ASSESSMENT OF WOOD GROWTH AND PROPERTIES OF SWAMPY AND NON-SWAMPY MYRISTICACEAE MEMBERS IN RELATION TO MAJOR ENVIRONMENTAL VARIABLES

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IN

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Affectionately Dedicated to My Guide and my family members

DEPARTMENT OF FORESTRY AND ENVIRONMENTAL SCIENCE
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CERTIFICATE

This is to certify that the thesis entitled "**ASSESSMENT OF WOOD GROWTH AND PROPERTIES OF SWAMPY AND NON-SWAMPY MYRISTICACEAE MEMBERS IN RELATION TO MAJOR ENVIRONMENTAL VARIABLES**" submitted by **Mr. VENKATESH, C. S.** in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **ENVIRONMENTAL SCIENCE** to the University of Agricultural Sciences, GKVK, Bengaluru is a record of bonafide research work done by him during the period of his study in this university under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

BENGALURU
MAY, 2016.

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May, 2016. ***(VENKATESH, C. S.)***
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ASSESSMENT OF WOOD GROWTH AND PROPERTIES OF SWAMPY AND NON-SWAMPY MYRISTICACEAE MEMBERS IN RELATION TO MAJOR ENVIRONMENTAL VARIABLES

VENKATESH, C. S.

ABSTRACT

Myristicaceae is one of the ancient families of flowering plants in tropical forests. India harbours 15 species belonging to four genera that are distributed in Andaman and Nicobar Islands, Meghalaya and Western Ghats. The Western Ghats harbours five species. Out of which, two of them are exclusively associated with swampy habitat. Whereas, others occur in and around the swamps in upland conditions in evergreen forests. Most of the species are economically important, endemic and also listed in the RET categories and the wood is soft, used for several purposes. The present study was conducted in Western Ghats to understand the changes in wood growth and properties of obligate swampy (*Gymnacranthera canarica*) and non-swampy (*Myristica malabarica*) species with respect to major environmental parameters. Based on preliminary survey, five ideal locations covering the three districts were selected. Following the random sampling quadrat method, demographic profile was enumerated. The wood core samples were obtained from trees using increment borer and three replications were maintained for each species in all the locations. The results indicated that, swampy species possess higher tree densities and show better regeneration compared to non swampy species. With regards to wood growth, significant variation was observed across the locations in both swampy and non-swampy species. The swampy species showed higher wood growth and fibre length while non-swampy species possess higher specific gravity in all the locations. The environmental parameters like mean annual temperature, rainfall and relative humidity showed no relationship with wood properties. In conclusion, the Myristicaceae species with respect to wood growth and properties do not show any kind of relationship with environmental parameters. Therefore, further studies are needed to understand the underlying factors and methods.

May, 2016.

M. MAHADEVA MURTHY
Chairman

ಜೌಗು ಮತ್ತು ಜೌಗುರಹಿತ ಪ್ರದೇಶದಲ್ಲಿ ಬೆಳೆದಿರುವ ಮಿರಿಷ್ಟಿಕೇಶಿಯೇ ಕುಟುಂಬದ ಸಸ್ಯ ಪ್ರಬೇಧಗಳ ಮರದ ಬೆಳವಣಿಗೆ ಮತ್ತು ಗುಣಗಳ ಮೇಲೆ ಪರಿಸರದ ನಿಯತಾಂಕಗಳ ಸಂಬಂದ ಕುರಿತು ವಿಶ್ಲೇಷಣೆ

ವೆಂಕಟೇಶ್, ಸಿ. ಎಸ್.

<u>ಸಾರಾಂಶ</u>

ಮಿರಿಷ್ಟಿಕೇಶಿಯೇ ಎನ್ನುವುದು ಪ್ರಾಚೀನ ಕಾಲಕ್ಕೆ ಸೇರಿದ ಹೂವು ಬಿಡುವ ಸಸ್ಯ ಕುಟುಂಬಗಳಲ್ಲಿ ಒಂದು. ಇದನ್ನು ಉಷ್ಣವಲಯದ ಕಾಡುಗಳಲ್ಲಿ ಕಾಣಬಹುದು. ಈ ಸಸ್ಯ ಕುಟುಂಬಕ್ಕೆ ಸಂಬಧಿಸಿದಂತೆ, ಭಾರತದಲ್ಲಿ ನಾಲ್ಕು ಸಸ್ಯ ಕುಲಗಳಿದ್ದು, ಅವುಗಳಲ್ಲಿ 15 ಪ್ರಭೇದಗಳು ಅಂಡಮಾನ್ ಮತ್ತು ನಿಕೋಬರ್, ಮೇಘಾಲಯ ಹಾಗೂ ಪಶ್ಚಿಮ ಘಟ್ಟಗಳಲ್ಲಿ ನೆಲೆಗೊಂಡಿದೆ. ಪಶ್ಚಿಮ ಘಟ್ಟಗಳು 5 ಪ್ರಬೇಧಗಳಿಗೆ ಆಶ್ರಯ ನೀಡಿದೆ. ಅದರಲ್ಲಿ ಮುಖ್ಯವಾಗಿ ಎರಡು ಪ್ರಬೇಧಗಳು ಜೌಗುಪ್ರದೇಶಕ್ಕೆ ವಾಸಸ್ಥಳವಾಗಿದೆ. ಇನ್ನುಳಿದ ಪ್ರಬೇಧಗಳು ಜೌಗುಪ್ರದೇಶದ ಸುತ್ತಮುತ್ತಲಿರುವ ಎತ್ತರದ ಪ್ರದೇಶಗಳಲ್ಲಿ ಕಾಣಬಹುದು. ಅತಿ ಹೆಚ್ಚಿನ ಪ್ರಬೇದಗಳು ಆರ್ಥಿಕವಾಗಿ ಉಪಯೋಗವಾಗಿದೆ, ಹಾಗೆಯೆ ರೋಗಗಳಿಗೂ ತುತ್ತಾಗಿದೆ ಮತ್ತು ಈ ಕೆಲವು ಪ್ರಬೇದಗಳನ್ನು RET ಗುಂಪಿನಲ್ಲಿ ಸೇರಿಸಲಾಗಿದೆ. ಜೌಗುಪ್ರದೇಶದಲ್ಲಿ ಬೆಳೆಯುವ ಮರಗಳು ಬಹಳ ಮೃದುವಾಗಿದ್ದು, ಅನೇಕ ಕಾರ್ಯಗಳಿಗೆ ಬಹುಉಪಯೋಗವಾಗಿವೆ. ಪ್ರಸ್ತುತ ಅಧ್ಯಯನದಲ್ಲಿ ಪಶ್ವಿಮಘಟ್ಟಗಳ ಜೌಗು ಮತ್ತು ಜೌಗುರಹಿತ ಪ್ರದೇಶದಲ್ಲಿ ಬೆಳೆದಿರುವ ಸಸ್ಯಪ್ರಬೇದಗಳ ಬೆಳವಣಿಗೆ ಮತ್ತು ಗುಣಗಳ ಮೇಲೆ ಪರಿಸರದ ನಿಯತಾಂಕಗಳ ಸಂಬಂಧವನ್ನು ತಿಳಿದುಕೊಳ್ಳಲಾಗಿದೆ. ಪ್ರಾಥಮಿಕ ಸರ್ವೆಯಲ್ಲಿ, ಮೂರು ಜಿಲ್ಲೆಗಳಲ್ಲಿ ಬರುವಂತಹ 5 ಸ್ಥಳಗಳನ್ನು ಆಯ್ಕೆಮಾಡಲಾಯಿತು. Random Sampling Quadrat Method ಮತ್ತು Demographic Profile ವಿಧಾನವನ್ನು ಮರಗಳ ಏಣಿಕೆಗೆ ಬಳಸಲಾಗಿದೆ. ಮರದ ತಿರುಳಿನ ಮಾದರಿಯನ್ನು Increment Borer ಎಂಬ ಉಪಕರಣವನ್ನು ಬಳಸಿ ತೆಗೆಯಲಾಯಿತು. ಹಾಗೆಯೇ ತದ್ರೂಪಿಯಾಗಿ ಮರದ ತಿರುಳಿನ ಮಾದರಿಯನ್ನು ಎಲ್ಲಾ ಸ್ಥಳಗಳಲ್ಲಿಯೂ ಪ್ರತಿಯೊಂದು ಪ್ರಬೇಧಗಳಲ್ಲಿ ಪಡೆಯಲಾಯಿತು. ಈ ಅಧ್ಯಯನದ ಫಲಿತಾಂಶದ ಪ್ರಕಾರ ಜೌಗುರಹಿತ ಪ್ರದೇಶಕ್ಕೆ ಹೋಲಿಸಿದಾಗ ಜೌಗು ಪ್ರದೇಶದಲ್ಲಿ ಹೆಚ್ಚು ಮರದಟ್ಟಣೆ ಮತ್ತು ಉತ್ತಮ ಪುನರ್ ಉತ್ಪಾದನೆಯನ್ನು ಕಂಡುಬಂದಿದೆ. ಮರದ ಬೆಳವಣಿಗೆಗೆ ಸಂಬಂಧಿಸಿದಂತೆ ಜೌಗು ಮತ್ತು ಜೌಗುರಹಿತ ಪ್ರದೇಶದ ಉದ್ದಘ್‌ಲಕ್ಕೂ ಮಹತ್ತರವಾದ ಬದಲಾವಣೆ ಕಾಣಬಹುದು. ಈ ಎಲ್ಲಾ ಸ್ಥಳಗಳಲ್ಲಿಯೂ ಜೌಗುಪ್ರದೇಶದ ಪ್ರಬೇಧಗಳಲ್ಲಿ ಹೆಚ್ಚಿನ ರೀತಿಯ ಮರದ ಬೆಳವಣಿಗೆ ಮತ್ತು ಮರದ ನಾರಿನ ಉದ್ದ ಕಂಡುಬಂದಿದ್ದು, ಹಾಗೆಯೇ ಜೌಗುರಹಿತ ಪ್ರದೇಶಗಳಲ್ಲಿ ಹೆಚ್ಚಿನ ವಿಶಿಷ್ಠ ಗುರುತ್ವ ಹೊಂದಿದೆ. ಪರಿಸರದ ನಿಯತಾಂಕಗಳಾದ ಸರಾಸರಿ ವಾರ್ಷಿಕ ತಾಪಮಾನ, ವಾರ್ಷಿಕ ಮಳೆ ಮತ್ತು ವಾರ್ಷಿಕ ಸಾಪೇಕ್ಷ ಆದ್ರತೆಗಳು ಮರದ ಗುಣಗಳಿಗೆ ಯಾವುದೇ ರೀತಿಯ ಸಂಬಂಧ ಕಂಡುಬಂದಿಲ್ಲ. ಈ ಅಧ್ಯಯನದ ಒಟ್ಟು ಸಾರಾಂಶದ ಪ್ರಕಾರ ಮಿರಿಷ್ಟಿಕೇಶಿಯೇ ಪ್ರಬೇಧದ ಮರದ ಬೆಳವಣಿಗೆ ಮತ್ತು ಲಕ್ಷಣವೆಂಬ ವಿಷಯಕ್ಕೆ ಸಂಬಧಪಟ್ಟಂತೆ ಬೌಗೋಳಿಕವಾಗಿ ಪ್ರಾಕೃತಿಕವಾಗಿ ಉತ್ತಮ ಬಾಂದವ್ಯನ್ನು ಹೊಂದಿಲ್ಲ ಆದರೆ, ಪ್ರಕೃತಿಯ ಇತಿಮಿತಿಗಳಿಗೆ ಒಳಗಾಗಿದೆ. ಆದ್ದರಿಂದ ಇನ್ನಿತರ ಉತ್ತಮ ಮಟ್ಟದ ಪ್ರಾಯೋಗಿಕ ಅಧ್ಯಯನ ನಡೆಸಲು ಕೆಲವೊಂದು ವಿಚಾರವಿಧಾನಗಳನ್ನ ಗ್ರಹಿಸಿ ಯಸಸ್ವಿಗೊಳಿಸಬೇಕಾಗುತ್ತದೆ.

ಮೇ, 2016

ಎಂ. ಮಹದೇವ ಮೂರ್ತಿ
ಮುಖ್ಯ ಸಲಹೆಗಾರರು

Assessment of Wood Growth and Properties of Swampy and Non-Swampy Myristicaceae members in relation to major Environmental Variables

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Introduction

Myristicaceae is one of the ancient families of flowering plants in tropical forests. There are about 500 species (21 genera) distributed in lowland wet evergreen forests, though some species also occur in montane regions. In India, 15 species representing 4 genera are available. In Western Ghats, 5 species namely *Gymnacranthera canarica, M. fatua var. magnifica, M. dactyloides, M. malabarica* and *Knema attenuate* are available. Among the five species, the first two are exclusively associated with swampy habitat and possess aerial/knee roots. The other species occur mostly in non-swampy habitats. The evolution history and significance of swampy and non-swampy Myristicaceae members is not yet understood.

In evolution of plant kingdom, one of the significant step is the migration of green plants from an aquatic environment to a terrestrial conditions (Delevoryas, 1974). Accordingly, it is hypothesized that non-swampy members have evolved from the swampy ancestors. Among the various characters, the wood growth and property appears to be the key feature that helps to understand the tree adaptations to the environmental conditions. In this study we propose to assess the wood growth and properties of *Myristica* members associated with swampy and non-swampy habitats. Further, attempt will be made to compare and also correlate the wood growth properties with environmental variables. Our findings will help to improve the understanding about tree species and will also help in management of Myristicaceae members.

Objectives

- To survey and identify with suitable locations with swampy and non swampy Myristicaceae members.
- To study the impact of major environmental variables on wood growth and properties of swampy and non-swampy species.
- To arrive at the suitable conservation strategies for Myristicaceae members.

Material and Methods

Study sites: Based on the prior information, a systematic field survey was conducted in the central Western Ghats (Karnataka state), India. Locations where both swampy and non-swampy species co-occurring were short-listed and selected (Figure 1).

Character	Swampy	Non-swampy
Water logged condition	Present	Absent
Myristicaceae species	*G. canarica, M fatua*	*M. malabarica, M dactyloides, Knema attenuata*
knee / aerial roots	Prominent	Sometimes aerial roots observed
Summer	Wet condition	Dry conditions
Soil	More acidic	Less acidic
Nutrient status	Poor in NPK but rich in Fe & Zn	Relatively rich in NPK & poor in Fe & Zn
Humus	large proportion	Less
Anaerobic bacteria	Present	Absent

Study system: Two species, one swampy (*Gymnacranthera canarica* synonym *Myristica canarica* or *G. furquarianan* present abundantly in swamps) and another one non-swampy species (*Myristica malabarica,* a species found around swamps) were selected for the present study. The wood core samples were collected from the trees (3 replications at each location) using increment borer.

Wood Properties Analysis: Each core sample was processed and growth rings using microscope, specific gravity and fiber length was measured by the following standard protocol**.** Wood properties were compared between co-occurring swampy and non-swampy species. Statistical analysis was performed using a software STATISTICA.

Results

Wood property (specific gravity): The wood specific gravity of non-swampy species (*M. malabarica*) found to be higher than co-occurring swampy species (*G. canarica*). The pattern was consistent across the five study locations (Table 1). The frequency distribution pattern of specific gravity values was also compared. The distribution pattern was significantly different for the swampy and non-swampy species (Figure 2).

Discussion

Siddiqi and Wilson (1974) Using available literature on the Asiatic genera of Myristicaceae, concluded that, the wood structure of the four genera (*Horsfieldia, Gymnacranthera, Myristica* & *Knema*) is remarkably similar. Later, Rao *et al.,* (1992) studied the wood anatomy of Indian Myristicaceae and indicated that four Indian genera can be easily distinguished from each other on the basis of their wood structure. Further, they also concluded that Indian species are more similar to African genera than the American. However, the important wood properties like specific gravity, fibre length, etc of Indian Myristicaeceae has not yet been studied. Though the wood property namely specific gravity reflects the amount of wood substance or biomass deposited per unit volume of living tree trunk (Woodcock, 2000). Further, the specific gravity of wood reflects the wood quality thus an important parameter of wood growth. Studies have indicated that wood specific gravity increases with increased abiotic stress. In tropical forest species, specific gravity found to be low in wet environments and higher in uplands/ drier conditions (Chudoff 1976; Barajas-Morales 1987; Wiemann & Williamson 1989). Parolin (2002) reported that increased specific gravity appear to be the growth strategies of trees to survive in drier environments. Our results are also inline with the earlier studies.

Figure 1.Map of the study locations in central Western Ghats

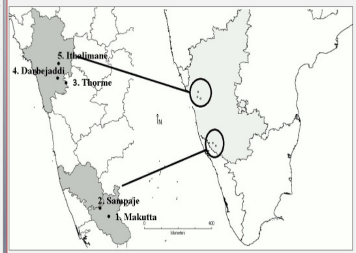

Table 1: Wood specific gravity of swampy and non-swampy species in central Western Ghats, India

SN	Location	Swampy		Non-swampy		t test
		Range	Mean± SD	Range	Mean± SD	Significance
1	Makutta	0.352-0.427	0.379± 0.026	0.489-0.586	0.539± 0.037	t=9.33 p<0.00
2	Sampaje	0.339-0.404	0.375± 0.022	0.460-0.498	0.478± 0.022	t=8.73 p<0.00
3	Thorme	0.459-0.547	0.503± 0.027	0.486-0.592	0.540± 0.045	t=1.88 p<0.08
4	Darbejaddi	0.453-0.571	0.506± 0.045	0.491-0.593	0.559± 0.035	t=2.47 p<0.03
5	Ithalimane	0.353-0.445	0.396± 0.030	0.387-0.491	0.441± 0.040	t=2.27 p<0.04
	Overall	0.339-0.571	0.424± 0.064	0.361-0.578	0.462± 0.065	t=3.35 p<0.00

Swampy species - *Gymnacranthera canarica*
Non-swampy species- *Myristica malabarica*

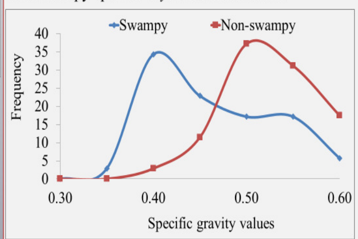

Figure 2. Frequency distribution of specific gravity values of swampy and non-swampy species (KS test significance @p<0.05

Summary

Specific gravity is one of the important wood properties that tend to increases with the adverse environmental conditions Compared to swampy species, the non swampy species have limited water supply particularly in summer. Hence, the specific gravity in non-swampy species is higher than the co-occurring swampy species. This appears to be the growth strategies of tree species to survive under upland drier environments. Further, studies are needed to relate wood properties with species distribution pattern.

