Variation in leaf mass per unit area (LMA) and phenological traits between evergreen and deciduous species in a seasonally dry tropical forest of northern Western Ghats

Thesis submitted towards the partial fulfilment of

BS-MS Dual degree programme

By

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Pune

Certificate

This is to certify that this dissertation entitled Variation in leaf mass per unit area (LMA) and phenological traits between evergreen and deciduous species in a seasonally dry tropical forest of northern Western Ghats towards the partial fulfilment of the BS-MS dual degree programme at the Indian Institute of Science Education and Research (IISER), Pune represents original research carried out by *Sheetal Sharma, Reg No.* 20091101 at IISER Pune under the supervision of *Dr.Deepak Barua,* Biology Division, IISER Pune during the academic year 2013-2014.

Date: Signature of the Supervisor(s)

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Declaration

I hereby declare that the matter embodied in the thesis entitled Variation in leaf mass per unit area (LMA) and phenological traits between evergreen and deciduous species in a seasonally dry tropical forest of northern Western Ghats is the result of the investigations carried out by me at the Biology division, IISER Pune under the supervision of Dr. Deepak Barua and the same has not been submitted elsewhere for any other degree.

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Contents

Abstract

There is considerable variation both within and among tropical forests and forest types in leaf structural characteristics or leaf traits. Leaf traits have several consequences of ecosystem functioning through processes of primary production, trophic transfer, etc. LMA is a key leaf trait shown to be correlated with other primary leaf traits. This study done with 76 species from Bhimashankar Wildlife Sanctuary, located in the northern extreme of Western Ghats, documents variation in LMA with light environment (habitat types), leaf habit, plant habit, and phenological traits - average canopy, duration of deciduousness, month of peak flush and month of peak senescence. Leaf area and LMA varied significantly among species both for mature and recently flushed (immature) leaves. LMA differed significantly between different plant habits and leaf habits in case of both mature and immature leaves. LMA of mature leaves differed significantly with month of peak flush. Light environment and month of peak senescence had no significant effect on LMA of mature as well as that of immature leaves. LMA (mature) was positively correlated with average canopy and negatively correlated with duration of deciduousness. The difference in LMA of mature and immature leaves did not differ for different leaf habits. It was positively correlated with average canopy, but showed no correlation with duration of deciduousness.

List of Figures

List of Tables

Acknowledgements

I would like to thank my supervisor Dr Deepak Barua for his valuable guidance and support throughout the project. The phenology data used was primarily collected by Shatarupa Ganguly and Souparna Chakraborty. I would also like to thank Shatarupa Ganguly for helping with the leaf collection and processing in the lab. Field assistants Kalu and Ganpath from Nigdale village near Bhimashankar Wildlife Sanctuary, also helped with the leaf collection and phenology monitoring. I would also thank Aboli Kulkarni, Kajal Patel, and Aniruddh Shastry. For kindly helping me for various things, I would finally thank Brihaspati Kumar Gaurav.

Introduction

Leaf is a primary photosynthetic organ of plants. Photosynthesis is one of the most important chemical reactions in the world converting the radiant energy of sun to chemical energy utilized by most living organisms on the earth. Photosynthate synthesized by the plant is employed in the construction of leaves; which in turn return ample photosynthates over their lifetime to the plant. These are then further employed to acquire mineral nutrients from the soil, carry out metabolism and in construction of the next generation of leaves. All these processes involve the acquirement and utilization of light, water, CO_2 and mineral nutrients; a characteristic of vascular land plants. Ecological differences arise in them on account of different strategies of acquiring these resources (Westoby et al., 2002). Across species the construction, lifespan and relative allocation of leaves, stem, roots and seeds varies. They are the result of different ecological strategy adapted by the species for securing carbon profit at the time of vegetative growth and ensuring the transmission of their genes into the next generation. This investment and reutilization of resources is economic in nature (Bloom et al., 1985; Givnish, 1986; Orians and Solbrig, 1977).

There is considerable variation both within and among tropical forests and forest types in leaf structural characteristics or leaf traits. Leaf traits have several consequences of ecosystem functioning through processes of primary production, trophic transfer; biogeochemical cycles are driven by several processes which involve carbon assimilation, nitrogen uptake, and decomposition of leaves (Díaz et al., 1998).

Focussing upon the key leaf traits which can give a picture of the leaf economics spectrum proposed by Wright et al. (2004):

1) Leaf mass per unit area (LMA) – it is the dry mass investment by the plant per unit area of the leaf. It iso be a key trait inter-related with other leaf trait.
2) Photosynthetic assimilation – carbon gains of the plant
3) Leaf nitrogen content – involved with photosynthetic component within the leaf (RUBISCO)

4) Leaf phosphorus content – it is mostly found in nucleic acids, bioenergetic molecules and lipid membranes
5) Dark respiration rate – is the photosynthate metabolically utilizied in the leaf
6) Leaf life span (LL) – duration on which the leaf returns the revenue invested in its construction by the plant

These traits occupy a central position in defining trends in variation of leaf function because they bear on the costs of leaf construction and photosynthetic functions that repay those costs over the life span of the leaf; also they bring about a wider and ecologically more consistent range of interspecific variation than other leaf traits. Wright et al. 2004 pooled data for 2,548 plant species from 218 families and 175 sites across the globe and showed definitively that photosynthetic assimilation, LMA, leaf nitrogen content, and leaf longevity were indeed integral parts of what they called the leaf economic spectrum. Their data documented the range of values to be expected for the key traits as well as the correlations among them: photosynthetic assimilation ranged from 5 to 660 nmol g^{-1} s^{-1}, leaf nitrogen content ranged from 0.2% to 6.4%, LMA ranged from 14 to 1,500 g m^{-2}, and leaf longevityranged from 0.9 to 288 months. They were able to compare values on a mass versus area basis and found that the correlations among traits were strongest when expressed on a mass basis.

This spectrum runs from species with a potential for fast growth accompanied with a rapid turnover of large and thin leaves with high carbon assimilation rates per unnit dry mass. Leaf respiration and photosynthesis rates are high; also leaf nutrient content is high wither shorter leaf life span and lower dry mass investment per unit area. Leaf defense especially physical defense is lower as otherwise their maintenance costs would then lower the growth rate. At the other end of the spectrum are species which much lower metabolic rate. They are species with longer leaf periods, higher nutrient content, higher LMA and lower photosynthetic and respiration rates. Conservation of resources and persistence are also prominent. They have long lived tissues (tougher leaves) which conserve resources and sustain growth for a longer period of time. Those species falling in the intermediate group are most flexible, producing high investment and high returning leaves in favoutable conditions

Climate effect on leaf trait relationship is modest but particular trait – pairs show significant differences with climate (Wright et al., 2004). Coordination of the key leaf traits is consistent across major plant functional types, growth forms and biomes. There are several traits that characterize leaves. Leaves vary in size, shape, texture and even in anatomical, chemical and physiological ways. Given a tree, they vary with their position at a given time, with age of the tree, growth environment of the tree and among individuals of the same species due to genetic and environmental factors. But characteristic trends are seen in leaves among groups of species within a forest or in types of forest along environmental gradients (rainfall, altitude). Leaf form/trait is important characteristic in defining tropical forest structure. A host of other traits (not a part of this study) are known to have effects on leaf traits and their correlative traits. Environmental factors and phenology of trees have relations with leaf traits. Taking LMA as the central trait, these relationships can be analysed.

Kikuzawa (1991) described LL as property of individual leaves while leaf habit (evergreenness and deciduousness) as property of population of leaves. Evergreen species have a much higher LMA compared to deciduous. Evergreen species do not lose their canopy completely unlike deciduous species which show 0% assimilation rate in the dry season. Thus evergreens have the whole year to photosynthesize and return their carbon gains to the plant while deciduous species have a limited life span of a few months and thus they need to have higher photosynthesis rates in order to cope up with the rate of returning the investment put in by the plant. So the deciduous mostly are seen to invest in photosynthetic tissue rather than supporting tissue which is other way round for evergreens. Thus, summarizing evergreens have a higher LMA, higher LL, low assimilation and low nutreint content than deciduous species (Reich et al., 1992; Westoby et al., 2002).

For studing the differences in evergreen and deciduous species there needs to be a clear demarkating line between the two, supposedly which would help to study them in a more consise manner. While moving from deciduous to evergreen species there is not a sudden change in the habitat but instead there are several intermediate stages to cross depending on their extent of deciduousness and evergreeness.

	Deciduous	Evergreen

Leaves	mesophytic	sclerophyllus
Canopy	Leafless in dry season	High canopy level throughout the year
Assimilation in dry season	Approaches zero	Declines but residual amt is present
Phenological traits (leafing, flowering)	No general pattern(site dependent) VARIES	No general pattern (site dependent) VARIES
Soil conditions	Fertile, rich in nutrients	Low fertility
Leaf economic spectrum (↑:increasing, ↓: decreasing)	↓LMA, ↓LL, ↑photosynthesis, ↑N, ↑P, ↑respiration (R_{mass})	↑LMA, ↑LL, ↓photosynthesis, ↓N, ↓P, ↓respiration (R_{mass})

Table1. A summary of differences between evergreen and deciduous species

Leaf traits are known to vary to a great extent depending upon the type of plant (evergreen/deciduous, tree/shrub) and the type of leaf (immature/mature, simple/compound leaf).

LMA is an indicator of plant strategy. It is the dry mass of the leaf per unit leaf area measured. Dry mass is a measure of investment in ecological studies as it probably reflects the amount of photosynthate involved in construction and maintenance. Leaf area a measure of the portion of the leaf exposed to the environment for photosynthesis and the pressure of herbivore and pathogens. LMA is easier to measure than internal volumes; thus

Increase in leaf thickness and density resulted in higher LMA; and accumulation of photosynthetic compounds per unit leaf area (NIINEMETS, 1999). Higher LMA species tend to achieve higher average leaf life span (Westoby et al., 2002; Williams-Linera, 2000). Species wherin the leaves thus exposed to environmental pressure for a longer period thus require proportionally greater carbon than nutrient investment (cell walls, waxy cuticles etc) and a dense structure. Longer leaf life spans are achieved by high C/N ratios and tougher leaves that help in protection from herbivores and wear and tear in the environment (Reich et al., 1999). Tougher leaves here belong to those species which have lower nutrient content, variety of secondary metabolites (Coley and Barone, 1996). Higher LMA thus implies greater tissue density and more allocation to structural rather than photosynthetic components enhancing leaf strength. In other words, the LMA-LL relationship is a trade-off between potential rate of return per leaf mass and duration of return of the investments made by the plant (Westoby et al., 2002).

Leaf is an investment on part of the plant. Kikuzawa predicted the theory for leaf life span which depicted the curve of cumulative return (expressed as net dry mass gain per unit leaf area) from the investment in the leaf put in by the plant. The costs include cost of leaf respiration and of root and stem activity to carry out photosynthesis in the leaf. Due to investment in constructing the leaf (dry mass per unit area) the return in initial stages is negative but becomes positive with increasing life span of the leaf. The optimum cumulative return and the lifespan of the leaf at which it is attained shift to longer lifespan if the initial investment is higher (high LMA). After a certain life span the leaf no longer returns net dry-mass revenue; this is the onset of the senescence phase of the leaf (Kikuzawa, 1995, Westoby et al., 2002).

In seasonally dry tropics, species respond to the timing of wet and dry periods and newly flushed leaves and senescing leaves are seen according to season. These leaf dynamics are highly variable when considered at the level of the canopy of a single forest. The evergreen habit of trees can be contributed by leaves that persist over many months (or years) or by overlapping generations of fairly short-lived leaves. The recording of broad patterns of phenology at the tree or forest level can help track the complexity in leaf dynamics. Focussing on leaf phenology is merited if for no other reason; that leaves are the most essential photosynthetic organs. Among the most other leaf traits, the most broadly relevant is LMA. LMA is strongly correlated with other leaf traits leaf life span (LL), photosynthetic activity, leaf nutrient content (Wright et al., 2004).

Species with low LMA tend to have higher photosynthetic capacity per unit leaf mass (Reich et al., 1997). These species have more light capture area per unit mass they generally have higher leaf nitrogen concentration (which is a reflection of concentration of RUBISCO and other photosynthetic proteins) Thus leaves with higher leaf nitrogen concentration are more attractive nutritionally and thus run the risks of higher herbivory and thus have a reduced life span. These species which grow fast and have a higher photosynthetic rate would be at a loss energetically and competitively if they maintained leaves with longer life span. Because this would not permmit for appropriate allocation of resources for other parts of the plant roots, stems etc. The plant would not thus grow tall enough to reach the portion of the canopy intercepted by light which is extremely necessary for species with high photosynthetic rate.

