REGENERATION ECOLOGY AND SUSTAINABILITY OF HARVEST OF BAY LEAF, *CINNAMOMUM TAMALA* FR. NEES (LAURACEAE) IN MEGHALAYA

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DECLARATION

I, Ms. Biswarupa Ghosh, hereby, declare that the subject matter of this thesis entitled, "Regeneration ecology and sustainability of harvest of bay leaf, *Cinnamomum tamala* Fr. Nees (Lauraceae) in Meghalaya" is the record of work done by me. I declare that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

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Chapter I

General Introduction

Forest dwellers all over the world have depended on a variety of forest products for livelihoods. They have utilized both timber and non-timber products. The latter are commonly known as NTFPs. In general, NTFPs contribute substantially to the livelihoods and income of the people living in and around forests. Of all the NTFPs used by the people, many are traded to augment income and several have been commercialized. Not all people depending on NTFPs are however involved in its trade and commerce. It is estimated that nearly 1.2 billion people use various tree species to generate food and cash in developing countries (World Bank 2002). About 350 million people are directly dependent on forest resources for subsistence and/or income generation and another 60 million depend highly on rainforests of Latin America, Africa and Southeast Asia.

Extraction of NTFPs has been debated in scientific parlance for sustainability. It is believed that not many NTFPs are harvested on a sustained-yield basis. Examples of many NTFPs such as *Prunus africana* (Cunningham and Mbenkum 1993), *Bertholletia excelsa* (Peres *et al.* 2003) and others from several countries do confirm that extractions of NTFPs are unsustainable.

Sustainable harvest of NTFPs depends on the part of the plant that is harvested. If an entire plant is harvested, as generally is the case with the herbs, the populations are most threatened. For example, *Allium tricoccum* (Nantel *et al.* 1996), *Panax quinquefolium* (Nantel *et al.* 1996), *Aechmea magdalenae* (Ticktin *et al.* 2002). In some cases, harvest of

entire tree as in case of *Aquilaria malaccensis* (Soehartono and Newton 2001, Paoli *et al.* 2001) has driven the species to threatened category. Similarly, if fruits and seeds are harvested in large quantities, seed banks may diminish to the extent that the regeneration of species does not occur as in *Brosiumum alicastrum* (Peters 1992) and *Grias peruviana* (Peters 1991). Notwithstanding, if the leaf is the commodity in demand, the possibilities of sustainable harvests are enhanced. This however may vary substantially with the species. In case of *Livingstonia rotundifolia*, the leaf harvest is unsustainable beyond 20% (O'Brien and Kinnaird 1996). On the other hand, rattan harvest from *Calamus zollingeri* may be ecologically sustainable in tropical rainforests of Sulawesi as nutrient levels are significantly higher in the foliage than the cane and the foliage is left on the ground after harvesting (Siebert 2001). Incidentally, both these species mentioned for leaf extraction belong to palms. Studies on sustainability of leaf harvests from tree species are hardly known (Ticktin 2004).

Sustainable harvest of NTFPs also depends on the technique of harvest. Hall and Bawa (1993) argued that harvesting of branches and leaves from the adult trees may not only divert resources meant for reproduction to regenerate branches, but also the number of sites of reproduction may be reduced and fruit production interrupted until the branches regrow. Continued pruning may lower reproductive output of affected individuals so severely that recruitment of new individuals in the population would be deterred. Overextraction of leaf may decrease the photosynthetic capacity of the harvested individual rendering it susceptible to disease and reduced reproductive vigor. In fact, defoliation is known to alter carbon content, C: N ratio and chlorophyll content in new

leaves, making them more susceptible to herbivores and decreasing photosynthetic capacity over the long term (O'Hara 1999).

Sustainable harvest of a NTFP also depends on life-history traits. Regeneration in natural conditions is determined by the successful completion of several events in the tree life cycle, such as seed production, dispersal to safe sites, seed germination and seedling emergence, establishment and onward growth. Seed production of trees may be limited by various extrinsic factors such as resource availability, pollinator abundance and predation of flowers, fruits and leaves, by climatic conditions as well as by intrinsic factors such as age and size of the plant and its genetic constitution (Winn and Werner 1987). Hence, regeneration of tree species is greatly influenced by the interaction of biotic and abiotic factors of the environment (Boring *et al.* 1981, Aksamit and Irving 1984, Khan *et al.* 1986). These factors may affect recruitment, survival and growth of tree seedlings and sprouts (Tripathi and Khan 1992). The presence of sufficient number of seedlings, saplings and young trees in a given population is considered as an indicator of good regenerability of a species (Saxena and Singh 1984a).

Two most important intrinsic factors that are of ecological importance in NTFP collection are the resource stock and the regenerability of the product. The natural populations of an NTFP constitute its resource stock that may decline due to deforestation or increase by proper management and cultivation on a temporal scale. The regenerability of an NTFP apparently depends on population size, reproductive potential, conducive microhabitat and anthropogenic pressures (Hall and Bawa 1993).

Fortunately, NTFPs offer enormous potential in improving rural economy without degrading the forests through the down-to-earth involvement of the people in practicing

sustainable means of harvesting and hence conserve biodiversity (Hedge *et al.* 1996, Murali *et al.* 1996, Uma Shankar *et al.* 1996, 2001). Godoy and Bawa (1993) hypothesized that NTFPs can be harvested on sustained yield basis from year to year for many years. However, overextraction may lead to local extinction of populations or to the domestication of the species if the product is demanded and a channel of marketing is developed.

NTFPs form an integral part of Indian culture and traditions for millennia. About 700 million rural Indian people depend on NTFPs for sustenance (Bhat *et al.* 2001). The Ayurveda system of medicine, which originated in India, is predominantly dependent on NTFPs such as *Centella asiatica*, *Artemisia meritima*, *Swertia chirayita*, *Juglans regia*, *Aconitum* spp.. In India, any festival is incomplete without the use of a variety of NTFPs.

In Meghalaya, the major tribes, namely, Khasi, Garo and Jaintia harvest many timber and NTFP species. Broomgrass, bay leaf and torchwood top the list of NTFPs traded in Meghalaya (Figure 1.1). These NTFPs have been notified by the Government of Meghalaya since a tax is levied on export out of the State. Other common NTFPs are fruits and berries (*Myrica esculenta, Elaegnus* spp., *Rubus* spp., *Castanopsis* spp., *Prunus nepaulensis*), mushrooms, rattan and canes, edible medicinal herbs (*Centella asiatica, Houttuynia cordata,*), medicinal plants (*Drymeria cordata, Costus specious, Meyna spinosa).*

Of the three major NTFPs in Meghalaya, bay leaf is derived from *Cinnamomum tamala* Fr. Nees. (Lauraceae) found predominantly in subtropical mixed evergreen forests. *C. tamala* is an evergreen tree mostly occurring in the sub-canopy. The harvest and trade of bay leaf has steadily increased in Meghalaya during last 10-12 years. It is believed that

the ban on timber harvest by the Supreme Court of India in 1996 from the forests in northeastern region of India triggered people shifting to NTFPs. Of late, *C. tamala* has been cultivated in some parts of Meghalaya.

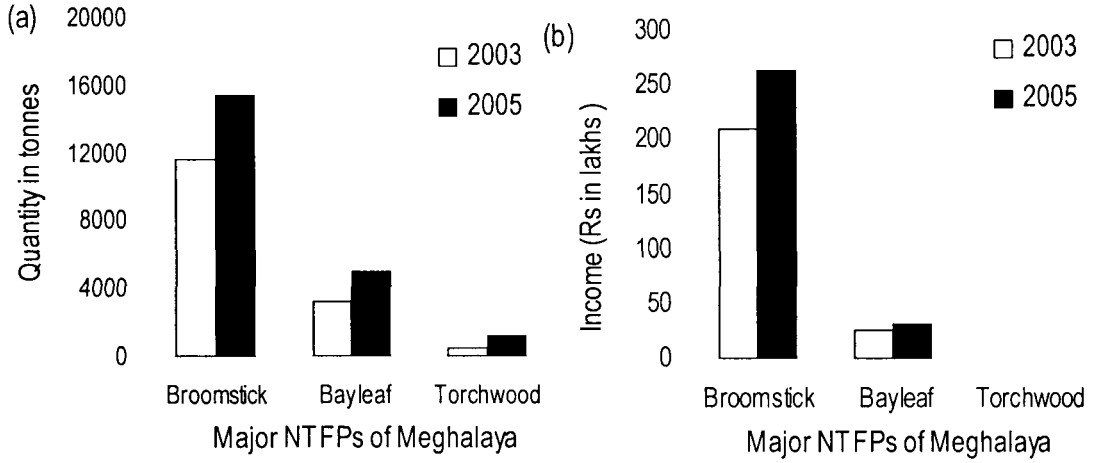


Figure 1.1. The maximally traded non-timber forest products of Meghalaya. Data from Mawiong Regulated Market, Shillong for collection quantities (Figure a) and revenue generated by the sale of NTFPs collected (Figure b). The revenue figures for torchwood were not available.

The studies on population ecology, regeneration, sustainability of harvest and trade are the prerequisites for evolving an effective conservation strategy for any NTFP while providing economic benefits to the rural people. The extraction of bay leaf from *C. tamala* offers a potential system for studying sustainability of leaf harvest from a tree. The present study is focused to investigate the community organization of the systems that house *C. tamala* trees, regeneration of *C. tamala*, sustainability of bay leaf harvest, and profitability of trade of bay leaf in Meghalaya. Hence, the objectives of the present study are to (i) study the regeneration ecology of *C. tamala* and (ii) examine the sustainability of the current harvest practices and trade of bay leaf in Meghalaya.

Chapter II

Review of Literature

Humans have accelerated the rate of forest clearance in recent decades. It has been estimated that about 1,800 populations are being lost per hour due to destruction of forests (Singh 2002). In this context, non-timber forest products (NTFPs) have assumed great significance to sustainably utilize and manage forest resources.

