hopea parviflora* plots. Neikha and Nagaraj (2019) carried out a study in Makutta wildlife sanctuary, Kodagu, Karnataka. They reported that Simpson's index of dominance is 0.97.

The work carried out by Maheswarappa and Vasudev (2018) in different landscapes of Kodagu reported that in evergreen forests the Simpson's index of dominance is 0.038 which is different from the present study.

The evenness measures a value between 0 and 1 with 1 being complete evenness (Magurran, 2003). The species evenness index in *Knema attenuata* (0.913) plots was more diverse than the *Dipterocarpus indicus* plots (0.836). The species evenness was observed more in *Kingiodendron pinnatum* (0.90) plots than in the *Hopea parviflora* plots (0.88). Maheswarappa and Vasudev (2018) carried out a study in the evergreen forest of Kodagu and reported that the species evenness is 0.687 which is different from the present study.

<u>*5.1.3 Importance value index (IVI) for tree species*</u>

The spatial occupancy of a given landscape by dominant tree species depicts the broad spectrum of population structure indicated through relative density, basal area and frequency of occurrence of the tree species. Based on the individuals recorded in the distinct sample plot, vegetation data were quantitatively analysed for basal area, relative density, and relative dominance. The importance value indices (IVI) of tree species were determined as the sum of relative frequency, relative density, and relative dominance (Curtis and Meintosh 1950).

In *Hopea parviflora* plots, species such as *Hopea parviflora, Drypetes elata, Dipterocarpus indicus, Holigarna arnottiana, Artocarpus hirsutus, Tectona grandis, Diospyros nilagirica, Bacaurea cortallensis, Myristica fatua,* and *Knema attenuata* were the top ten dominant tree species (Fig 5.1). Whereas, in *Kingiodendron pinnatum* plots *Dipterocarpus indicus*, *Hopea parviflora, Knema attenuata, Drypetes elata, Artocarpus hirsutus, Kingiodendron pinnatum*, *Vateria indica, Palaquium ellipticum, Pterygota alata* and *Diospyros nilagirica* were the dominant tree species (Fig 5.2).

The importance value index of *Hopea parviflora* plots reports that *Hopea parviflora* (53.39) was found to be the most dominant tree species followed by *Drypetes elata* (29.43) and *Dipterocarpus indicus* (25.56). The important value index of *Kingiodendron pinnatum* plots *(Table* 4.4*)* reports that *Dipterocarpus indicus* (35.52) was the dominant tree species followed by *Hopea parviflora* (25.58) and *Knema attenuata* (24.85).

Neikha and Nagaraj (2019) carried out a study in the Brahmagiri wildlife sanctuary, Kodagu, Karnataka. They reported that *Hopea parviflora* with an IVI value of 16.69 was the most important species followed by *Vepris bilocularis* (15.23) and *Olea dioica* (13.42).

Karthik and Viswanath (2012) carried out a study in the Makutta forest of Kodagu, Karnataka. They reported that the permanently marked plots are dominated by *Dipterocarpus indicus, Vateria indica and Kingiodendron pinnatum.*

5.1.4 Family importance value index (IVI) for tree species

The family importance value index (IVI) indicates the dominant family present in that area. The dominant families of the *Hopea parviflora* plots were Myristicaceae, Lythraceae, Apocynaceae, Lauraceae and Euphorbiaceae. In *Kingiodendron pinnatum* plots, Dipterocarpaceae, Myristicaceae, Euphorbiaceae, Moraceae and Caesalpiniaceae were the dominant families present. The results of the study indicated that these forests were dominated by Dipterocarpaceae and Myristicaceae family. Similar results were reported by Somasundaram and Vijayan (2010) in Kukkal forest, Palni hills of Southern Western Ghats.

A similar study conducted by Neikha and Nagaraj (2019) in Makutta wildlife sanctuary, Kodagu, Karnataka and the results revealed that the family Anacardiaceae and Dipterocarpaceae dominated the forest canopy cover followed by Calophyllaceae, Fabaceae, Lauraceae, Phyllanthaceae and Meliaceae which is similar to the present study. Mohanan *et al.,* 1997 carried out a study in the Agasthyamalala hills, Southern Western Ghats of Kerala and reported that the Dipterocarpaceae, Myristicaceae and Anacardiacee families are the dominant family in this region which is similar to the present study.

5.1.5 Reproductive phenology

The reproductive phenology of a tree species is paramount in detecting the flower bud initiation, flowering, fruiting and maturation of fruits. In the present study, flower initiation of *Hopea parviflora* was noticed in the last week of January and continued till the last week of March (Plate 5.1). However, as per the earlier literature, the flower initiation was recorded from the start of January and extended up to March. The shift of flower initiation may be attributed to changes in environmental Factors. These observations are in line with studies by Kamarudeen *et al.* (2017) where flower initiation was noticed in January (Fig 5.3). However, the peak flowering recorded in the last week of February in the present research is also on par with earlier studies. Fruit initiation in *Hopea parviflora* was noticed in the last week of February. However, earlier studies indicated there were more days taken for fruit initiation due to colder temperatures, higher moisture retention and even distribution of rainfall. These results are similar to the studies by Kamarudeen *et al.* (2017).