On the other hand, species with high LMA have lower nitrogen content in leaves because they have a greater concentration of fibers; cell walls etc and have thus less photosynthetic machinery. They are generally slow growing in low light, low nutrient content and environmentally poor conditions. Here the nutrient use efficiency is probably more important than higher growth potential. They tend to have thicker leaves with low nitrogen content, high LMA, long life span and lower photosynthetic rates.

A focus on the phenology of leaves is highly important if for no other reason than that leaves are the most essential reason that leaves are the important photosynthetic organs. The defining characteristic of leaf phenlogy in seasonally dry tropics is the seasonality in presence and production of leaves.

Phenology is extremely sensitive to the environment; thus is an indicator of plants response to changing environment. The early response which plants manifest on account of changes in environment can be as a result of changing vegetative phenology. Phenological events occurring in tree species include the timing and duration of leafing, flowering and fruiting. Phenological processes are influenced by a wide array of biological (biotic) and physical (abiotic) factors. An organism’s phenotype is often determined by its genotype and its constituent environment. Not only abiotic environmental conditions such as temperature, rainfall and humidity, but also biotic factors including intraspecific and interspecific competition for various resources, i.e., interactions with other organisms such as herbivores, pollinators, and seed dispersers, can be selective agents for plant phenology.

Long phases of phenological observations usually ranging over a period of few years include periodical observations of growth stages and studying the regularities and dependency of the yearly cycles of plant development on environmental conditions. Several phenological studies on global scale have been conducted. Phenology is probably the simplest and most cost effective means of observing the effects of changes in temperature, and consequently, phenology has become an important tool in global research. Monitoring phenological events in a given ecosystem can combine the fluctuation of abiotic environmental parameters and developmental responses of individual species (Lieth and Sciences, 1974).

Phenological study especially in intact environments those not subject to frequent disturbances) is important for knowledge of dynamics of plant species in different ecosystems, how any particular speices operates in a given environment. These relationships between species and their environment may vary at different geographical locations. This probably might be the reason for seeing differences in a species at the extreme of a range.

Studies relating to phenology and other traits distinction in tropics (Hasselquist et al., 2010; Sakai, 2001) are very few compared to those done in the temperate regions.

The need to conduct phenological studies in tropical environments is extremely urgent. The analysis of these ecosystems and communities will help understand how these systems are organized biologically (Lieth and Sciences, 1974). Phenological stations need to be established in India taking into account the vast diversity of flora and fauna of the Indian subcontinent. Phenological observations go along with several different applications like climatic change impacts, forest management, agriculture issues, biodiversity/ecology, tourism etc. Especially in India several factors contribute to uncertainty in length of the growing season like different drought related adaptation mechanisms and length of deciduousness (Kushwaha and Singh, 2008).

Leaf dynamics is complex showing the necessity to come to the level of individual leaves rather than just describing broad phenological patterns at the tree, community or forest level. By monitoring individual leaves for estimation of leaf traits we can obtain estimates for fundamental parameters, that is, leaf mass per unit area (LMA), leaf longevity, leaf size, and in this way move phenology from just a descriptive science to that of a modern science providing quantitative and predictive understanding of plant function (Kikuzawa and Lechowicz, 2011).

Leaf phenology has an impact on tree carbon return which is effected by timing of leaf exposure to herbivore damage, timing of leaf loss and energy investment in leaf construction (Franco et al., 2005). Leaf phenology is influenced by several factors, such as soil moisture, stem water storage, photoperiod (Borchert, 1994; Borchert and Rivera, 2001; Wright and Cornejo, 1990).

This study considered leaf phenology through the perspective of leaf mass per unit area (LMA) which can possibly yield important insights into functional ecology of plants. The main emphasis was on woody species in seasonally dry tropical forest. The timing of emergence and senescence of leaves in a plant can be determined by interactions among leaves in a growing plant canopy as by seasonal variations in climatic conditions (Kikuzawa, 1995).

Several events linked with leaf flush (growth of shoots, development of buds for future shoots) and be highly inter-linked. The control of bud break for flushing leave sin tropics is still unclear but for species in seasonal tropical regions water balance of the plant can serve as a cue (Borchert, 1994). Leaves being the primary photosynthetic organs, the benchmark for leaf maturation can be attainment of full photosynthetic capacity. Evergreen species having longer-lived leaves and higher LMA take longer to develop their full photosynthetic capacity (Miyazawa et al., 1998).

Leaf fall or senescence of leaves is a genetically regulated degradation involving upregulation of more than 800 genes (Lim et al., 2007). Senescence involves recovery of nutrients from leaves and recycling them within the plant. In deciduous species the senescing leaves often show variation in appearance as the chlorophyll degrades.

Variation in leaf life spans create a distinction between and evergreen and deciduous species. There are variations in the overall canopy cover throughout the year (seasonal fluctuations). The plant canopy is a site of physical and biochemical processes associated with the terrestrial biosphere. The functional and structural attributes of plant canopies are dependant on species composition, microclimatic conditions, nutrient dynamics, herbivore activities, and many other activities like management. The amount of leaves in a plant canopy is one of the basic ecological characteristics reflecting the integrated effects of these factors in an ecosystem. The primary production, water and nutrient use, energy exchange, and other physiological functions are a range of ecosystem aspects to be considered. Understanding the organization and function of plant canopies is of central importance when conducting many types of comparative ecological studies (Chaffey, 2010). A reasonable parameter to account for the overall plant canopy can be average canopy of a tree species measured over a certain period of time (usually more than 12 months); and is a continuous trait for the complete set of species. For deciduous species for a particular time period the plant canopy is either completely leafless or shows a considerable decline to alleast more than 50% of the overall canopy. The time duration when the plant canopy is entirely leafless can be termed as the duration of deciduousness for these species. It is thus a quantitative measure of deciduousness (leafless period) which is also a reciprocal of leaf longevity (Reich et al., 1991).

The major objectives of this study are:

- Examine the variation in LMA in a seasonally dry tropical forest
- Understand the relationship of LMA to leafing phenology
- Variation in LMA (of mature and recently flushed leaves) with habit (growth form), light conditions, leaf habit, average canopy, deciduous duration, leaf flush and leaf fall.

Material and Methods

Study Site: The Bhimashankar Wildlife Sanctuary (BWS) situated in the northern part of Western Ghats of Maharashtra spread across over an area of 130.78 km^2 ($19^o21`N$- $19^o11`N$, $73^o31`E$-$73^o37`E$ approximately). It includes portions of Ambegaon and Rajgurunagar (Khed) Talukas in Pune District, Karjat taluka in Raigad District and Murbad taluka in Thane District. This region spans the crest of the main Sahyandri range (approx altitude 1000m) and portions running gradually into the eastern plains as well as steep terraced western slopes leading to the Konkan which are mainly deep valley forests. Geologically, the mother rock of the area is basalt and laterite is exposed in a few patches (Borges and Rane, 1992). The Bhima, Ghod and Arala rivers originate in the crest forests and flow eastwards to join the Krishna. In the crest portion, the average annual rainfall is approximately 3000mm and is delivered by the south-west monsoon winds only from the months of June to September/ October; remaining completely fog bound and also creating distinct time periods; wet and dry season. The average maximum and minimum daily temperatures are 36^oC in May and 7^oC in December. High velocity winds are experienced in this region from December to March.

The major forest types found in here are (Borges, 1996):

1) Moist semi-evergreen seasonal cloud forest
   a) Stunted crest line forest (near western edge of deccan plateau)
   b) Taller statured forest (in catchment area of Bhima, Ghod and the tributaries Guhiri and Hadki) and Arala rivers
2) Moist deciduous forests (on western slopes leading to Konkan region; and eastern valleys falling into the rain shadow region)
3) Dry deciduous forests

Many forest areas are still unexploited; mainly preserved as sacred groves or devrais. BWS comprises of highly fragmented forest patches interspersed with plateaus, agricultural land and villages. Highly deciduous species are dominated in the crest regions while evergreens go on to dominate in the deep valley forests. This wide diversity in landscape is due to gradient in rainfall that exists here. BWS forms

the extreme end of the Western Ghats where evergreen species are found. These features together make it a good location for this study.
The sites selected for study were topologically quite different from each other. A brief description of each of them is given below.

Husa: This region usually consists of fragmented vegetation with trees occuring in a narrow belt along the edges. Most of the region is comprised of plateau region. There are rocky patches on the plateau region. The soil cover is not very deep in this region. It is mostly dominated by *Memecylon umbellatum* and associated species are mainly *Atlantia racemosa; Xantolis tomentosa*. The plateau and the edge vegetation is mainly 3-5m tall; while that falling on to the slopes consists of 5-10m tall vegetation. *Carvia callosa* occurs quite often. The evergreen vegetation found mainly at the edges and the little interior forest mainly consists of *Syzyzium cumini, Actinodaphne angustifolia, Olea dioica, Mallotus philippensis, Glochidion hohenackeri, Macaranga peltata, Leea indica, Callicarpa tomentosa, Allophyllus cobbe, Canthium diococcum, Ziziphus sp*. ; while deciduous vegetation consists of Topli Karvi, *Ficus racemosa, Lasiosiphon eriocephalus, Flacourtia indica, Randia dumetorum, Terminalia Chebula, Woodfordia fruticosa, Premna coriacea, GymnosporIa rothiana, Bridelia retusa, Pavetta indica, Grewia tiliaefolia*. The lianas or climbers include *Piper sp, Jasminium malabaricum, Rourea santaloides, Smilax ovalifolia, Embelia ribes, Elaeagnus conferta, Embelia sp, Diploclisia macrocarpa*.
Sheel: This region usually consists vegetation in sparse fragmented parts. The key species here being *Diospyros montana* and *Heterophragma quadriloculare*. Mostly the landscape is rocky here with a not very thick layer of soil. The vegetation height here is around 3-8m tall. The other vegetation here includes mostly those prominently found in the Husa region.

Hindola: This region consists of dense vegetation; with a little portion interspresed in between with sparse vegetation. The topography in this region is varied with high and low regions. Region is covered maily by black soil and during most part of the year the forest floor is covered by dry leaves. Vegetation height here is 2-8m. Different parts here are selectively dominated by different species; namely, *Psychotria sp., Litsea stocksii, Garcinia talbotii, Celtis cinnamomea, Symplocos beddomei*.

Chowra: This region is situated close to the Bhimashankar grove. It consists of dense vegetation; the height being 5-15m. The key species found here are *Amoora lawii, Cassine glauca, Macaranga peltata, Murraya koenegii, Murraya paniculata, Callicarpa tomentosa, Diospyros montana, Diospyros sylvatica, Ficus nervosa, Lepisanthes tetraphylla, Syzygium gardneri*.

Rai: This region lies close to the Bhimashankar temple, with continuous stretch of dense vegetation. The soil layer her is relatively deeper compared to the other regions mentioned here. The study area selected in this portion of BWS also consisted of sacred groves and devrais. The vegetation in the above regions of the canopy consists of *Actinodaphne angustifolia, Artocarpus heterophylla, Amoora lawii, Cassine glauca, Macaranga peltata, Murraya koenegii, Dysoxylum binectariferum, Diospyros sylvatica, Ficus nervosa, Garcinia indica, Gnetum ula, Mezoneuron cucullatum, Myristica dactyloides, Mangifera indica,* Paba*, Premna coriacea, Syzygium gardneri*, Erandi. The lower regions of the canopy mainly consiste of *Acacia concinna, Ventilago bombaiensis, Carallia brachiata, Rourea santaloides, Dimorphocalyx lawianus, Ancistrocladus heyneanus*, Tambdatelya.
Kondhwal: This is a long stretch 5 km long nearby Nigdale village leading to Kondhwal village. The vegetation studied in this region mainly lies by the roadside with few of them lying in the interior forest. The vegetation gradually changes as one traverse this path beginning with medium statured (3-5m) vegetation in the beginning ending up will tall stature vegetation and lianas (5-8m) at the end. The most species found here include the prominent ones from Husa and Rai; namely *Gnetum ula, Actinodaphne angustifolia, Symplocos beddomei, Dysoxylum binectariferum, Ficus tsjahela, Garcinia indica, Mangifera indica, Elaeagnus conferta, Leea indica, Syzygium cumini, Xantolis tomentosa, Mallotus phillipensis, Memycelon umbellatum, Olea dioica*.