Non-timber forest products are biological resources derived from either managed or natural wooded area (Peters 1996). FAO described NTFPs as any material of biological origin that is derived from the forests other than timber (FAO 2006). NTFPs include a variety of fruits, nuts, seeds, oils, spices, resins, gums, medicinal plants, fuel wood and products specific to the particular areas from which they originate (Marshall and Newton 2003). NTFP utilization not only facilitates the conservation of biodiversity in tropical regions but also opens up the door for alleviating rural economy (Gillls 1992, Leakey and Newton 1994, Hegde *et al.* 1996, Uma Shankar *et al.* 1996, Bawa and Gadgil 1997).

It is estimated that about 4,000 to 6,000 non-timber plant species are of commercial importance worldwide (Iqbal 1993, SCBD 2001). More than 95% of 400 plant species predominantly used in the production of medicines by the Indian herbal industry are harvested from wild populations (Uniyal *et al.* 2000).

A vital reason for paradigm shift in NTFP utilization has been the renewable nature of NTFPs. The global hypothesis for NTFP utilization states that NTFPs can be culled or harvested on sustained-yield basis from year to year for many years without threatening the survival of associate species. On the other hand, excessive or

unsustainable harvests of NTFPs may lead to the extinction of local populations or domestication of the species involved (Godoy and Bawa 1993). There are many instances of overexploitation of NTFP species affecting regeneration adversely (Daniels *et al.* 1995, Murali *et al.* 1996, Ganeshaiah *et al.* 1998, Uma Shankar *et al.* 1998a,b). Hence, sustainable harvest of NTFP species is a prerequisite for their utilization as well as perpetuation.

Sustainable harvest of a product from a system essentially means maintaining the natural capital/resources and carrying capacity of the ecological organization within the ecosystem as well as at landscape level (Goodland 1995). In addition to the production of goods, ecosystems offer services to support life through the purification of air and water, cycling of nutrients, pollination of crops, preservation and renewal of soil fertility, partial stabilization of climate and the control of pests (Odum and Barret 2005).

The genesis of the word sustainability (German: *Nachhaltigkeit*) dates back to 1712 when it was used for the first time by the German forester and scientist Hans Carl von Gilinscee in the book *Sylvicultura Oeconomica* (Garde *et al.* 2007). French and English scientists adopted the concept of planting trees and used the term 'sustained yield forestry'. The 1987 Brundtland Report defined sustainable development as a method that "meets the needs of the present generation without compromising the ability of future generation to meet their own needs".

Godoy and Bawa (1993) advocated that sustainability could only be determined by directly measuring the rate of extraction and comparing it to the rate of natural replacement. Thus, if the rate of NTFP extraction is higher than the rate of its replacement, it is likely that the method of NTFP harvest is unsustainable. Harvesting can have both short-term and long-term effects. Immediate short-term effects of

harvesting can result in the decline of the harvested product. While, long-term effects may be visible in lowering of density, growth rates and reproductive capacity of the species rendering it vulnerable to extinction (Hall and Bawa 1993). Moreover, excessive harvesting of NTFPs can have a negative impact on biodiversity conservation due to changes in the structure and function of the ecosystem.

In 2002 World Summit on Sustainable Development, three overarching objectives of sustainable development were identified as (a) eradication of poverty, (b) protection of natural resources, and (c) changing of unsustainable production and consumption patterns. In this regard, NTFPS can be considered as an important tool in alleviating rural economy and preventing deforestation. However, it is not clear if the commercial use of NTFPs will result in increased conservation of natural forests (CARPE 2004). In fact, use of NTFPs has been considered as an indicator of poverty.

Nevertheless, there are several records of NTFPs contributing substantially to the rural income worldwide. In the Amazon, the Brazil nut (*Bertholletia excelsa*) is a very important NTFP contributing to the overall economy of Brazil. Brazil nut is a valuable food source with a huge market in Europe and North America where up to 7,000 t of unshelled nuts and 20,000 t of shelled nuts are shipped every year (BBC 2007).

In Cameroon, some non-conventional NTFPs such as *Gnetum* spp., *Irvingia* spp., *Ricinodendron heudelotti* and *Dacryodes edulis* have recently emerged as export commodities to Central African region at large. These products had a total import value of 8,648,000 FF (US$ 1,729,600) to Paris alone in 1999 (Tieguhong and Ndoye 2006).

In the El Terrero community of Sierra De Manantlan Biosphere Reserve in Mexico, NTFPs were identified as the most important source of cash income for 30% of the woman interviewed (Marshall and Newton 2003).

In Sri Lanka, the NTFPs collected from the lowland rain forests have been estimated to fetch US$ 300 per ha per year (Liyanaarachchi 2004). In the knuckles range of forests of the National Wilderness Area of Sri Lanka, NTFPs are reported to contribute 16.2% of the total income or US$ 253 per household per year to the local community (Guantilleke *et al.* 1993). The net income from NTFPs from the entire Sinharaja Forest of Sri Lanka and surrounding villages for a period of one year was reported to be US$ 113,075 (Guantilleke *et al.* 1993).

Nearly, 50 million people living in and around forests in India depend on NTFPs as a critical component for their sustenance (NCHSE 1987). In India, NTFPs provide about 40% of total official forest revenues and 55% of forest-based employment (World Resources Institute 1990). A wide gap exists in the estimated need of products such as fuelwood, fodder and timber obtained from the forests and their sustainable yield (Table 2.1).

Table 2.1. Gap between the estimated need and the sustainable yield of forest products in India (After Lal 1989).

Forest product	Estimated need	Sustainable yield
Fuelwood (million m^3)	236	40
Fodder (million tons)	882	434
Timber (million m^3)	264	52

In Madhya Pradesh, India, indigenous women collect NTFPs worth Rs. 21 billion (US$ 700 million) annually (Worldwatch Institute 1991). In West Midnapore district

in West Bengal, many village communities derive as much as 17% of their annual household income from NTFPs (Malhotra *et al.* 1991). Other estimates suggest that up to 35% of the income of tribal households in India comes from the collection of NTFPs. Small-scale forest-based enterprises focusing on NTFPs, provide up to 50% of income for 20 to 30 per cent of the rural labor force in India (Campbell 1988). In Darjeeling Hills in India, *Thysanolaena maxima*, i.e., broomgrass has been found to have a potential to enhance rural economy by a return of 1.7 times the investment cost to the farmers (Uma Shankar *et al.* 2001).

The risk of unsustainable harvests increases as the pressure for enhancing income from NTFP collection rises. Another important reason is increasing demand that can make people disregard traditional harvesting techniques as in case of *Buchanania lanzan* and *B. latifolia* (chironji). The price of chironji seeds or Cuddapah almond which is used as a substitute for almond in various delicacies increased more than 150 times in a span of five years in India (Tewari and Campbell 1995). This led to the premature harvest of chironji fruits and hampered natural regeneration of the species in India, especially in Madhya Pradesh.

In Central India, forests dominated by mahua (*Madhuca indica*) are burnt repeatedly to simplify collection of yellow flowers from the forest floor. Consequently, regeneration of mahua trees is becoming scarce and experts have suggested that the species will be locally extinct by next century (Tewari and Campbell 1995). In West Bengal, mahua flowers were collected by breaking the apical twigs which affects flowering in the following year (Rama Krishna Mission Lokashiksha Parishad 1992).

Similarly, indiscriminate collection of raw material from the forests for incense stick (*agarbatti*) industry in Karnataka has caused extensive losses of *Machilus*

macarantha (gulmavu), *Ailanthus malabarica* (halmaddi) and *Boswellia serrata* (Parameswarappa 1992) especially in Coorg and Malanad districts. Similarly, the indiscriminate felling and collection of NTFPs from *Garcinia cambogia* (uppage) trees in Karnataka has resulted in widespread losses.

American ginseng *(Panax quinquefolius)* is probably one of the best-known examples of a NTFP that was harvested unsustainably for its highly valued medicinal properties. A long-lived perennial ginseng is now an endangered species in Canada and exports of wild ginseng are now prohibited. Despite being successfully domesticated in Canada, domestic sales of wild ginseng are still taking place and wild populations continue to decline. This is primarily because of ten-fold higher economic returns from wild ginseng than the domesticated ginseng (AAFC 2000). Species recovery activities have marked wild populations of ginseng to deter illegal harvesting.

Fortunately, there has been a spurt of interest in NTFP-related studies during the last decade. Studies by Campbell (1988), Peters *et al.* (1989), De Beer and McDermott (1989), Schwartzman (1989), Padoch and de Jong (1989), Malhotra *et al.* (1991), Wickens (1991) have reviewed the issues related to the development of NTFPs. Richards (1992) had raised serious concerns about the viability of commercializing NTFPs as "eco-protection enterprises". May (1991) has studied the role of institutions in the NTFP markets in Brazilian Amazon. Case-studies by FAO (FAO 1991a,b) have analyzed the problems of value addition and organizational management in Southeast and East Asia. The International Tropical Timber Organization has developed guidelines for the sustainable use of all natural resources. These guidelines specifically stress the need for estimation of the present and potential values of

NTFPs (Arnetz 1993). In India, pioneering work has been done by Gupta *et al.* (1982).

Majority of research on NTFP harvest at species level has focused on experimental assessments of harvest methods and clearly illustrates that vital rate of non-timber resources may be significantly affected by differences in harvest techniques. These differences include seasonal timing of harvest, timing of harvest in the plant life cycle, frequency of harvest, size of individuals harvested and intensity of harvest (Geldenhuys and Van der Merwe 1988, Nantel *et al.* 1996, Anderson and Rowney 1999, Zuidema 2000, Ticktin *et al.* 2002 a, b, Freckleton *et al.* 2003).

In scrub forests of Karnataka, intensive NTFP harvesting from tree species appears to have led to replacement of large woody species by small woody species with a decline in stand density and basal area and skewing of populations toward smaller size classes (Uma Shankar *et al.* 1998).