The flowering, flower duration, fruit formation and matured fruit formation vary with individuals within and among tree species. In the present study, flower initiation and flowering duration (FLD) of *Kingiodendron pinnatum* was recorded from the second week of February and continued up to the last week of March. However, as per earlier literature, these observations were very different from the present study where in, flower initiation and flower duration were from the first week of January and continued up to the last week of March. Fruit initiation of

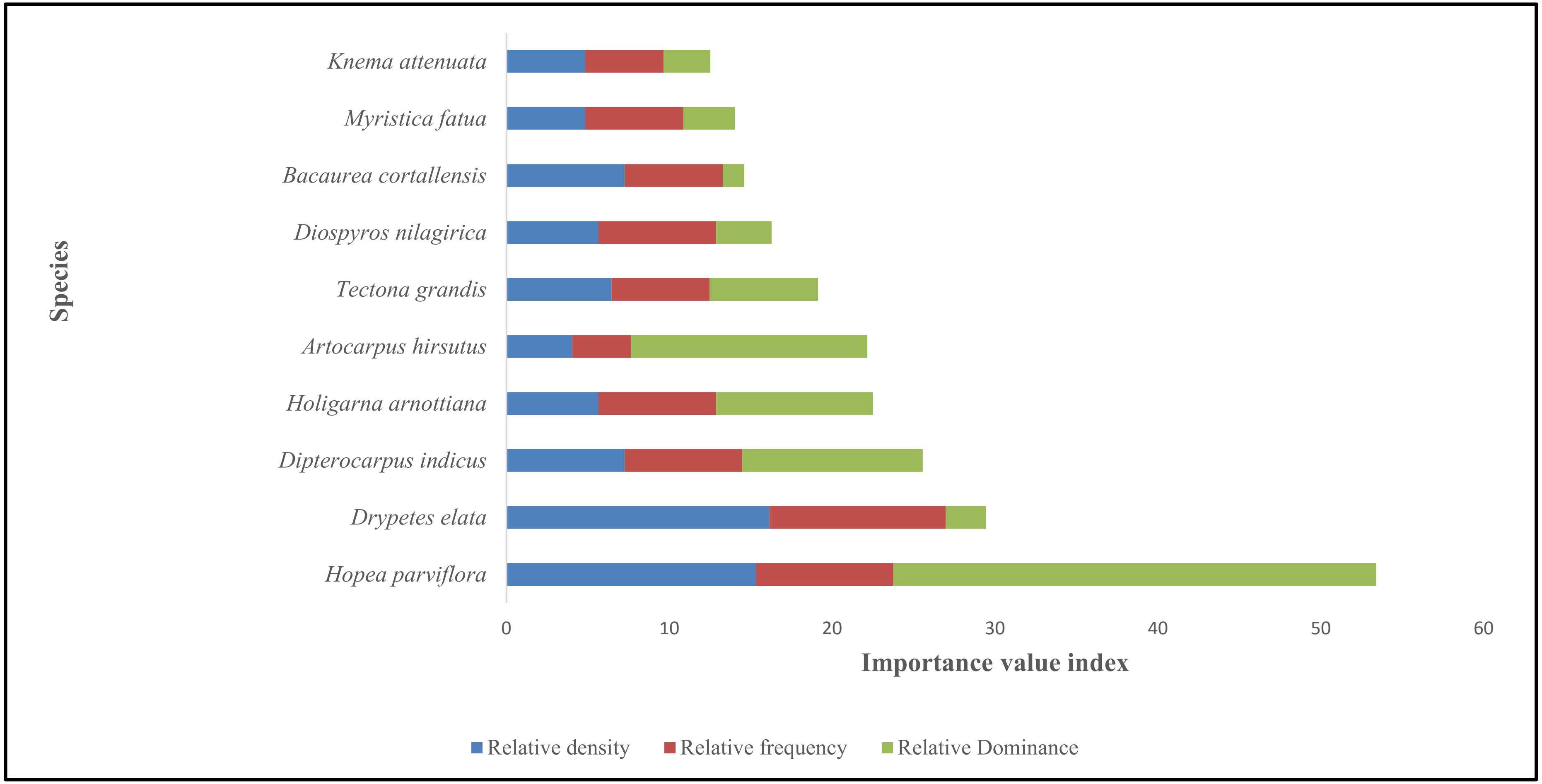


Fig. 5.1: Importance Value Index of *Hopea parviflora* plots

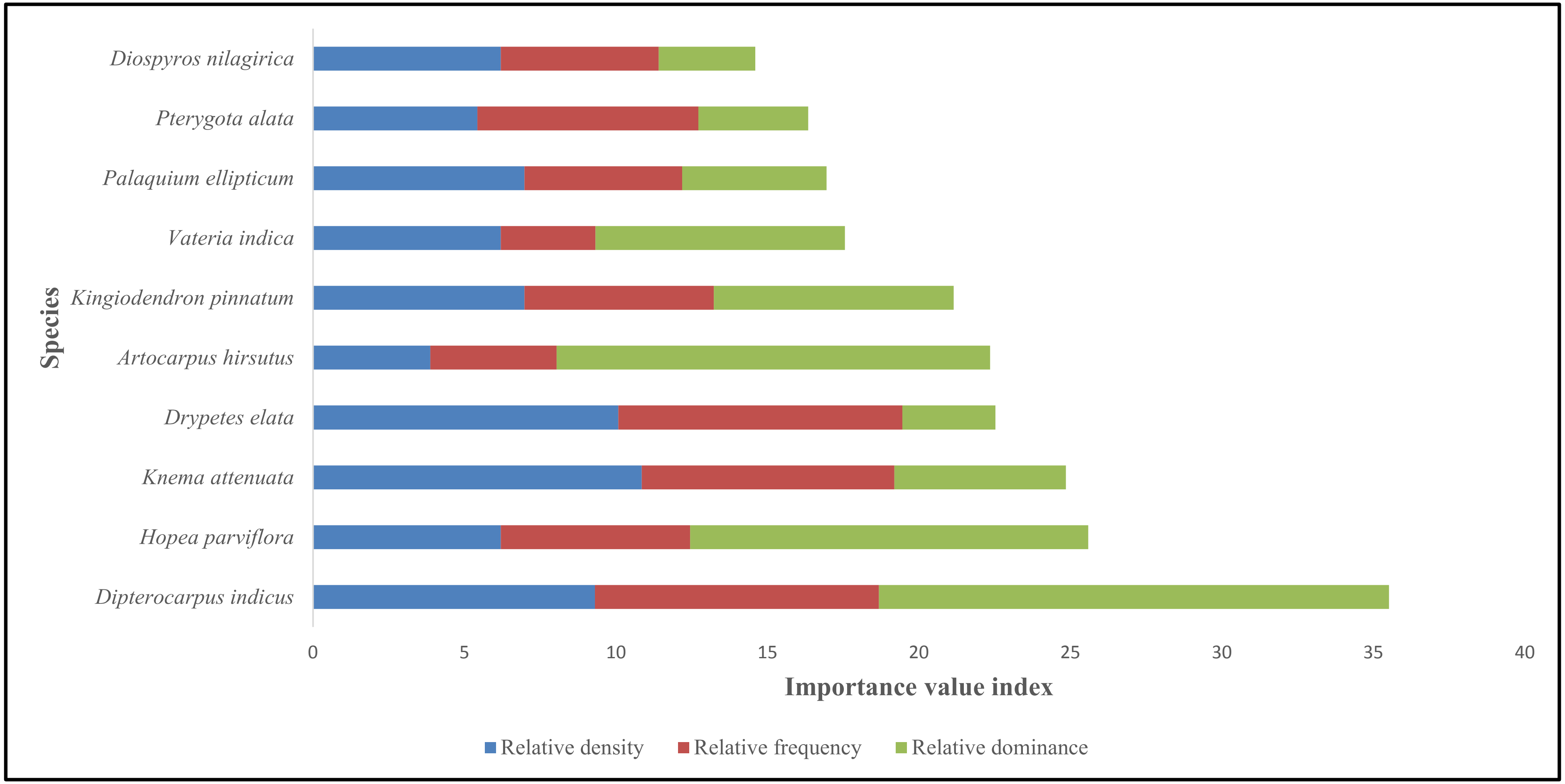
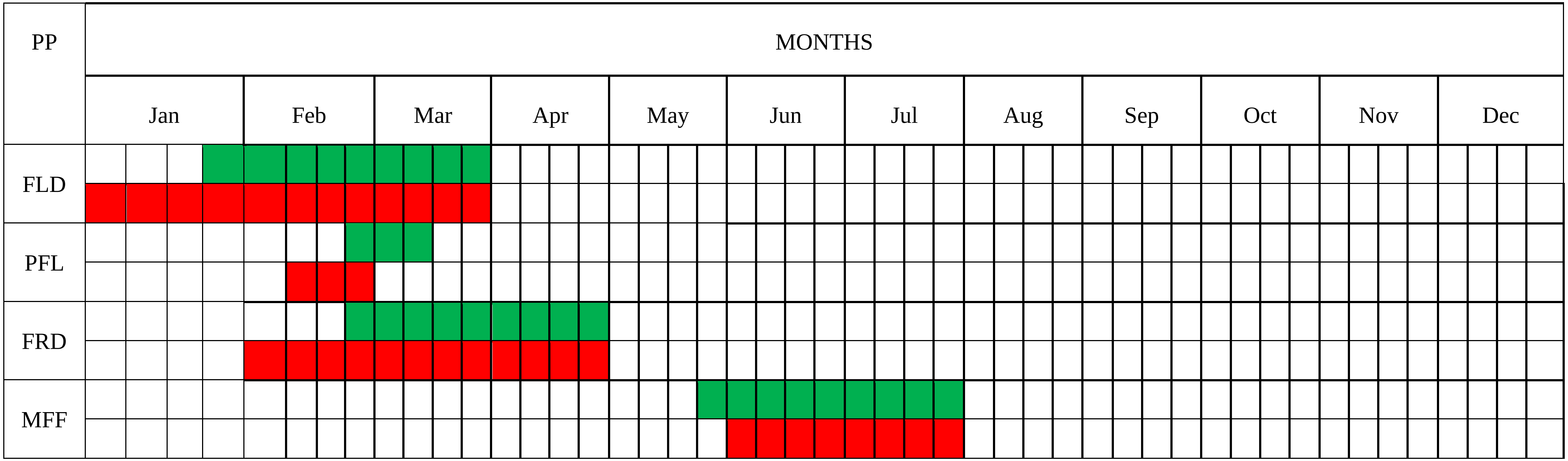