Behind Field station: This region has a hilly terrian. Most of the vegetation being studied is located along the slopes while the hill top vegetation has some rocky patches interspursed. The vegetation height in this region is around 3-5m height. The key species found here are *Actinodaphne angustifolia, Caesaria sp., Bridelia retusa, Careya areborea, Carissa carandas, Macaranga peltata, Colebrookea* *oppositifolia, Callicarpa tomentosa, Grewia tiliaefolia, Flacourtia indica, Carvia Callosa, Lagerstromoea parviflora, Memycelon umbellatum, Randia dumetorum, Terminalia tomentosa, Terminalia bellerica, Terminalia Chebula, Vangueria spinosa.*

<u>Phenology:</u> Approximately 100 species have been identified at the study site. Of these, 76 species have been selected for study (list of species is given in Appendix I); which seem to truly represent the woody species of this region. The rare, herbaceous and non-woody species are not included. Mostly, 15 trees per species are monitored except for dioecious species where 30 trees per species are monitored; or for the rare ones where less than 15 trees are selected. Phenology census is carried out on a monthly basis; except for in the dry months when monitoring is carried out fortnightly when the activity is at a peak in this region. Currently approximately 1500 trees are being monitored at the site. The data in this study is from January 2013 to March 2014. Leaf data is collected concerning the amount of leaves on the tree i.e. canopy (% of flushing, mature and senescing leaves). Flowering percentage is recorded further splitting it into % of buds and open flowers. Similarly, the fruiting phenology is recorded with respect to the no. of fruits that should ideally have been on to the tree in that season and specifically in those climatic conditions.

<u>Leaf Collection:</u> For both simple and compound leaves, petiole was collected. Criteria of selection for leaves were either size, color of leaves or both. Sometimes it was based on texture of leaves. It is made sure that atleast 3 or at the most 6 individuals leaves are collected for one species to make sure the results are statistically significant. Atleast 3 leaves are collected from an individual tree. If possible, 6 leaves can be collected from an individual. This same procedure was employed for leaves at two developmental stages: recently flushed leaves and mature leaves. Recently flushed leaves from 62 species; while mature leaves were collected from 76 species. Approximately, 3500 leaves were collected from the field site (combined number for both stages of leaves. For flushing leaves, the first fully expanded leaves were collected when the species had their peak flushing time; just before the premature stage of maturity, making sure the collected leaves are not reddish, or too newly flushed to be collected. For mature leaves, too mature leaves were not collected but when the species were in post peak flushing period. In the

whorl of leaves, the first mature leaf after the flushed leaves was collected. For sun/shady conditions, leaves were collected from different branches exposed to the sun.

Storage: The leaves of individual trees were kept in paper envelopes. If the leaves were compound and there was any possibility that leaflets might get mixed then it was made sure that they were well separated from each other by wrapping in sheets and using another envelope. Such paper bags were then put in a plastic zip lock bag and sealed after saturating them with sufficient water to make sure that water content of leaves did not change while transporting them from field to laboratory which was approximately 5 hours. The zip lock bags were stored in refrigerator and processing was started within 8 hours of putting the leaves in the refrigerator.

Measurement of LMA: LMA of leaves collected from field was calculated using the following protocol. The fresh weight of leaves collected was measured. Then the leaves were scanned under a fixed resolution to get their area and then dry weight of leaves was measured after oven drying them at 70^{o}C for 3 days. It was made sure that the measurement of fresh weight and scanning were completed within 24 hours of leaf collection from the field. Dividing the above measured dry weight of leaves with the area of that particular leaf calculated using ImageJ software gave the leaf mass per unit area (LMA) of that leaf.

Statistical Analysis: All data were analysed using STATISTICA. One way ANNOVA was done to examine variation of LMA/leaf area/ΔLMA [LMA (mature)-LMA (immature)] with species, plant habit, light condition (habitat), leaf habit.
Pearson correlation and Spearman rank order correlation tests were done to check for possible correlation between LMA/ΔLMA and average canopy, deciduous duration.
Chi square test was done to find out relationships between month of peak flush and leaf habit.

Results

Leaf area ranged from 10.359 (*Lasiosiphon eriocephalus*) to 773.853 (*Leea indica*) cm^2 LMA ranged from 0.0034 (*Smilax Ovalifolia)* to 0.0293 (*Memecylon umbellatum)* g cm^{-2}. Leaf area and LMA varied significantly among species both for mature and recently flushed (immature) leaves (Table 2).

Table 2: ANNOVA table for variation in LMA and leaf area of mature and immature leaves of different species.

Trait	Df	SS	F	P
LMA (Immature)	61	0.002101	13.073	<0.001
LMA (Mature)	73	0.006750	17.380	<0.001
LA (Immature)	61	2811107	49.8610	<0.001
LA (Mature)	73	4386392	16.9262	<0.001

Average leaf area for evergreen species was not significantly different from that for deciduous species, in cases of both mature and immature leaves (Table 3, Figure 1).

Table 3: ANNOVA table for variation in area of mature and immature leaves of species with different leaf habits

	Df	SS	F	P
Mature LA	1	2475.0	0.21163	0.647
Immature LA	1	2793.8	0.30378	0.583

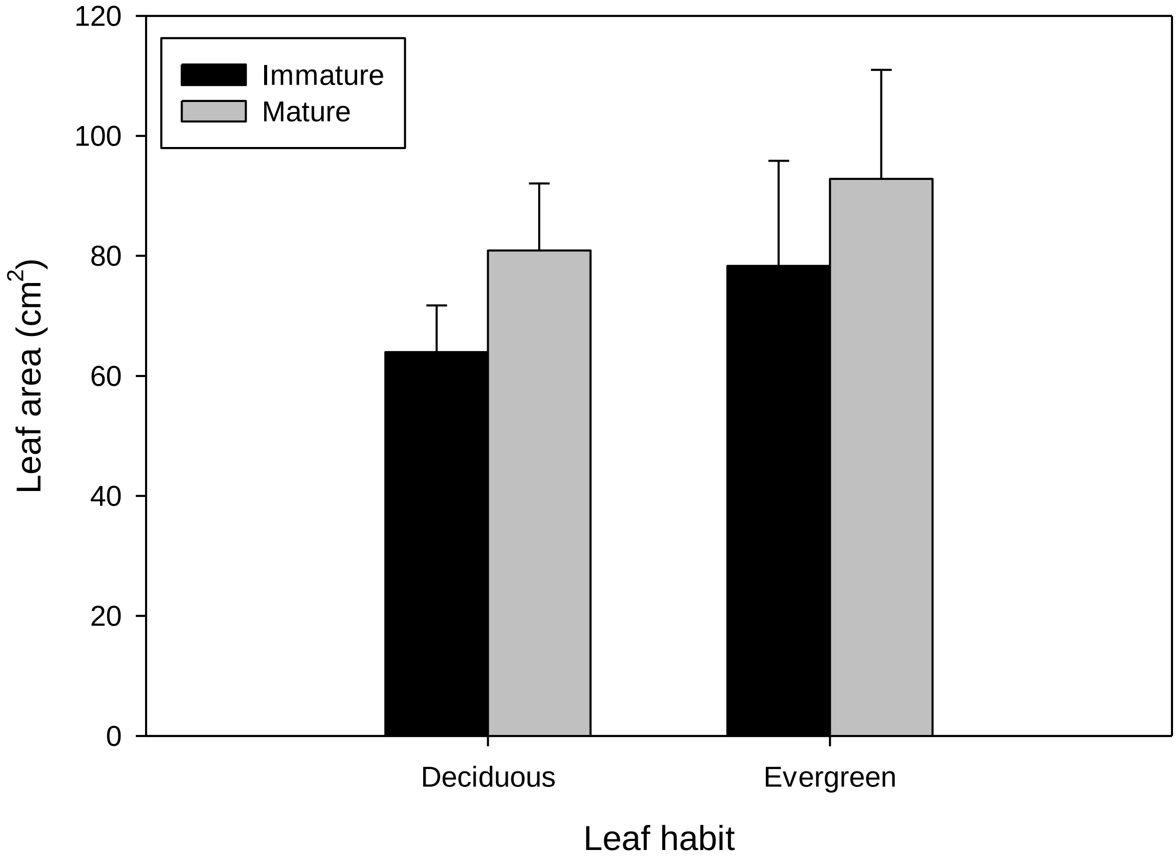

Figure 1: Average area of mature and immature leaves for different leaf habits. Error bars represent ± standard error. Sample size for leaf habit: [mature: Deciduous – 27, evergreen – 49; immature: Deciduous – 20, evergreen – 42]

Average LMA for evergreen species was greater than that for deciduous species, in cases of both mature and immature leaves (Table 4, Figure 2).

Table 4: ANNOVA table for variation in LMA of mature and immature leaves of species with different leaf habits

	df	SS	F	p
Mature LMA	1	0.000060	4.0228	0.048
Immature LMA	1	0.000039	3.8715	0.054

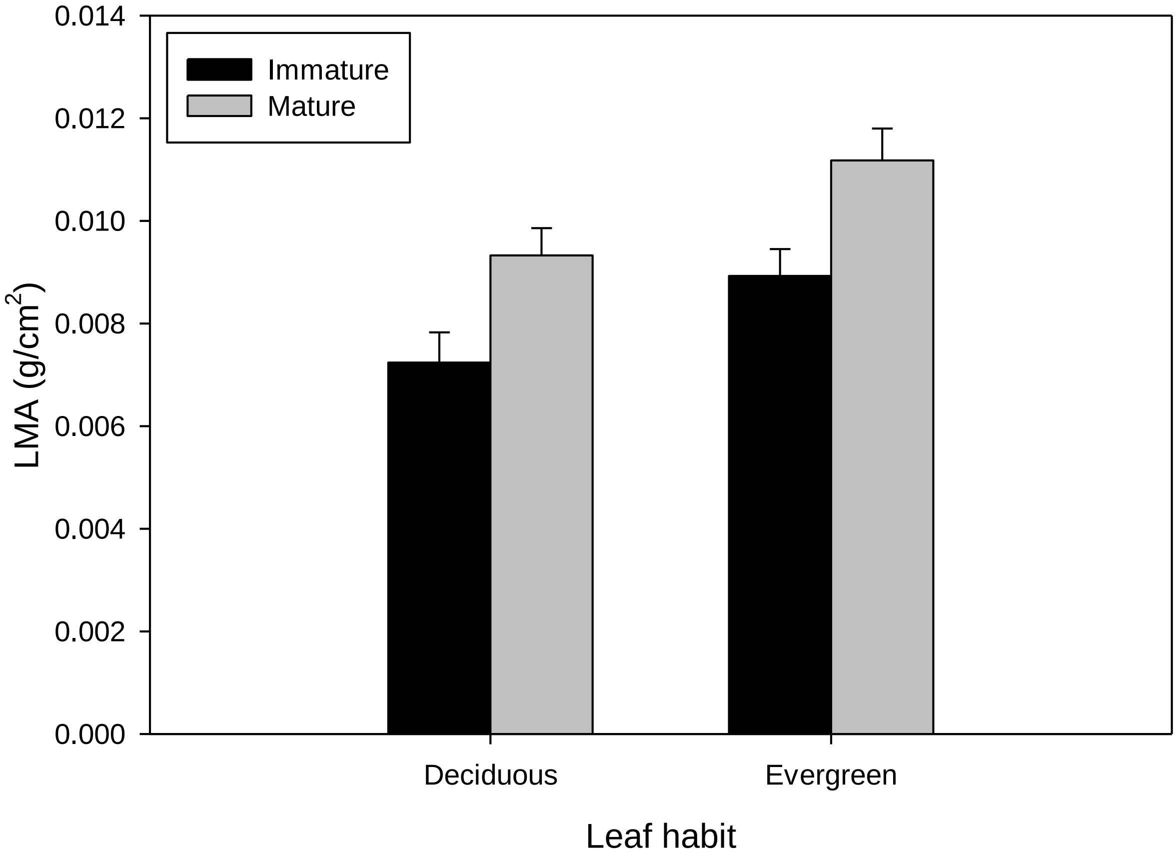

Figure 2: Average LMA of mature and immature leaves for different leaf habits. Error bars represent ± standard error. Sample size for leaf habit: [mature: Deciduous – 27, evergreen – 49; immature: Deciduous – 20, evergreen – 42]

Average difference in LMA of mature and immature leaves for evergreen species was not significantly different from that of deciduous species (ANNOVA: $F(1,60)=0.09345$, $p=0.76089$) (Figure 3).