Ticktin (2004) observed that impact of harvesting on woody perennials depends upon the reproductive adults, juveniles or both that are being harvested. Since, woody perennial species reach reproductive maturity at different sizes, harvesting of the same material may affect their population dynamics in very different ways. In many cases, high levels of fruit or seed harvest may allow the persistence of the population over long terms, except for instances where fruit and seed harvest involves damage of other plant parts like cutting of branches leading to decline of many species.

The annual sustainable rate of harvest for seeds and fruits of *Neodypsis decaryi*, a canopy palm (Ratsirarson *et al.* 1996) and *Brosiumum alicastrum*, a canopy tree (Peters 1992) were up to 95%. The extraction of tila flowers and fruits from *Ternstroemia lineata* population within the El Terrero community of Sierra De Manantlan Biosphere Reserve in Mexico has been reported to be sustainable as the

species shows a good regeneration with reverse J-shaped curve. However, Marshall and Newton (2003) have reported that there has been a considerable decline in the availability of the tila in the last 15 years since it became a marketable produce. As for the Brazil nut, *Bertholletia excelsa* which is a major NTFP of Brazil, there are contrasting reports on the sustainability of its harvest. Zuidema and Boot (2002) have reported that the annual sustainable harvest rate for the Brazil nut is about 93%. Whereas, other studies evince the poor regeneration of *Bertholletia excelsa* due to nut extraction. Reining *et al.* (1991) have shown that two palm species collected and exported for floral arrangements are harvested on an unsustainable basis in the Maya Biosphere Reserve in Guatemala. Nepstad *et al.* (1992) present evidence for depletion of plant populations in Amazonian forests used by rubber tappers.

A recent review on ecological implications of harvesting non-timber forest products by Ticktin (2004) showed that the studies for quantitative assessment of the effects of leaf harvest from tree species are warranted. It has been stated that leaf may be easily harvested from juveniles of large tree species while leaves of shrubs and small tree species may be harvested from both juveniles and reproductive individuals. O'Hara (1999) has reported that defoliation of bay leaf palm may alter carbon content, C:N ratios and chlorophyll content in new leaves, making them more susceptible to herbivores and decreasing photosynthetic capacity over the long term and affect nutrient cycling in the ecosystem. Similarly, Witkowski and Lamont (1996) have reported that harvest of nutrient rich leaves of *Banksia hookeriana* along with the blooms may affect nutrient cycling of the ecosystem in the already nutrient poor soils of Australian heathlands. Siebert (2001) showed that the harvest of *Calamus zollingeri*, where the canes are harvested and leaves are left behind on the forest floor

of Sulawesi tropical forests does not appear to affect the nutrient cycle of the ecosystem.

The extraction of agaru from *Aquilaria malaccensis* in Gunung Palung National Park, Indonesia has been reported to be highly unsustainable due to the lack of skilled harvesters (Paoli *et al.* 2001). However, Varschney (1991) has recommended a sustainable method of harvest where trees can be felled 5 years after inoculation on an 8 years cycle. Ticktin and Johns (2002) have stated that the growth rate of a harvested population will directly depend on the knowledge of the harvester and less on the intensity of harvest.

It is believed that bark harvest is sustainable from juvenile as well as reproductive individual of large trees, but not from juveniles of shrubs and small tree species. In Central Africa, tree species such as *Prunus africana* (pygeum) and *Pausinystalia yohimbe* (yohimbe) are said to be sustainably harvested. However, the harvest method that involves partial stripping of bark from live trees that exposes them to stem boring insects that can result in 50-90% post harvest tree mortality (CARPE 2004). Stewart (2001) has recommended sustainable extraction of *Prunus africana* on an 8-10 year rotation.

Harvests of NTFPs can also increase susceptibility of harvested plants to herbivory by insects, at least for several *Protea* species in South African Fynbos (Mustart and Cowling 1992). In some plants where harvesting patterns mimic biotic interactions for which the plants have developed evolutionary responses, such as resprouting (Siebert 2000, Ticktin 2003) may be most tolerant species to harvest. However, the intensity of biotic interactions with such species needs to be reduced in human impacted areas.

The harvest from trees requires monitoring of subsequent reproductive outputs and disease incidences associated with the damage. The plant resources are not only

diverted from reproductive processes to regenerate the branches, but actual sites of reproduction may be lost and fruit production may reduce until branches have regrown. Reproductive output of the harvested individuals may be lowered due to repeated pruning at short intervals (Hall and Bawa 1993). Nonetheless, disturbance may increase seed production in *Lithocarpus dealbata* and *Schima khasiana* in the subtropical humid forests of Meghalaya. This could be due to where partial thinning of the tree canopy that might favor the production of heavier seeds, probably by improving the availability of resources (Barik *et al.* 1996).

Interestingly, overharvesting is not restricted to the products that are being collected for commercial markets. Browder (1992) has cited examples of NTFPs that are used primarily by the local communities of South America for subsistence. Browder also points out that once NTFPs enter the commercial markets, their harvest cannot be sustained without external inputs.

It has been observed that multiple uses of forests for commercial purposes, for subsistence needs and for ecological security have led to several conflicts and overexploitation. Schulze *et al.* (1994) suggested that a combination of economic and ecological data provides a powerful tool for identifying key parameters that could be manipulated in a managed system to improve the profitability and sustainability of extraction. In such cases social forestry is both economically and ecologically viable option to resolve such conflicts (Nadkarni *et al.* 1992).

The foresight of ONADEF (Office National de Development des Forests) in implementing medicinal tree (*Cinchona, Prunus* etc.) cultivation in plantations and through enrichment planting in Africa, is a source of valuable information applicable not only in Cameroon, but in other countries as well (Cunningham 1993).

It is believed that on-farm cultivation of high value NTFPs may reduce pressure to harvest from the wild, but may increase incentives to clear forest to cultivate new crops. The importance of NTFPs has been overshadowed in the Knuckles ranges of Sri Lanka, by the higher values generated by shifting cultivation and cardamom cultivation. However, Gunatilake *et al.* (1993) suggested the possibility of integrating the use of NTFP into proposed conservation plans for Knuckles by the forest department of Sri Lanka. The success of such innovative policies would depend on the rate of NTFP extraction and the rate of natural regeneration.

In the Singharaja forest, floristic richness, particularly of the endemic component, declined due to selective logging (de Zoysa *et al.* 1990) while abundance of non-timber forest species such as the sugar palm (*Caryota urens*), medicinal vine (*Coscinium fenestratum*), wild cardamom (*Elettaria ensal*) and rattans (*Calamus* spp.) greatly increased (Guantilleke *et al.* 1993) in the recent past.

Even though broomgrass has played an important role in the economic upliftment of the rural population of Darjeeling Hills, the regeneration of the species is reported to be poor as a result of inflorescence extraction. It has been observed that extraction of the inflorescence reduces the soil seed bank of the species. Further, biotic (grazing) and abiotic (fire) factors adversely affect seedling survival. Uma Shankar *et al.* (2001) suggested that the domestication of *Thysanolaena maxima* is advisable for sustained yield of broomgrass as it promises conservation of the species, upliftment of rural economy as well as restoration of fragile soil systems of the rugged terrains of Darjeeling Hills.

The northeastern region of India is rich in biodiversity and serves as a treasure house of potential NTFPs of medicinal and economic importance (Rao 1994). The region belongs to Indo-Burma hotspot of biodiversity (Myers 2000). This region is also

considered as the *cradle of flowering plants* (Takhtajan 1969). The State of Meghalaya in northeastern region reportedly is known to have 3,128 species of flowering plants including 1,236 endemic species (Khan *et al.* 1997). The rich biodiversity of the State is often attributed to its varied topographical locations and climatic conditions.

Several authors have opined that rates of growth and reproduction of NTFPs growing in agroforestry systems such as enhancement forest plantings and homegardens may also differ significantly from those unmanaged forest environments, due to differences in intraspecific competition (Ticktin *et al.* 2003), light (Velasquez-Runk 1998) or a combination of factors (Martinez- Balleste *et al.* 2002).

Homegardens over the world provide a wide array of NTFPs for food and subsistence. Homegardens have been described as land use systems involving deliberate management of multipurpose trees and shrubs in intimate association with annual and perennial agricultural crops and invariably livestock within the compounds of individual houses, the whole tree-crop-animal unit being intensively managed by family labor (Fernandes and Nair 1986). Homegardens are known by different names such as mixed garden, house garden, kitchen garden in Indian subcontinent (Nair 1993), *pekarangan* (in Java), *kebun* (in Malaysia), *Kampung* (in Indonesia), *jardin* creole (in West Indies), dooryard gardens in Americas (Michon 1983), *Quintal* and *Calmil* in tropical America (Budowski 1990).

The genus *Cinnamomum* Schaeffer belongs to Lauraceae. It has nearly 250 species distributed mostly in Indian subcontinent, Europe, Australia and Sri Lanka. The members of *Cinnamomum* are highly polymorphic and are characterized by great variability of morphological and chemical characters, and hence considered as one of the most critical genus among the higher plant groups (Kostermanns 1983). The genus

is represented by primitive land plants which have close affinities with the members of Magnoliaceae, Annonaceae and Myristicaceae in the floral construction and woody arboreal habit which may probably be due to their origin from some ranalian ancestors (Mitra 1964).

The diagnostic characters of the genus are alternate, sub-opposite or opposite leaves with usually three strong basal nerves, i.e. acrodromous or rarely brochydodromous type of venation pattern. Flowers are small pale yellow hermaphrodite, perianth 3+3, persistent, segments subequal, stamens 9, arranged in 3 whorls of 3 each, filaments of whorl I and II eglandular, while glandular in whorl III, anther 4-locular, dehiscence takes place through the splitting valves, staminodes 3, forming the whorl IV, staminode head cordate or sagittate, fruits berry, seated on enlarged perianth cup. The species under the genus *Cinnamomum* are generally aromatic. Several ecological theories attribute the presence of essential oil in plants with the task of attracting insects thus aiding in cross pollination of the flowers or may act as insect or animal repellents (defense agents), thus preventing the destruction of flowers and leaves (Amelio 1998).