Fig. 5.2: Importance Value Index of *Kingiodendron pinnatum* plots



PP-Phenophase, FLD-Flower duration, PFL-Peak Flowering, FRD-Fruit duration, MFF-Matured Fruit Fall

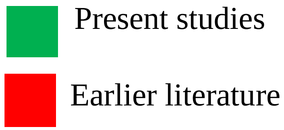
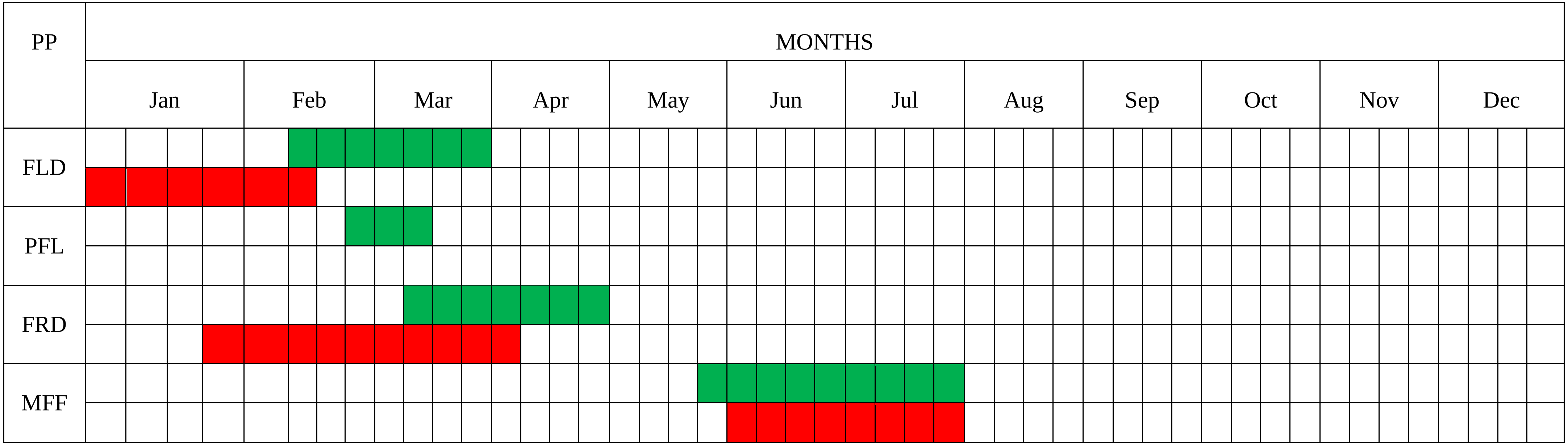


Fig. 5.3: Phenogram of comparison between present and earlier studies in *Hopea parviflora*



PP-Phenophase, FLD-Flower duration, PFL-Peak Flowering, FRD-Fruit duration, MFF-Matured Fruit Fall

Present studies

Earlier literature

Fig. 5.4: Phenogram of comparison between present and earlier studies in *Kingiodendron pinnatum*

Kingiodendron pinnatum in the present study was noticed in the second week of March and continued up to the last week of April (Plate 5.2).