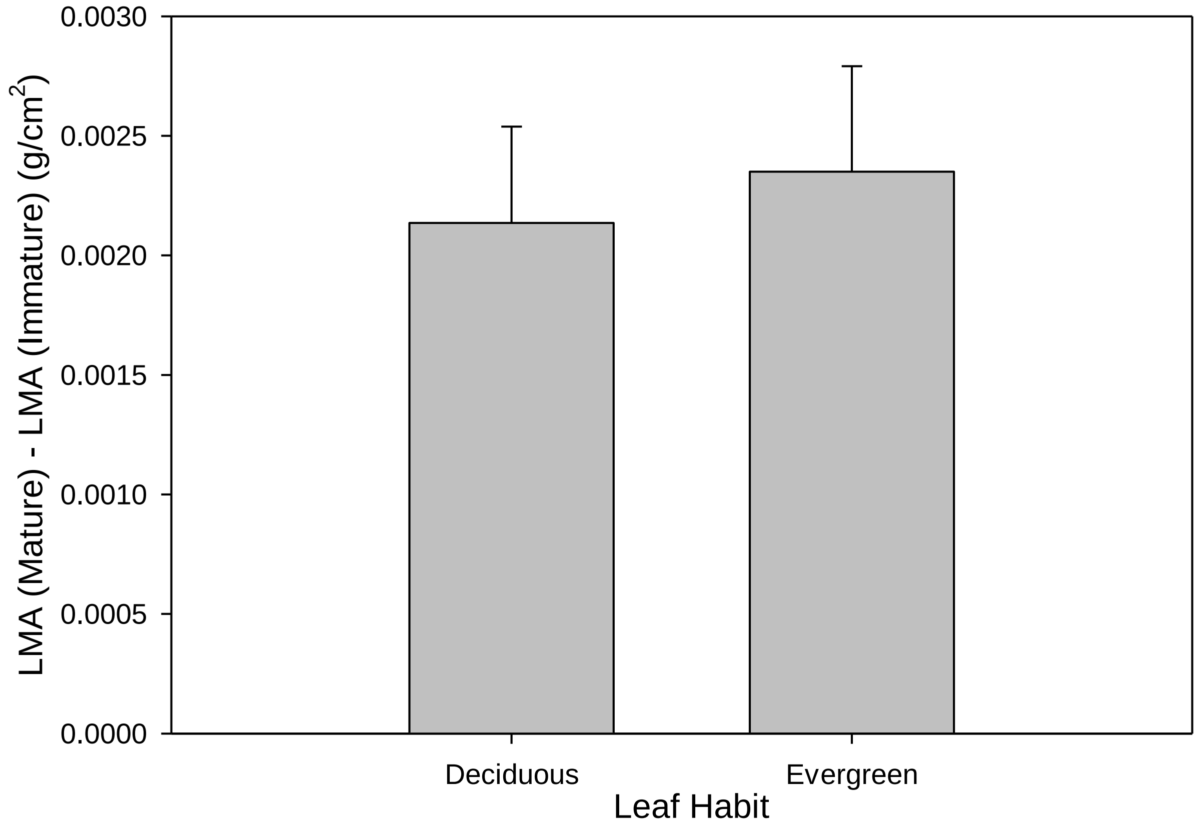

Figure 3: Average difference in LMA of mature and immature leaves for different leaf habits. Error bars represent ± standard error. Sample size for leaf habit: Deciduous – 20, Evergreen – 42.

LMA of mature leaves was positively correlated with average canopy over the year (Pearson: r=0.43, p=0.003; Spearman: r=0.42, p=0.005) (Figure 4a). The difference in LMA of mature and immature leaves was also positively correlated with average canopy over the year (Pearson: r=0.35, p=0.034; Spearman: r=0.33, p=0.044) (Figure 4b).

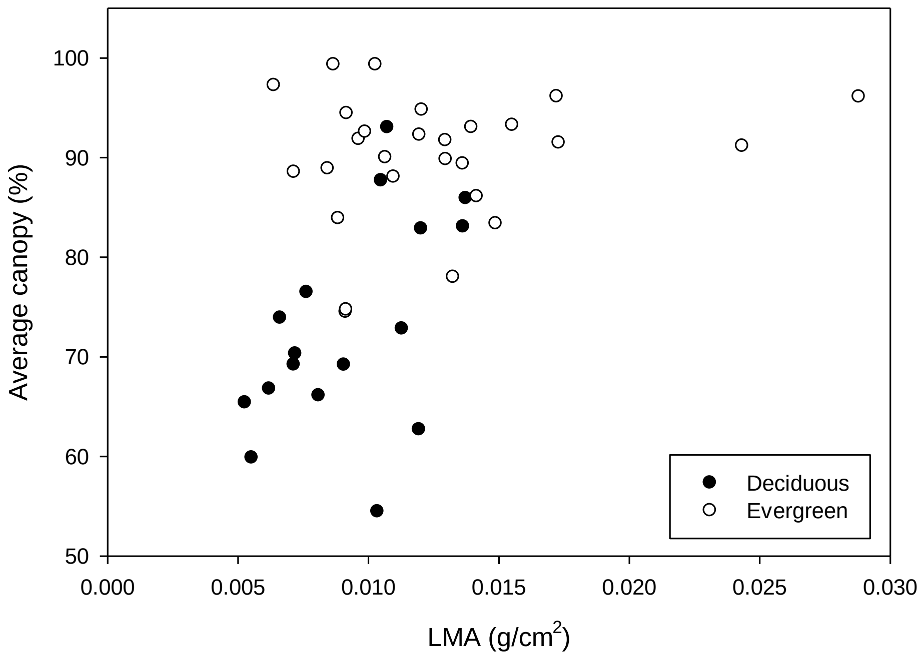

Figure 4a: The variation in LMA of mature leaves with average canopy over the year

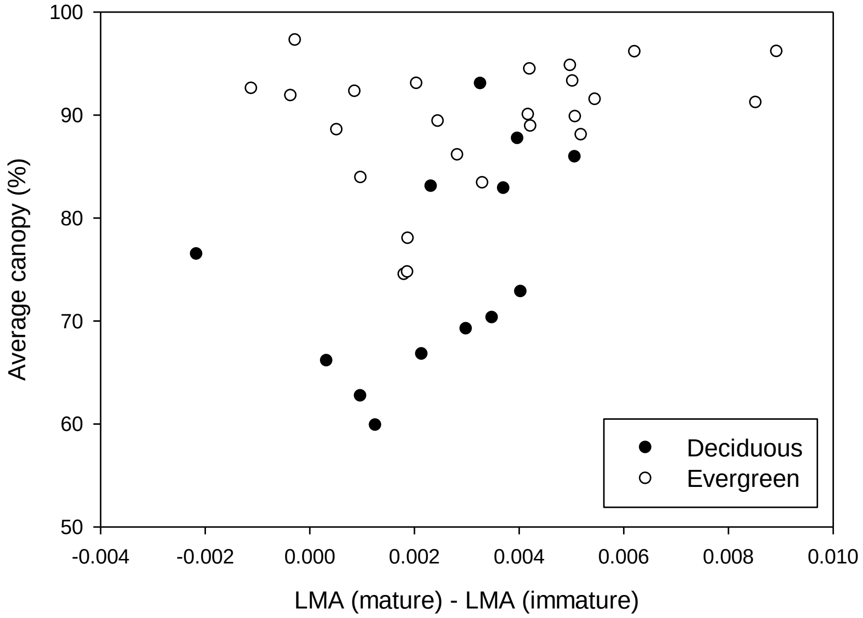

Figure 4b: The variation in difference in LMA of mature and immature leaves with average canopy over the year

Deciduous duration was negatively correlated with LMA of mature leaves (Pearson: r= -0.304, p=0.008) (Figure 5a). However, there was no correlation between deciduous duration and difference in LMA of mature and immature leaves (Pearson: r= -0.085, p=0.52) (Figure 5b)