The genus *Cinnamomum* is considered as one of the most important groups of economic plants. There are, nearly 35 species of *Cinnamomum* that occur in India, spanning Western Ghats, Andaman Islands, Eastern Himalayas including the Sub-Himalayan tracts and Northeastern region (Hooker 1885, Kostermanns 1983, Manilal and Shylaja 1986). Baruah and Nath (1997) reported 26 species of *Cinnamomum* in India. In Meghalaya, five species of *Cinnamomum* are found, viz., *C. tamala, C. glaucescens, C. pauciflorum, C. glanduliferum* and *C. bejolghota* (Haridasan and Rao 1985-87).

Of these, *Cinnamomum tamala* Fr. Nees, commonly known as Indian bay leaf, is widely extracted from the wild for spice and medicine. Most Indian languages have a name for Indian bay leaf and these names are invariably derived from Sanskrit (Table 2.2). The most widely understood name in India is 'tejpatta' which has origin in Hindi and some related tongues, and it literally means 'pungent leaf'.

Several variants of *C. tamala* based on the leaf phenotypes have been recognized (Baruah 1998). *C. tamala* variants I, II, III and IV are indicative of two distinct varietal status. The variant I, II and IV is one, while the variant III alone constitutes the other group of varietal status, indicative of leaf phenotypes. Variants I, II and III of *C. tamala* yield 2.1% to 3% oil with 68.1% to 82.5% eugenol. A variant V of *C. tamala* which yielded linalool (60.7%) as the major active principle was confirmed as a taxa of *C. sulphuratum*. The best quality bay leaf is from variant IV of *C. tamala* with smaller leaf size found abundantly in wild and cultivated conditions in Meghalaya and North Cachar Hills district of Assam at an altitude between 600-1250 m asl. (Baruah 1998).

Table 2.2. Vernacular names of Indian bay leaf in different languages of India and abroad.

Language	Common name
Sanskrit	Tamalapattra
Hindi	Tejpatta
Assamese	Mahpat, Tej pat
Bengali	Tejpata
Khasi	Deing latyrpat
Garo	Tejbol
Jaintia	Deing latyrpat
Gujarati	Tamaal patra
Marathi	Tamal patra
Nepalese	Tejpatta
Oriya	Tejpatra
Punjabi	Tejpata, Tez patta
Tamil	Talishapattiri
Telugu	Patta akulu, Talisha
Kannada	Patraka
Burmese	Thitchabo
Chinese (Mandarin)	Chai gui
Danish	Indisk Laurbærblad
Esperanto	Hinda cinamomo
Estonian	Malabari
Finnish	Kanelilaakeri
French	Laurier des Indes
German	Indisches Lorbeerblatt
Hungarian	Indiai babérlevél
Japanese	Tamara-nikkei, Tezipatto
Russian	Malabarskaya koritsa
Thai	Ob choey tan

Bay leaf occurs in mixed plantations in Khasi and Jaintia hills, Garo Hills, Mikir Hills, Manipur and Arunachal Pradesh. It is also grown in homegardens by the local people. Approximately six hundred acres of area is covered under bay leaf in northeastern region of India and most of it is grown between 1,000 and 2,000 m.

Bay leaf is harvested from trees as early as 8-10 years of age and may continue for several decades (Pandey 1984). The price of raw bay leaf ranges from Rs. 500-900 per quintal. At an average purchase price of Rs. 7 kg^{-1}, bay leaf brings approximately Rs. 20 million cash to the growers in Meghalaya (Tiwari 2006). At Chamoli in Gharwal, scanty collection of bay leaf is reported, i.e., 40 quintal in 1996-97 and 75 quintal in 2000-01 (Dhar *et al.* 2002).

The air-dried leaf of *Cinnamomum tamala* is known as Indian bay leaf and it is an important NTFP of Meghalaya. Bay leaf is harvested in large quantities in Meghalaya and exported to various parts in the country. Shillong is the major hub of export of bay leaf. The bay leaf has been widely regarded as a spice, e.g., by the International Organization of Standardization, Hungary, Budapest (Atal and Kapur 1982). Indian bay leaf has been one of the five essential ingredients of Indian spices since ages. However, it was during the reign of the Mughal Empire in India, that this spice was popularized due to its inevitable use in *Mughalai* recipes. Sometimes, leaves from other species of *Cinnamomum* are also sold as bay leaf. These species are *C. impressenervium* and *C. sulphurtaum* in North Cachar Hills (Baruah 1998).

The bay leaf produces an essential oil (bay oil), which finds extensive use in Ayurveda and other traditional systems of medicine since time immemorial (Anonymous 1950). The medicinal properties of *C. tamala* are carminative, hypoglycaemic and antioxidant. It is used in the treatment of colic, coughs, diabetes, gonorrhea, diarrhoea, rheumatism, loss of memory, urinary problems, conjunctivitis,

sleepiness, irritations, boils and wounds, itching and fatigue (Atal and Kapur 1982). The leaves of *C. tamala* have reportedly been used in birth control (Vedavathy *et al.* 1991). The pharmaceutical industry uses *C. tamala* for the production of antiseptic, stimulant, carminative, diuretic, analgesic, counter irritant, deodorants, pesticides and insecticides (Pandey 1984, Warrier *et al.* 1993 and Kirtikar and Basu 1935). Nath *et al.* (1999) worked out a correlation between leaf size and eugenol content. It was found that smaller the leaf size, higher was the oil content. The alcohol-soluble essential oil of bay leaf is called Indian Cassia Lignea oil (Anonymous 1950). The bark of the tree is known as Indian Cassia bark or Indian Cassia Lignea and also used as spice (Atal and Kapur 1982). Bay leaf is used as a substitute for betel leaf in Kashmir and in some places the leaves are employed in calico printing (Anonymous 1950). It is also used as a clarifier for tanning and dyeing leather (Anonymous 1950). Bay leaf is used along with *Phyllanthus emblica* as an antifungal agent against a large number of both plant and human pathogenic fungi (Mishra and Batra 1987).

A few diseases that have been reported to occur on bay leaf, e.g., leaf spots, galls and blight caused by *Cercospora* sp., *Zoocecidia*, *Acedium cinnamoni* (Goswami and Bhattacharjee 1973), *Colletrichum gloesporiodes* (Roy *et al.* 1976), and *Exobasidium cinnamoni, Glomerella cingulata* (Khan and Hussain 1985). Plant death due to impaired vascular system caused by stem borers such as *Pestalotia cinnamomi* has also been reported in *C. tamala. Cercospora* sp. has been reported to cause both leaf spot and stem hole in *C. tamala* population growing in shaded and crowded situations (Anonymous 1950).

Chemical analysis of essential oil of *Cinnamomum* species in northeastern India has been done. Baruah *et al.* (2001) reported that methyl cinnamate was the major component of leaf and stem bark oils in *C. sulphuratum*. In *C. iners*, the stem bark oil

showed the natural existence of two chemotypes of the species growing in Peninsular Malaysia and northeast India (Baruah *et al.* 2001). In *C. impressinervium,* eugenol content was higher from cultivated sources (88.3%) than from the wild sources (83.2%) (Nath and Baruah 1994). Cinnamaldehyde was the major component of the leaf, stem bark and root bark oil of *C. pauciflorum* with highest percentage found in leaf oil (94%) (Nath *et al.* 1999). This finding was in contrast to the previous findings where safrole was found to be the main constituent of the Chinese *C. pauciflorum,* indicating the existence of two natural chemotypes for *C. pauciflorum.*

A unit has been recently set up at Mawshamok, Meghalaya to manufacture cinnamon leaf oil from tezpatta leaf. The Meghalaya Essential Oils & Chemicals Ltd., a joint venture of Meghalaya Industrial Development Corporation Ltd. and Camphor & Allied Products Ltd. Attractive financial returns from the sale of bay leaf has enthused villagers to undertake plantations of *C. tamala* in farmlands and community forests. Rising interest of cultivators in bay leaf plantations has invoked knowledge of nursery protocols and germination ecology. On the other hand, excess and unscientific extraction of bay leaf has necessitated a scientific study of the impact of harvest on the population demography and reproductive potential of *C. tamala.* This study makes an attempt to study the regeneration process and sustainability of bay leaf harvest from *C. tamala* in Meghalaya.

Chapter III

Study Site

The present study was conducted in Meghalaya where the populations of *C. tamala* occur both in wild and in human-managed forest ecosystems. Leaves of *C. tamala* are harvested and sold from both these systems. The State of Meghalaya in India (25^0 02' to 26^0 10' N latitude and 89^0 45' to 92^0 45' E longitude) encompasses Khasi, Jaintia and Garo Hills across an area of 22,429 km^2.

Geographical location

In all, three sites were selected for the study, viz., Pahamrioh (671 m, 25^0 54' N latitude and 91^0 53' E longitude) in Ri-Bhoi district, Mawpen (762 m, 25^0 18' N latitude and 91^0 35' E longitude) and Mawpen Suburb (838 m, 25^0 18' N latitude and 91^0 35' E longitude) in East Khasi Hills district (Figure 3.1). Mawpen Suburb is 10 km south of Mawpen. Pahamrioh is on the northeastern aspect of the Shillong plateau, while Mawpen and Mawpen Suburb are at the southern aspect facing the plains of Bangladesh (Table 3.1).

Table 3.1. Geographical location and physiographic attributes of the study sites.