Advisory Committee

Chairman: **Dr. M. Mahadeva Murthy**
Members: **Dr. S. Hattappa**
Dr. B. Mohan Raju
Dr. B. Tambat

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I INTRODUCTION

Myristicaceae is one of the ancient families of flowering plants in tropical forests. There are about 500 species (21 genera) distributed in lowland wet evergreen forests (Tambat *et al.,* 2004). The nutmeg, *Myristica fragrans*, a widely cultivated spice is a native of Mollucas Island. Hence, the family is often referred as nutmeg family (Chandran and Mesta, 2001). The members of the family are pantropical, being associated with the rain forests of Asia, Africa, Madagascar, South America and Polynesia. The genus *Myristica* with 120 species is the largest of the genu with New Guinea has the largest number of species (Corner, 1976). *Virola* is major component of the Amazon forests. *Iryantha* and *Virola* are found in the swamp forests of Venezuela. *Knema sp*. is found in Southeast Asia and Malaysia (Takhtajan, 1969; Ahmedullah and Nayar, 1986). India harbours 15 species of which four are major genera namely, *Horsfieldia, Gymnacranthera, Knema* and *Myristica*. The members occur in the evergreen forests of Andaman and Nicobar Islands, Meghalaya and the Western Ghats.

Worldwide, members of Myristicaceae share several common features. They are shade-tolerant, evergreen trees with pink or red resinous juice in the bark. The trees have central shaft like main stem producing horizontal branches. The leaves are simple, dark green and alternate. The flowers are small, dull in appearance, either male or female with only one whorl of perianth. The stamens in the male flower together form a central column. The ovary in the female has one chamber and one ovule. The wall of the fruit is fleshy and fibrous, and when mature splits into two halves exposing a single large seed covered with a bright orange or red juicy cover called aril. The kernel of the seed is rich in starch and oil. Many members of the family, being equipped with aerial roots can endure water-logging (Kuhn and Kubitzki, 1993).

Vijendra *et al.,* (1992) made a study on anatomical description of Indian Myristicaceae, The genus *Gymnacranthera* Warb is represented in India by only one species *viz. Gymnacranthera canarica* (King) Warb. Syn. *Myristica canarica* King. It occurs in the Western Ghats from South Canara southwards.

Microscopic structure analysis indicated *Myristica* genus possesses a diffuse porous wood; growth rings are distinct, delimited by concentric lines/ bands of parenchyma in all the species. They also reported that based on the wood properties, *Gymnacranthera canarica* can be distinguished from other two genera in possessing vessels perforations which are predominantly (94 %) simple. However, their differentiation at species level, on the basis of both qualitative and quantitative anatomical features, is little difficult.

A wood property has been noticed throughout the world (Zobel, 1983) and therefore, the causes of the change must be known. In order to use wood efficiently, the variation patterns within trees, among trees within the species and among species must be understood (Zobel and Van, 1989). Over the years, tree breeding programs the world over have aimed at improving volume growth through selection (Zobel and Talbert, 1984). However, many tree improvement programs for major tree species have not included wood quality, although wood is the desired product. For the utilization of wood resources, criteria for evaluating wood quality should be included in tree breeding (Zobel and Van, 1989). In recent times, it has been realized that, wood quantity (volume growth) and wood quality cannot be treated as independent traits and that wood quality improvement should form. Therefore, form an integral part of tree breeding programs (Zobel and Telbert, 1984; Zobel and Van, 1989).

Wood specific gravity is one of the most important traits affecting the quality and quantity of pulp and the strength of wood products. It is a complex feature influenced by cell wall thickness, proportion of different kinds of tissues and percentage of lignin, cellulose and extractives (Valente *et al.,* 1994). Wood density and fibre length determine whether the quality of raw material is suitable for a specific use in the paper industry. Fibre length also has impact on paper characteristics such as strength, optical properties and surface quality.

The Western Ghats of India harbours 5 species of Myristicaceae namely *Gymnacranthera canarica, Myristica. fatua var. magnifica, Myristica dactyloides, Myristica malabarica* and *Knema attenuate*. Among the five species, the first two are exclusively associated with swampy habitat and possess aerial/knee roots. The other species occur mostly in non-swampy habitats. The evolution, history and significance of swampy and non-swampy Myristicaceae members are not yet understood. In evolution of plant kingdom, one of the significant steps is the migration of green plants from an aquatic environment to a terrestrial condition (Delevoryas, 1974). Among the various characters, the wood growth and property appears to be the key feature that helps to understand the tree adaptations to the environmental conditions.

The impact of anthropogenic pressure on swamps in Western Ghats has been documented. Studies indicate that, disturbance alters species composition and facilitates the invasion of non-swampy species (Vasudev *et al.,* 2001, Chithra and Tambat, 2007 and Tambat *et al.,* 2014). The disturbance affects the swampy species population, pollination and dispersal process; it facilitate inbreeding depression thereby reduces reproductive fitness and recruitment of swampy species (Tambat *et al.,* 2005).

Tambat *et al.,* (2007) have reported seed abnormality in *Gymnacranthera canarica*, a dominant tree species of *Myristica* swamp. Several people have reported that, at disturbed sites, swampy species show poor regeneration (Chandran and Mesta, 2001, Tambat *et al.,* 2004, Tambat *et al.,* 2012). The anthropogenic pressure on swamps has transformed several habitat specific species, rare and endemic species into threatened category. *Myristica* swamp associated dominant species namely; *Gymnacranthera canarica*, *Myristica fatua* var. *magnifica* and *Myristica malabarica* are listed under threatened category (FRLHT, 2000 and IUCN, 2003).

In view of the above, present study is directed towards understanding and comparing the responses of obligate swampy and non-swampy species of Myristicaceae with respect to wood growth across different locations in Western Ghats. Further, to understand the changes in wood properties with respect to the environmental parameters. Our finding helps to improve the understanding about tree species and thereby helps in management of Myristicaceae members. Thus, the objectives of the study are as follows:

1. To survey and identify suitable locations of swampy and non-swampy Myristicaceae members.

2. To study the impact of major environmental variables on wood growth and properties of swampy and non-swampy species (Myristicaceae members).

3. To arrive at suitable conservation strategies for Myristicaceae members.

II REVIEW OF LITERATURE

This chapter deals with the reviews and current understanding about the *Myristica* swamps. Besides, it also deals with the information pertaining to wood growth ring, its properties like specific gravity, fibre length, with relationship between environmental variables. This information has been found relevant for the present study.

2.1. Western Ghats

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. Myristicaceae members are endemic to the Western Ghats of India and distributed in the tropical lowland forest areas of Karnataka, Kerala and Tamil Nadu. In Karnataka, the species are abundant in the wet evergreen forest of Coorg, Uttara Kannada, Dakshina Kannada and Shimoga (Ravikumar *et al.,* 2000).

The Western Ghats (8º to 20º N and 73º to 77º E) extending from Tapti in Gujarat to Kanniyakumari in Tamil Nadu, traversing through Maharashtra, Goa, Karnataka, Tamil Nadu and Kerala along the west coast and forming a practically unbroken relief for about 1600 km, with the exception of the Palghat Gap, are a magnificent stretch of hill ranges, presenting rich and varied flora and fauna. Different types of vegetation occur here namely, scrub forests, grasslands at lower altitudes, moist and dry deciduous forests, tropical evergreen forests and montane grasslands and sholas.

About 50,000 species of the estimated 1700 species of the flowering plants of India are found in the Western Ghats (Nayar, 1996). It is also one of the 25 'Hotspots of Biodiversity' identified in the world (Myers *et al.,* 2000). A large proportion of the plants found here *viz.,* 54 genera, and 1720 species and 135 infra specific taxa are endemic (Shetty and Kaveriappa, 1991). Nearly a third of the endemic taxa found here are rare or threatened and several are believed to be extinct or at serious risks of becoming extinct.

2.2. Myristicaceae family

Myristicaceae is one of the important families that are dominating freshwater swamps in the Western Ghats, India. The family has 18 genera and 300 species that are distributed in tropical forest of the world. The nutmeg, *Myristica fragrans,* a native of Mollucas Island and cultivated widely in the gardens of the Western Ghats, is a well-known species. The members of the family are pantropical, being associated with the rainforests of Asia, Africa, Madagascar, South America and Polynesia. *Myristica* with 120 species is the largest of the genus; New Guinea has the largest number of species. *Virola* is major component of the Amazon forests. *Knema* spp. is found in Southeast Asia and Malaysia (Takhtajan, 1969, Ahmedullah and Nayar, 1986).

Distribution, habitat and leaf characteristics of the Myristicaceae species in the Western Ghats

Sl. No	Species	Habitat	*Reference*	Roots	Reference	Tree height (in feet)	Leaf character	Forest types	Distribution	Reference
1	*Gymnacranthera canarica* (King) Warb.	Swampy	Tambat *et al.,* 2004	Knee roots	Chandran and Mesta, 2001	Large (Up to 80)	Thin and smooth	Occasional in evergreen forest on windward side of Western Ghats	Endemic to WG	Ramesh and Pascal, 1997
2	*Myristica fatua* Houtt. Var. *magnifica* (Bedd.) Sinclair	Swampy	Gamble, 1935	Prominent stilt root	Chandran and Mesta, 2001	Lofty (Up to 100)	Thick and smooth	In swampy areas of evergreen forest of Western Ghats	Endemic to WG	Ramesh and Pascal, 1997
3	*Myristica malabarica* Lam.	Both	Tambat *et al.,* 2004	Stilt root	Chandran and Mesta, 2001	Moderate (Up to 50)	Thin and smooth	Occasional in evergreen forest of Western Ghats	Endemic to WG	Ramesh and Pascal, 1997
4	*Myristica dactyloides* Gaertn.	Non-swampy	Tambat *et al.,* 2004	No prominent stilt root	Chandran and Mesta, 2001	Large (Up to 90)	Thick and smooth	Frequent in evergreen forest of Western Ghats	Widespread	Ramesh and Pascal, 1997
5	*Knema attenuate* (J. Hk. &Thw.) Warb.	Non-swampy	Tambat *et al.,* 2004	No prominent stilt root	Chandran and Mesta, 2001	Moderate (Up to 50)	Thin and rough	Frequent in semi- evergreen forest of Western Ghats	Endemic to WG	Ramesh and Pascal, 1997

(Source : Tambat *et al*., 2004)

India has four genera namely *Horsfieldia, Gymnacranthera, Knema* and *Myristica* and altogether 15 species. Characteristic feature of the Western Ghats *Myristica* swamps is the abundance of Myristicaceae members, particularly *Gymnacranthera canarica* and *Myristica fatua var. magnifica*. These two species which are not common under other condition. The species have very dense stilt roots, which sprouts 6 m above the soil (Pascal, 1988). The other members of Myristicaceae occur in the evergreen forests of Andaman and Nicobar Islands, Meghalaya and the Western Ghats. *Iryantha* and *Virola* are found in the swamp forests of Venezuela. Apart from the South Indian Western Ghats swamps dominated by Myristicaceae are also reported from New Guinea (Corner, 1976).

The members of Myristicaceae, the world over, share several common features. They are shade-tolerant, evergreen trees with pink or red resinous juice in the bark. The trees have central shaft like main stem producing horizontal branches. The leaves are simple, dark green and alternate. The flowers are small, dull in appearance, either male or female with only one whorl of perianth. The stamens in the male flower together form a central column. The ovary in the female has one chamber and one ovule. The wall of the fruit is fleshy and fibrous, and when mature splits into two halves exposing a single large seed covered with a bright orange or red juicy cover called aril. The kernel of the seed is rich in starch and oil. Many members of the family, being equipped with aerial roots can endure water-logging (Kuhn and Kubitzki, 1993).

2.3. Swampy and non-swampy Myristicaceae members

Swamps are subjected to seasonal flooding thus support characteristic vegetation types. In the tropics, such vegetation occurs frequently amid natural forests and along the flood plains of major rivers. They form integral part of the wetland ecosystems, serving as habitats, nursery grounds and sources of food for many organisms (Brown *et al.,* 1979). The characteristic feature of the *Myristica* swamps of Western Ghats is the abundance of trees belonging to the family Myristicaceae, particularly two species viz. *Myrisitica fatua var. magnifica* and *Gymnacranthera canarica*. Myristicaceae dominated the swamps with maximum Importance Value Index of 102.63 represented mainly by *G. farquhariana* (57.83) and *M. fatua var. magnifica* (38.49). The forest floor is covered by knee roots. Other *Myristica* species found (although less frequently) is *Myristica malabarica*. The two species *Myristica dactyloides* and *Knema attenuate* also found in Western Ghats but in non-swampy uplands.

Besides, *Myristica* swamps are also dominated by the plant species like *Mastixia arborea, Lopopetalum whitianum* and many other important medicinal and NTFP species like *Garciniagum migutta, Calamus sp,* and *Cinnamomum sp, Dipterocarpus indicus, Ochlandrarheedii and Caryotaurens, Arengawhitii and Pinangadicksonii* (Vignesh and Vinayak, 2014). In *Myristica* swamps, plant species (especially Myristicaeae members) have special physiological adaptations for their habitat. They will develop special type of roots for their anaerobic respiration. They are called as “aerial roots”, with many pneumatophores. Since, swamp soil shows deficiency of oxygen.

Evergreen trees such as *Gymnacranthera canarica, Knema attenuata, M. fatua var. magnifica, M. dactyloides* and *M. malabarica* represent Myristicaceae in the Western Ghats. Of these, the first two species are exclusively associated with lowland swampy habitats and possess aerial roots to survive under anaerobic condition. The rest are more widely distributed in the non-swampy upland habitats, although *M. malabarica* may sometimes be found in the swamps (Tambat *et al.,* 2012). It has been reported that except *M. dactyloides* all other species are endemic to Western Ghats of India. Further the evolution history and significance of swampy and non-swampy Myristicaceae is not understood clearly.

2.4. Environmental parameters in an around of *Myristica* swamps

The *Myristica* swamps of remain water-logged between June and January. Restricted gas exchange between rhizosphere and the aerial environment is a major problem in this context. It decreases oxygen concentration in the root zone, elevates carbon dioxide levels and increases root resistance to water uptake (Smith and Stachowiak, 1988).

Flooding also decreases the redox potential of the soil and other physical and chemical changes (Ponnamperuma, 1984). Response to environmental parameters inundation is the salient feature of any swamp. The Myristicaceae members mainly *Gymnacranthera canarica* and *Myristica fatua* show much tolerance to inundation. When compared to other Myristicaceae species found in and around swamps. The other species namely *Semecarpus auriculata, Syzygium travancoricum, Strombosi aceylanica, Mesua ferrea* and *Diospyro spaniculata* also show more tolerance to inundation (Dempsey and Chew, 2011).

In the swamps, profuse undergrowth is rare due minimal penetration of sunlight to the forest floor, inundated condition and profusion of Ariel roots of the *Myristica* species. However, comparatively dry swamps shows growth of *V. indica* in the peripheral areas of the well inundated swamp (Dempsey and Chew, 2011). *Syzygium travancoricum* prefers high rainfall areas with plenty of soil moisture. Leaf fall begins in January followed by flushing by mid-February. Leaves attain maturity at the end of April. Flowering begins at the end of March. Fruiting begins at the end of April and extends up to September. At the end of September most of the fruits fall. Germination of the seeds follows within one month.

2.4.1. Wood growth influenced by environmental parameters

At present the dipterocarp dominates the international tropical timber market due to its wood quality. Tree to tree variability is especially wide, with difference within species, often being strongly influenced by plant's genetic and environmental factors (Zobel and Van, 1989). A difference in environmental condition can result in the production of wood with varying properties. Wood properties were influenced by a few physical and chemical soil properties (Moya and Perez, 2008). The physical and chemical soil properties are associated to the cell division and differentiation of cambial cells, and this interaction is influenced as well by environmental or ecological conditions (Aguilar-Rodriguez *et al.,* 2006).

2.4.2. Wood

Wood is a hard, fibrous structural tissue found in the stems and roots of trees and other woody plants. It has been used for thousands of years for both fuel and as a construction material. It is an organic material, a natural composite of cellulose fibres (which are strong in tension) embedded in a matrix of lignin which resists compression. Wood is sometimes defined as only the secondary xylem in the stems of trees, or it is defined more broadly to include the same type of tissue elsewhere such as in the roots of trees or shrubs. In a living tree it performs a support function, enabling woody plants to grow large or to stand up by them. It also mediates the transfer of water and nutrients to the leaves and other growing tissues. Wood may also refer to other plant materials with comparable properties, and to material engineered from wood, or wood chips or fibre (Comvalius, 2001).