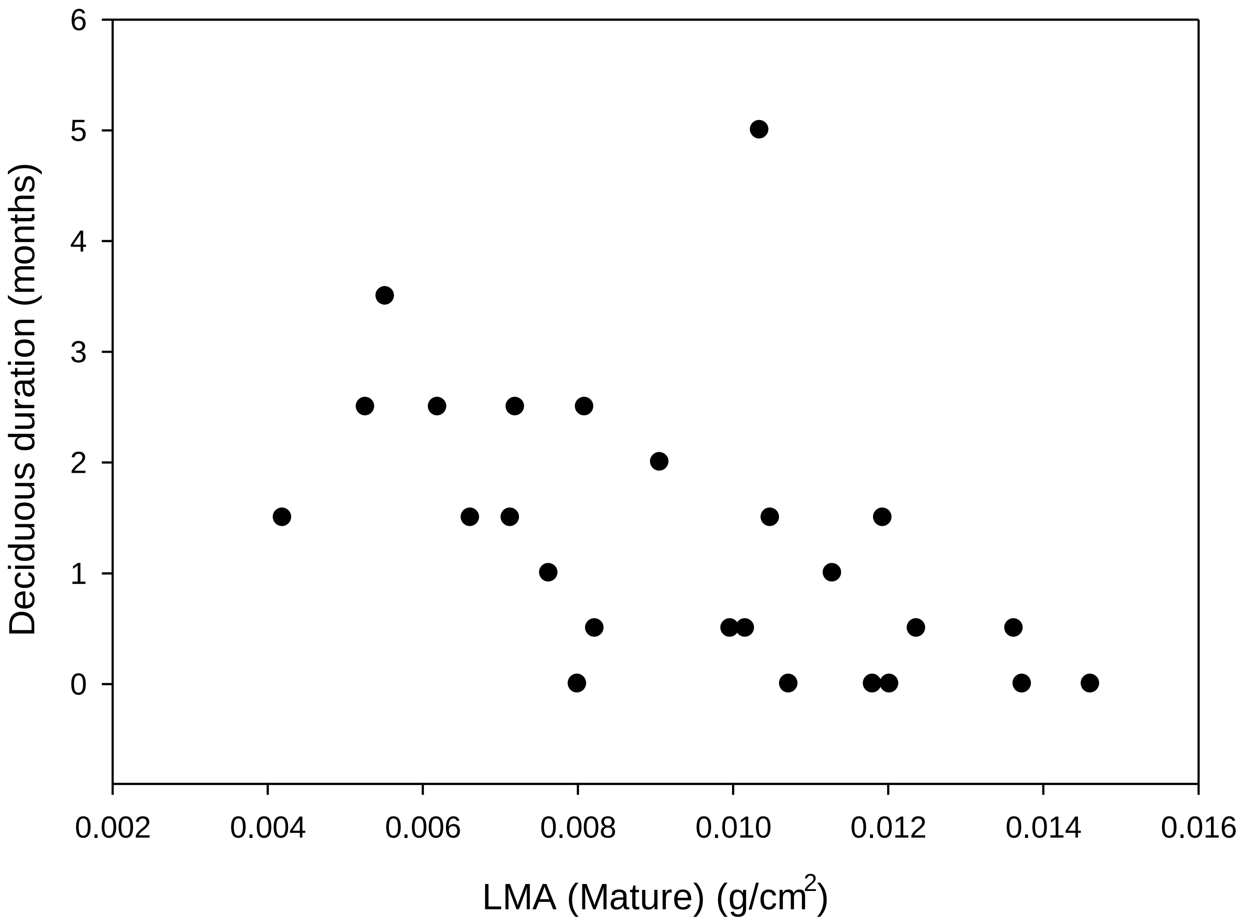

Figure 5a. The variation of LMA of mature leaves with duration of deciduousness

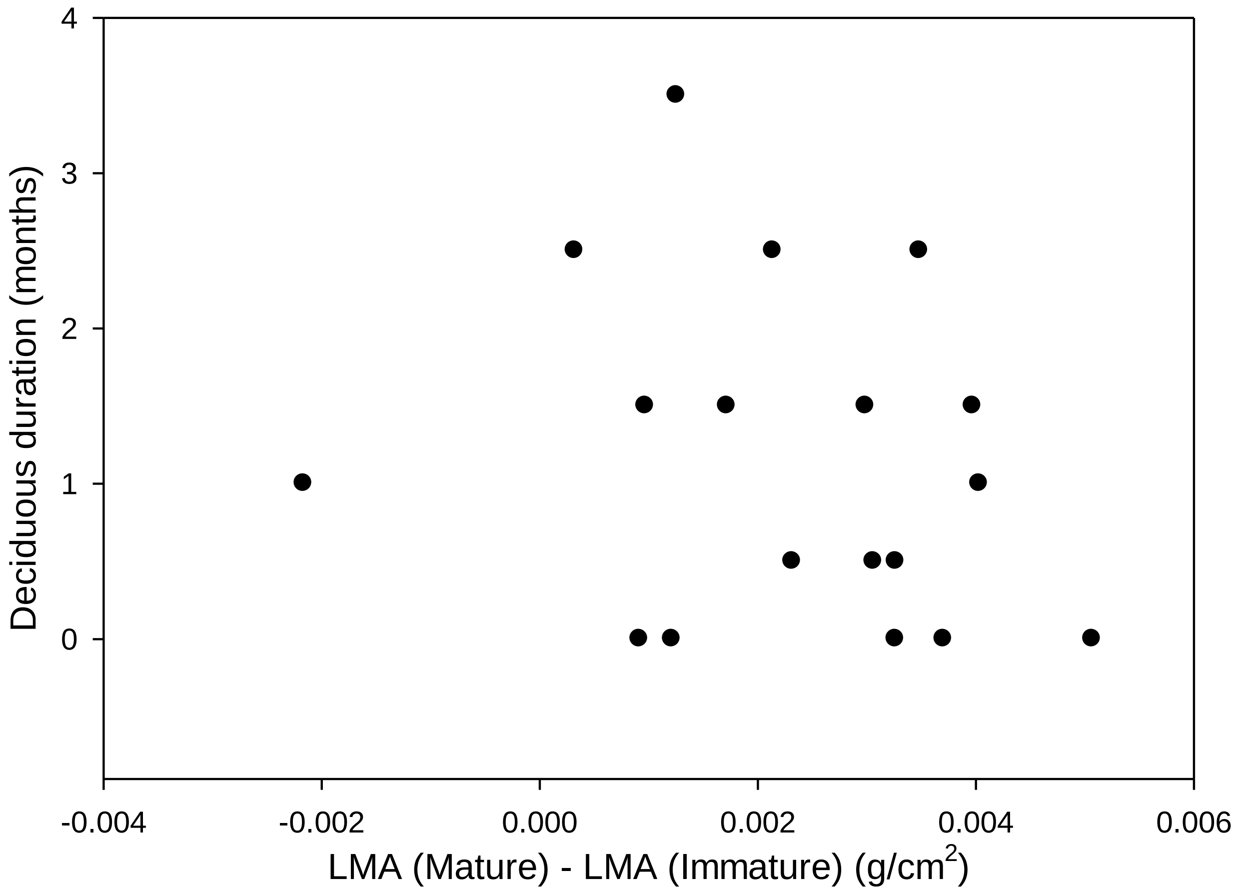

Figure 5b. The variation in difference in LMA of mature and immature leaves with duration of deciduousness

Average LMA of mature leaves varied significantly with different months of peak flush (ANNOVA: $F (9,34)=2.853$, $p=0.013$) (Figure 6a). Number of species flushing at peak in different months is shown in Figure 6b. Month of peak flush was not associated with leaf habit (Pearson chi-square: df = 9, $p=0.187$).

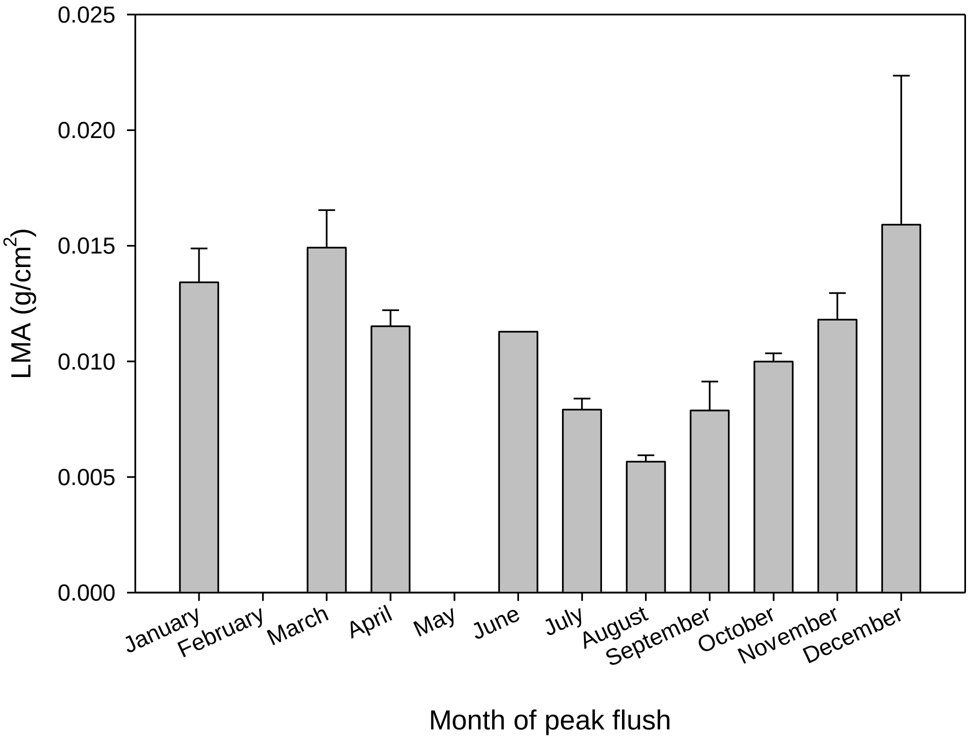

Figure 6a: Average LMA of mature leaves for different months of peak flush

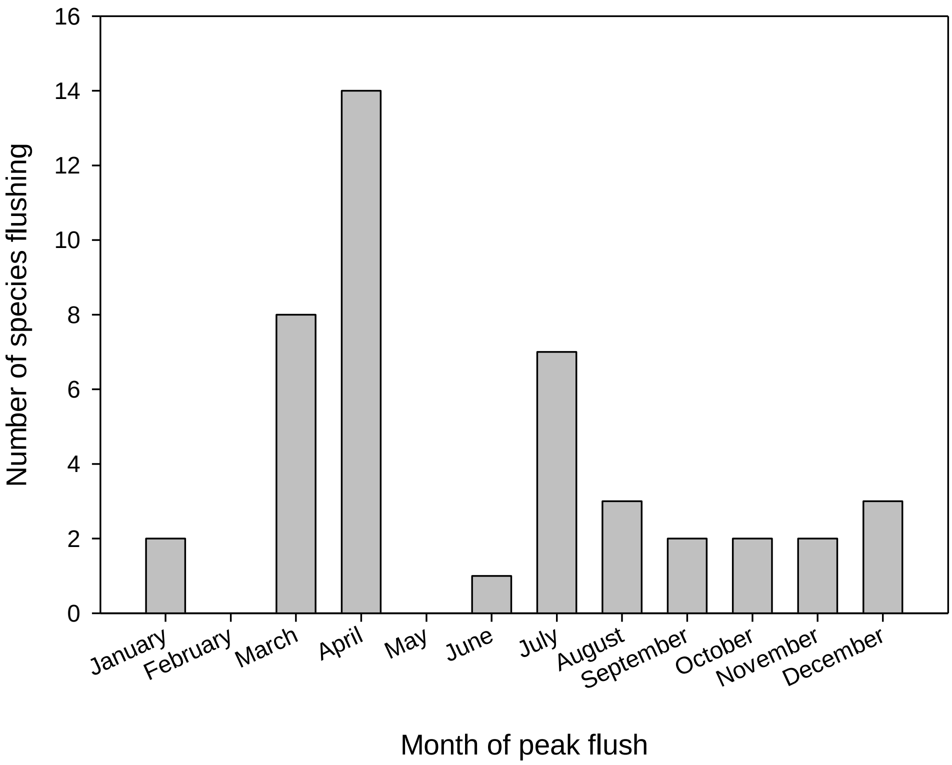

Figure 6b: No of species at peak flush in different months of the year

Average LMA did not vary significantly with different months of peak senescence (ANNOVA: F(8,35)=0.221, p=0.985) (Figure 7a). Number of species flushing in different months is shown in Figure 7b.

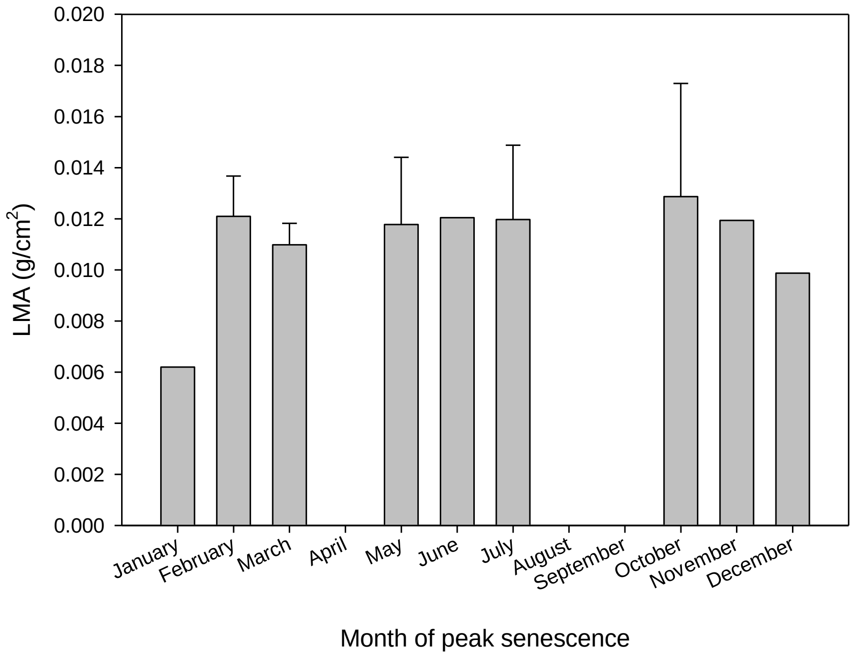

Figure 7a: Average LMA of mature leaves for different months of peak senescence

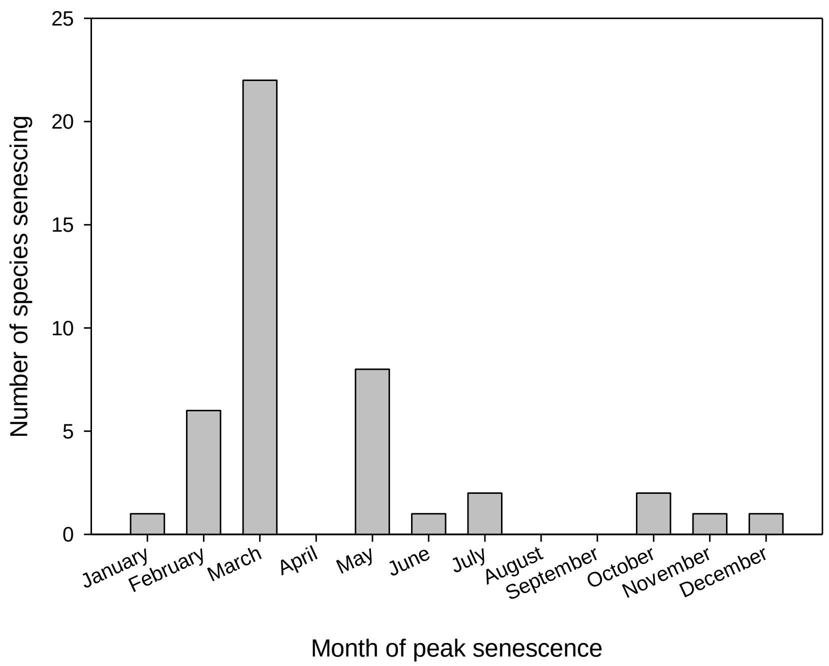

Figure 7b: No of species at peak senescence in different months of the year

Average LMA differed significantly between different plant habits, in cases of both mature and immature leaves. Average LMA for trees was significantly greater than that for lianas and shrubs (Table 5, Figure 8).

Table-5: ANNOVA table for variation in LMA of mature and immature leaves of species with different plant habits.