Physical attributes	Pahamrioh	Mawpen	Mawpen Suburb
District	Ri Bhoi	East Khasi Hills	East Khasi Hills
Altitude (m asl)	671	762	838
Latitude	25° 54′ N	25° 18′ N	25° 18′ N
Longitude	91° 53′ E	91° 35′ E	91° 35′ E
Angle of Slope	20°-30°	30°-40°	>40 °
Direction of Slope	North-East	South-East	South-East

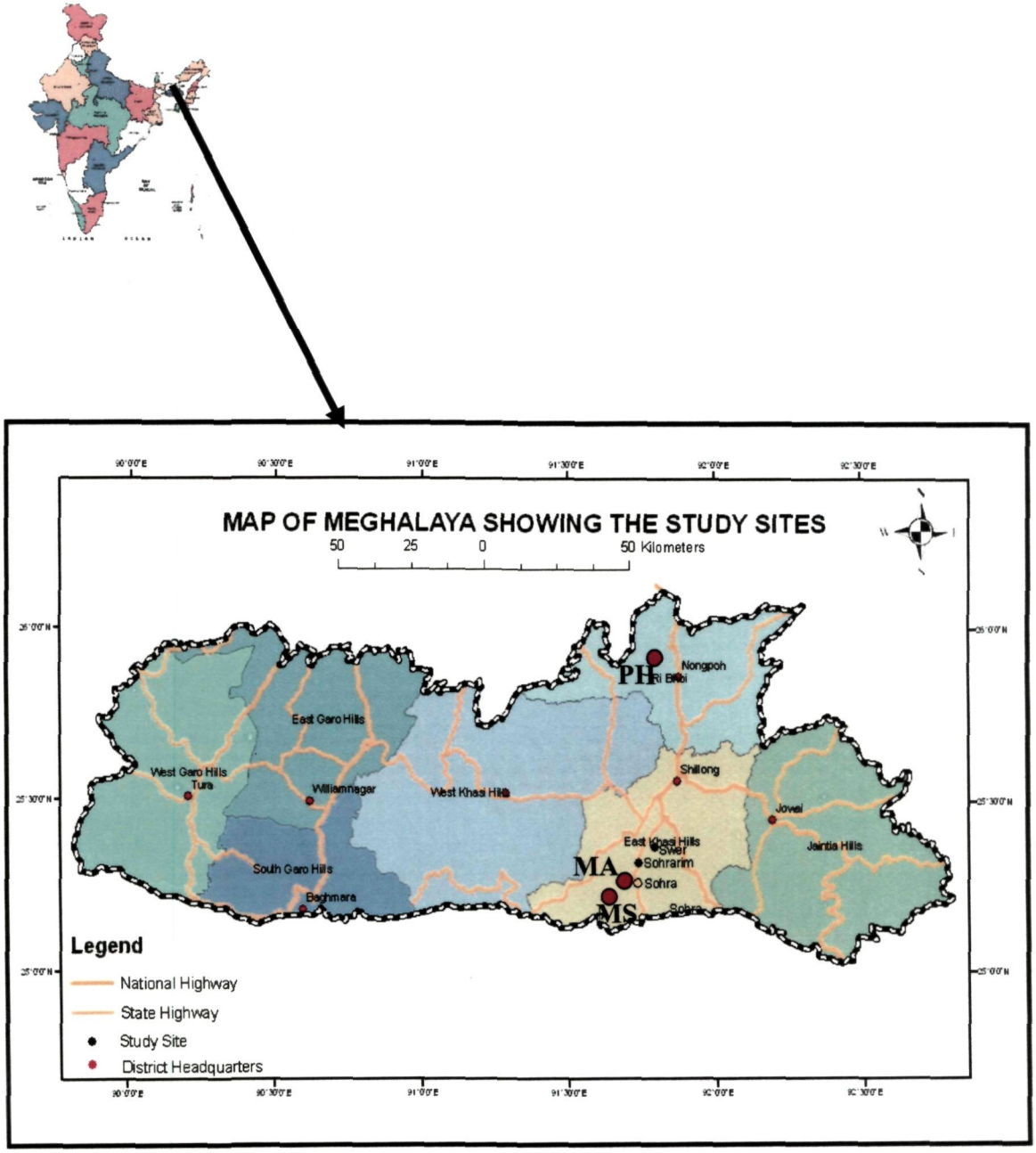


Figure 3.1. Location of three study sites in Meghalaya: Pahamrioh (PH), Mawpen (MA) and Mawpen Suburb (MS).

Climate

The general climate of the three study sites is monsoonic with marked seasonality (Figure 3.2). The spring (March to mid-May) is characterized by relatively high temperatures and pre-monsoon showers. The rainy season (mid-May to mid-October) receives >70% of annual rainfall and is characterized by high humidity and high temperatures. July and August are the rainiest months. A short autumn (October to November) is followed by winter (December to February), which is characterized by scanty rainfall, low humidity and low temperatures. The temperature may go down to 3° C.

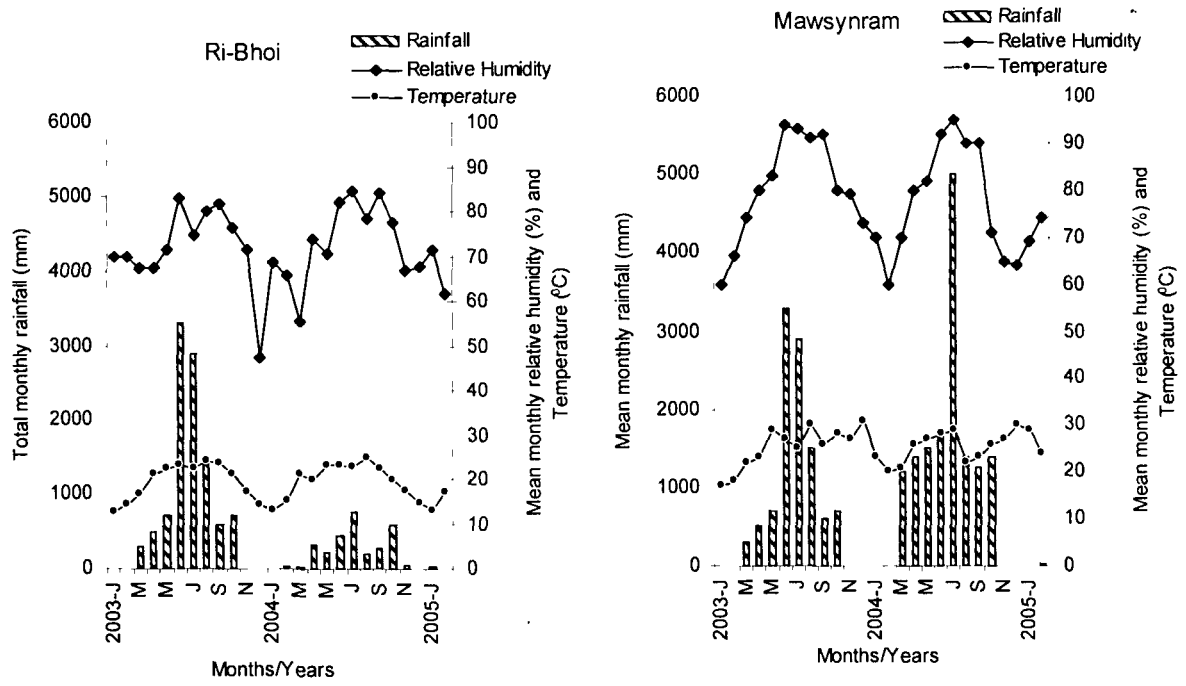


Figure 3.2. Mean monthly rainfall, relative humidity and temperature showing seasonality in climate at Ri-Bhoi (Pahamrioh) and Mawsynram (Mawpen and Mawpen Suburb).

The annual rainfall recorded at Pahamrioh was 3,325 mm during 2003 and 4,751 mm during 2004. Mawpen and Mawpen Suburb fall in Mawsynram Block, which represents a

regime of highest rainfall in the world, receiving an annual rainfall of 9,000-11,000 mm. In 2003, Mawpen and Mawpen Suburb received a rainfall of 3,250 mm in June and 2,900 mm in July. In 2004, Mawpen and Mawpen Suburb received a rainfall of 5000 mm in July. However, rainfall was negligible during December to February. Daily maximum temperature may touch 32° C in June and 19 °C in January. Relative humidity is high, up to 95% in June and as low as 61% in January.

Soil

The physiochemical properties of soils of the three study sites were characterized based on randomly collected soil samples from 0-30 cm depth from the surveyed fields (Table 3.2). The soil at Pahamrioh was lateritic, light-grey and loamy silt in texture (43% silt, 16% clay and 41% sand). The soil at Mawpen was lateritic, loamy silt (48% silt, 8% clay and 44% sand) and at Mawpen Suburb sandy loam (24% silt, 6% clay and 70% sand). The pH, soil organic matter and total Kjeldhal nitrogen were highest at Pahamrioh followed by Mawpen and Mawpen Suburb and differed significantly between the sites ($p=0.05$).

Table 3.2. Physiochemical properties of the soil at three study sites.

Soil parameter	Pahamrioh	Mawpen	Mawpen Suburb
Texture	Loamy Silt	Loamy Silt	Sandy Loam
pH	5.45 ± 0.16	5.35 ± 0.20	4.83 ± 0.18
Organic matter (%)	4.29 ± 0.86	3.32 ± 0.37	1.27 ± 0.02
Total Kjeldahl nitrogen (%)	0.22 ± 0.02	0.19 ± 0.01	0.12 ± 0.01

Soil moisture content varied significantly (p=0.05) between the months at the three study sites (Figure 3.3). Soil moisture content shows marked seasonality with a peak during July when it is saturated to a minimum of 19.5% during January-February. Soil temperature varied significantly (p=0.05) between months at the three study sites (Figure 3.4). Soil temperature varied from a maximum of 25° C during rainy season and a minimum of 20° C during winter. Light interception was more during autumn and winter than in rainy season (Figure 3.5).