2.4.3. Wood Growth rings

Wood, in the strict sense, is yielded by trees, which increase in diameter by the formation, between the existing wood and the inner bark, of new woody layers which envelop the entire stem, living branches, and roots. This process is known as secondary growth; it is the result of cell division in the vascular cambium, a lateral meristem, and subsequent expansion of the new cells. Where there are clear seasons, growth can occur in a discrete annual or seasonal pattern, leading to growth rings; these can usually be most clearly seen on the end of a log, but are also visible on the other surfaces. If these seasons are annual these growth rings are referred to as annual rings. Where there is no seasonal difference growth rings are likely to be in distinct. If there are differences within a growth ring, then the part of a growth ring nearest the center of the tree and formed early in the growing season when growth is rapid, is usually composed of wider elements. It is usually lighter in colour than that near the outer portion of the ring, and is known as early wood or springwood. The outer portion formed later in the season is then known as the latewood or summerwood (Bodig and Jayne, 1982).

Wood density has recently emerged as a key variable in carbon cycle research. Reyes *et al.,* (1992) and Fearn (1997) have highlighted the need to develop wood density databases for tropical biomass estimation, in greenhouse gas emissions mitigation programs. A number of studies have shown that community-level wood density averaged across all trees in a given locality varies considerably among Neo tropical forests (Wiemann and Williamson, 2002, Muller, 2004, Baker *et al.,* 2004) and should therefore be included as a predictive variable in large-scale tropical biomass estimation protocols (De and Chave, 2004, Baker *et al.,* 2004, Chave *et al.,* 2005).

All these studies point to contrasting trends in the regional and environmental variability of wood density, although they were based on a limited number of study sites or were restricted to one region of the Neotropics. These regional patterns are largely driven by ecological processes and wood density should not solely be considered as a predictive parameter for aboveground biomass estimation. One of the major axes of life-history variation in self-supporting woody plants separates species that allocate their resources into fast growth and early reproduction from those that are slower-growing and better able to withstand environmental hazards (Tilman, 1988, Niklas, 1992, Wright *et al.,* 2003). The fast-growing species tend to be better colonists and to dominate the early stages of ecological succession; while the slower-growing species dominate later succession stages (Uhl and Jordan, 1984, Lugo and Scatena, 1996).

Wood density is a good indicator of where species lie along this continuum: fast-growing species are characterized by low-cost conductive tissues of low wood density (Wright *et al.,* 2003 and Muller, 2004) that allow for fast growth in size because it is less expensive to construct (Favrichon, 1994, Suzuki, 1999, Santiago *et al.,* 2004) while high wood density provides a stronger defense against physical damage, predators, and pathogens (Rowe and Speck, 2005) as well as a lower vulnerability to drought stress.

Wood density variation in geotropically forests (Carlquist, 1977, Tyree and Sperry, 1989, Hacke *et al.,* 2001 and Meinzer, 2003). The close relationship between wood density and life history traits reflects the fact that wood plays both a physiological role in the transport of sap through vessels and a mechanical role in support and resistance against bending or buckling. Understanding the evolution and current spatial patterns in wood density is therefore important to our understanding of ecological and physiological processes in tropical trees.

Higher wood densities are often found in environments with lower light, higher stress (wind, abundance of wood-rotting fungi, or xylophageous insects), and lower soil fertility (Wilson and Archer, 1977, Hillis and Brown, 1984, Wiemann and Williamson 1989, Parolin *et al.,* 1998).

Available quantitative genetic studies show high heritability in wood density (Cornelius, 1994, Grattapaglia *et al.,* 1996), suggesting that plastic responses to the environment may be limited for this character, and implying that most of this variation in community-averaged wood density is due to ecological sorting of species by habitat. However, community level wood density variation may also be explained in part by plastic responses to the environment (Koubaa *et al.,* 2000, Woodcock and Shier, 2003), within the more fundamental physical/developmental constraints in available lineages due to the fixation of ancestral traits (Webb *et al.,* 2002, Cavender *et al.,* 2004).

2.4.4. Wood growth and its relationship with Rainfall

Tree rings are valuable climate archives. They have a seasonal resolution, are absolutely dated and available in a wide range of climate settings. Climatic and environmental conditions at the time of ring formation affect their width, density, and the isotopic composition of cellulose. Tree ring width and maximum latewood density can be sensitive palace climate indicators at sites where tree grow this strongly limited by a single climate variable (Esper *et al*., 2007).

Tree-rings provide opportunities for generating annually resolved climatic signals. It has been found that pronounced dry season (6 months or longer) induces cambial dormancy, and hence ring formation, in some tropical tree species, even in areas where above freezing temperatures occur throughout the year (Worbes, 1995). tropical tree ring- width analysis possess peculiar challenges which includes rings frequently become incoherent or indistinguishable in some segments, even for those species that otherwise show clearly countable rings (Tarhule and Hughes, 2002). Ring growth may also display various eccentricities such as lack of circuit uniformity (Maingi, 1998), which complicates attempts to cross-date.

Numerous studies have also shown how the wood density of conifers can be strictly correlated to environmental conditions (Chave *et al.*, 2006), in particular, temperature (Gindl and Grabner, 2000). Recent studies were based on manipulations of the growing conditions of mature black spruce in the field (Lupi *et al.,* 2011, 2012, Belien *et al.,* 2012), which could not control all environmental parameters. In comparison, an artificial control of environmental conditions in a greenhouse provides a localized effect on the whole plant. This can allow xylem development and wood formation of black spruce to be studied in saplings, an age category that has been largely overlooked.

2.4.5. Wood growth and its relation with temperature

In boreal ecosystems, temperature is the most important factor for tree growth (Körner, 2003a, 2003b). Cambial activity and cell differentiation are determined by temperature (Oribe *et al.*, 2001, Begum *et al.*, 2007, Rossi *et al.*, 2007, 2008b). Recent studies have estimated temperature thresholds regulating different phases of xylem phenology in mature black spruce [Piceamariana (Mill.) B.S.P.], linking the passage between thermally favorable and unfavorable periods (Rossi *et al.*, 2011). Other research confirmed the influence of cambial age or tree size on radial growth (Rossi *et al.*, 2008a, Rathgeber *et al.*, 2011). It is also documented in different species that the climatic sensitivity of radial growth changes with tree age (Rozas *et al.*, 2009; Vieira *et al.*, 2009)

Ecosystems at high latitudes and altitudes are considered biological indicators of climate change (Pisaric *et al.,* 2003, Kullman, 2007). Within a global perspective, tree line position seems to coincide with a mean temperature during the growing season of 6–7 °C (Korner, 2003a, Korner and Paulsen, 2004), suggesting that growth processes might be strongly limited below this threshold. At the alpine timberline, Rossi *et al.,* (2007) found that xylogenesis was active at a daily air temperature of 5.6–8.5 °C and a stem temperature of 7.2–9.0 °C. Temperature increase in early spring or late autumn would therefore lead to an increased duration of wood formation. During the growing season, some variability exists in growth onset and duration because of intra-annual differences in weather (Deslauriers and Morin, 2005, Rossi *et al.,* 2006), with cambial reactivation in spring being highly dependent on temperature (Oribe *et al.,* 2001, 2003, Griear *et al.,* 2006, 2007).

Wood formation involves cambial cell division and cell expansion followed by secondary wall production. These processes are regulated by several intrinsic factors, such as gene expression (Schrader *et al.,* 2004) and hormonal signals (Schrader *et al.,* 2003) and environmental factors, such as temperature and precipitation (Gorsuch and Oberbauer 2002; Deslauriers and Morin 2005; Zweifel *et al.,* 2006; Grièar *et al.,* 2007).

Climate change is an additional source of stress for those species already threatened by local environmental modifications and human activity (McCarty, 2001).

In the Pollino massif (southern Italy), the tree line is formed by *Pinus leucodermis* Ant., an endangered species at the limit of its geographical range.

Todaro *et al.,* (2007) recently found a positive influence of temperature on the growth of *P. leucodermis* during the period 1953–2000, although gaps in age structure and growth decreases indicated a strong impact of human activity. An annual temperature increase, from 10.1 to 10.9 °C between 1925 and 2000, was recorded in this area (Todaro *et al.,* 2007), indicating a changing environment that might affect tree growth. Eleven of the last twelve years (1995–2006) rank among the 12 warmest years in the instrumental records of global surface temperature (IPCC 2007).

The high temperatures and prolonged drought in 2003 affected several forest areas from northern to southern Europe (Rebetez *et al.,* 2006). During that year, only trees growing above a certain altitude benefited from the higher temperatures, with decreases in growth occurring in trees at lower altitude (Jolly *et al.,* 2005). We studied cambial phenology in several-hundred-year-old trees of *P. leucoderm* is growing at a tree-line in southern Italy with the aim of describing xylem cell formation at the weekly scale over two spring seasons that differed widely in temperature. Intra-annual growth during 2003 and 2004 was monitored by assessing differences in the phenological phases and their effects on tree-ring formation.

2.5. Wood specific gravity influenced by environmental parameters

2.5.1. Wood Specific gravity

Specific gravity is the ratio of the weight of a given volume of wood to that of an equal volume of water. As specific gravity increases, strength properties increase (USDA, 1999) because internal stresses are distributed among more molecular material. A mathematical approximation of the relationship is between specific gravity and various mechanical properties.

Comvalius (2001) reported that the specific gravity of wood is its single most important physical characteristic. Most mechanical properties of wood are closely correlated to specific gravity and density. In general discussion the term specific gravity and density are often used interchangeably. The strength of wood as well as the stiffness increases with specific gravity. The physical characteristics of specific gravity are used to describe the mass of a material per unit volume. These characteristics are commonly used in connection with all types of materials. Specific gravity is the ratio of the density of a material to the density of water. With most materials the weight and the volume are determined under the same conditions.

Specific gravity can be considered as the most evident manifestation of the wood substance to free space ratio. Josefina (1987) measured the specific gravity of 220 woody species, in which half of them from a tropical rainforest and another half from a tropical deciduous forest. He compared these two groups using a Student t - test. The results showed highly significant differences in specific gravity between the species from the two areas and results revealed that woods from the dry deciduous forest tend to be much heavier than those from the rainforest.

Tropical rainforests have the highest biodiversity of terrestrial ecosystems of the world. Especially richness in tree flora is one of the striking features of this type of ecosystem. Tree species have many ecological properties viz., shade-tolerant, maximum size, growth rates, modes of propogule dispersal, branching, wood specific gravity and also water contents, leaf size and shape. Among all these properties specific gravity is one of the property which correlated with wood strength (Niklas, 1993) and also affects the type of tree death and gap formation (Putz *et al.,* 1983). In addition studies have also been showed that specific gravity may also play an important role in determining the growth rate, life span, and maximum size of an individual plant and consequently affecting the function and structure of forest. Suzuki (1999) measured wood properties for trees in lowland dipterocarp in west Kalimantan. He measured the specific gravities and water contents of the wood including bark. Results showed wide range of specific gravities and suggested that forest had high diversity in wood properties.

Specific gravity is considered as an important trait directly connected with biomass production (Keays, 1971); and wood with higher specific gravity is generally considered less susceptible to decay (Schmidtling and Amburgey, 1982). Many factors of site, climate, geographic location, and species affect the specific gravity wood. Since many of these occur in combination, it is difficult to separate the independent effects. There is a great deal of scientific literature dealing with these relationships, the inconsistencies of which indicate the complex interactions among these factors. Site-related factors such as moisture, availability of sunlight and nutrients, wind temperature can affect specific gravity. These are determined to a large extent by elevation, aspect, slop, latitude, soil type, stand composition and spacing. All these factors can affect the size and wall thickness of the cell and thus the density. Species differ greatly, however, in their sensitivity to these factors. It is common for density to vary significantly within a tree.

A wood core can provide a complete wood sample if it stretches from the pith to the bark A pith to bark core over represents the proportion of wood toward the pith, so an area-weighted mean of segments of the core should be employed to determine the average wood SG for an individual tree, not simply measuring SG of the core itself .If the core has been divided into segments for SG determinations, then the area of the ring of each core segment can be determined and the weighted mean specific gravity was calculated, as demonstrated by Muller(2004).

According to Zobel and Van (1989), specific gravity is not a simple characteristic but is determined by several characteristics of wood such as cell size and wall thickness, the ratio of early wood to late wood, the amount of ray cells, the size and amount of vessel elements, and other factors.

Seth *et al*., (1988) investigated on radial pattern of whole- ring specific gravity variation from pith to bark has been studied in Six blue pine trees with straight boles and uniform crown and they reported that there specific gravity does not vary significantly and also does not show any distinct pattern of radial variation from pith to bark and no substantial and definite relationship appears to exist between whole ring specific gravity and independent variables like age, distance from pith, ring width and growth rate.

2.5.2. Wood specific gravity in relation to rainfall

Analysis is made of the effects of five ranges of summer precipitation and three ranges of elevation on variation in specific gravity of coast Douglas-fir (pseudo tsugamenziesii (Mirb.) Franco). The average specific gravity of coast Douglas-fir wood formed during single growing season varied from 0.52 for dry summer to 0.45 for wet summers. The negative linear trend held for three elevation levels. Wood produced under a combination of dry summers at low elevation averaged 0.55 in specific gravity, where as wood produced during wet summer at higher elevations averaged only 0.44 specific gravity. Both percentage of late wood and thickness of latewood tracheid wall followed trends that were similar to those of specific gravity with summer rainfall and elevation. Gilmore (1968) reported that factors which extended the production of early wood, such as growing trees at the bottom of a slope, or growing trees on northern slopes where more rainfall was preserved produced a lower wood specific gravity.

2.5.3. Wood specific gravity in relation to temperature

Wiemann and Williamson (2002) reported that in a comparison of temperate and tropical woods, Williamson (1984) found no difference in mean SG between woods in Indian and those in Costa Rica and Trinidad. Here, with a more extensive dataset, we found that mean SG responds to a fundamental change in the environment-namely, temperature. The regression of mean SG on MAT for all 20 sites gave a coefficient of determination of 0.62, as mean SG increased by 0.0049 per ^{0}C. Furthermore, variation in mean SG was better explained by temperature than by latitude. Obviously, latitude and temperature are correlated, but not perfectly, for example r2 = 0.56 in our dataset. Therefore, it is important to distinguish which factor is a better predictor of variation in mean SG.

Wiemann and Williamson (2002) reported that, angiosperm mean wood SG increases gradually with decrease in latitude. However, mean annual temperature is a much stronger correlate of mean SG than is latitude. In addition, mean wood SG decreases with increasing mean annual precipitation, especially among tropical sites. Variability in SG among species at a site increases much more dramatically with mean annual temperature than does the mean SG. Both SG range and standard deviation show steep increases from temperate to subtropical/tropical habitats. Although the much larger number of tree species growing at subtropical/tropical sites could account for the larger ranges in SG, the larger standard deviations can only be attributed to greater overall diversity in woods.

This table indicates the authors from different countries who worked on effect of environmental variables on specific gravity of wood.

Species	Reference	Results
Liriodendron tulipifere	Sluder (1970)	Environmental variability affects specific gravity by its effect on moisture availability
Populus tremuloides	Einsphar *et al.,* (1972)	Specific gravity was only slightly reduced as a result of irrigation plus fertilization
Pinus radiate	Nicholls (1971)	The proportion of latewood was increased 20-30% and mean density 19-28% by supplementary watering
Pinus elliottii	Smith *et al.,*(1971)	Specific gravity was not affected by irrigation
Pinus strobes	Trior and Barnett (1974)	Specific gravity increased with greater soil moisture holding capacity
Pinus taeda	Kao and Walters (1975)	Maintaining soil moisture in the range of 30-60% of field capacity plus use of nitrate fertilizer increased bending strength and stiffness. There was 57% latewood in non irrigated plots compared to 36 % on the irrigated plots.
Ouercu srubre	Szopa *et al.,*(1977)	Irrigation studies were made to determine the effect on wood
Pinus elliottii	Van der slooten *et al.,*(1976)	Rainfall and its distribution are a major determinant of the quality of wood of slash pine
Pinus radiate	Nicholls and Waring (1977)	Specific gravity was greatest in irrigated trees due to an increase in maximum density. In trees subject to drought specific gravity also increased due to an increase in minimum wood density
Pinus abies	Madsen and Jensen, (1999)	The basic wood density is negatively correlated with the moisture content of the soil
Pinus caribaea	Plumptre (1984)	Trees on poor, dry iron latosols had a spiral grain angle of 4.3 % compared to 3.2 % in trees on humiclatosols

2.5.4. Radial variations in the specific gravity

Radial variations of selected wood properties of *Acacia auriculiformis* were examined by Choudhury *et al.,* (2009). The basic density increased up to 80 mm radial distance from the pith then was almost constant towards bark. Donaldson *et al.,* (2004) reported in compression wood variation in radiata pine that severe compression wood showed an increase in basic density compared to opposite wood which can be attributed to increased tracheid wall thickness throughout the growth ring counteracted by an increase in radial lumen diameter.

Radial variation in the wood quality parameters of cell wall thickness, tissue proportion and basic specific gravity were determined for three natural and nine plantation grown trees of Light Red Meranti (*Shorea leprosula* and *S. parvifolia*). In both naturally and plantation grown trees variation in specific gravity was most significant within trees, *i. e*. it increases from pith to bark. The plantation grown trees have slightly less variable wood than the "wild" trees. Within and among trees specific gravity and anatomical parameters vary considerably (Bosman *et al.*, 1994).

Within tree density gradient in *Gmelina arborea* plantation in Venezuela was examined. Variation in wood specific gravity from pith to periphery was investigated. Specific gravity was obtained using an X-ray densitometer. The results showed that there was an increase in specific gravity from pith to bark (Espinoza, 2004).