Trait	Df	SS	F	P
Mature LMA	3	0.000185	4.5422	0.006
Immature LMA	3	0.000078	2.6976	0.054

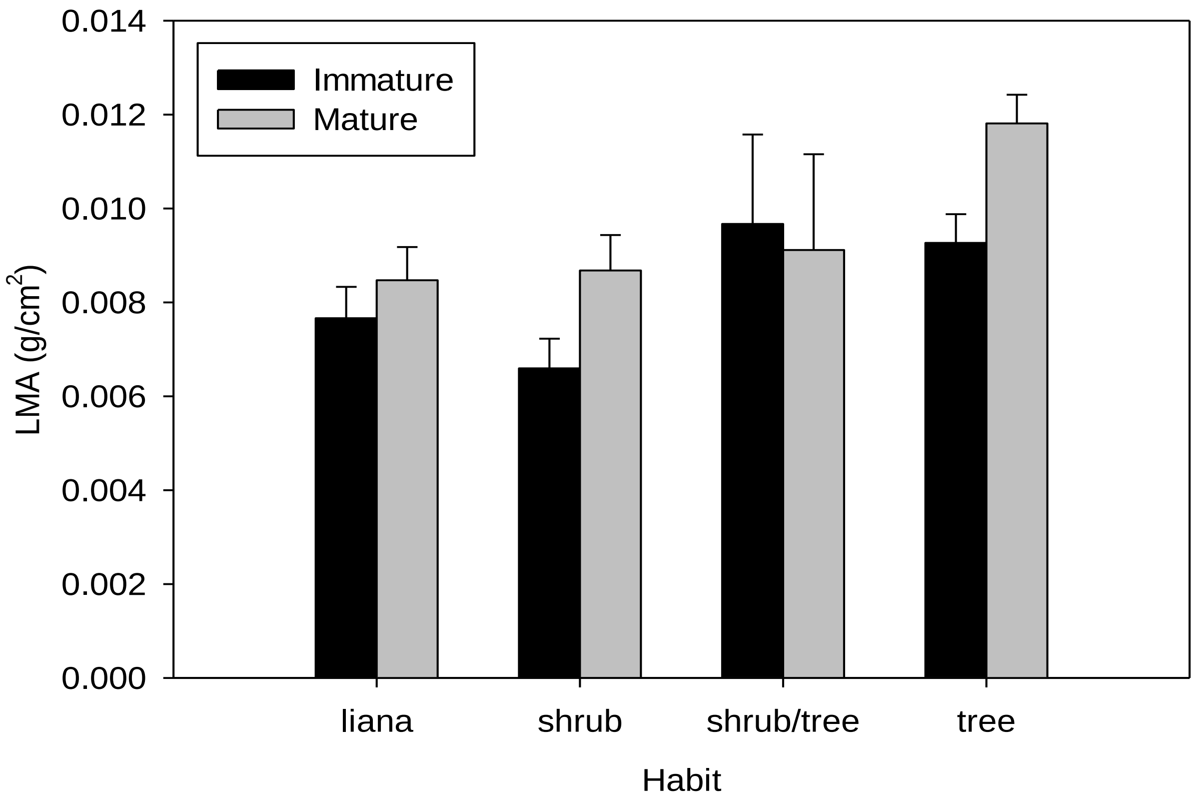

Figure 8: Average LMA of mature and immature leaves for different plant habits. Error bars represent ± standard error. Sample size for plant habit: [mature: liana – 13, shrub – 14, shrub/tree – 4, tree – 45; immature: liana – 13, shrub – 13, shrub/tree – 2, tree – 34]

Average LMA of mature and immature leaves for different light environments (habitat types) were not significantly different from each other (Table 6, Figure 9).

Table 6: ANNOVA table for variation in LMA of mature and immature leaves of species with different light environments (habitats)

Trait	Df	SS	F	P
Mature LMA	5	0.000112	0.8662	0.508
Immature LMA	5	0.000049	0.7183	0.612

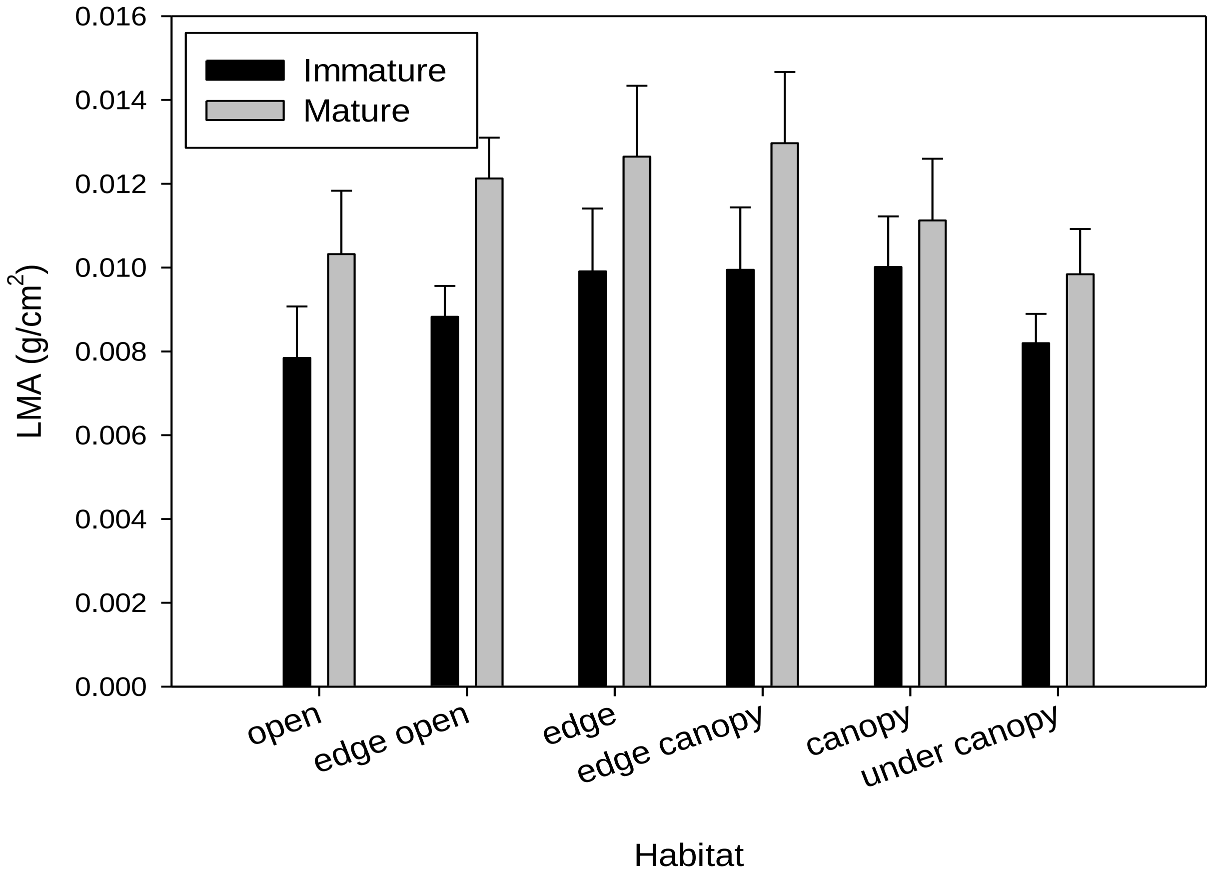

Figure 9: Average LMA of mature and immature leaves of species for different light environments (habitats). Error bars represent ± standard error. Sample size for habitats: [mature: open - 14, edge open - 18, edge - 14, edge canopy - 9, canopy - 11, under canopy - 17; immature: open - 11, edge open - 16, edge - 12, edge canopy - 6, canopy - 8, under canopy – 16]

Discussion

As expected, average LMA for evergreen species was significantly greater than that for deciduous species. This may be due to differences in allocation to protective tissue, supporting tissue photosynthetic tissue. Deciduous trees have a limited time each year to photosynthesize. Thinner leaves would allow more efficient gas exchange and leaves that incorporate high water content could expand more quickly with the sudden onset of rain. In contrast, evergreen trees can photosynthesize year-round. These plants should invest in durable leaves that can persist through the low-resource dry season, survive predation by insects and herbivores; but they do not need to invest in highly efficient photosynthetic machinery, as they have the entire time of the leaf life span to return to the plant the carbon gains, which it had invested.

As deciduous species remain leafless for some time period, it is expected that the average canopy of evergreen species would be more than deciduous species. This combined with the result that average LMA for evergreen species was greater than that of deciduous species, leads to the prediction that average canopy would be positively related with LMA, which was observed.

A strong negative correlation between LMA and deciduousness duration was expected. Increase in deciduous duration would mean that life span of leaves would decrease. So, for a plant with a long duration of deciduousness, it is beneficial to invest minimum in non-photosynthetic components (supporting tissue, secondary metabolites, etc), which should result in low LMA. The change in LMA over the developmental stages of the leaf was not found to significantly differ with deciduous duration.

Highly deciduous species were seen to flush in the post-monsoon period in August. As seen previously LMA varied with leaf habit; it could be predicted that leaf habit had some influence on the timing of peak flush duration. The total number of spcies flushing after July (monsoon period) declined but later there was a rise in the number of species flushing per month in the drier season. Majority of the species flushed in the beginning months of dry season (in April). Chi-Square Test Analysis did not yield significant results for relation between peak flush time of species and leaf habit.

Majority of the species were seen to senesce their leaves in March just prior to the leaf flush period. The average LMA of senescing leaves did not vary much with time of peak senescence. But the no of species senescing after the dry season i.e. may drastically decreased (with the average LMA for senescing species remaing constant) thus suggesting that species senescing after May till onset of next dry season in March where those with higher LMA.

LMA of mature leaves had a significant relationship with plant habit grouped into trees, shrubs, lianas. Significant difference was found for variation in LMA between tree and shrubs and trees and lianas. Trees having accumulated a higher biomass over their lifetime tend to utilize more resources in a given span of time compared to shrubs and lianas. They adopt a profitable strategy to reach the top portions of the forest canopy to access light. But they incur a cost of slower growth rate owing to production of non-photosynthetic tissue to persist for longer time periods. Thus tree species tend to have a higher LMA compared to shrubs and lianas. Similar trend was not seen for the plant habit, shrub/tree.

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Appendix I: Species List (list of species whose leaves were collected or phenology was monitored from January 2013-March 2014) with data on plant habit, leaf habit and habitat type from various secondary sources

Family	SPECIES	MARATHI NAME	habit	habitat	Leaf habit
Acanthaceae	*Carvia Callosa*	Karvi	shrub	open	D
Anacardiaceae	*Mangifera indica*	Amba	tree	canopy	E
Ancistrocladaceae	*Ancistrocladus heyneanus*	Hardal	liana	under canopy	E
Apocyanaceae	*Carissa carandas*	Karvandi	shrub	open	E
Bignoniaceae	*Heterophragma quadriloculare*	Varas	tree	edge	D
Celastraceae	*Cassine glauca*	Luir	tree	canopy	E
Celastraceae	*Gymnosporia rothiana*	Balvand	shrub	open	E
Celastraceae	Unknown 1	Vikhar	tree	edge	E
Cesalpiniaceae/ Fabaceae	*Mezoneuron cucullatum*	Gharnighi	liana	under canopy	E
Combretaceae	*Terminalia bellerica*	Behda	tree	egde open	D
Combretaceae	*Terminalia Chebula*	Hirda	tree	edge open	D
Combretaceae	*Terminalia tomentosa*	Sadada	tree	edge open	D
Connaraceae	*Rourea santaloides*	Kalivel	liana	under canopy	E
Ebenaceae	*Diospyros montana*	Maskudal	tree	edge open	D
Ebenaceae	*Diospyros sylvatica*	Kala Telya	tree	canopy	E
Eleaegnaceae	*Elaeagnus conferta*	Ambeli	liana	edge open	E
Euphorbiaceae	*Dimorphocalyx lawianus*	Rai	shrub	under canopy	E
Euphorbiaceae	*Macaranga peltata*	Chandiya	tree	edge	E
Euphorbiaceae	*Mallotus phillipensis*	Shendri	tree	edge	E
Gnetaceae	*Gnetum ula*	Kombalvel	liana	under canopy	E
Guttiferae/ Clusiaceae	*Garcinia indica*	Kokkum	tree	canopy	E
Guttiferae/ Clusiaceae	*Garcinia talbotii*	Phansada	tree	under canopy	E
Lamiaceae	*Colebrookea oppositifolia*	Dasai	shrub	open	D
Lauraceae	*Actinodaphne angustifolia*	Malwa	tree	edge	E
Lauraceae	*Litsea stocksii*	Powti	tree	under canopy	E