As per earlier literature, there was a prolonged fruit development in these species which was initiated in the last week of January and reminds up to the first week of April. These variations in flower initiation and fruit formation might be due to climate change, *i.e.,* an increase in temperature and uneven distribution of rainfall. The matured fruit fall almost lies with the rainy season where in it starts from the last week of May and remained until the last week of July (Fig 5.4). The similar observations were recorded by Anonymous (2017), reported that fruit collection can be initiated from May onwards. The results of present study are in line with study conducted by Meha and Kevin (2022). These observations are also helpful for foresters, researchers and scientists to collect the seeds for the conservation of important RET species.

5.2 Different stages of fruit and seed development

5.2.1 Fruit or seed colour

The fertilisation to harvest, fruits or seeds undergo a series of physiochemical changes and the sum of total of which is called seed maturation (Grassi *et al*., 1973). It is essential to know the occurrence of various sequential changes taking place during the fruit or seed development at maturation because the self-life of the fruit or seed is directly related to the level of maturity of the fruit or seed at the time of harvest (Bharathi, 1999).

Changes in the fruit and seed colour are the physiological process which indicates the maturation of fruit or seed. These changes are due to environmental factors which contribute to early or late expressions of hormones. In stressed conditions, there will be early changes in fruit or seed colour. In all the plant species, initially the fruit colour or seed colour will be green and later it changes to yellow or brown colour which indicates the maturity of the fruit or seed for collection.

In the present study, the colour of the *Hopea parviflora* fruit changed over the collections at monthly intervals from the initiation of fruit development. The colour was yellowish green in the first collection, then turned to green and changed to brown in the final collection (Plate 5.3).

The colour of the *Kingiodendron pinnatum* fruit changed from green in the first collection to dark brown in the final collection whereas the colour of the seed was creamy white in the first collection and changed to brown in the final collection from the initiation of the fruit development (Plate 5.4).

Similar observations were reported from the study done by Kamarudeen *et al.* (2017) in *Hopea parviflora*, in which the colour changes gradually from yellowish green to brown. The results from the study by Singh and Saralch (2013) in *Gmelina arborea* were in line with the results of the present study and colour change is the indicator of fruit maturity.

5.2.2 Fruit or seed size

The fruit or seed size varies with the tree species depending upon the nature of seed dispersal. The viviparity of seeds enables long-distance dispersals of seeds. However, the fruit or seed development is particularly attributed to edaphic factors and climatic factors such as rainfall, temperature and relative humidity of the area. The size of the *Hopea parviflora* fruit increased over the collections at monthly intervals from the initiation of fruit development. The mean length and breadth of the *Hopea parviflora* fruits increased during their development *i.e.,* 5.83 ± 1.32 mm to 12.54 ± 1.46 mm and 2.84 ± 0.74 mm to 7.98 ± 0.67 mm respectively (Plate 5.5).

The mean length and breadth of *Kingiodendron pinnatum* fruits increased from 17.35 ± 2.15 mm to 36.41 ± 3.13 mm and 12.45 ± 1.46 mm to 26.93 ± 3.42 mm, respectively. The mean length and breadth of *Kingiodendron pinnatum* seeds increased from 11.02 ± 1.27 mm to 32.43 ± 4.61 mm and 8.1±0.52 mm to 25.93 ± 3.45 mm, respectively. From the results, it is evident that the fruit and seed size of *Hopea parviflora* and *Kingiodendron pinnatum* increased over the collections. Similar findings were reported by Kamarudeen *et al*. (2017), the results from their study reveal that the length and breadth of *Hopea parviflora* fruits increased over the collections.

5.2.3 Fresh weight of the fruit or seed

Measuring the fresh weight of fruit or seed depicts the quality of the seed, where more of the food is stored for further quality production of seedlings. However, the initial collection of fruit or seed measures lesser fresh weight as compared to later development stages of its maturity.

The fresh weight of the *Hopea parviflora* fruit increased over the collections at monthly intervals from the initiation of fruit development. The fresh weight of the 100 fruits was 15.64 g in the first collection and increased to 38.52 g in the last collection. The fresh weight of 100 *Kingiodendron pinnatum* seeds was 183.54 g in the first collection and increased to 434.25 g in the last collection.

The results from the study infer that the weight of fruits/seeds of both species gradually increased over the collections and was recorded highest in the final collection. Similar results were reported by Kamarudeen *et al.* (2017).

5.2.4 Seed germination (%)

Seed germination is a parameter which indicates the quality and maturity of seeds of a particular tree species. Seed germination is a characteristic of both

Flowers

Pre-mature fruit fall

Fruits

Mature fruits

Plate 5.1: Phenological events of *Hopea parviflora*

Flower

Fruit primordia

Mature fruits

Plate 5.2: Phenological events of *Kingiodendron pinnatum*


Plate 5.3: Observed fruit and seed colour of *Hopea parviflora*


Plate 5.4: Observed fruit and seed colour of *Kingiodendron pinnatum*

Plate 5.5: Measurement of fruits and seeds dimensions in *Hopea parviflora*

exogenous and endogenous factors. The germination percentage in *Hopea parviflora* was highest in the final collection and 47 % of germination was observed.