Different patterns for the variation of specific gravity from pith to bark were found in hardwoods. Some species such as *Swieteniam acrophylla*, *Liquidambar styraciflua*, *Liriodendron tulipifera* and others have an increase in specific gravity from the pith to outward (Briscoe *et al*., 1963; Hunter and Goggans, 1968; van Eck and Woessner, 1964; Herpka, 1965; Sluder, 1970). Of particular importance are the Eucalyptus, which generally show a small increase from the tree centre outward (Ferreira, 1972; Hans *et al*., 1972; Skolman, 1972).

Radial variation in wood specific gravity, for *Hyeronima alchoreneoides* and *Vochysia guatemalens is* natural and plantation-growth hardwood trees increased radially from pith to bark for both species ranging from 0.23 to 0.70 (natural) and 0.23 to 0.50 (plantation) for *Hyeronima*; and from 0.27 to 0.51 (natural) and 0.26 to 0.38 (plantation) for *Vochysia.* Natural-grown trees of both species had significant tree-to-tree variation in specific gravity (Butterfield *et al*., 1993).

Specific gravity continued to increase with distance from pith (Butterfield *et al*., 1993). Specific gravity was studied in six-year-old plantation grown trees of red meranti (*Shorea leprosula*, *Shorea parvifolia* and *Shorea pauciflora*). Specific gravity in the planted trees is not significantly correlated to the growth rate parameters, height and diameter. It also showed that light and humidity may influence specific gravity (Bosman, 1997).

2.5.5. Vertical variation in the specific gravity

Physical and mechanical properties of *Grevillea robusta* were evaluated by Kamala *et al.,* (2000). Variation was significant for specific gravity with height. Results also indicated that average specific gravity increases with height.

Variation of wood specific gravity from the base to top of the tree was investigated in *Gmelina arborea* in Venezuela by Espinoza (2004). Increment cores were taken from thirty trees at five different sections up the stem. These trees were chosen from commercial plantation located at three different sites. The results showed that there was a decrease in specific gravity from stump to half of the total height then increased towards the top of the stem. No correlation was found between specific gravity and height.

Lindgren (1951) states that the much higher specific gravity and lower moisture content of freshly cut butt logs compared to top logs have a major effect on pulp yields, much more pulp would be obtained from the butt logs based on either volume or weight. The usual trend is to have longer tracheids at the base of the tree and shorter ones near the top (Zobel and Van, 1989).

Variations in specific gravity were found significant in different clones of *Delbergia sissoo* (Pande and Singh, 2005). The higher value for specific gravity was noticed at breast height, thereafter it decline and again increased up. In this report they stated that significance difference in specific gravity due to height within a ramet showed that height has an impact on specific gravity due to differential sapwood and heartwood ratio.

The effect of height on wood properties is equally as variable in hardwoods as it is in conifers. Perhaps the most common pattern is to have only minor changes with height, but some species, such as *Swietenia macrophylla* (Briscoe *et al.,* 1963), *Liriodendron tulipifera* (Taylor, 1963), *Populus tremuloides* (Einspahr *et al.,* 1972, Yanchuk *et al.,* 1983) and *Liquidambar styuraciflua* by Webb (1964) showed a high density at the base, a decrease for some distance up the tree, followed by an increase toward the merchantable top.

Basic specific gravity and some microscopic wood characteristics such as length of vessel elements and fibres, tangential diameter of vessels, vessel frequency and fibre wall thickness of 29 species from a xerophytic region from the state of Puebla were obtained (Rodriguez *et al*., 2001). Results showed significant differences in specific gravity, length of vessel elements, fibre length and fibre wall thickness. There was a positive relationship between specific gravity and fibre wall thickness. It was cleared that species with thick walled fibres and high density were predominant in dry forest, whereas species with medium or low specific gravity and thin walled fibres were found in places with high humidity.

2.6. Wood fibre length influenced by environmental parameters

Wood fibres are natural composite structures in which cellulose fibrils are held together by lignin and hemi-cellulose. The major constituents of wood fibres are lignin, cellulose, hemi-cellulose, and extractives. Each of these components contributes to fibre properties, which ultimately impact product properties (Comvalius, 2001).

Dai and Fan (2011) reported that wood fibres are the most abundantly used cellulose fibres. They have been extensively used in the modern composite industry due to their specific characteristics. Describes the structure, properties, processing and applications of wood fibres as reinforcements in natural fibre composites: first, the nature and behavior of wood fibres and the developed technologies for the modification of wood fibres to enhance physical and mechanical properties (e.g. surface functionality and tensile strength) are investigated; the matrices and processing techniques for the development of wood fibre composites are then discussed; and finally, the properties and applications of wood fibre composites in industrial sectors are presented.

Kern *et al*., (2014) made a study on the mechanical properties of polypropylene (PP) composites with short, wheat straw natural-fibre reinforcements are studied in tension at various temperatures and rates of loading and specimens of two fibre lengths have been considered with both closed-form, microcellular voids and in solid form. Results of mechanical stress-strain tests are given at static to moderate rates of strain, specifically 0.0005/s, 0.025/s and 14/s. Testing at these strain rates is conducted up to specimen failure at low, room and high temperatures of -30 °C, 22 °C, and 107 °C, respectively. resulting that primary findings suggest that fibres increase the tangent modulus and ultimate stress, while reducing the failure strain, compared to pure polymer. The performance difference between the two fibre cases studied here is largest at room temperature and quasi-static strain rates, and in most cases becomes insignificant with increasing or decreasing temperature and increasing strain rates

Knowledge of the factors including genotype and spacing that influence wood and fibre characteristics is vital for improving the quality of timber. Study was conducted to examine the effect of genotype and spacing at a dry land site, on core wood anatomical (micro fibril angle, fibre length, fibre width and cell wall thickness), physical (density) and mechanical (MOE) properties. Results indicated that Relative to wide spacing, close initial stand spacing significantly reduced Micro Fibril Angle (MFA) and ring width and significantly increased dynamic modulus of elasticity (MOE), fibre length, latewood percentage and cell wall thickness. Density and fibre width were not significantly different between spacing treatments. The influence of genetic population on wood properties indicated that genotype significantly influenced MFA, MOE and ring width (Lasserre *et al.,* 2009).

The source of strength in solid wood is the wood fibre. Wood is basically a series of tubular fibres or cells cemented together. Each fibre wall is composed of various quantities of three polymers: cellulose, hemicelluloses, and lignin. Cellulose is the strongest polymer in wood and, thus, is highly responsible for strength in the wood fibre because of its high degree of polymerization and linear orientation. The hemicelluloses act as a matrix for the cellulose and increase the packing density of the cell wall; hemicelluloses and lignin are also closely associated. The actual role of hemicelluloses in wood strength has recently been shown to be far more critical toward the overall engineering performance of wood than had previously been assumed. We suspect the primary role of hemicelluloses is to act as a highly specific coupling agent capable of associating both with the more random areas (i.e., non-crystalline) of hydrophilic cellulose and the more amorphous hydrophobic lignin. Lignin not only holds wood fibres themselves together but also helps bind carbohydrate molecules together within the cell wall of the wood fibre. The chemical components of wood that are responsible for mechanical properties can be viewed from three levels: macroscopic (cellular), microscopic (cell wall), and molecular (polymeric) (Winandy and Rowell, 1984).

The differences between populations in different traits are influenced by the latitude and total site factors as well as the ecotype of the stand (Varghese *et al.,* 2000). Found that wood density parameters and fibre dimensions were related to growth rates. The minimum and mean wood density, cell wall thickness, fibre width and lumen diameter decreased with increase in growth rate. In addition, fibre length is directly connected to the strength of inter-fibre bonding and tear strength (Perez and Fauchon, 2003).

Fibre length exhibited significant variation among sites in juvenile Pinus radiata, strongest significant relationships with stem slenderness and average air temperature. The average air temperature is found to be the major environmental determinant of fibre length while soil fertility, phosphorus, total nitrogen and pH had little influence on fibre length (Watt *et al.,* 2008).

2.6.1. Wood Fibre in relation to Temperature

Temperature Strength is related to the temperature of the working environment (USDA, 1999, Gerhards, 1982). At constant moisture content, the immediate effect of temperature on strength is linear and usually recoverable when the temperature returns to normal. In general, the immediate strength of wood is higher in cooler temperatures and lower in warmer temperatures. However, permanent (non-recoverable) effects can occur. This relationship of permanent strength loss during extended high-temperature exposure can be dramatically influenced by higher moisture contents.

The immediate effects of increased temperature are an increase in the plasticity of the lignin and an increase in spatial size, which reduces intermolecular contact and is, thus, recoverable. Permanent effects manifest themselves as an actual reduction in wood substance or weight loss via degradative mechanisms and are thereby non recoverable. This permanent thermal effect on wood strength has been extensively studied (Winandy and Lebow, 2001, Green *et al.,* 2003) and predictive kinetic-based models have been developed (Lebow and Winandy, 1999, Green *et al.,* 2003). The reasons for these permanent thermal effects on strength relate to changes in the wood polymeric substance and structure, and predictive models have been developed (Winandy and Lebow, 2001).

Fibre length exhibited significant variation among sites in juvenile *Pinus radiata*, strongest significant relationships with stem slenderness and average air temperature. The average air temperature is found to be the major environmental determinant of fibre length while soil fertility, phosphorus, total nitrogen and pH had little influence on fibre length (Watt *et al.,* 2008).

Climate and site play an important role in tree growth, and many studies have reported correlations between fibre attributes and climatic variables. For example, temperature and precipitation influence wood density (Watt *et al.,* 2008)

Mäkinen *et al.,* (2003) proposed that the annual maximum growth rate of *Piceaabie*s *karst* L. in Finland was regulated by temperature, as xylem formation occurred most rapidly in the first 10 d of July, corresponding to the highest temperatures observed during the year. Several authors also observed higher wood formation rates around June to July (Schmitt *et al.,* 2004).

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2.6.2. Wood fibre in relation to rainfall

Bakhshi *et al.,* (2011) reported that, the influence of climate on the fibre length, fibre diameter and cell wall thickness of maple wood (*Acer velutinumboiss*) was studied. A total of 5 normal maple trees were sampled in Khanican forests (north part of Iran). Disks were taken at breast of stem height. Fibres of the early wood from each ring (1978 to 2005) were separated by Jeffrey's solution method and the dimensions of fibres were measured by Leica Image Analyzer. To determine the response to the climate, correlation coefficients (Pearson correlation) between fibre properties and climatic data were calculated during biological years from October of the previous year to September of the current year. Results of Pearson correlation showed that the climate condition had no effect on fibre length and fibre cell wall thickness and had significant effect on the fibre diameter. The fibre diameter correlated with the monthly total precipitation of November, June and August and monthly maximum temperature of August and November. In addition, the relationship between fibre diameter and monthly minimum temperature of January and monthly mean temperature of August were negative and positive, respectively. The significant variables obtained from Pearson correlation results were analyzed by forward stepwise. Results of forward stepwise indicated that the fibre diameter values was related to precipitation of November (52.9 %), precipitation of August (19.6 %), minimum temperature of January (5.6 %) and maximum temperature of November (4.4 %).

2.6.3. Radial variation wood fibre dimensions

The patterns of radial variation are not the same for all wood characteristics. The radial pattern of variation for fibre length shows a marked transition from juvenile to mature wood at both heights. A similar conclusion was drawn in studies of other hardwoods (Dinowoodie, 1961; Bendtsen and Senft, 1986; Zobel and Van, 1989; Peszlen, 1994).

Radial variation of fibre morphology of five different popular clones grown in the forest station in the suburb of Tianc chang city of Anhui Provenance, China, were selected as the materials to study the radial variation of fibre length, fibre width, lumen diameter, double cell wall thickness, the ratio of fibre length to width. Result showed that from pith outward, the fibre length, the fibre width and the ratio of fibre length to fibre width of five popular clones all increased with the increase of growth rings; reached a maximum in a certain year and then decrease or level off (Zha *et al*., 2005).

Variation in fibre length within the tree, including branches has been studied by Bhat *et al.,* (1989) in eleven tropical Indian hardwoods growing in Kerala. Branch fibres were significantly shorter then stem fibres. Radial pattern of fibre length variation in their study, in the majority of the species studied showed a decline in fibre length near the bark after an initial increase from the pith to outwards.

Rao *et al.,* (2003) studied radial variation in anatomical properties of plantation grown *Tecomella undulata.* Significant pith-to-periphery variations in fibre length, fibre diameter, fibre lumen diameter were reported. All fibre characters were found inter-related.

The radial variation of fibre length increment and its relation with internal and external factors were investigated for *Acacia mangium* trees collected in Indonesia and Malaysia. The result showed that the radial variation of fibre length was related to the growth rate rather than the age of the cambium (Honjo *et al*., 2002).

Fibre length increased radially from pith to bark for natural and plantation trees of both species; ranging from 1.92 to 2.98 mm (natural) and 1.45 to 2.71 mm (plantation) for *Hyeronima*; and from 0.63 to 1.75 mm (natural) and 0.69 to 1.47 mm (plantation) for *Vochysia*. Neither species had a clearly defined juvenile wood zone. Fibre length continued to increase with distance from pith (Butterfield *et al*., 1993).

2.6.4. Vertical variation in wood fibre dimensions

Along the axis of stem or branch, the decrease in fibre length from the base to 50 % and 70 % of the stem height or branch length observed by Bhat *et al.,*(1989) in their study on fibre length variation in stem and branches of eleven tropical hardwoods.

Dimensional variation was investigated in fibre along vertical and horizontal axes of a 40-year-old tree of *Afzelia africana* felled in Gerei forest Nigeria by Idu and Ijomah (1996). Mean dimensional values were: fibre length 1116.23 µm, fibre diameter 21.94 µm, lumen diameter 11.8 µm, fibre wall thickness 5.55 µm, Runkel

Ratio 0.98, flexibility coefficient 0.5, relative fibre length 50.56, vessel length 194.02 µm and fibre length varied significantly on both axes investigated (showing patterns of alternate increase and decrease with increasing height and distance to pith), while fibre diameter and lumen diameter varied significantly only along vertical axis. Other traits analyzed showed considerable variation but were not significantly related to distance along either axis.

In an analytical study on cell size variation in *Acacia nilotica*, Iqbal and Ghouse (1983) concluded that the length of vessel segments decreased from base to top and later stabilizing in the old trunk. Length of xylem fibres after an initial increase became more or less constant. Variation in fibre-length and cell wall percentage along the height of the tree was studied in *A. mangium* and *A. auriculiformis* trees by Wu and Wang (1988). Variation was generally less in *A. auriculiformis*. Similar studies were also made by Ku and Chen (1984) in the above two *Acacia* species.

The variability of fibre length in wood and bark in ten trees of *Eucalyptus globules* Labill from three different locations within Portugal were studied. The axial variation was small and in wood and bark; fibre length decreased in the wood and increased in the bark from the base to the top (Jorge *et al*., 2000).

Many trees have wood properties that vary at different heights in the tree. For those species in which juvenile wood greatly differs from mature wood, a change in wood properties with height is automatic since the proportion of juvenile wood in stem increases extensively from the base to top. Fibre length was largest in *Liquidambar styraciflua* at the stump and decreased steadily with increasing height (Webb, 1964). *Acacia mangium* trees showed a decrease in fibre length from the base of the tree to upwards (Wang *et al*., 1989).

Variation was generally less in *Acacia auriculiformis*. Similar studies were also made by Ku and Chen (1984) in the above two *Acacia* species. Anatomical characters were investigated in stems of Rotan semambu (*Calamus scipionum*), 6-12 years old, from a plantation in Sarawak, Malaysia. The fibre length, diameter and wall thickness decreased with height of stem while the fibre lumen diameter increased with height.

2.7. Threats to *Myristica* swamps

Fresh water ecosystems such as swamps have been threatened worldwide. For example, Bottomland hardwood forests in the valley Mississippi were extensively liked Cleared and most often planted with soybeans and other crops, Natural swamps and extremely rare in Sweden because of extensive drainage and logging activities (Ohlson *et al*., 1997). Myristica swamps of the Western Ghats and restricted to the sluggish streams as frigging forest below 300 m elevation. Major changes in the Myristica swamps have been brought by their conversion to rice fields and betel nut gardens (Krishnamoorthy, 1960; Nair and Daniel, 1986; Varghese and Menon, 1999).

Gadgil and Chandran (1989) observed that swamps in Malemane Ghat of Uttara Kannada district, central Western Ghats have been destroyed due to illegal timber logging. They also expressed their concern about impacts of such logging on swamp ecology. Because of human intervention the swamps are highly fragmented and are threatened (Raghuram, 2003). The presumed widespread loss of perennial freshwater swamps such as *Myristica* swamps, as evidenced by their present-day rarity and fragmentation is perhaps a reminder of the progressive desiccation in the Western Ghats. The swamp of the Western Ghats are threatened with extinction even before much is known about them, such as nutrient cycling, mycorhizal relationships, plants-animal interactions, species diversity, etc.

Pascal (1988) reported conversion of these swamps to paddy fields highlighted the systematic destruction of these swamps and called for Priority I level implementation of their proposed Myristica swamp Wildlife Sanctuary. Studies (Joyce *et al.,* 2007; Tambat *et al*., 2004, 2007) have also outlined many threats to this ecosystem. Dasappa (2000) reported that, special abiotic conditions are prerequisites for the development of *Myristica* swamp forests; these swamp forests have become highly restricted and fragmented. Anthropogenic interferences have further threatened the existence of these ecosystems.