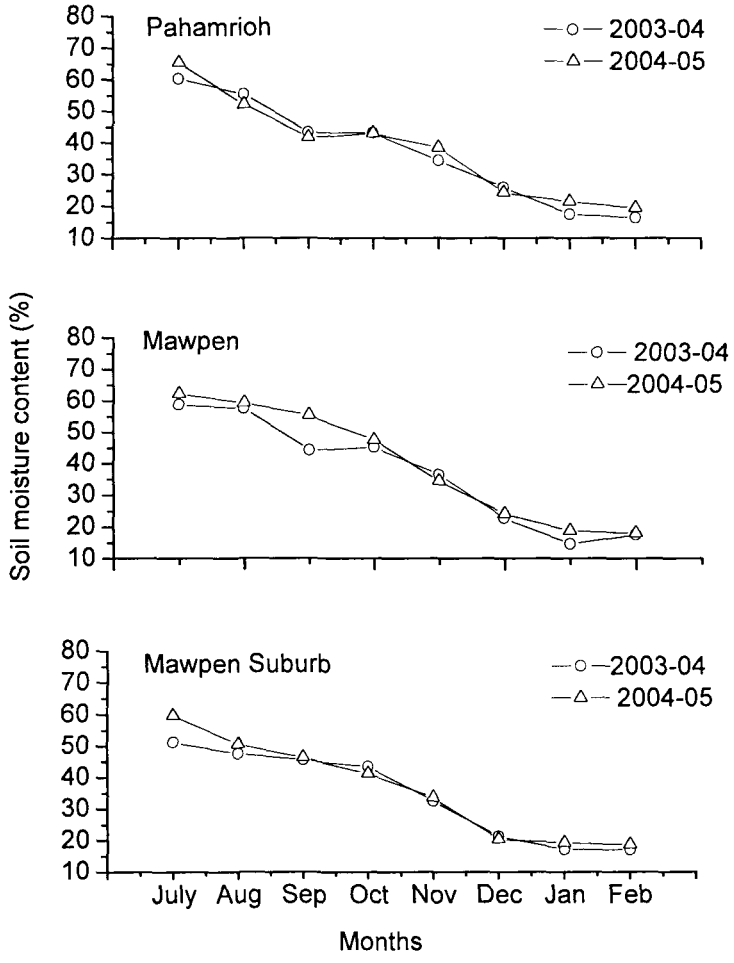


Figure 3.3. Mean monthly soil moisture content (%) at the three study sites.

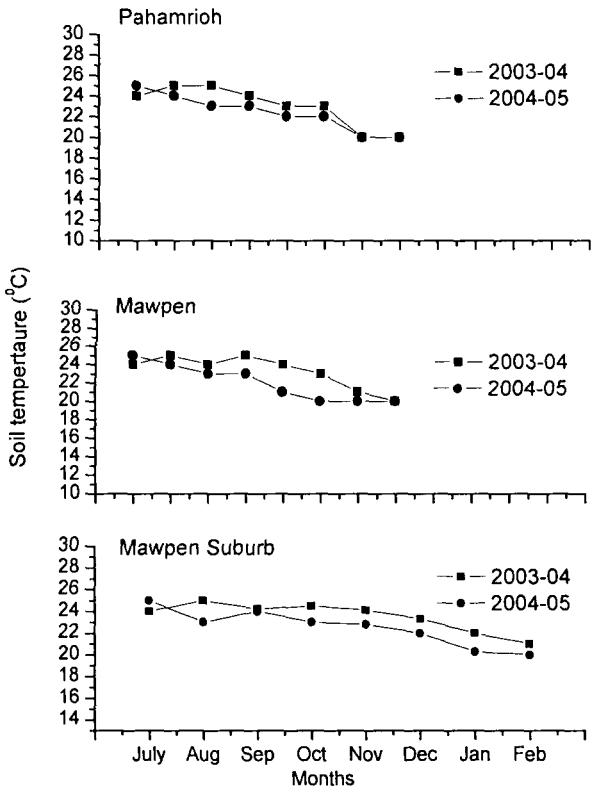


Figure 3.4. Mean Monthly soil temperature (°C) at the three study sites.

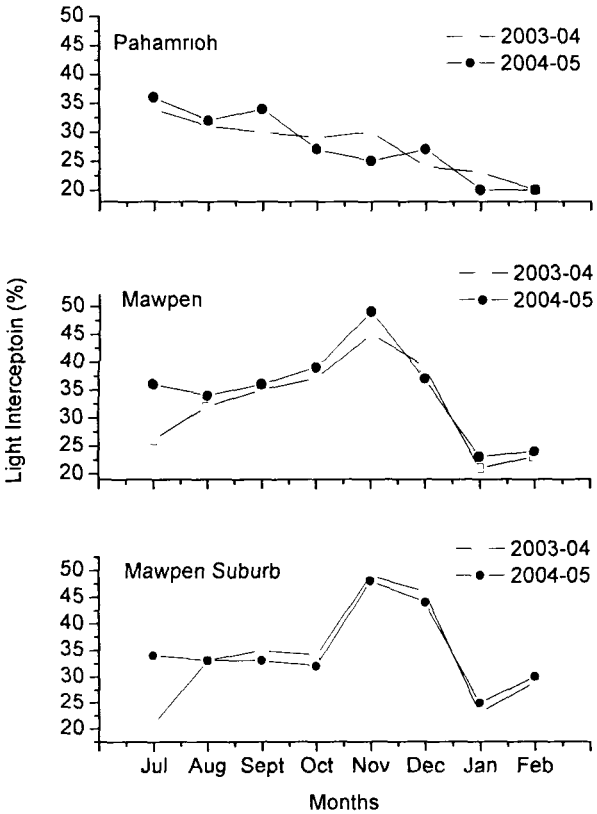


Figure 3.5. Mean monthly light interception (%) at the three study sites 2003-04.

Vegetation and stand characteristics

The site at Pahamrioh represents a mixed broadleaved subtropical forest (Champion and Seth 1968) which has been developed into an agroforestry system with predominance of *C. tamala*. Principally, this conversion occurred around 18 years ago and is continuing with occasional enrichment of *C. tamala* and other multipurpose trees. The selected stand here exhibited a good population of *C. tamala*. The agroforestry system at Pahamrioh exhibited multistoried vegetation. The stand comprised of large timber trees such as *Bauhinia purpurea, Actinodaphnae obovata, Sterculia versicolor* and *Schima wallichii*, a number of fruit trees such as *Artocarpus heterophyllus, Mangifera indica, Litchi chinensis, Phyllanthus emblica, Citrus aurantifolia* and a large population of *C. tamala*. Currently, the site is characterized by the cultivation of cash crops on the forest floor (Table 3.3).

Table 3.3. The floristic composition and density (ha^{-1}) of cultivated species (herbs, shrubs and climbers) at the three study sites.

Species	Common name	Density		
		Pahamrioh	Mawpen	Mawpen Suburb
	Shrubs			
Capsicum annuum L.	Chilly	60	-	-
Manihot esculenta Crantz.	Tapioca	40		
Carica papaya L.	Papaya	6	-	-
	Herbs			
Ananas comosus L. Murr.	Pineapple	782	-	-
Calamus sp. (clumps)	Cane	-	-	72
Thysanolaena maxima (Roxb.) Kuntze (clumps)	Broomgrass	480	492	360
Zingiber officinale Roscoe	Zinger	1120	-	-
Musa paradisica L.	Banana	26	4	28
	Climbers			
Piper betle L.	Betel leaf	184	-	-
Piper longum L.	Local pepper	10	236	28

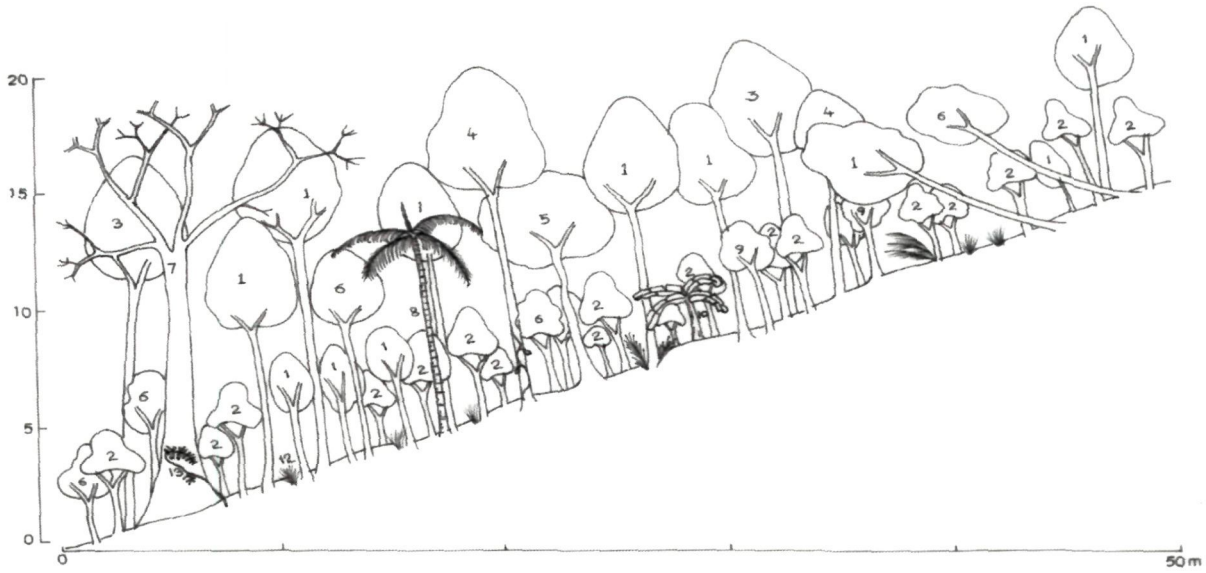
The presence of human settlements coupled with livestock such as piggery and poultry gave Pahamrioh site an appearance of a tropical homegarden (*sensu* Fernandes and Nair 1986). The forest floor had distinct cultivated and uncultivated patches. The stand had a gentle slope with a thick layer of litter (Figure 3.6). Here, a 0.5 ha plot was selected for analysis of community structure.