In *Kingiodendron pinnatum* germination percentage of 63 % was recorded in the final collection. From the results, it is evident that the seeds from the final collections showed the highest germination percentage when compared to the previous collections.

The germination results obtained in the present study are in line with the results of the study conducted by Singh and Saralch (2013) in *Gmelina arborea,* the better germination was observed in final collections.

5.2.5 Moisture content of the fruit or seed (%)

The moisture content of *Hopea parviflora* fruits recorded in the first collection was 52.23 % and 45.24 % in the last collection. The moisture content of the *Kingiodendron pinnatum* seeds was 54.32 % in the first collection and 42.45 % in the last collection. From the results, it is evident that the moisture content of *Hopea parviflora* fruits and *Kingiodendron pinnatum* seeds decreased over the collections. The initial moisture content was reduced over the collections when the seed attained maturity. However, the dry matter accumulation drastically increased with the reduction in moisture content. Similar findings were reported from the study carried out by Kamarudeen *et al.* (2017) in *Hopea parviflora.*

5.2.5 Correlation analysis

The correlation studies were carried out to know the relationship between the physical parameters and the germination of seeds. The fruit length showed a significant positive correlation with fresh weight (r=0.986 at $p < 0.05$) and seed germination (r=0.960 at $p < 0.05$). Fruit length also shows a positive and highly significant correlation with fruit width (r= 0.992 at $p < 0.01$). Fresh weight shows s significant positive correlation with fruit breadth.

The fruit length of the *Kingiodendron pinnatum* showed a highly significant positive correlation with seed length (r=1 at $p < 0.01$) and it also exhibited significant positive correlation with fruit width and seed width. Fruit width shows d highly significant positive correlation with seed width and it also exhibits a positive significant correlation with fresh weight (r= 0.974 at $p < 0.05$) and seed length (r= 0.982 at $p < 0.05$). Seed germination shows a significant negative correlation with moisture content(r= -0.978 at $p < 0.05$**)**.

Similar observations were recorded by Anusha *et al*. (2021) where the fruit weight of *Gymnacranthera canarica* shows a significant positive correlation between rind weight, fruit length, seed length, seed breadth, fruit breadth, and aril weight. A strong correlation was seen between fruit weight and rind weight (r = 0.994).

Seed weight shows a correlation with seed length (r = 0.964), followed by seed breadth, rind weight, fruit length, fruit breadth, and aril weight.

5.3 Phenological variation in relation to environmental factors

5.3.1 Relationship of flowering and fruiting phenology of Hopea parviflora with weather parameters

The Spearman's rank correlation coefficients between the flowering phenology of *Hopea parviflora* and weather parameters. The flowering of *Hopea parviflora* showed a highly significant positive correlation with the maximum temperature (r_s= 0.533 at $p < 0.01$) and precipitation (r_s= 0.699 at $p < 0.01$). It also exhibits a highly significant negative correlation with the minimum temperature (r_s= -0.594 at $p < 0.01$) and relative humidity (r_s= -0.587 at $p < 0.01$).

The fruiting of *Hopea parviflora* exhibits a highly significant positive correlation with maximum temperature (r_s= 0.695 at $p < 0.01$) and it shows a significant negative correlation with relative humidity and precipitation. These results are in line with Nadarajan and Pujari (2018) opined that the correlation experiments showed that flowering of *Syzygium caryophyllatum* was significantly and positively correlated with temperature (r_s = 0.500 for 2012–2013; r_s = 0.788 for 2013–2014; r_s = 0.792 for 2014–2015). However, there was no significant correlation between flowering and precipitation. Fruiting was positively correlated with precipitation (r_s = 0.706 for 2012–2013; r_s = 0.663 for 2013–2014; r_s = 0.887 for 2014–2015).

5.3.2 Relationship of flowering and fruiting phenology of Kingiodendron pinnatum with weather parameters

The flowering of *Kingiodendron pinnatum* showed a highly significant positive correlation with maximum temperature (r_s= 0.640 at $p < 0.01$). It showed a highly significant negative correlation with the relative humidity (r_s= -0.647 at $p < 0.01$) and precipitation (r_s= -0.525 at $p < 0.01$) and also did not exhibit any significant correlation with the minimum temperature.