The swamps of the Western Ghats have high degree of endemic plants. The fruits of the *Myristica* are used as spice and also as on ingredient in many drugs, thus affecting the regeneration of the species. *Myristica malabarica, Myristica dactyloides and Gymnacranthera canarica* species are already listed as threatened (FRLHT, 2000). Another swampy species *Semecarpus kathalekanensis*, (Anacardiaceae) a dioecious canopy tree, is restricted to merely four swamps in the Western Ghats with a total population of 91 individuals, of which there are only 42 breeding individuals (Vasudeva *et al.,* 2001). Several of these species in swamps may face the fate of becoming end or globally extinct if immediate measures are not taken to address their conservation concerns.

2.8. Conservation strategies of swampy and non-swampy *Myristicaceae* members

The *Myristica* swamps are undoubtedly, priceless assets for the evolutionary biologist. Members of the nutmug family, Myristicacae, which dominate the swamps, belong to one of the most ancient group of flowering plants of the planet, the magnolias (Kuhn and kubitzki, 1993).

Corner (1976) considers swamps forests to be the home of angiosperms. The pan tropical distribution of the nutmug family, one of the evergreen woody plants with large fleshy fruit and animal dispersed heavy seeds covered with brightly coloured, nutrient rich aril, points towards its origin in the gondvana land, before it broke into ancient continents and landmasses 140 million years ago.

The flowering plants, according to the latest theory originated 150 million years ago (Kuhn and kubitzki, 1993). It was the late Jurassic period, when the mammals and birds were on the rise and dinosaurs and flying reptiles, ferns and cycads on the decline. Notwithstanding the scattering of the family in the rain forest of Amazonia. Or Africa, Madagascar or Malaysia, the south Indian Western Ghats or New Guinea, the members are unified by striking similar characters. These include the blood red exudation, dark green leathery leaves, unisexual flowers, stamens in a column ovary with a single ovule, large sized seed wreathed in an orange to red colour aril inside a fleshy fruits which splits in two and primitive wood.

Raven and Axelrod (1974) think that the nutmug family originated before the continental drift. The many primitive features of myristicacace made Takhtajan (1969) to characterize it as composed of “living fossils”, which due to some favorable circumstances escaped extinction and survived to the present day. The shallow seas, which were believed to have covered much of the earth surface, had withdrawn by then, probably favoring the sudden revolution of flowering plants. This gives more credence to the hypothesis liking swamps as the homes of early angiosperms.

The members of the family are anyway, invaluable relics of angiosperms evolution. Armstrong and Irvine (1989) refer to the kind of pollination of Myristica, involving small beetles, as ‘micro anthrophylly’, a relatively archaic and perhaps relictual mode of pollination. Further they hypothesize that, the pollination involving Beetle, Thrips, Micropterygid, Moths, Stoneflies, and possibly ancestors of dipterans and hymenopterans were characteristic of the proto angiosperms (ancestors of today’s flowering plants). Immense beaked birds belonging to ancient group like the toucans in tropical South America and hornbills in Africa and Asia are among the dispersers of the seeds of Myristicecae.

(Kuhn and Kubitzki, 1993) reported that the *Myristica* swamp, with its entanglement of aerial roots, and canopy of dark green, large leaves and high levels of Western Ghats endemism is doubtlessly, one of the most primeval land ecosystems of the humid tropics. The swamps with their specialized tree and undergrowth of plants and herbs, and little known fauna, could very well be a live museum of ancient life of great interest. If the present pressures continue, as in Uttara Kannada, Kodagu the last few acres of this many million years old eco system will give way to, may be more of arecanut gardens, within the first one or two decades of the new millennium.

III MATERIAL AND METHODS

This chapter deals with the material used and various methodologies adopted in this study.

The main objective of the present investigation was to survey and select swampy locations that have both swampy and non-swampy Myristicaceae members and further, to assess the wood growth ring and its properties like specific gravity and fibre length of obligate swampy *Gymnacranthera canarica* and non-swampy *Myristica malabarica* and compare across the locations. The details of various experiments conducted to address the envisaged objectives are as follows.

3.1. Study site

The study was carried out in the central Western Ghats of India, one of the 34 mega-biodiversity hot spots of the world (www.conservation.org). The variability in the precipitation and topography generates a wide variety of vegetation types. It has wet evergreen and semi-evergreen forests on the western side and at high altitudes, while it harbours dry deciduous and scrub forest on the eastern slopes and lowlands (Jha *et al.,* 2000). The forests of Western Ghats are some of the best representatives of non-equatorial tropical evergreen forests in the world. Of the 18,000 species of flowering plants recorded from India, about 4000 species are found in the Western Ghats, including 1800 endemic species (Manoharan *et al.,* 1991; Daniel *et al*., 1995; Jha, *et al.,* 2000). The central Western Ghats in the state of Karnataka account for over 60 % of the entire Ghats and are home to some of the unique swamps in southern India (Chandran and Mesta, 2001). Western Ghats is densely inhabited with human settlements that depend upon the forest directly for a number of forest products and indirectly for a number of ecosystem services such as water, farm nutrients, etc.

3.2. Survey and selection of swamps

Based on the previous studies, an exhaustive list of swamps, which are having both swampy and non-swampy in the central Western Ghats were prepared. Afterwards, swamps in each district were shortlisted and visited. Then following five locations were selected for the present study.

Selected locations for Swampy and non-swampy Myristicaceae members

Sl. No	Locations	Districts
1	Ithalimane	Uttara Kannada
2	Thorme	Uttara Kannada
3	Darbejaddi	Uttara Kannada
4	Sampaje	Dakshina Kannada
5	Makutta	Kodagu

3.2.1. Criteria for selection of locations

- Each location should have at least two swamps *viz.* Swampy and Non-swampy areas.

- To have representations from different latitude and longitudinal gradient.

- To have maximum similarity among the swamps with respect to species composition, accessibility, etc.

- Relatively less subjected to anthropogenic pressure

Plate 1: *Myristica* swamp view

3.3. Study species for wood analysis

Gymnacranthera canarica was selected as an ideal candidate for wood growth analysis based on the following criterion; firstly because it is an obligatory swampy species that helps to understand the wood growth behavior of swampy species (Tambat *et al*., 2004, 2014). Secondly, among the species associated with the *Myristica* swamps, only *G. canarica* is present across the latitude and longitudinal gradient. Thirdly, it is the most abundant species in the *Myristica* swamps (Chandran and Mesta, 2001, Vasudev *et al*., 2003, Tambat, 2007).

Myristica malabarica was selected as the non-swampy species because, phylogenetically it is more closely related to *Gymnacranthera* than any other

Myristicaceae members (Tambat *et al.,* 2007). The species often occurs in and around swamps. The growth habit of both the species is apparently similar.

3.4. Criteria for selection of species

A. Gymnacranthera canarica

- *G. canarica* is an obligatory swampy species that helps to understand the wood growth behaviour of swampy species.

- It is the most abundant species in the *Myristica* swamps (Chandran, *et al*., 2001, Vasudev *et al*., 2003; Tambat 2007; Tambat *et al.,* 2003).

- *Thus G. canarica* was selected as an ideal candidate for wood growth analysis.

Plate 2: *Gymnacranthera canarica* seeds and leaves

B. Myristica malabarica

- *Myristica malabarica* is often occurs in and around swamps. The growth habit of both species is apparently similar.

- The species is phylogenetically more closely related to *Gymnacranthera* than any other Myristicaceae members (Tambat *et al.,* 2007).

- *Myristica malabarica* was selected as the non-swampy species

Plate 3*: Myristica malabarica* leaves and seeds

3.5. Study Species descriptions (Kingdom-Plantae; Order-Magnoliales; Family-Myristicaceae)

A. Gymnacranthera canarica: It is an evergreen, endangered and endemic tree of Western Ghats. The tree has characteristic loop like breathing roots, protruding out of the water logged soil all around the main trunk. These roots are covered with large air pores or lenticels. These roots are slim and spongy when young, but turn large and woody with age. The seeds of the species have very short viability period and require swampy conditions for germination. The plant is sometimes harvested from the wild for the oil that is obtained from its seed. The species is exclusively associated with swampy conditions and habitat and destruction seems to be the major threat. The species name *canarica* refers to the north Karnataka region called Kanara. It is an evergreen tree grows up to 25m tall. Bark is dark brown to reddish brown. Red sap is reddish from cut end of bark. Leaves are simple, alternate and flowers are unisexual. Male flowers are yellowish, while female flowers are larger than the male flower, borne in racemes in leaf axils. Capsules are spherical up to 3.2 cm across, hairless with one spherical seed, pale brown with laciniate aril.

B. Myristica malabarica: It is evergreen tree growing up to about 15 to 25m tall. The fruit is used in condiment and also in Ayurvedic medicine. Bark is greenish-black and Red sap oozes from cut end of bark. Alternately, arranged leaves are around 10 cm with pointed tips and narrow or flat base. Flowers are unisexual, urn-shaped and white. Male flowers are numerous, smaller than female flowers, borne in cymes in leaf axils. Female flowers are borne in 5-6 flowered umbels with one oblong seed aril covering the seed yellow and stringy. Most of the natural habitat of *M. malabarica* has been fragmented due to human activity leading to the declined in the natural population of *M. malabarica*. This species has been designated as ‘endangered’ considering the threat and economic importance of *M. malabarica*.

3.6. Density of swampy and non-swampy Myristicaceae members

At each location by laying 10 x 10 m random quadrats, the trees saplings and regenerating individuals were enumerated. For regeneration (seedlings), 1 x 1 m nested quadrats within the main quadrat were laidout and then individuals less than 1 m height (<1 cm GBH) were recorded. The average number of individuals per quadrat was computed and represented as the density.

3.7. Collection of wood core samples for analysis

The trees which were having uniform girth (around 1.5 m GBH) were selected for collection of core sample. In each location, the wood core samples were collected by using increment borer (Hegloff, 5.15 mm, 2 tread borer) at DBH (1.37 m). Two cores were collected from each tree and three replications were maintained for each swamp. Similarly, the wood core samples were collected from the non-swampy species in and around the swampy. After removing the core, the hole created in the tree was sealed with wax and cycocil to prevent damage to the trees. The core samples collected were removed from increment borer and sealed in a container, labeled and then transported to the laboratory. Samples were dried for 1-2 days inside the laboratory (shade drying) before mounting on to the wooden mounts for further processing. While mounting, care was taken to mount all the samples in such a way that the bark end of the core was placed towards the outer edge of the mount and pith end was towards the inner side of the grove of the wooden mount. The core samples thus prepared were stored at room temperature in a cool and dust free condition.

Plate 4: Collection of wood core sample

3.8. Wood growth ring analysis

Samples were brought to the laboratory and mounted on the sample holder and were dried. Samples were polished (sanded) according to standard dendrochronological techniques to observe the growth rings (Stokes and Smiley, 1968). Progressively, finer grades of sandpaper (220,320,400 Grit) were used to surface the increment cores until the individual cells were visible. Ring width was established by measuring the ring width from the core (first ring formed) to the outer most rings towards the bark. All growth rings from bark to pith were measured to the nearest 0.01 mm on the radial strips using Leica S8 Stereozoom microscope (magnification 25 X) loaded with software Leica Application Suite (Switzerland) interfaced with computer and using Tree ring measuring system, Linear stage J2 X measurement system software package (New York). Ring width was expressed in mm.

Plate 5: Measuring of Wood Growth Rings

3.9. Specific gravity

The length of the core samples varies depending on the tree GBH. Therefore, handling a long core sample is practically difficult. Hence, the wood core samples were divided into segments (starting from pith to periphery) and then specific gravity of each segment was measured following maximum moisture content method (Smith, 1954).

3.9.1. Segment preparation

The length of the wood core samples was measured using a scale. Then segments were made from each core of size 1 inch (2.54 cm) using sharp knife. Each sample and its segment were numbered. The diameter and length of the segment was measured using digital caliper.

3.9.2. Saturation

The core samples (segments) were soaked in water for 4 days to reach saturation. After saturation of samples again diameter & length were measured by using digital caliper and weight of each core segment was recorded by using weighing machine. Then green volume of each core was calculated.

For convenience each ring was considered as a cylinder and volume was calculated using the volume formula for cylinder. The segment diameter was measured using the digital caliper and then radius *r* was computed. The length of the core segment was treated as the height (*h*) and was measured using the digital calliper. Then volume was calculated using the formula

$V = \pi r^2 h$, Where r is radius and h is length of segment

3.9.3. Weight (Oven dry condition)

The saturated core samples were kept in oven at 100-102 ^{0}C for 48 hours. Afterwards, weight of dried core segment was recorded by using weighing machine. Specific gravity was calculated using the formula.

Sp. Gr. = Oven dry weight of the sample / Volume of water displaced by saturated sample

3.9.4. Specific gravity of the core

The specific gravity of all the segments of a core was recorded and then average specific gravity of all the segments was computed and treated as the standard specific gravity of core sample.

3.10. Determination of fibre length

Wood core sample were divided in to pith, middle and periphery. Macerations were carried by Schultz's method - small slivers of wood was taken from rings in a test-tube and boiled in water till the slivers settled down in water, the water was discarded. To this test tube, a little 30 % nitric acid and a few crystals of Potassium chlorate were added. The test tube was warmed gently and after the splinters assume a white ragged appearance, the chemical reaction was stopped by filling the test tube with cold water. The material was washed several times in running water. Fibre length was measured from macerated material for all the collected core samples.

Plate 6: Measuring of wood fibre length

3.10.1. Microscopy

All fibres were measure in accordance with the procedure recommended by the International Association of Wood Anatomists (Anon, 1989). Using Leica Image Analysis System (Quantimet 500 +) attached to Leica Laborlux 12 Pol research microscope precise quantification of wood anatomical features was done. In which fibres having tapering ends on both sides were recorded. The fibres which are short were cut down during the maceration and they were ignored. Counting the number of fibres per mm^2 per field of view using 2.5 x lenses, microscope interfaced with a video monitor. Thirty numbers of measurements were taken for fibre length. Average was calculated and it was expressed in micrometer.

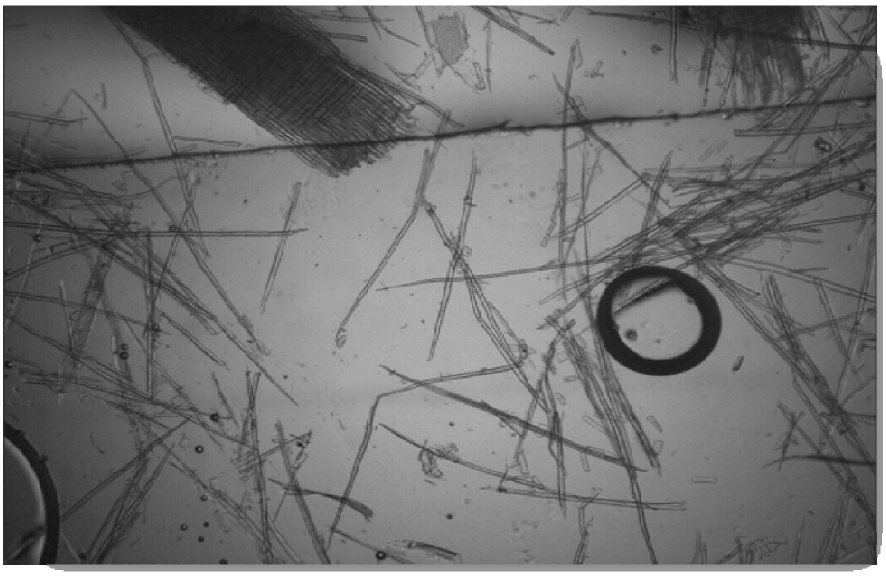

Plate 7: Microscopic view of wood fibre

3.11. Correlations

The wood properties like wood growth rings, specific gravity and fibre length were correlated with various environmental parameters. Further the relationship was analyzed using the regression test.

IV EXPERIMENTAL RESULTS

The results pertaining to survey and identification of swamps, wood growth (ring width), and properties like specific gravity, fibre length with relationship between environmental variables are described in this chapter.

4.1a. To survey and identify suitable location of swampy and non-swampy Myristicaceae members

Based on the published literature and primary information gathered and field survey was planed covering the five districts in the central Western Ghats region. Further, in consultation with the state forest department officials, a systematic filed survey was undertaken. Finally, five locations with both swampy and non-swampy Myristicaceae were selected for the present study (Table 1 and Fig. 1).

Table 1: Suitable locations of swampy and non-swampy Myristicaceae members

Sl. No	Locations	Districts	Latitude ^{O}N	Longitude ^{O}E	Altitude (m)
1	Ithalimane	Uttara Kannada	14^{o}25’967”	74^{o}46’097”	482
2	Thorme	Uttara Kannada	14^{o}16’705”	74^{o}46’026”	855
3	Darbejaddi	Uttara Kannada	14^{o}25’967”	74^{o}46’097”	482
4	Sampaje	Dakshina Kannada	12^{o}28’29.8”	75^{o}35’30.7”	178
5	Makutta	Kodagu	12^{o}21’05.6”	75^{o}45’22.3”	897

4.1b. To compare the microclimate variations in swampy and non-swampy areas

Through the literature survey, variations exist in the swampy and non-swampy conditions were studied. Further, through primary field survey the variations reported were validated in the selected locations. The microclimatic variations with respect to pH, water level, slope, etc are given in the Table 2.

4.1c. Densities of swampy and non-swampy Myristicaceae members in selected swamps

The number of trees (>10 cms GBH), saplings (1-10 cms GBH), seedlings (< 1 m height) per quadrat (10x10 m) across the locations was assessed. The Sampaje showed higher densities of swampy *Gymnacranthera canarica* than other swamps. The Makutta swamp showed lowest densities of swampy species. Similarly, the non-swampy *Myristica malabarica* densities were computed in and around the swamps of all the five locations. Here also the Sampaje showed higher densities of non-swampy *Myristica malabarica* than other locations and Thorme showed lowest density. Compared to the swampy species the non-swampy had lower densities in all the locations (Table 2).