Figure 3.6. Profile diagram (above) and pictorial views of the study site at Pahamrioh. Species legend: 1. *Cinnamomum tamala*, 2. *Schima wallichii*, 3. *Stereospermum chelonoides*, 4. *Cordia grandis*, 5. *Mangifera indica*, 6. *Gynocardia odorata*, 7. *Aporusa roxburghii*, 8. *Actinodaphnae obovata*, 9. *Artocarpus heterophyllus*, 10. *Sterculia versicolor*, 11. *Albizia lebbeck*, 12. *Bauhinia purpurea*, 13. *Grewia elastica*, 14. *Caryota urens*, 15. *Ficus hispida*, 16. *Olea dioca*, 17. *Macaranga denticulata*, 18. *Schima khasiana*, 19. *Musa paradisica*, 20. *Carica papaya*, 21. Cacti, 22. *Piper betle*, 23. *Ananas comosus*, 24. *Zingiber officinale*, 25. *Thysanolaena maxima*, 26. *Ficus nervosa.*

Mawpen is a mixed evergreen subtropical forest (Champion and Seth 1968) which has been enriched with several economically important NTFP species mainly during last three decades. In tree canopy, intensification of *C. tamala* is predominant and *Thysanolaena maxima* and pipali (*Piper longum*) are cultivated on the forest floor (Table 3.3). The stand had a moderate slope with high number of cut stumps, poor vertical stratification and with no individuals >15 m height. The common timber trees species were *Schima wallichii, Lithocarpus dealbatus, Quercus serrata* and fruit trees were *Mangifera indica* and *Artocarpus heterophyllus*. The forest floor is characterized with a thick undergrowth of herbs and shrubs which is annually slashed before the leaf harvest from *C. tamala* (Figure 3.7). However, there was no evidence of burning the ground vegetation for farming activities. Here, a 0.25 ha plot was selected for analysis of community structure.

At Mawpen Suburb, the stand is a modified mixed evergreen subtropical forest converted into a semi-wild orchard with introduction of orange (*Citrus aurantifolia*) and *C. tamala*, (Figure 3.8), broom grass (*T. maxima*), rattans (*Calamus* sp.), arecanut (*Areca catechu*), betel leaf (*Piper betle*) and pipali (*Piper longum*) (Table 3.3). The stand evinced a three layered vertical stratification with predominance of *Citrus aurantifolia* in the under canopy, *C. tamala* species in the sub canopy and timber species like *Schima wallichii* and fruit trees like *Artocarpus heterophyllus, Mangifera indica* in the canopy layer. The stand was characterized by a steep slope with predominantly grasses and climbers in the ground vegetation. The ground vegetation is cleared during November for collection of oranges and drying of tezpatta. Here, a 0.25 ha plot was selected for analysis of community structure. Interestingly, there was no fire or grazing at three study sites.

Figure 3.7. Profile diagram (above) and a pictorial view of the study site at Mawpen. Species legend: 1. *Cinnamomum tamala*, 2. *Mangifera indica*, 3. *Lithocarpus elegans*, 4. *Artocarpus* sp., 5. *Quercus serrata*, 6. *Syzygium macrocarpus*, 7. *Schima wallichii*, 8. *Psychotria eractica*, 9. *Olea dioca*, 10. *Bauhinia purpurea*, 11. *Rhus chinensis*, 12. *Bischofia javanica*, 13. *Premna latifolia*, 14. *Litsea laeta*, 15. *Musa paradisica*, 16. *Thysanolaena maxima*, 17. *Piper longum*.



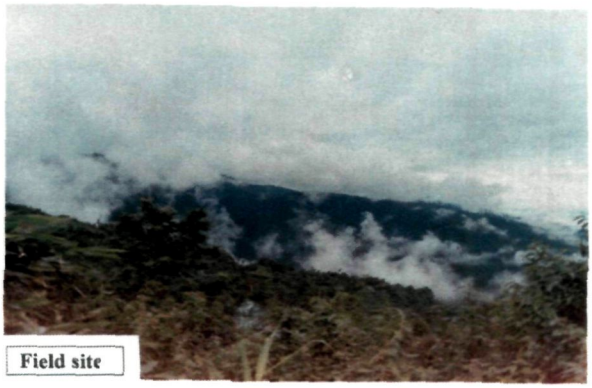


Figure 3.8. Profile diagram (above) and pictorial views of the study site at Mawpen Suburb. Species legend: 1. *Cinnamomum tamala*, 2. *Citrus aurantifolia*, 3. *Artocarpus heterophyllus*, 4. *Mangifera indica*, 5. *Ficus hirta*, 6. *Schima wallichii*, 7. Unidentified, 8. *Areca catechu*, 9. *Phyllanthus emblica*, 10. *Musa paradisica*, 11. *Calamus* sp., 12. *Thysanolaena maxima*, 13. *Piper betle.*

Chapter IV

Community Structure

In Meghalaya, 90% of the total geographical area is forested, of which 54% is under private supervision. The undulating topography of the State limits agricultural activities to traditional shifting cultivation in and around the forest and terrace cultivation in the valleys and foothills. Many areas have been brought under managed forestry systems as an alternative to traditional shifting cultivation. These systems range from homegardens to enriched natural forests to semi-wild orchards (Gupta 2002, Ramakrishnan 1992). The community structure of managed forestry systems such as homegardens in northeastern region of India depict a compact multistoried system of fruit crops, vegetables, medicinal plants and cash crops (Ramakrishnan 1992, Tiwari 2002). Fernandes and Nair (1986) and Torquebiau (1992) have considered homegardens as economically efficient, ecologically sound and biologically sustainable agroforestry systems.

The managed forestry systems of Meghalaya basically represent natural forests or secondary forests (recovering after shifting cultivation) that are enriched with multipurpose species without removing the natural vegetation. In semi-wild orchards on steep slopes of the Shillong plateau, the horticultural trees are incorporated at the expense of forest trees.

Hence, the structure of these forests is often a function of forest use and management activities carried out by the local people. This Chapter deals with the community structure of three managed forest systems dominated by *C. tamala*. The study was

undertaken to address the differences in the floristic composition and community attributes and to determine the dominance of *C. tamala* in three plant communities.

Methodology

Vegetation sampling

The floristic composition and phytosociology of the community were studied by sampling managed forestry systems at three sites as described in Chapter III. The sampling area was 0.5 ha at Pahamrioh and 0.25 ha at Mawpen as well as Mawpen Suburb. The sampling area was divided into 10 m x 10 m contiguous grids (quadrats). The girth and height of each individual ≥10 cm gbh (girth at breast height) were measured. The cut stumps and horticultural species were counted within each grid.

Plant identification

Identification of the species was done at the Herbarium of the Department of Botany, North-Eastern Hill University (NEHU), Shillong, Botanical Survey of India (BSI), Eastern Circle, Shillong and Central National Herbarium (CNH), Howrah. The nomenclature of the species follows regional floras (Haridasan and Rao 1985-1987) and (Balakrishnan 1981-1983).

Data analysis

Methods outlined by Misra (1968) and Mueller-Dombois and Ellenberg (1974) were employed to determine the density, frequency, dominance and importance value index of the enumerated species. The community indices such as Shannon's diversity index, Simpson's dominance index, and Pielou's evenness index (Pielou 1966) were calculated using the formulae (Magurran (1988) as given below.

Shannon-Wiener diversity index (H') = $-\sum (n_i)/N \times \log (n_i)/N$

Simpson's dominance Index (D) = $(n_i)/N \times (n_i)/N$

Where, n_i = importance value of ith species

N = sum of importance value of all species

Pielou's evenness index (e) = $-\sum \{(n_i)/N \times \log (n_i)/N\} / \log_e S$

Where, $\underline{n_i}$ = importance value of ith species

N = sum of importance value of all species

S = number of species

Dispersion pattern of species was computed following Whitford's index (Whitford 1948).

Whitford's index (A/F ratio) = abundance/frequency

When, A/F ratio ≤ 0.025 = regular dispersion

A/F ratio >0.025 to ≤ 0.05 = random dispersion

A/F ratio >0.05 = clumped dispersion

Similarity between sites was calculated following Sorensen's similarity index (Sorensen 1948).

Sorensen's Similarity Index (S) = $\{2C/ (A+B)\} \times 100$

Where, A = number of species in stand A

B = number of species in stand B

C = number of species common to both stand A and B

Species richness index was estimated following (Whittaker 1972).

Species richness index (d) = $S-1/ \log_e N$

Where, S = number of species

N = number of individuals

The disturbance index was calculated following Rao *et al.* (1990).

Disturbance Index = (number of cut stems / total stems including cut stems) x 100

Results

Floristic composition and taxonomic diversity

Altogether, 123 species were recorded from the three study sites: 79 species from Pahamrioh belonging to 65 genera and 40 families, 63 species from Mawpen in 54 genera and 33 families and 14 species from Mawpen Suburb in 11 genera and 10 families (Table 4.1). Taxonomic diversity at family level was high with 49 families at the three sites (Table 4.2). A few individuals from each of the three sites could not be identified and were placed under family 'undetermined'. At all sites, nearly two-third families were monospecific and the rest had two or more species (Table 4.2). Only 35.2% species were common between Pahamrioh and Mawpen, 17.2% between Pahamrioh and Mawpen Suburb and 18.2% between Mawpen and Mawpen Suburb.

Table 4.1. Floristic attributes of plant communities at three sites in Meghalaya.

Attributes	Study site			All Sites
	Pahamrioh	Mawpen	Mawpen Suburb	
Area sampled (ha)	0.50	0.25	0.25	1.00
Families recorded (#)	40	33	10	49
Genera recorded (#)	65	54	11	88
Species recorded (#)	79	63	14	123

At Pahamrioh, Lauraceae was the most species rich family with 9 species followed by Euphorbiaceae with 8 species and Verbenaceae with 6 species (Table 4.2). At Mawpen, Euphorbiaceae was the most species rich family with 10 species followed by Lauraceae, and Fagaceae (each with 5 species). At Mawpen Suburb, Moraceae was the most species rich family with 3 species followed by Anacardiaceae and Rutaceae (each with 2 species).