The fruiting of *Kingiodendron pinnatum* showed a significant positive correlation with maximum temperature (r_s= 0.496 at $p < 0.05$) and shows a significant negative correlation with relative humidity (r_s= -0.477 at $p < 0.05$). It did not exhibit any significance with minimum temperature and precipitation. These results are also similar to the work of Ramasubbu and Kasi (2021) who opined that the Spearman's rank correlation coefficient for the flowering and fruiting of *Eleocarpus gaussenii* was positive and significantly correlated with the temperature and rainfall.

5.4 Future line of work

- Since both species belong to the RET category, the nursery techniques for the production of seedlings has to be carried out.
- Seed handling and seed storage techniques can be developed for both the species.
- Germplasm conservation can be done in order to protect the species from being extinct.

SUMMARY

VI SUMMARY

The present study entitled "Studies on reproductive phenology of *Hopea parviflora* Bedd. and *Kingiodendron pinnatum* (DC.) Harms. in Western Ghats" was carried out during 2021-2022 to investigate the reproductive phenology, seed maturity and phenological variation in relation to environmental factors in *Hopea parviflora and Kingiodendron pinnatum* in Makutta territorial range, Kodagu district, Karnataka, India. The findings of the present study are summarized below.

Objective 1: To study the reproductive phenology of *Hopea parviflora* Bedd. and *Kingiodendron pinnatum* (DC.) Harms.

- The average height of the marked *Hopea parviflora* trees was 31.18 ± 2.34 m with a range of 27.4 m to 34.6 m and the average GBH was 2.28 ± 0.54 m with a range of 1.65 m to 3.34 m respectively.
- The average height of the marked *Kingiodendron pinnatum* trees was 29.45±1.64 m with a range of 27.1 m to 32.3 m and the average GBH was 1.92 ± 0.37 m with a range of 1.35 m to 2.62 m respectively.
- The species richness of associated species was 22 in *Hopea parviflora* plots and 26 in *Kingiodendron pinnatum* plots respectively.
- The highest Shannon-Wiener index (*H'*) of 2.95 was reported in *Kingiodendron pinnatum* plots followed by *Hopea parviflora* plots (2.72).
- In *Hopea parviflora* plots, the highest Simpson's dominance index (D) value of 0.083 was observed and the lowest was observed in *Kingiodendron pinnatum* Plots (0.06). From the results, it is evident that the *Kingiodendron pinnatum* plots were more diverse than *Hopea parviflora* the plots.
- The species evenness was observed more in *Kingiodendron pinnatum* (0.90) plots than in the *Hopea parviflora* plots (0.88).
- In *Hopea parviflora* plots, species such as *Hopea parviflora, Drypetes elata, Dipterocarpus indicus, Holigarna arnottiana, Artocarpus hirsutus, Tectona grandis, Diospyros nilagirica, Bacaurea cortallensis, Myristica fatua,* and *Knema attenuata* were the top ten dominant tree species.
- In *Kingiodendron pinnatum* plots, *Dipterocarpus indicus*, *Hopea parviflora, Knema attenuata, Drypetes elata, Artocarpus hirsutus, Kingiodendron pinnatum*, *Vateria indica, Palaquium ellipticum, Pterygota alata* and *Diospyros nilagirica* were the dominant tree species.
- The dominant families of the *Hopea parviflora* plots were Myristicaceae, Lythraceae, Apocynaceae, Lauraceae and Euphorbiaceae.

- In *Kingiodendron pinnatum* plots, Dipterocarpaceae, Myristicaceae, Euphorbiaceae, Moraceae and Caesalpiniaceae were the dominant families present.
- The flowering in *Hopea parviflora* started in the last week of January and continued till March. Peak flowering was observed during the last week of February. The fruit initiation started from February to April. The mature fruit fall was observed from the end of May till July.
- The flowering in *Kingiodendron pinnatum* was initiated in the second week of February and extended up to March and peak flowering was observed during mid-March. The fruit initiation started in the second week of March. The mature fruit fall was observed from the last week of May up to July.

Objective 2: To understand the different stages of fruit and seed development

- The colour of the *Hopea parviflora* fruit changed over the collections at monthly intervals from the initiation of fruit development. The colour was yellowish green in the first collection, then turned to green and changed to brown in the final collection.
- The colour of the *Kingiodendron pinnatum* fruit changed from green in the first collection to dark brown in the final collection whereas the colour of the seed was creamy white in the first collection and changed to brown in the final collection from the initiation of the fruit development.
- The mean length and breadth of the *Hopea parviflora* fruits increased during their development *i.e.,* 5.83 ± 1.32 mm to 12.54 ± 1.46 mm and 2.84 ± 0.74 mm to 7.98 ± 0.67 mm respectively.
- The mean length and breadth of *Kingiodendron pinnatum* fruits increased from 17.35 ± 2.15 mm to 36.41 ± 3.13 mm and 12.45 ± 1.46 mm to 26.93 ± 3.42 mm, respectively.
- The mean length and breadth of *Kingiodendron pinnatum* seeds increased from 11.02 ± 1.27 mm to 32.43 ± 4.61 mm and 8.1±0.52 mm to 25.93 ± 3.45 mm, respectively.
- The fresh weight of the 100 fruits was 15.64 g in the first collection and increased to 38.52 g in the last collection.
- The fresh weight of 100 *Kingiodendron pinnatum* seeds was 183.54 g in the first collection and increased to 434.25 g in the last collection.
- The germination percentage in *Hopea parviflora* was highest in the final collection and 47 % of germination was observed.