Table 2: Microclimatic variations across swampy and non-swampy condition

Sl. No	Character	Swampy	Non-swampy
1	Water logged condition	Present	Absent
2	Myristicaceae species	*Gymnacranthera canarica, Myristica fatua* var. *magnifica*	*Myristica malabarica, M. dactyloides, Knema attenuate*
3	Knee / aerial roots	Prominent	Sometimes aerial roots observed
4	Summer season	Wet condition	Dry conditions
5	Soil pH	More acidic	Less acidic
6	Nutrient status	Poor in NPK but rich in Fe & Zn	Relatively rich in NPK & poor in Fe & Zn
7	Humus	large proportion	Less
8	Anaerobic bacteria	Present	Absent
9	Aspect / Slope	Relatively flat	Sloppy Upland

Note: Soil nutrient status and humus (sl. no 6 and 7) were not analyzed in this study

Table 3: Densities of *Gymnacranthera canarica* individuals across the locations

Sl. No	Locations	Trees	Sapling	Seedling*
		Mean±SD	Mean±SD	Mean±SD
1	Ithalimane	1.18±0.15	0.43±0.15	0.58±0.05
2	Thorme	0.98±0.05	0.12±0.08	0.38±0.06
3	Darbejaddi	1.14±0.17	0.14±0.03	2.43±0.50
4	Sampaje	0.77±0.03	2.08±0.32	4.92±0.25
5	Makutta	1.08±0.25	0.08±0.01	0.23±0.14

**Seedling density measured in four 1*1 m^2 nested quadrates within the main quadrates*

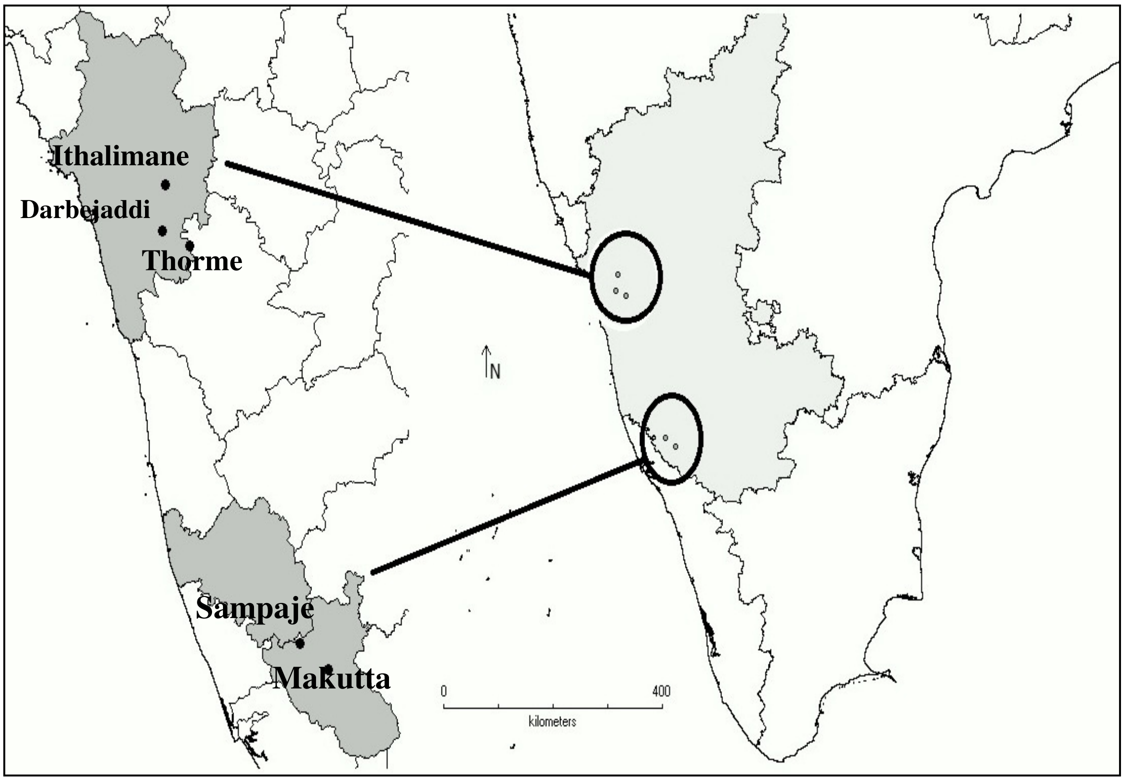

Fig. 1: Distribution Map of the study locations in Central Western Ghats

Table 4: Densities of *Myristica malabarica* individuals across the locations

Sl. No	Locations	Trees	Sapling	Seedling*
		Mean±SD	Mean±SD	Mean±SD
1	Ithalimane	0.65±0.03	0.71±0.02	0.54±0.09
2	Thorme	0.52±0.11	0.54±0.03	0.74±0.02
3	Darbejaddi	0.30±0.01	1.30±0.25	0.40±0.10
4	Sampaje	0.44±0.03	0.67±0.01	1.11±0.90
5	Makutta	0.55±0.02	0.64±0.02	0.64±0.12

**Seedling density measured in four 1*1 m^2 nested quadrats within the main quadrats*

4.2. To study the impact of major environmental variables on wood growth and Properties of swampy and non-swampy species

4.2.1. Wood growth analysis of swampy and non-swampy Myristicaceae Members across the locations

The wood core samples collected from the trees were brought to the laboratory and processed. The growth rings were observed under microscope. The wood growth rings of obligate swampy species *G. canarica* samples ranged from 0.16 to 5.84 mm across the locations and it ranged from 0.05 to 5.03 mm for non-swampy *Myristica mabarica*. The details of wood growth at each location are given in the (Table 5). The average wood growth of swamps species (pooled over five locations) was found to be higher (1.84±0.87) than the non-swampy species (1.62±0.87). Further, comparison of swampy and non-swampy species within locations also yielded similar results. The results indicated out of five locations studied, except Thorme all the locations showed statistically significant differences.

Table 5: Wood growth analysis of *Gymnacranthera canarica* (swampy) and *Myristica malabarica* (Non-swampy) across the locations

Sl. No	Locations	Swampy		Non-swampy		t-test Significance
		Range	Mean±SD	Range	Mean±SD	
1	Ithalimane	0.39-4.45	1.61±0.78a	0.16-4.43	1.44±0.92a	t=2.22 p<0.02*
2	Thorme	0.40-4.33	1.81±0.77b	0.40-3.92	1.77±0.73b	NS
3	Darbejaddi	0.24-4.85	2.01±0.87c	0.05-4.55	1.43±0.92c	t=-6.88 p<0.00**
4	Sampaje	0.37-4.97	2.05±1.08c	0.37-4.86	1.61±0.81a	t=-4.29 p<0.00**
5	Makutta	0.39-5.84	2.22±1.15c	0.29-5.03	1.69±1.01ab	t=-5.39 p<0.00**
Overall		0.24-5.84	1.84±0.87	0.05-5.03	1.62±0.87	t=-5.44 p<0.00**

*Dissimilar letter indicate the 't' test significance @ p<0.0, * significance @ 5 %, ** significance @1 %*

4.2.2. Frequency distribution of annual wood growth rings

Frequency distribution of wood growth values of swampy and non-swampy species were computed. The frequency distribution of growth values between two categories of Myristicaceae members was statistically different (KS test). For both the species the normal distribution pattern was not observed, rather the distributions were skewed negatively (Fig. 2).

4.2.3. Specific gravity of swampy *Gymnacranthera canarica* across the locations

The wood core samples collected from the trees were brought to the laboratory and specific gravity was computed following maximum moisture content method. The specific gravity of *G. canarica* wood core ranged from 0.339 to 0.571. The mean specific gravity varied across the locations (Fig. 3A). The mean specific gravity was lowest for Sampaje (0.375±0.022) and was highest for Darbejaddi (0.506±0.045) samples.

4.2.4. Specific gravity of non-swampy *Myristica malabarica* across the locations

The specific gravity values for *Myristica malabarica* wood core samples ranged from 0.339 to 0.570. The mean specific gravity was varied across the locations (Fig. 3B). The mean specific gravity was lowest for Ithalimane (0.441±0.041) and was highest for Darbejaddi (0.560±0.036) samples.

4.2.5. Average Specific gravity of swampy *Gymnacranthera canarica* and non-swampy *Myristica malabarica*

The mean specific gravities of two species were compared using student's t-tests. The wood specific gravity was higher for non-swampy *Myristica malabarica* than the obligate swampy *Gymnacranthera canarica*. The pooled data from 5 locations (overall) indicated *Myristica malabarica* (0.462±0.065) has significantly higher wood specific gravity than its swampy relative *Gymnacranthera canarica* (0.424±0.064). Further, the location wise analysis indicated among the five locations, except Thorme all the four locations indicated that *Myristica malabarica* possess higher wood specific gravity than *Gymnacranthera canarica* (Table 6).

4.2.6. Frequency distribution of specific gravity values

The specific gravity values for each species from the five locations were pooled and then frequency distribution was observed. The frequency distribution of specific gravity was positively skewed for the *Myristica malabarica* whereas it was negatively skewed for *Gymnacranthera canarica* indicating specific gravity decreases under swampy conditions and increases under upland dry conditions (Fig. 4). The frequency distribution of specific gravity for two species was compared using KS test, which indicated that distribution pattern is statistically different.

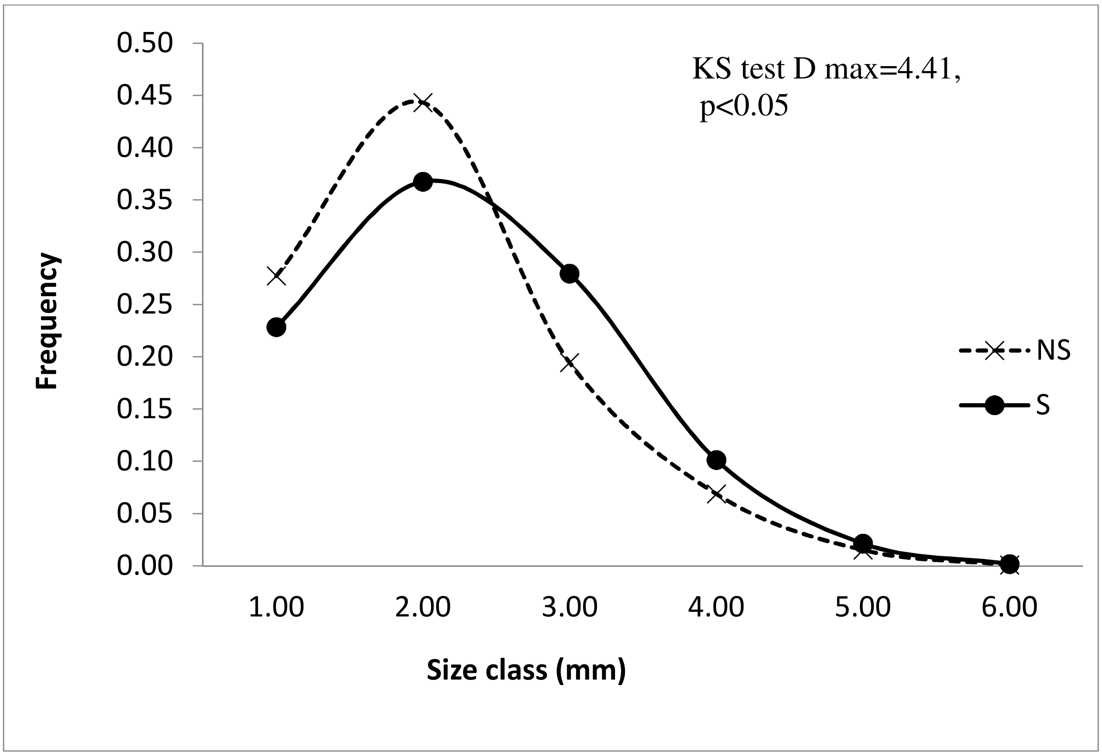

Fig. 2: Frequency distribution of growth ring values across the swampy (S) and non-swampy (NS) species of family Myristicaceae (KS test significant at 5 % probability).

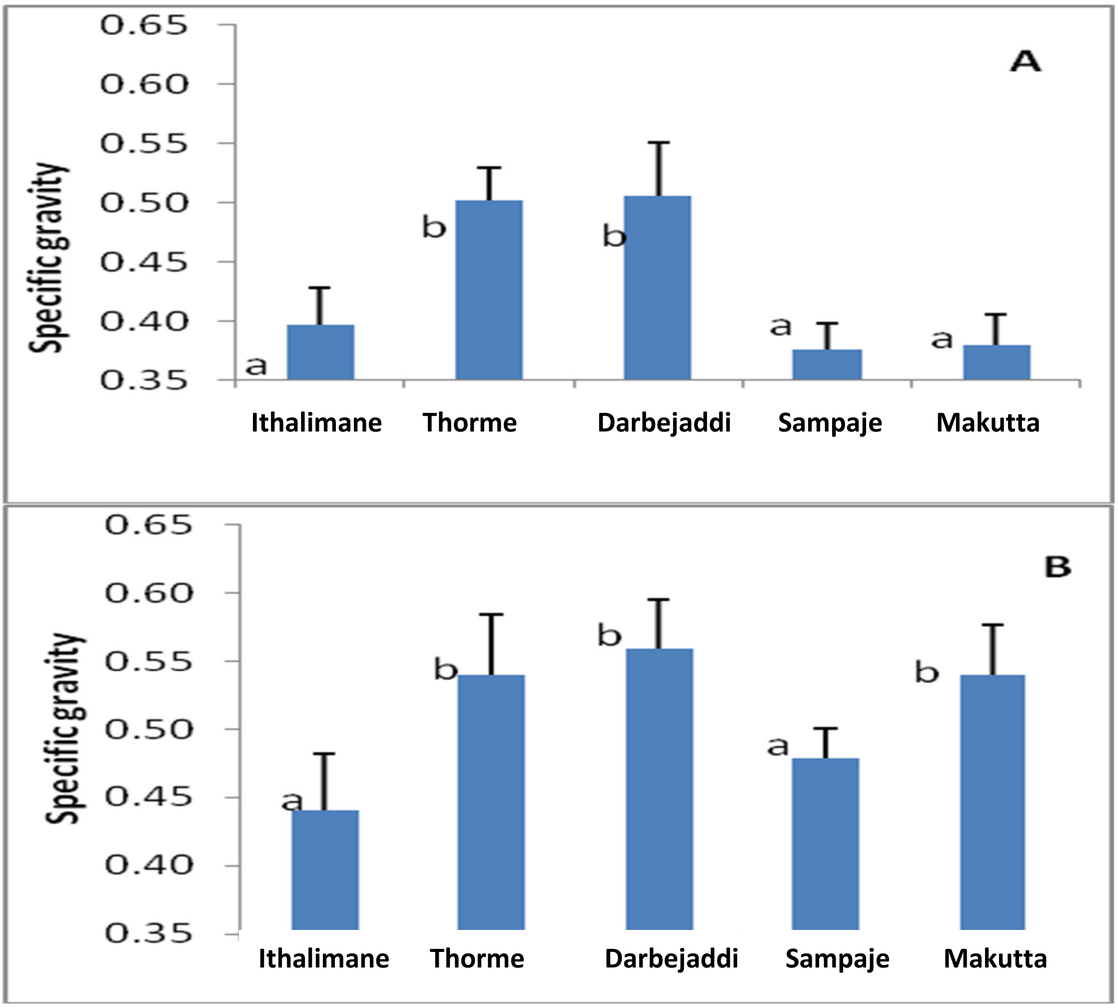

Fig. 3: Wood specific gravity of swampy *Gymnacranthera canarica* (Fig A) and non-swampy *Myristica malabarica* (Fig B) across the locations in Western Ghats, India. Dissimilar letter indicates the t-test significance at 5 % probability.

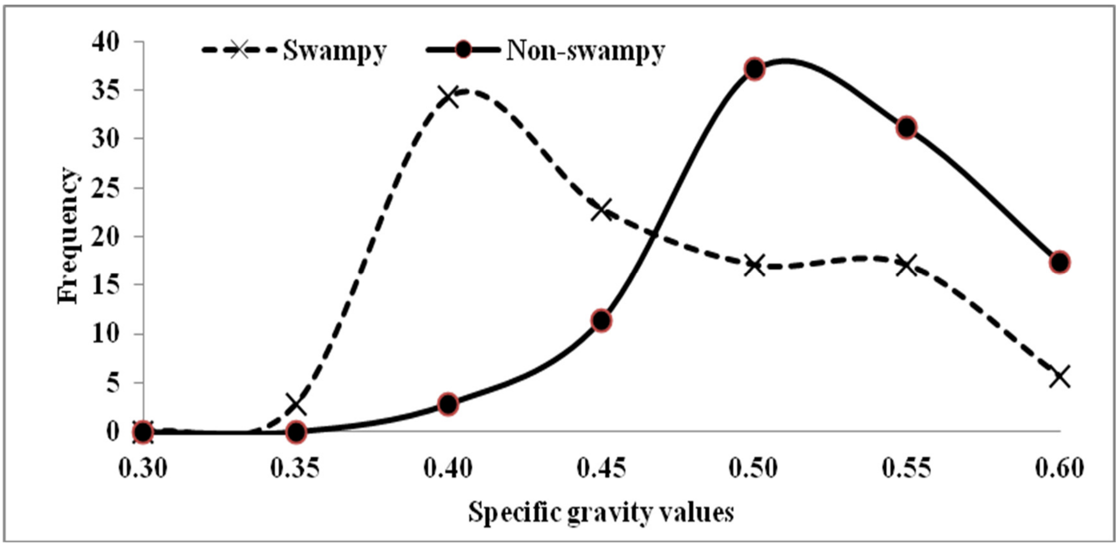

Fig. 4: Frequency distribution of specific gravity values of both swampy and non-swampy species of family Myristicaceae (KS test significant at 5 % probability).