Lauraceae	*Litsea zeylanica*	Tamalpatra	tree	under canopy	E
Lecythidaceae	*Careya areborea*	Kumbhayi	tree	edge open	D
Lythraceae	*Lagerstromoea parviflora*	Bondara	tree	open	D
Lythraceae	*Woodfordia fruticosa*	Dayti	shrub	open	D
Melastomataceae	*Memycelon umbellatum*	Karab	tree	everywhere	E
Meliaceae	*Dysoxylum sp.*	Varna 2	tree	edge canopy	E
Meliaceae	*Amoora lawii*	Pandhra Telya	tree	edge	E
Meliaceae	*Dysoxylum sp.*	Varna 1	tree	edge canopy	E
Menispermiaceae	*Diploclisia macrocarpa*	Naloti	liana	under canopy	E
Mimosaceae/ Fabaceae	*Acacia concinna*	Shikekai	tree	canopy	E
Moraceae	*Artocarpus heterophylla*	Phanas	tree	canopy	E
Moraceae	*Ficus nervosa*	Loth	tree	canopy	E
Moraceae	*Ficus racemosa*	Umbar	tree	edge open	D
Moraceae	*Ficus tsjahela*	Kel	tree	edge open	D
Myristicaceae	*Myristica dactyloides*	Jayphal	tree	canopy	E
Myrsinaceae	*Embelia ribes*	Ambati/Kokla/	liana	under canopy	E
Myrtaceae	*Syzygium cumini*	Jambhal	tree	edge canopy open	E
Myrtaceae	*Syzygium gardneri*	Parjambhal	tree	edge canopy open	E
Oleaceae	*Jasminum malabaricum*	Kusar	liana	open	E
Oleaceae	*Olea dioica*	Karambu	tree	edge canopy	E
Phyllanthaceae	*Bridelia retusa*	Ashind	tree	edge	D
Phyllanthaceae	*Glochidion hohenackeri*	Bhoma	shrub/tree	edge open	E
Piperaceae	*Piper sp.*	Nagvel	liana	under canopy	E
Rhamnaceae	*Ventilago bombaiensis*	Madvel	liana	under canopy	E
Rhamnaceae	*Ziziphus sp.*	Thoran	liana	edge	D
Rhizophoraceae	*Carallia brachiata*	Erandi	tree	canopy	E
Rubiaceae	*Canthium diococcum*	Kandkudal	tree	edge	E
Rubiaceae	*Pavetta indica*	Asavla	shrub	edge open	D
Rubiaceae	*Psychotria sp*	Psychotria	shrub	under canopy	E

Rubiaceae	*Randia dumetorum*	Gel	tree	edge open	D
Rubiaceae/ Sapotaceae	*Vangueria spinosa*	Aoul	tree	edge open	D
Rutaceae	*Atlantia racemosa*	Chinger	tree	edge canopy	E
Rutaceae	*Murraya koenegii*	Curry patta	shrub/tree	under canopy	D
Rutaceae	*Murraya paniculata*	Curry patta	shrub/tree	under canopy	D
Rutaceae	*Zanthoxylum rhetsa*	Kokhali	tree	edge open	D
Salicaceae	*Caesaria sp.*	Bogada	shrub	edge	E
Salicaceae	*Flacourtia indica*	Tambat	shrub/tree	edge open	D
Sapindaceae	*Allophyllus cobbe*	Tipna	shrub	edge	E
Sapindaceae	*Lepisanthes tetraphylla*	Ambakarap	tree	edge canopy	E
Sapotaceae	*Xantolis tomentosa*	Kombal	tree	edge canopy	E
Symplocaceae	*Symplocos beddomei*	Lothadi	tree	canopy	E
Teliaceae	*Grewia tiliaefolia*	Dhaman	tree	edge open	D
Thymelaeaceae	*Lasiosiphon eriocephalus*	Rameta	shrub/tree	open	D
Verbenaceae	*Callicarpa tomentosa*	Patgira	tree	edge	E
Verbenaceae	*Premna coriacea*	Chambhari	shrub	under canopy	D
Vitaceae	*Celtis cinnamomea*	Lokhandi	tree	edge open	E
Vitaceae	*Embelia sp1*	Ambetivel	liana	edge open	D
Vitaceae	*Leea indica*	Andhphod	shrub	open	E
Vitaceae	*Smilax ovalifolia*	Gotveli	liana	open	D
	Unknown 2	Tambdatelya	shrub	under canopy	E
	Unknown 3	Paba	tree	edge	E
	Unknown 4	pandhriyeli	liana	under canopy	E
	Unknown 5	Toplikarvi	shrub	open	D

Appendix II: Data for LMA and leaf area (LA) for mature and immature leaves. Average canopy, duration of deciduousness, peaf flush month, peak senescence month recorded from phenology monitoring [ΔLA or ΔLMA = LA/LMA (mature)-LA/LMA (immature)]

Species	Mature LA	Immature LA	Δ LA	Mature LMA	Immature LMA	Δ LMA	Average canopy	DD (months)	Peak flush month	Peak senescence month	Leaf habit
Acacia concinna	76.837	26.993	49.843	0.0060	0.0072	-0.0013		0			E
Actinodaphne angustifolia	57.311	68.710	-11.399	0.0139	0.0119	0.0020	93.050	0	March	February	E
Allophyllus cobbe	96.852	115.360	-18.507	0.0091	0.0073	0.0019	74.736	0	April	March	E
Amoora lawii	32.945			0.0091				0			E
Ancistrocladus heyneanus	187.701	134.263	53.438	0.0073	0.0062	0.0011		0			E
Artocarpus heterophylla	94.438			0.0109				0			E
Atlantia racemosa	24.768			0.0130			91.723	0			E
Bridelia retusa	51.313	31.486	19.827	0.0136	0.0113	0.0023	83.068	0.5	April	March	D
Caesaria sp.	92.577	63.384	29.194	0.0080	0.0071	0.0009		0			D
Callicarpa tomentosa	130.227	88.198	42.030	0.0096	0.0100	-0.0004	91.857	0	October	March	E
Canthium diococcum	56.505	36.499	20.006	0.0288	0.0226	0.0062	96.116	0	December	May	E
Carallia brachiata	57.327			0.0105							E
Careya areborea	197.000	146.920	50.079	0.0118	0.0106	0.0012		0			D
Carissa carandas	14.560	14.237	0.323	0.0155	0.0105	0.0050	93.274	0	March	May	E
Carvia Callosa	133.252	70.713	62.539	0.0062	0.0041	0.0021	66.785	2.5	August	January	D
Cassine glauca	44.932	43.017	1.915	0.0087	0.0069	0.0018		0			E
Celtis cinnamomea	28.040	20.558	7.482	0.0172	0.0083	0.0089	96.152	0	April	February	E
Colebrookea oppositifolia	69.793	64.019	5.774	0.0042	0.0025	0.0017		1.5			D
Dimorphocalyx lawianus	66.384	43.577	22.807	0.0077	0.0083	-0.0006		0			E
Diospyros montana	35.928	16.087	19.841	0.0120	0.0083	0.0037	82.874	0	March	February	D
Diospyros sylvatica	54.807	52.668	2.139	0.0085	0.0074	0.0011		0			E
Diploclisia macrocarpa	50.076	28.472	21.604	0.0092	0.0050	0.0042	94.448	0	April	March	E
Dysoxylum sp.	233.927			0.0087			99.348	0	July	May	E
Dysoxylum sp.	509.699			0.0103			99.348	0	July	May	E

Elaeagnus conferta	15.959	16.377	-0.418	0.0136	0.0112	0.0025	89.392	0	March	March	E
Embelia ribes	59.587	47.100	12.487	0.0094	0.0082	0.0013		0			E
Embelia sp1	39.642	26.101	13.540	0.0071	0.0041	0.0030	69.218	1.5	July	February	D
Ficus nervosa	47.691			0.0117				0			E
Ficus racemosa	50.247			0.0091			69.195	2	December	July	D
Ficus tsjahela	55.162	75.440	-20.278	0.0107	0.0075	0.0033	93.031	0	April	March	D
Flacourtia indica	35.910	22.776	13.134	0.0081	0.0078	0.0003	66.116	2.5	July	February	D
Garcinia indica	25.307	18.071	7.236	0.0077	0.0070	0.0006		0			E
Garcinia talbotii	110.857	138.753	-27.896	0.0165	0.0124	0.0040		0			E
Glochidion hohenackeri	17.792	12.917	4.875	0.0149	0.0116	0.0033	83.390	0	January	July	E
Grewia tiliaefolia	86.004	90.189	-4.185	0.0113	0.0073	0.0040	72.832	1	June	March	D
Gymnosporia rothiana	54.664	33.653	21.010	0.0091	0.0073	0.0018	74.507	0	September	May	E
Heterophragma quadriloculare	197.129			0.0103			54.465	5	October	March	D
Jasminum malabaricum	34.422	36.500	-2.078	0.0132	0.0114	0.0019	78.007	0	April	March	E
Lagerstromoea parviflora	44.561			0.0102				0.5			D
Lasiosiphon eriocephalus	10.359			0.0053			65.402	2.5	August	March	D
Leea indica	773.853	707.595	66.258	0.0120	0.0071	0.0050	94.797	0	April	June	E
Lepisanthes tetraphylla	75.020	93.885	-18.865	0.0129	0.0077	0.0052		0			E
Litsea stocksii	86.594	63.729	22.866	0.0106	0.0084	0.0022		0			E
Litsea zeylanica	89.860	53.048	36.812	0.0084	0.0042	0.0042	88.903	0	March	October	E
Macaranga peltata	167.724	226.591	-58.867	0.0130	0.0079	0.0051	89.824	0	April	March	E
Mallotus phillipensis	54.069	40.638	13.431	0.0071	0.0066	0.0005	88.557	0	April	March	E
Mangifera indica	89.253	109.676	-20.423	0.0142	0.0113	0.0028	86.109	0	March	February	E
Memycelon umbellatum	24.060	15.643	8.417	0.0243	0.0158	0.0085	91.187	0	March	March	E
Mezoneuron cucullatum	101.789	92.606	9.183	0.0061	0.0079	-0.0018		0			E
Murraya sp.	86.675			0.0082				0.5			D
Myristica dactyloides	168.180	131.592	36.588	0.0101	0.0134	-0.0033		0			E
Olea dioica	54.481	40.899	13.582	0.0120	0.0111	0.0009	92.276	0	January	March	E
Paba	180.944	259.823	-78.879	0.0114	0.0029	0.0085		0			E

Pandhriyeli	79.109	81.941	-2.832	0.0093	0.0099	-0.0006		0			E
Pavetta indica	62.703	55.773	6.930	0.0072	0.0037	0.0035	70.310	2.5	July	March	D
Piper sp.	62.183	59.977	2.206	0.0064	0.0067	-0.0003	97.261	0	July	May	E
Premna coriacea	68.641	75.574	-6.933	0.0105	0.0065	0.0040	87.705	1.5	April	March	D
Psychotria sp	46.076	38.802	7.274	0.0107	0.0092	0.0015		0.5			E
Randia dumetorum	16.872	26.478	-9.606	0.0083	0.0095	-0.0012					D
Rourea santaloides	79.450	109.140	-29.690	0.0088	0.0079	0.0010	83.902	0	April	May	E
Smilax ovalifolia	188.782	90.786	97.996	0.0055	0.0043	0.0013	59.871	3.5	August	March	D
Symplocos beddomei	59.518	70.832	-11.314	0.0099	0.0110	-0.0011	92.570	0	December	December	E
Syzygium cumini	39.343	24.105	15.238	0.0173	0.0118	0.0055	91.501	0	March	October	E
Syzygium gardneri	28.514	19.639	8.875	0.0077	0.0067	0.0010		0			E
Tambdatelya	22.367	18.395	3.972	0.0073	0.0074	-0.0001		0			E
Terminalia bellerica	108.702			0.0146				0			D
Terminalia Chebula	91.572	97.549	-5.978	0.0137	0.0087	0.0051	85.914	0	April	March	D
Terminalia tomentosa	101.947	96.245	5.702	0.0124	0.0093	0.0031		0.5			D
Toplikarvi	48.642	31.302	17.340	0.0072	0.0049	0.0024					D
Vangueria spinosa	37.760	63.668	-25.908	0.0119	0.0110	0.0010	62.711	1.5	April	November	D
Ventilago bombaiensis	26.305	19.377	6.928	0.0065	0.0073	-0.0007		0.5			E
Vikhar	32.494	22.698	9.796	0.0110	0.0058	0.0052	88.065	0	April	March	E
Woodfordia fruticosa	16.646			0.0066			73.903	1.5	September	May	D
Xantolis tomentosa	23.542	12.471	11.071	0.0106	0.0065	0.0042	90.016	0	November	March	E
Zanthoxylum rhetsa	211.610	107.221	104.388	0.0100	0.0067	0.0033		0.5			D
Ziziphus sp.	44.860	27.294	17.567	0.0076	0.0098	-0.0022	76.481	1	July	March	D