- In *Kingiodendron pinnatum* germination percentage of 63 % was recorded in the final collection.
- The moisture content of *Hopea parviflora* fruits recorded in the first collection was 52.23 % and 45.24 % in the last collection.
- The moisture content of the *Kingiodendron pinnatum* seeds was 54.32 % in the first collection and 42.45 % in the last collection.
- In *Hopea parviflora,* the fruit length showed a significant positive correlation with fresh weight ($r=0.986$ at $p < 0.05$) and seed germination ($r=0.960$ at $p < 0.05$). Fruit length also shows a positive and highly significant correlation with fruit width ($r=0.992$ at $p < 0.01$). Fresh weight shows a significant positive correlation with fruit breadth.
- The fruit length of the *Kingiodendron pinnatum* showed a highly significant positive correlation with seed length ($r=1$ at $p < 0.01$) and it also exhibit a significant positive correlation with fruit width and seed width. Fruit width showed a highly significant positive correlation with seed width and it also exhibits a positive significant correlation with fresh weight ($r=0.974$ at $p < 0.05$) and seed length ($r=0.982$ at $p < 0.05$). Seed germination shows a significant negative correlation with moisture content.

Objective 3: To understand the phenological variation in relation to environmental factors

- The flowering of *Hopea parviflora* showed a highly significant positive correlation with the maximum temperature ($r_s= 0.533$ at $p < 0.01$) and precipitation ($r_s= 0.699$ at $p < 0.01$). It also exhibits a highly significant negative correlation with the minimum temperature ($r_s= -0.594$ at $p < 0.01$) and relative humidity ($r_s= -0.587$ at $p < 0.01$).
- The fruiting of *Hopea parviflora* exhibits a highly significant positive correlation with maximum temperature ($r_s= 0.695$ at $p < 0.01$) and it shows a significant negative correlation with relative humidity and precipitation.
- The flowering of *Kingiodendron pinnatum* showed a highly significant positive correlation with maximum temperature ($r_s=0.640$ at $p < 0.01$). It showed a highly significant negative correlation with the relative humidity ($r_s= -0.647$ at $p < 0.01$) and precipitation ($r_s= -0.525$ at $p < 0.01$) and also did not exhibit any significant correlation with the minimum temperature.
- The fruiting of *Kingiodendron pinnatum* showed a significant positive correlation with maximum temperature ($r_s= 0.496$ at $p < 0.05$) and shows a significant negative correlation with relative humidity ($r_s= -0.477$ at $p < 0.05$). It did not exhibit any significance with minimum temperature and precipitation.

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APPENDICES

VIII APPENDICES

Appendix 1: Monthly average rainfall, maximum and minimum temperature during the study period from December 2021 to December 2022

Month	Mean maximum temperature (°C)	Mean minimum temperature (°C)	Average rainfall (mm)
December-2021	30.83	20.31	17.71
January-2022	28.41	19.54	7.65
February-2022	31.92	20.75	2.14
March-2022	33.98	22.61	36.25
April-2022	32.39	24.08	97.42
May-2022	28.82	23.43	347.92
June-2022	27.48	22.58	309.17
July-2022	25.97	22.27	773.50
August-2022	26.05	21.96	700.02
September-2022	26.78	21.90	210.72
October-2022	27.23	21.62	155.11
November-2022	27.15	21.04	75.71
December-2022	27.29	20.67	112.39

Appendix 2: Mean annual distribution of rainfall, maximum and minimum temperature of the study area from 2011- 2021

Year	Average rainfall (mm)	Mean annual maximum temperature (°C)	Mean annual minimum temperature (°C)	Mean annual Relative humidity (%)
2011	3232.62	35.87	14.71	79.81
2012	2678.91	36.83	16.67	78.81
2013	4129.1	37.18	15.87	79.62
2014	3601.76	37.37	16.50	79.75
2015	2383.59	35.73	15.81	80.50
2016	1750.78	37.50	15.99	77.19
2017	2114.65	36.90	17.19	78.75
2018	2336.13	36.58	16.33	78.56
2019	2552.34	37.62	16.71	77.75
2020	2742.19	37.81	17.25	80.19
2021	2940.17	36.64	17.20	82.38