Table 6: Comparison of wood specific gravities of *Gymnacranthera canarica* (swampy) and *Myristica malabarica* (non-swampy) across the locations

Sl. No	Locations	Swampy		Non-swampy		t-test Significance
		Range	Mean±SD	Range	Mean±SD	
1	Ithalimane	0.353-0.445	0.396±0.030	0.387-0.491	0.441±0.040	t=2.27 p<0.04*
2	Thorme	0.459-0.547	0.503±0.027	0.486-0.592	0.540±0.045	NS
3	Darbejaddi	0.453-0.571	0.506±0.045	0.491-0.593	0.559±0.035	t=2.47 p<0.03*
4	Sampaje	0.339-0.404	0.375±0.022	0.460-0.498	0.478±0.022	t=8.73 p<0.00**
5	Makutta	0.352-0.427	0.379±0.026	0.489-0.586	0.539±0.037	t=9.33 p<0.00**
	Overall	0.339-0.571	0.424±0.064	0.361-0.578	0.462±0.065	t=3.35 p<0.00**

** significance @ 5 %, ** significance @ 1 %*

4.2.7. Wood fibre length of swampy *Gymnacranthera canarica* across the locations

The wood core samples collected from the trees were brought to the laboratory and fibre length was measured following standard procedure. The fibre length of *G. canarica* wood core ranged from 1001-1814 µ. The mean fibre length was varied across the locations (Fig. 5A). The mean fibre length was lowest for Darbejaddi (1421±176) and was highest for Makutta (1509±117) samples.

4.2.8. Wood fibre length of non-swampy *Myristica malabarica* across the locations

The fibre length of wood core sample for *Myristica malabarica* ranged from 0970-2305 µ. The mean fibre length was varied across the locations (Fig. 5 B). The mean fibre length was lowest for Thorme (1495±171) and was highest for Ithalimane (1671±122) samples.

4.2.9. Average wood fibre lengths of swampy *Gymnacranthera canarica* and non-swampy *Myristica malabarica*

The mean fibre length of two species was measured using the microscope and compared using student's t-tests. The wood fibre length was higher for non-swampy *Myristica malabarica* than the obligate swampy *Gymnacranthera canarica*. The pooled data from 5 locations (overall) indicated *Myristica malabarica* (1599±177) has significantly higher fibre length than its swampy relative *Gymnacranthera canarica* (1485±145). Further, the location wise analysis indicated among the five locations, except Thorme all the four locations indicated that *Myristica malabarica* possess higher fibre length than the *Gymnacranthera canarica* (Table 7).

Table 7: Comparison of wood fibre lengths of *Gymnacranthera canarica* (swampy) and *Myristica malabarica* (non-swampy) across the locations

Sl. No	Locations	Swampy		Non-swampy		t-test Significance
		Range	Mean±SD	Range	Mean±SD	
1	Ithalimane	1251-1708	1507±115	1366-1991	1671±122	t=09.24 p<0.00**
2	Thorme	1256-1790	1474±135	1049-2185	1495±171	NS
3	Darbejaddi	1001-1814	1421±176	0970-2305	1560±264	t=04.12 p<0.00**
4	Sampaje	1168-1696	1491±114	1442-2123	1648±120	t=09.00 p<0.00**
5	Makutta	1296-1721	1509±117	1309-1889	1643±117	t=07.68 p<0.00**
Overall		1001-1814	1485±145	0970-2305	1599±177	t=10.61 p<0.00**

** significance @ 5 %, ** significance @ 1 %*

4.2.10. Frequency distribution of fibre length values

The fibre length values for each species from the five locations were pooled and then frequency distribution was observed. The frequency distribution of fibre length values showed normal distribution pattern for both the species. However, the peak for the non-swampy *Myristica malabarica* was slightly higher than the *Gymnacranthera canarica* indicating fibre length decreases under swampy conditions and increases under upland dry conditions (Fig. 6). The frequency distribution of fibre length values for two species was compared using KS test, which indicated that distribution pattern is statistically different.

4.2.11 Correlation of wood growth ring width of swampy and non-swampy with Mean annual rainfall across the locations

The wood growth ring width was observed under the microscopes. The outer most rings were considered as the latest ring and were also assumed that this was the last year growth. The rainfall data for each selected location was obtained from the Karnataka State Natural Disaster Monitoring Centre (Ksndmc), Yelahanka, Bangalore. (The data was obtained for the past 29 years from 1984 to 2013). Rainfall data was correlated with the wood growth ring. We correlated across the locations with the mean annual rainfall (both in swampy and non- swampy). All correlations indicated insignificant relationship between the rainfall and wood ring width. The details are given in the Table 8.

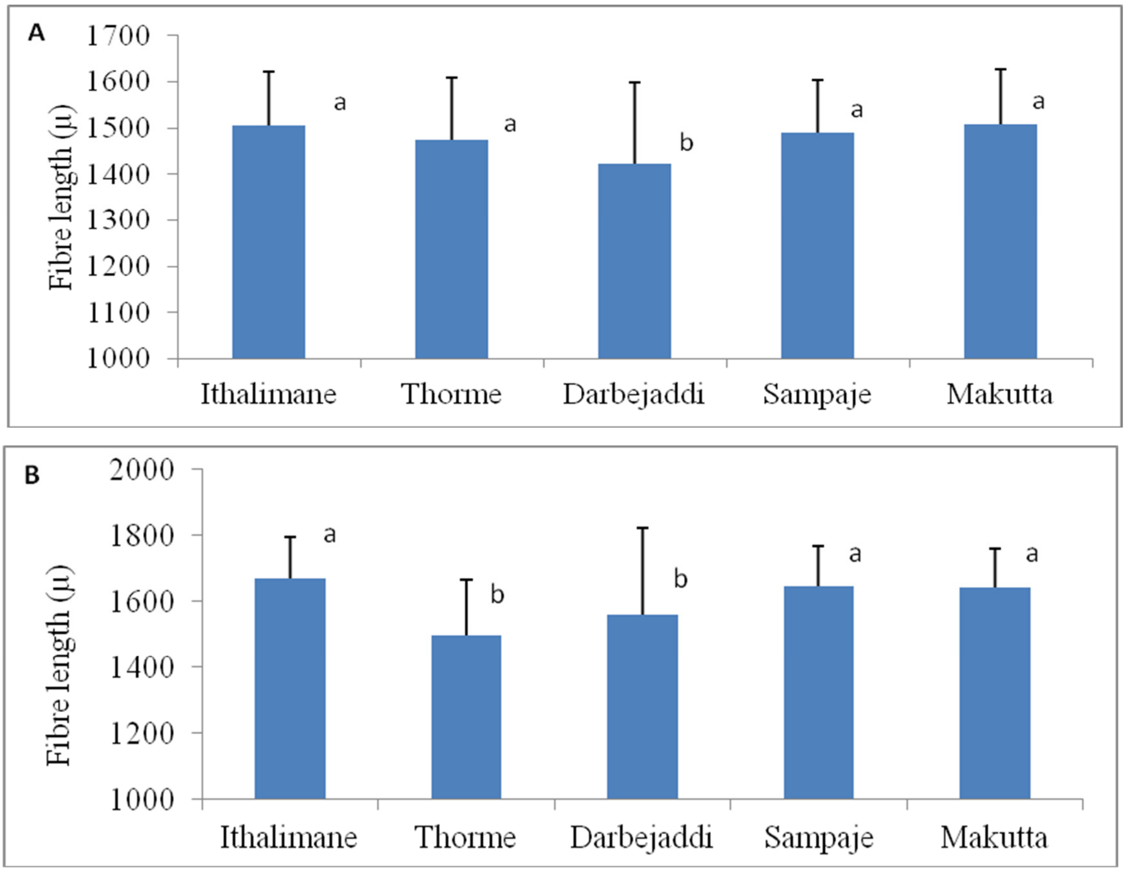

Fig. 5: Wood fibre length of swampy *Gymnacranthera canarica* (Fig A) and non-swampy *Myristica malabarica* (Fig B) across the locations in Western Ghats, India. Dissimilar letter indicates the t-test significance at 5 % probability.

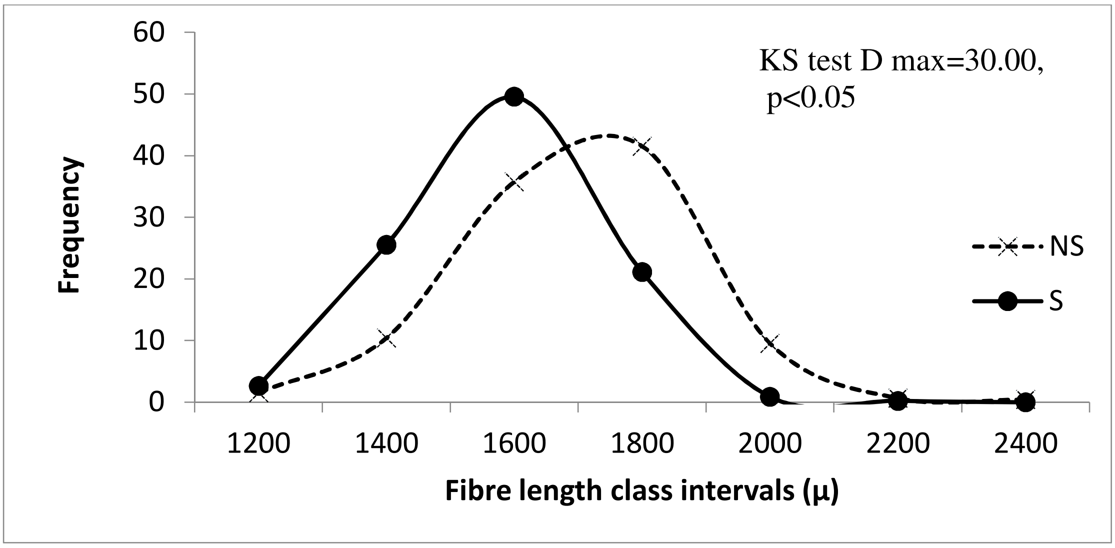

Fig. 6: Frequency distribution of fibre length values of both swampy and non-swampy species of family Myristicaceae (KS test significant at 5 % probability).

Table 8: Correlation (r-values) of *Gymnacranthera canarica* (swampy) and *Myristica malabarica* (non-swampy) wood growth ring width with mean annual rainfall across the locations.

Locations	Non-swampy	Swampy
	Tree1	**Tree1**
Ithalimane	0.34	0.10
Darbejaddi	-0.22	***0.39***
Thorme	***-0.39***	-0.15
Sampaje	-0.02	0.02
Makutta	0.19	-0.11

Bold and italics indicate 'r' values statistical significance @ p<0.05

Note: the annual ring width at the each location obtained for 3 trees, however for correlation the average ring width over three trees were used.

4.2.12 Correlation of wood growth ring width of swampy and non-swampy with mean minimum and maximum temperature across the locations

The temperature data for each selected location was obtained obtained from the Karnataka State Natural Disaster Monitoring Centre (Ksndmc), Yelahanka, Bangalore. Then the average minimum temperature and average maximum temperature annually (the data was obtained for the past 11 years from the year 2002 to 2013) was correlated with the ring width. The data indicated there no relationship exists between the ring width and temperature (Table 9).

Table 9: Correlation (r-values) of *Gymnacranthera canarica* (swampy) and *Myristica malabarica* (non-swampy) wood growth ring width with average minimum and maximum temperature across the locations.

Locations	Non-swampy		Swampy	
	Minimum	**Maximum**	**Minimum**	**Maximum**
Ithalimane	0.12	-0.28	0.25	-0.15
Darbejaddi	***-0.59***	0.45	***-0.41***	0.25
Thorme	-0.06	0.50	***-0.41***	-0.25
Sampaje	0.01	***-0.63***	0.43	-0.25
Makutta	0.35	-0.52	-0.53	-0.46

Bold and italics indicate 'r' values statistical significance @ p<0.05

Note: the annual ring width at the each location obtained for 3 trees, however for correlation the average ring width over three trees were used.

4.2.13 Correlation of wood growth ring width of swampy and non-swampy with mean minimum and maximum relative humidity across the locations

The relative humidity data for each selected location was obtained from the Karnataka State Natural Disaster Monitoring Centre (Ksndmc), Yelahanka, Bangalore. Then the average minimum relative humidity and average maximum relative humidity annually (the data was obtained for the past 11 years from the year 2002 to 2013) was correlated with the ring width. The data indicated there no relationship exists between the ring width and relative humidity (Table 10).

Table 10: Correlation (r-values) of *Gymnacranthera canarica* (swampy) and *Myristica malabarica* (non-swampy) wood growth ring width with average minimum and maximum relative humidity across the locations.

Locations	Non-swampy		Swampy	
	Minimum	**Maximum**	**Minimum**	**Maximum**
Ithalimane	0.27	-0.35	0.13	0.35
Darbejaddi	0.00	0.11	-0.48	0.41
Thorme	-0.35	0.14	***-0.60***	***-0.62***
Sampaje	0.27	-0.35	0.13	-0.35
Makutta	***-0.67***	***-0.75***	-0.31	-0.16

Bold and italics indicate 'r' values statistical significance @ p <0.05

Note: the annual ring width at the each location obtained for 3 trees, however for correlation the average ring width over three trees were used.

V DISCUSSION

The discussion pertaining to the results obtained from the studies which including survey and identification of swamps, wood growth ring its properties like specific gravity, fiber length with relationship between environmental variables are described in this chapter.

5.1. Survey and identification of suitable location

India has four genera namely *Horsfieldia, Gymnacranthera, Knema* and *Myristica* and altogether 15 species belongs to family Myristicaceae. In Western Ghats particularly *Gymnacranthera canarica* and *Myristica fatua var. Magnifica* occur in *Myristica* swamps and are exclusively associated with swampy conditions. These Myristicaceae members have very dense stilt roots, which sprouts 6 m above the soil (Pascal, 1988). Apart from the South Indian Western Ghats swamps dominated by Myristicaceae are also reported from New Guinea (Corner, 1976). Other *Myristica* species found (although less frequently) is *Myristica malabarica*. The two species *Myristica dactyloides* and *Knema attenuate* also found in Western Ghats but in non-swampy uplands. In this study based on the published information we conducted a systematic survey and identified the locations, which has both swampy and non-swampy Myristicaceae members. The locations selected for the present study includes Makutta, Sampaje, Thorme, Darbejaddi and Ithalimane situated in Karnataka state, central Western Ghats.

5.1.1. Demographic profile of swampy and non-swampy Myristicaceae members

A number of reports specified that species such as *Gymnacranthera canarica, Myristica fatua var. magnifica, Semecarpus kathalekanensis, Mastigxia arborea,* etc. as swamp adapted endemic tree species of Western Ghats (Ramesh and Pascal, 1977; Verghese and Menon, 1999; Chandran *et al*., 1999; Dasappa and Swaminath, 2000; Vasudeva *et al*., 2001, Tambat *et al*., 2005). Similarly, the species such as *Knema attenuate, M. dactyloides and M. malabarica* are non-swampy ones (Tambat *et al.,* 2005, 2007). However, the later Myristicaceae members occur more frequently in swamp adjoining habitat. Thus a few studies did mention these species (namely *Knema attenuate, M. dactyloides and M. Malabarica* etc) as swampy species (Verghese and Menon, 1999; Chandran *et al*., 1999; Chandrashekara and Sreejith, 2003). A study by Tambat *et al.,* (2005) based on the species occurrence and swampyness index clearly classified the obligate swampy and the occurring non-swampy species.

The demographic inventory in the present study indicated the density of individuals varies across the locations in both the species. The Sampaje showed higher densities of both swampy and non-swampy species compared to other location. This may be due to land topography. In Sampaje the swamps occur in relatively plain areas and had place for water stagnation. The other thing that was noticed was human interference which was less. The Makutta swamp that showed lowest densities of swampy species though geographically near to Sampaje but, the topography of the land is difficult. The Makutta swamps are deep inside the forest and well protected from human interference but the land possess many slopes and are frequently visited by the elephants (personal observation). Thus it is likely that seedlings have been trampled. The other places in Uttara Kannada are more accessible to the human settlements, thus are subjected to human interference. In fact, the earlier studies on swamps of Uttara Kannada have indicated that people do visit the swamps for seed & mace collection and also allow the cattle for grazing besides water diversion (Chandran *et al.,* 2001, Vasudev *et al.,* 2001). Thus we believe that the lower densities in these swamps are attributed to disturbance and the land topography though we do not have the supporting data in the present investigation. Further studies may through light on this aspect.

Further, compared to the non-swampy *M. malabarica* the swampy species *Gymnacranthera canarica* possess higher density. All though the climatic and edaphic factors are similar yet, the demographic profile varied between the two Myristicaceae members (swampy and non-swampy species) within the given location. In all the locations, the non-swampy *M. malabarica* had very low regeneration perhaps due to collection of fruits as NTFP in the Western Ghats (Chandran *et al.,* 1999; FRLHT, 2003). There are indications that *G. canarica* seed and mace are also collected by the local people but not as much as the *M. malabarica.* The mace of *M. malabarica* is used as spice in the local market and popularly referred as Bombay nutmeg. The fruit (mace) collection needs to be reduced to increase the regeneration and survival ability of *Myristica malabarica* in the Western Ghats.