Appendix IIIa: Collection Data for mature leaves from BWS. Data includes collection date, collection site and no of individuals collected. Collection Date: (8-12-2013, 15-02-2014); No. of individuals: (3, 2) indicates 3 individuals were collected on 8-12-2013 and 2 individuals on 15-02-2014

Species	Marathi name	Collection Date	Collection site	No. of individuals
Acacia concinna	Shikekai	8-12-2013, 15-02-2014	Husa	3,2
Actinodaphne angustifolia	Malwa	19-09-13	Husa	6
Allophyllus cobbe	Tipna	19-09-13	Husa	6
Amoora lawii	Pandhra Telya	16-10-2013, 15-02-2014	Chowra, Rai	4,3
Ancistrocladus heyneanus	Hardal	16-01-14	Rai	6
Artocarpus heterophylla	Phanas	3-01-2014, 16-01-2014	Rai	1,1
Atlantia racemosa	Chinger	19-09-13	Husa	6
Bridelia retusa	Ashind	15-08-2013, 6/7/2013	B-FS	5,1
Caesaria sp.	Bogada	6/7-9-2013	B-FS	6
Callicarpa tomentosa	Patgira	16-01-14	Rai	6
Canthium diococcum	Kandkudal	19-09-13	Husa	6
Carallia brachiata	Erandi	16-10-2013, 8-12-2013, 16-01-2014	Hindola, Husa, Chowra	2,1,4
Careya areborea	Kumbhayi	6/7-9-2013	B-FS	4
Carissa carandas	Karvandi	19-09-13	Husa	6
Carvia Callosa	Karvi	6/7-9-2013	B-FS	6
Cassine glauca	Luir	3-01-2014, 15-02-2014	Rai	4,1
Celtis cinnamomea	Lokhandi	17-10-13	Husa	4
Colebrookea oppositifolia	Dasai	6/7-9-2013	B-FS	6
Dimorphocalyx lawianus	Rai	3-01-2014, 15-02-2014	Rai	2,3
Diospyros montana	Maskudal	17-10-13	Husa	6
Diospyros sylvatica	Kala Telya	16-10-2013, 3-01-2014, 16-01-2014	Hindola, Rai, Rai	1,1,4
Diploclisia macrocarpa	Naloti	6/7-9-2013	Husa	5
Dysoxylum sp.	Varna 1	03-01-14	KO	3
Dysoxylum sp.	Varna 2	03-01-2014, 15-02-2014	KO, Rai	3,2
Elaeagnus conferta	Ambeli	19-6-2013, 19-9-2013	Husa	3,3
Embelia ribes	Ambati/Kokla/	19-6-2013, 16-10-2013, 15-02-2013	Husa, Hindola	3,1
Embelia sp1	Ambetivel	6/7-9-2013	Husa	6
Ficus nervosa	Loth	3-01-2014, 16-01-2014	Rai	1,2
Ficus racemosa	Umbar	19-9-2013, 16-01-2014	Husa, Chowra	3,3
Ficus tsjahela	Kel	6,7-9-2013, 16-01-2014	Husa, Nigdale	1,3

Flacourtia indica	Tambat	6/7-9-2013	Husa	6
Garcinia indica	Kokkum	8-12-2013, 15-02-2014	Rai	3,2
Garcinia talbotii	Phansada	16-10-13	Hindola	6
Glochidion hohenackeri	Bhoma	19-09-13	Husa	6
Grewia tiliaefolia	Dhaman	6,7-9-2013, 3-01-2014, 15-02-2014	Husa	1,3
Gymnosporia rothiana	Balvand	02-10-13	Husa	6
Heterophragma quadriloculare	Varas	17-10-2013, 8-12-2013	Sheel	6,4
Jasminum malabaricum	Kusar	6/7-9-2013	Husa	6
Lagerstromoea parviflora	Bondara	16-01-14	B-fs	3
Lasiosiphon eriocephalus	Rameta	6/7-9-2013	Husa	7
Leea indica	Andhphod	02-10-13	Husa	6
Lepisanthes tetraphylla	Ambakarap	16-10-13	Hindola	6
Litsea stocksii	Powti	16-10-13	Hindola	6
Litsea zeylanica	Tamalpatra	4/5-06-2013, 3-01-2014	Husa, Rai	1,2
Macaranga peltata	Chandiya	19-09-13	Husa	6
Mallotus phillipensis	Shendri	19-6-2013, 19-9-2013	Husa	3,3
Mangifera indica	Amba	16-10-2013, 17-10-2013	Chowra, Husa	4,2
Memycelon umbellatum	Karab	19-09-13	Husa	7
Mezoneuron cucullatum	Gharnighi	3-01-2014, 15-02-2014	Rai	3,4
Murraya sp	Curry patta	3-01-2014, 16-01-2014, 15-02-2014	Chowra	1,4,3
Myristica dactyloides	Jayphal	03-01-14	Rai	3
Olea dioica	Karambu	2/10/2013, 16/10-2013, 17-10-2013	Husa, Hindola	1,3,3
Pavetta indica	Asavla	6/7-9-2013	Husa	5
Piper sp.	Nagvel	8-12-2013, 15-02-2014	Husa, Rai	4,2
Premna coriacea	Chambhari	6,7-9-2013, 3-01-2014, 15-02-2014	Husa, Rai	2,1,3
Psychotria sp.	Psychotria	16-10-13	Hindola	6
Randia dumetorum	Gel	6/7-9-2013	Husa	6
Rourea santaloides	Kalivel	16-10-2013, 8-12-2013, 15-02-2012	Hindola, Husa	4,1,1
Smilax ovalifolia	Gotveli	6/7-9-2013	Husa	6
Symplocos beddomei	Lothadi	16-10-2013, 8-12-2013	Hindola	2,1
Syzygium cumini	Jambhal	6/7-9-2013	Husa	6
Syzygium gardneri	Parjambhal	4/5-06-2013, 3-01-2014	Rai	1,2
Terminalia bellerica	Behda	8-12-2013, 3-01-2014	B-FS	2,1
Terminalia Chebula	Hirda	6/7-9-2013	Husa	6
Terminalia tomentosa	Sadada	08-12-13	B-FS	4

Unknown 4	Pandhriyeli	16-10-2013, 3-01-2014, 15-02-2014	Chowra	1,3,2
Unknown 5	Toplikarvi	6/7-9-2013	Husa	6
Unknown 2	Tambdatelya	3-01-2014, 15-02-2014	Rai	3,3
Unknown 3	Paba	08-12-13	B-FS	3
Unknown 1	Vikhar	17-10-13	Husa	4
Vangueria spinosa	Aoul	6/7-9-2013	B-FS	6
Ventilago bombaiensis	Madvel	3-01-2014, 15-02-2014	Rai	3,3
Woodfordia fruticosa	Dayti	02-10-13	Husa	6
Xantolis tomentosa	Kombal	17-10-13	Husa	6
Zanthoxylum rhetsa	Kokhali	17-10-2013, 8-12-2013	Husa	1,4
Ziziphus sp.	Thoran	6/7-9-2013	Husa	7

Appendix IIIb: Collection Data for immature leaves from BWS. Data includes collection date, collection site and no of individuals collected. Collection Date: (4/5-06-2013, 19-06-2013); No. of individuals: (2, 1) indicates 2 individuals were collected on 4/5-06-2013 and 1 individual on 19-06-2013

SPECIES	MARATHI NAME	Collection Date	Collection site	No. of individuals
Acacia concinna	Shikekai	4/5-06-2013, 19-06-2013	Nigdale	2,1
Actinodaphne angustifolia	Malwa	16-03-13	Husa	3
Allophyllus cobbe	Tipna	13/14-04-2013, 14/15-04-2013	Husa	2,2
Ancistrocladus heyneanus	Hardal	4/5-06-2013	Rai	3
Bridelia retusa	Ashind	13/14-04-2013, 14/15-04-2013, 16-05-2013	Husa, B-FS	1,1,2
Caesaria sp.	Bogada	16-05-13	B-FS	4
Callicarpa tomentosa	Patgira	16-05-13	Husa	4
Canthium diococcum	Kandkudal	16-03-13	Husa	4
Careya areborea	Kumbhayi	16-05-2013, 4/5-06-2013	B-FS	2,1
Carissa carandas	Karvandi	16-03-13	Husa	4
Carvia Callosa	Karvi	04-07-13	Husa	3
Cassine glauca	Luir	4/5-06-2013	Rai	2
Celtis cinnamomea	Lokhandi	16-03-2013, 13/14-04-2013, 14/15-04-2013	Husa	2,1,1
Colebrookea oppositifolia	Dasai	17-07-13	Husa	3

Dimorphocalyx lawianus	Rai	4/5-06-2013	Rai	3
Diospyros montana	Maskudal	16-03-13	Husa	4
Diospyros sylvatica	Kala Telya	4/5-06-2013	Rai	3
Diploclisia macrocarpa	Naloti	16-03-2013, 13/14-04-2013	Husa	1,2
Elaeagnus conferta	Ambeli	16-03-13	Husa	3
Embelia ribes	Ambati/Kokla/	19-06-13	Husa	3
Embelia sp1	Ambetivel	4/5-06-2013, 04-07-2013	Husa	1,2
Ficus racemosa	Umbar	19-06-13	Husa	3
Ficus tsjahela	Kel	14/15-04-2013	Husa	1
Flacourtia indica	Tambat	16-03-2013, 14/15-04-2013	Husa	3,1
Garcinia indica	Kokkum	4/5-06-2013, 19-06-2013	Rai	1,2
Garcinia talbotii	Phansada	4/5-06-2013	Rai	4
Glochidion hohenackeri	Bhoma	4/5-06-2013	Rai	3
Grewia tiliaefolia	Dhaman	4/5-06-2013, 19-06-2013	Husa	2,1
Gymnosporia rothiana	Balvand	02-10-13	Husa	6
Jasminum malabaricum	Kusar	13/14-03-2013	Husa	4
Lasiosiphon eriocephalus	Rameta	17-07-13	Husa	3
Leea indica	Andhphod	16-05-13	Husa	6
Lepisanthes tetraphylla	Ambakarap	4/5-06-2013	Chowra	4
Litsea stocksii	Powti	4/5-06-2013	Chowra	3
Litsea zeylanica	Tamalpatra	13/14-04-2013, 4/5-06-2013	Husa, Rai	1,1
Macaranga peltata	Chandiya	16-03-2013, 13/14-04-2013	Husa	1,2
Mallotus phillipensis	Shendri	13/14-03-2013	Husa	3
Mangifera indica	Amba	14/15-04-2014	Husa	3
Memycelon umbellatum	Karab	16-03-13	Husa	5
Mezoneuron cucullatum	Gharnighi	4/5-06-2013, 19-06-2013	Rai	2,1
Myristica dactyloides	Jayphal	4/5-06-2013	Rai	1
Olea dioica	Karambu	13/14-04-2013, 14/15-04-2013	Husa	1,4
Pavetta indica	Asavla	17-07-13	Husa	3

Piper sp.	Nagvel	4/5-06-2013	Chowra	4
Premna coriacea	Chambhari	13/14-04-2013, 4/5-06-2013	Husa	1,2
Psychotria sp.	Psychotria	4/5-06-2013	Hindola	3
Randia dumetorum	Gel	16-05-2013, 4/5-06-2013	Husa, B-FS	1,2
Rourea santaloides	Kalivel	4/5-06-2013	Rai	2
Smilax ovalifolia	Gotveli	17-07-13	Husa	3
Symplocos beddomei	Lothadi	16-03-2013, 4/5-06-2013	Husa, Rai	1,1
Syzygium cumini	Jambhal	16-03-13	Husa	3
Syzygium gardneri	Parjambhal	4/5-06-2013, 19-06-2013	Rai	1,2
Terminalia Chebula	Hirda	13/14-03-2013	Husa	3
Terminalia tomentosa	Sadada	16-05-2013, 4/5-06-2013	B-FS	1,3
Unknown 5	Topli karvi	04-07-13	Husa	4
Unknown 2	Tambdatelya	4/5-06-2013	Rai	3
Unknown 3	Paba	19-06-13	B-FS	1
Unknown 1	Vikhar	16-03-2013, 17-10-2013	Husa	1,2
Vangueria spinosa	Aoul	13/14-04-2013, 14/15-04-2013	B-FS	2,1
Ventilago bombaiensis	Madvel	4/5-06-2013, 19-06-2013	Rai	2,1
Xantolis tomentosa	Kombal	17-10-13	Husa	1
Zanthoxylum rhetsa	Kokhali	17-10-13	Husa	2
Ziziphus sp.	Thoran	16-05-13	Husa	4