5.1.2. Wood growth in Myristicaceae

Wood, in the strict sense, is yielded by trees, which increase in diameter by the formation, between the existing wood and the inner bark, of new woody layers which envelop the entire stem, living branches, and roots. This process is known as secondary growth; it is the result of cell division in the vascular cambium, a lateral meristem, and subsequent expansion of the new cells. Where there are clear seasons, growth can occur in a discrete annual or seasonal pattern, leading to growth rings; these can usually be most clearly seen on the end of a log, but are also visible on the other surfaces. If these seasons are annual these growth rings are referred to as annual rings. Where there is no seasonal difference growth rings are likely to be indistinct or absent.

Growth rings are a useful tool for the determination of age and growth rate of the trees in wood production of managed stands. Vijendra *et al*., (1992) made a study on anatomical description of Indian Myristicaceae members. They reported on microscopic structure of all the species and reported that Myristicaceae member have diffuse porous wood comprising of wood growth rings and it is delimited by concentric lines/ bands of parenchyma. Further, reported that wood of *Gymnacranthera canarica* tree species can be distinguished from other two genera in possessing vessels perforations which are predominantly (94 %) simple. However, their differentiation at species level, on the basis of both qualitative and quantitative anatomical feature is difficult.

5.2. Wood growth analysis of swampy and non-swampy species across the locations

Myristicaceae members possess the diffused porous wood and bands of parenchyma separate the growth rings. Thus in this study, we considered the band of parenchyma (brown colour) as an indicator of wood growth. The distance between the two bands of parenchyma was considered as the annual growth. The outer most (next to bark) growth was assumed as the last year annual wood growth. The annual wood growth of both the species was compared across the locations. We observed the variation in wood growth across the locations in both swampy and non-swampy species. According to Panshin and de (1980) ring width indicate the resultant annual growth patterns of the trees, representing the aggregate effect of many environmental factors, including climate, biological ageing, local endogenous disturbances due to competition amongst the trees and exogenous disturbances caused by fire, pests, disease, pollution, logging, etc.

In the present study, we observed variation in wood growth between trees at a given location. This indicated that wood growth is mostly governed by genetic factor rather than the climatic factors. Thus the variations in wood growth across the locations could be attributed to genetic factor rather than climate. Further, in a given location (similar climatic conditions) variation with respect to wood growth between species strengthens this assumption. Thus, it is likely that wood growth in both the species governed mainly by genetic factor and other factors play minor role. Among the two species, swampy species showed higher wood growth than non-swampy species. This might be due to, species adaptation to the swampy habitat, where throughout the year water is available that influence cells growth and thereby the wood growth. Whereas the non-swampy species though grows in a similar habitat but do not grow in water logged conditions. Thus the soil water availability influences the cell and wood growth. The study on understanding genetic diversity with wood growth helps confirm our assumption.

5.2.1. Correlation of annual growth rings with environmental parameters

Worbes (1995) reported that Cambial dormancy and annual rings in tropical trees are induced by annually occurring dry periods or flooding. Growth periodicity is indicated by the leaf fall behaviour and is connected with an annual periodicity of shoot elongation. Changes in stem diameter are measured with a dendrometer or by measurable differences in the electrical resistance of the cambium. Dendrochronological methods applied to carefully prepared samples can serve as proof of the annual periodicity of growth zones. Several studied have indicated that the rainfall has a strong relationship with wood growth (Jacoby and Arrigo, 1990; Pumijumnong *et al.,* 1995; Rigozo *et a.,l* 2005).

The mean annual rainfall ranged from 2543 to 7277 mm across the study locations. The mean annual rainfall of the location (nearest) was collected from the Karnataka State Natural Disaster Monitoring Centre (Ksndmc), Yelahanka, Bangalore. The outer most ring of the wood core was treated as the last year's growth. Further, subsequent growth rings were treated as one year older to the existing year.

With measurement from the periphery to the pith, last thirty years annual growth was marked. Rainfall data was correlated with the wood growth ring. We correlated across the locations with the mean annual rainfall (both in swampy and non- swampy). Both the swampy and non-swampy species show no relationship with the mean annual rainfall. The no relationship obtained might be due to the followings reasons; firstly the species used in the study occur in wet evergreen forest that receives relative higher rainfall and the trees might not have been subjected to drought. Secondly these species occur at lower altitude and most of the times possess swampy conditions. Thirdly, the growth rings studied might be pseudo rings as we do not know the actual age of the trees to authenticate the rings as annual rings. Thus further studies are needed this area. The growth rings were also correlated with the mean annual temperature and relative humidity. However, here also we observed no relationship between growth ring and mean annual temperature in both the selected species.

5.2.2. Specific gravity analysis of swampy and non-swampy Myristicaceae members across the locations

Specific gravity is the ratio of the weight of a given volume of wood to that of an equal volume of water. Zobel and van (1989) indicated that specific gravity is not a simple characteristic but is determined by several characteristics of wood such as cell size and wall thickness, the ratio of early wood to late wood, the amount of ray cells, the size and amount of vessel elements, and other factors. The specific gravity of wood is its single most important physical characteristic. The strength of wood as well as the stiffness increases with specific gravity (Niklas, 1993; USDA 1999). In addition, specific gravity may also play an important role in determining the growth rate, life span, and maximum size of an individual plant and consequently affecting the function and structure of forest. Specific gravity is considered as an important trait directly connected with biomass production (Keays, 1971); and wood with higher specific gravity is generally considered less susceptible to decay (Schmidtling and Amburgey, 1982).

The present study indicated that the specific gravity of the swampy species *Gymnacranthera canarica* and the co-occurring non-swampy species *Myristica malabarica* varied across the sites. Both the species followed similar pattern indicating sites play important role in determining wood specific gravity. Compared to the swampy species, the non-swampy species possessed higher specific gravity.

Many factors of site, climate, geographic location, and species affect the specific gravity wood. Site-related factors such as moisture, availability of sunlight and nutrients, wind temperature can affect specific gravity. These are determined to a large extent by elevation, aspect, slop, latitude, soil type, stand composition and spacing (Schmidtling and Amburgey, 1982). Many environmental factors affect wood but the one most commonly cited is the moisture regime. This was shown by Nicholls (1967), who marked with *Pinus pinaster* in drier climates. He emphasized that wood quality improvement can only be wholly successful if proper attention is also given to growing conditions, particularly to those factors that are associated with moisture availability to the mature tree. Ferraz *et al.,* (*2011*) in Eucalyptus showed that there was a considerable effect of moisture deficiency on wood properties and that different species and sources did not have their wood affected in the same way. Josefina, 1987 measured the specific gravity of 220 woody species, in which half of them from a tropical rainforest and another half from a tropical deciduous forest. He compared these two groups using a Student t -test. The results showed highly significant differences in specific gravity between the species from the two areas and results revealed that woods from the dry deciduous forest tend to be much heavier than those from the rainforest. Wood specific gravity is influenced by the moisture availability to trees (Sluder, 1970) reported that tree species that are subject to drought situation tend to increase their specific gravity by minimizing wood density. Gilmore (1968) reported trees at the bottom of a slope, or growing slopes where more rainfall was preserved possess a lower wood specific gravity. Suzuki, 1999, measured wood properties for trees in lowland Dipterocarp in west Kalimantan. He measured the specific gravities and water contents of the wood including bark. Results showed wide range of specific gravities and suggested that forest had high diversity in wood properties.

In the present study, the wood species gravity could be related to the moisture availability and nutrient status. The studies have indicated that swampy habitat possess different physicochemical properties than the adjoining non-swampy habitat. Similarly the nutrient status also varies between the habitats (Ponnamperuma, 1984; Varghese and Menon, 1999, Tambat *et al.,* 2007). The swampy species always possess water and the non-swampy species may be subjected to dry period thus the specific gravity is higher, perhaps this could be adaptive strategy of the species. The altitude of the location was correlated with the specific gravity. The correlation indicated, swampy species show no relationship, whereas the non-swampy species show strong positive relationship (data not shown). Indicating the specific gravity depends on altitude. These results perhaps indicating that specific gravity depends on moisture content as the soil moisture content deceases with increased altitude. At lower altitude soil moisture remains higher due to the gravitational pull and lower temperature.

5.2.2. Fibre length gravity analysis of swampy and non-swampy Myristicaceae members across the locations

Wood fibres are natural composite structures in which cellulose fibrils are held together by lignin and hemicelluloses. The major constituents of wood fibres are lignin, cellulose, hemicelluloses, and extractives. Each of these components contributes to fibre properties, which ultimately impact product properties. Wood fibres are the most abundantly used cellulose fibre. They have been extensively used in the modern composite industry due to their specific characteristics (Dai and Fan, 2011). Dai and Fan (2011) reported that wood fibers are the most abundantly used cellulose fibers to enhance physical and mechanical properties.

Genetic improvement of wood quality traits is particularly attractive since most wood quality traits are strongly inherited (Shelbourne *et al.,* 1998). Knowledge of the factors including genotype and spacing that influence wood and fibre characteristics is vital for improving the quality of timber. To examine the effect of genotype and spacing at a dryland site, on core wood anatomical (microfibril angle, fibre length, fibre width and cell wall thickness), physical (density) and mechanical (MOE) properties Lasserre *et al.*, 2009 conducted a study. Their results indicated that relative to wide spacing, close initial stand spacing significantly reduced microfibril angle (MFA) and ring width and significantly increased dynamic modulus of elasticity (MOE), fibre length, latewood percentage and cell wall thickness. Density and fibre width were not significantly different between spacing treatments. The influence of genetic population on wood properties indicated that genotype significantly influenced MFA, MOE and ring width (Lasserre *et al.*, 2009).

In the present study, wood fibre length of both swamp and non-swampy species were measured by following Schultz's method. The study indicated that the wood fibre length of swampy species *Gymnacranthera canarica* and the co-occurring non-swampy species *Myristica malabarica* show variations across the sites. However, these differences were not found statistically significant. Both the species followed the similar pattern indicating sites play important role in determining wood fibre length. Compared to the swampy species, the non-swampy species possessed statistically higher fibre length in all the locations.

The variability in wood characteristics exists within a single tree more than among trees growing on the same site or between trees growing on different sites (Larson, 1967). A large variability was reported for loblolly pine (McGraw 1985) and hardwoods (Koch 1985). Cheng and Bensend (1979) reported using Populus clones, that the variation in fibre length mainly a result of physiological and environmental factors rather than a genetic factor. Yanchuk *et al.,* (1983) reported radial variation of fibre length in fifteen genetically distinct clones of trembling aspen (*Populus tremuloides*) from natural stands in central Alberta, Canada. Fibre length in young Populus stems, relation to clone, age, growth rate and pruning was studied by Debell *et al*., (2002). They reported that clones differed significantly in ring width and fibre length. The fibre length varies with the age, height and clones have been reported by a number of authors (Bhat. 1990; Chauhan *et al*., (1999), Yang and Sheng (2003); Pande and Singh, 2009). The horizontal variation in the fibre length has also been reported. The fibre length increases from pith to outwards in some Eucalyptus clones (Ishiguri *et al.,* 2007; Pande and Dhiman, 2011).

In the present study, the fibre length variation observed could be due to variation in the microclimate and site factor. The correlation between fibre length and climatic factors mainly mean annual rain fall and temperature showed no significant relationship. We presume, due to species intrinsic genetic make-up they behave differently in a given location and thus we observed significantly difference in fibre length. Further, the genetic and environmental interaction yields different results across the locations. Further studies are needed to look into the relationship including the analysis of horizontal and vertical variation within tree.

5.3. Conservation strategies for Myristicaceae members

The present study based on the demographic profile indicated that non-swampy species regeneration is significantly affected than to the obligate swampy species. Thus *Myristica malabarica* needs priority attention in order to survive in near future. However, the swamps itself are affected due to anthropogenic activities it is also important to identify and prioritize the swamps in the central Western Ghats that are highly threatened and those that could serve as long-term repositories of species endemic to the swamps. These swamp associated and non-swampy Myristicaceae members that are used as NTFP must be conserved by physical protection and also by motivating the swamp adjoin people to harvest the fruits on sustainable basis. Awareness on the fruit maturity and importance of seed material for future needs to be created. Participatory approach must be adapted to conserve the swamps as well as other Myristicaceae member in Western Ghats.

The wood growth and wood properties analysis indicated both the species behave differently, thus the impact of local microclimate change and climate change at large varies. The local factors influencing the Myristicaceae must be identified and appropriate measures should be taken. Developing a comprehensive strategy and action plan for the long-term conservation of swamps and adjoining species in the central Western Ghats would be beneficial.

VI SUMMARY

Myristicaceae is one of the ancient families of flowering plants in tropical forests. Out of 500 species (21 genera) distributed in lowland wet evergreen forests. India has four genera and 15 species. The two species namely *Gymnacranthera canarica* and *Myristica fatua* var. *Magnifica* occur in swampy and non swampy. The other two species namely *Myristica dactyloides* and *Knema attenuate* found in non-swampy uplands. The one species *Myristica malabarica* more often found in adjoining areas of Myristica swamps. In the present study through a systematic field survey we identified five locations that have both swampy and non-swampy Myristicaceae members. The locations identified for the present study were Makutta, Sampaje, Thorme, Darbejaddi and Ithalimane situated in Karnataka state, central Western Ghats.

From the past studies we know that, which density of individuals varies across the locations. Further, compared to the non-swampy *M. malabarica* and the swampy species possess higher density. Although the climatic and edaphic factors are similar, the demographic profile varied between the two Myristicaceae members (swampy and non-swampy species) within the given location. Regeneration capacity of non swampy members was low compared to swampy mainly because of collection of its fruits as NTFP by forest people. Hence, this has to b reduced to the regeneration and survival of non swampy members in Western Ghats.

Growth rings are a useful tool for the determination of age and growth rate of the trees in wood production of managed stands. Vijendra *et al.,* (1992) made a study on anatomical description of Indian Myristicaceae members and indicated that they have diffuse porous wood comprising of wood growth rings and it is delimited by concentric lines/ bands of parenchyma.

In the present study, we considered the band of parenchyma (brown colour) as an indicator of wood growth. The study indicated that there exists a significant variation in wood growth across the locations in both swampy and non-swampy species. Geographically closer locations showed similar growth pattern, indicating climatic factors play a role in the wood growth. Compared to the non-swampy species, the swampy *Gymnacranthera canarica* showed higher growth (diameter) perhaps due to availability of more water in swampy condition.

The mean annual rainfall of the locations was collected from the Karnataka State Natural Disaster Monitoring Centre (Ksndmc), Yelahanka, Bangalore. Both the swampy and non-swampy species showed no relationship with the mean annual rainfall. This might be due to the following reasons; firstly the species used in the study were from wet evergreen forest that receives relatively higher rainfall and they are not exposed to drought conditions. Secondly, the disadvantage of growth rings analysis is it considers pseudo rings and we do not know the actual age of the trees to authenticate the rings as annual rings. Similar results were obtained when mean annual temperature and growth rings were correlated. Thus further studies are needed in this area.

Specific gravity is considered as an important trait directly connected with biomass production (Keays, 1971); and wood with higher specific gravity is generally considered less susceptible to decay (Schmidtling and Amburgey, 1982). The present study indicated that the specific gravity of the swampy species *Gymnacranthera canarica* and the co occurring non swampy species *Myristica malabarica* varied across the sites. Both the species followed similar pattern indicating sites play important role in determining wood specific gravity. Compared to the swampy species, the non-swampy species possessed higher specific gravity. Which may be due to available of water, the wood species gravity was related to the moisture availability and nutrient status was found indicating that swampy habitat possess different physicochemical properties than the adjoining non-swampy habitat and nutrient status varies between the habitats (Ponnamperuma, 1984; Adams, 1990; Tambat *et al*., 2007). The altitude of the location was correlated with the specific gravity and swampy species showed no relationship, whereas the non-swampy species show strong positive relationship (data not shown) indicating the specific gravity depends on altitude. These results perhaps indicating that specific gravity depends on moisture content as the soil moisture content deceases with increased altitude. At lower altitude soil moisture remains higher due to the gravitational pull and lower temperature.

Wood fibres are the most abundantly used cellulose fibres to enhance physical and mechanical properties (Dai and Fan, 2011). In the present study, wood fibre length of both swamp and non-swampy species were measured by following Schultz's method and it was found that, the wood fibre length of both swampy and non-swampy species varied across the sites indicating sites play important role in determining wood fibre lenght. Compared to the swampy species, the non-swampy species possessed statistically higher fibre length in all the locations.

This variation in fibre length could be due to variation in the microclimate and site factor. But, correlation between fibre length and climatic factors mainly mean annual rain fall and temperature showed insignificant relationship. Hence, we presume the difference in fibre length is due to species intrinsic genetic make-up. Further studies are needed to look into the relationship including the analysis of horizontal and vertical variation within tree.

As mentioned early, the non-swampy species regeneration is significantly affected compared to the swampy species and needs priority attention in order to survive in near future. However, the swamps itself are affected due to anthropogenic activities indicating the importance to identify and prioritize the swamps in the central Western Ghats that are highly threatened and those that could serve as long-term repositories of species endemic to the swamps. The non-swampy Myristicaceae members that are used as NTFP must be conserved by physical protection and also by educating people adjoining the swamps about the importance of these species so that the harvest the fruits on sustainable basis. Awareness on the fruit maturity and importance of seed material for future needs to be created. Participatory approach must be adapted to conserve the swamps as well as other Myristicaceae member in Western Ghats.

The wood growth and wood properties analysis indicated that, both the species behave differently, thus the impact of local microclimate change and climate change at large varies. The local factors influencing the Myristicaceae must be identified and appropriate measures should be taken. Developing a comprehensive strategy and action plan for the long-term conservation of swamps and adjoining species in the central Western Ghats would be beneficial.

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