Table 4.2. Floristic diversity in plant families at three study sites.

Family	Pahamrioh		Mawpen		Mawpen Suburb	
	Genera	Species	Genera	Species	Genera	Species
Anacardiaceae	2	2	3	3	2	**2**
Annonaceae	1	1	1	1	-	-
Araliaceae	1	1	1	1	-	-
Arecaceae	1	1	-	-	1	1
Bignoniaceae	1	1	-	-	-	-
Bischofiaceae	-	-	1	1	-	-
Boraginaceae	1	1	-	-	-	-
Burseraceae	1	1	-	-	-	-
Caesalpinaceae	1	1	1	1	-	-
Cactaceae	1	1	-	-	-	-
Capparaceae	1	1	1	1	-	-
Caprifoliaceae	-	-	1	1	-	-
Celastraceae	1	1	1	1	-	-
Caricaceae	1	1	-	-	-	-
Clusiaceae	2	2	-	-	-	-
Dilleniaceae	1	1	-	-	-	-
Ebenaceae	1	1	1	2	-	-
Elaeocarpaceae	1	1	1	1	-	-
Erythroxylaceae	1	1	1	1	-	-
Euphorbiaceae	7	**8**	8	**10**	1	1
Fabaceae	1	1	1	1	-	-
Fagaceae	1	2	3	**5**	-	-
Flacourtiaceae	1	1	-	-	-	-
Lauraceae	7	**9**	4	**5**	1	1
Leeaceae	-	-	1	1	-	-
Melastomaceae	-	-	1	1		
Meliaceae	1	1	2	2	-	-
Mimosaceae	2	2	-	-	-	-
Moraceae	2	4	1	1	2	**3**
Musaceae	1	1	1	1	1	1
Myristicaceae	1	1	-	-	-	-
Myrsinaceae	1	1	1	1	-	-
Myrtaceae	-	-	1	2	-	-
Oleaceae	1	2	2	2	-	-
Pittosporaceae	1	1	-	-	-	-
Rosaceae	2	2	-	-	-	-
Rubiaceae	1	1	2	2	-	-
Rutaceae	3	4	1	1	1	**2**
Sabiaceae	1	1	-	-	-	-
Sapindaceae	2	2	1	1	-	-
Sapotaceae	-	-	1	1	-	-
Saurauiaceae	-	-	1	1	-	-

Simaroubaceae	-	-	-	-	1	1
Sterculiaceae	2	2	1	1	-	-
Symplocaceae	-	-	1	1	-	-
Theaceae	2	3	2	3	1	1
Tiliaceae	1	2	1	1	-	-
Verbenaceae	4	6	4	4	-	-
Undetermined	-	2	-	1	-	1
Total	**65**	**79**	**54**	**63**	**11**	**14**

The members of Lauraceae were dominant at Pahamrioh with 9 species, viz., *Actinodaphnae obovata*, *Beilschmiedia roxburghiana*, *C. tamala*, *Cryptocarya andersonii*, *Lindera glutinosa*, *L. latifolia*, *Litsea salicifolia*, *L. sebifera* and *Phoebe lanceolata.* At Mawpen, Lauraceae had 5 species and three of these were different from those at Pahamrioh (*Litsea laeta*, *L. lancifolia* and *Persea duthiei*). At Mawpen Suburb, Lauraceae was represented only by *C. tamala.* Euphorbiaceae was most diverse at Mawpen with 10 species, viz., *Alchornea tiliaefolia*, *Antidesma acidum*, *Aporusa aurea*, *Cleidon spiciflorum*, *Croton joufra*, *Glochidion acuminatum*, *G. lanceolarium*, *G. sphaerogynum*, *Mallotus philippensis* and *Phyllanthus emblica* and at Pahamrioh with 8 species, viz., *Aporusa oblonga*, *Aporusa roxburghii*, *Cleistanthus chartaceus*, *Croton joufra*, *Glochidion assamicum*, *Macaranga denticulata*, *Mallotus philippensis* and *P. emblica.*

Species-area curve

The species-area curve showed an increase with increase in sampling area at Pahamrioh and Mawpen (Figure 4.1). At Mawpen Suburb, the number of species increased in the first 10 sampling plots and then the number of species stabilized. The species area curve approached asymptote at the three sites.

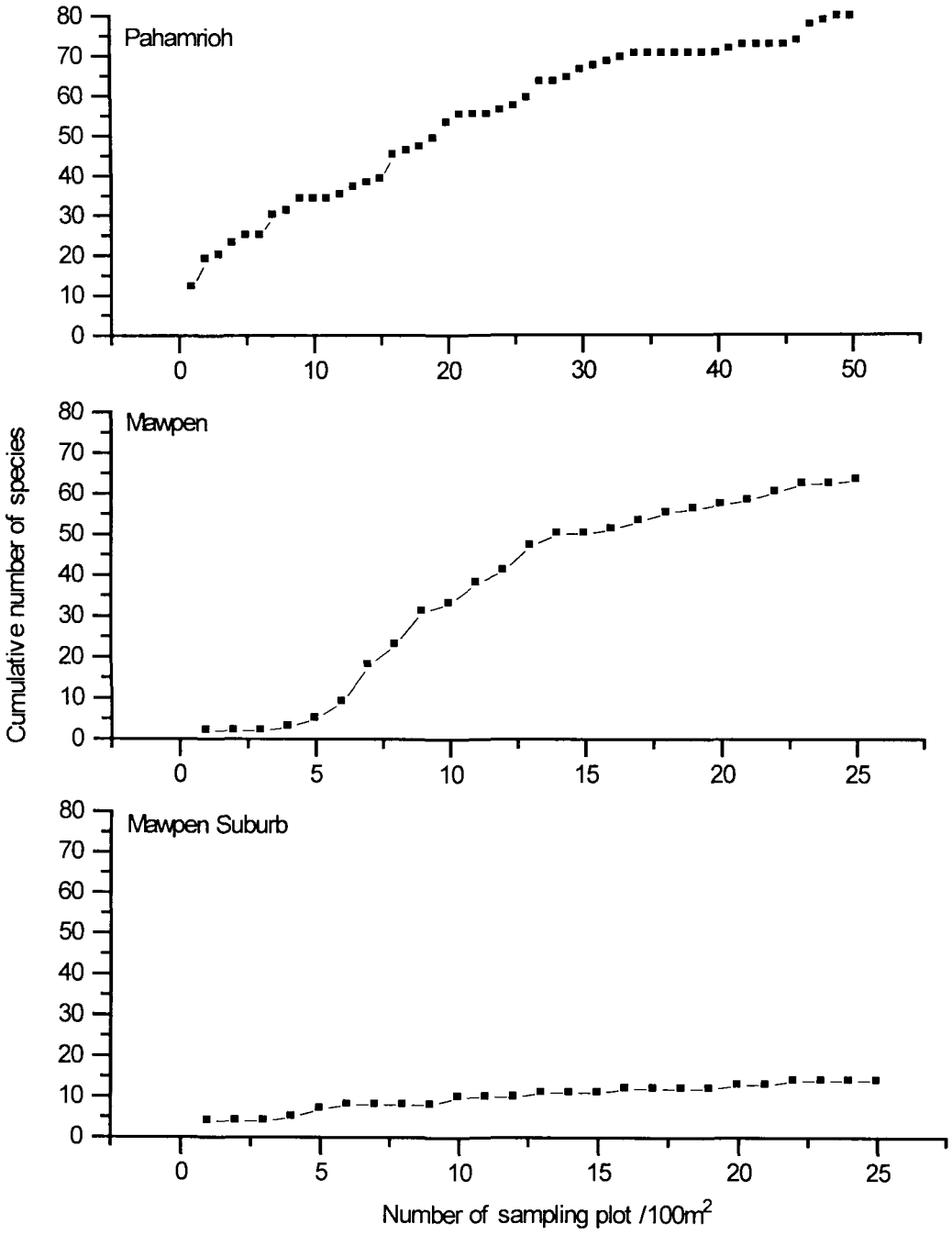


Figure 4.1. Species-area curve at three study sites. Each sampling plot is 100 m^2.

Species richness and diversity

The Whittaker's species richness index, Shannon's diversity index and Pielou's evenness index were maximum at Pahamrioh followed by Mawpen and Mawpen Suburb (Table 4.3). The difference in diversity index between Pahamrioh and Mawpen was less pronounced than between Mawpen and Mawpen Suburb. On the contrary, Simpson's dominance index was the least at Pahamrioh and increased at Mawpen and then at Mawpen Suburb (Table 4.3).

Table 4.3. Community indices for three study sites.

Community index	Pahamrioh	Mawpen	Mawpen Suburb
Whittakar's species richness index (d)	12.02	10.78	2.35
Shannon Wiener 's diversity index (*H*)	3.39	2.91	1.79
Pielou's evenness index (*e*)	0.77	0.70	0.68
Simpson's dominance Index (cd)	0.06	0.15	0.24
Disturbance index (%)	0.6	15.3	1.6

The dominance-diversity curve using IVI values followed a log-normal distribution pattern at Pahamrioh (Figure 4.2a) and Mawpen (Figure 4.2b), and a broken-stick model at Mawpen Suburb (Figure 4.2c). *C. tamala* was the dominant species with an IVI of 40.8 at Pahamrioh and 106.7 at Mawpen. At both these sites, *Schima wallichii* was the co-dominant species with an IVI of 36.5 at Pahamrioh and 42.4 at Mawpen. At Mawpen Suburb, *C. tamala* was dominant with an IVI of 115.9 and *Citrus autrantifolia* was co-dominant with an IVI of 78.7. The dominance-diversity curve based on density also showed a log-normal distribution at Pahamrioh (Figure 4.2d) and Mawpen (Figure 4.2e) and broken-stick model at Mawpen Suburb (Figure 4.2e). In this case, however, *C. autrantifolia* exhibited more density than *C. tamala* at Mawpen Suburb.

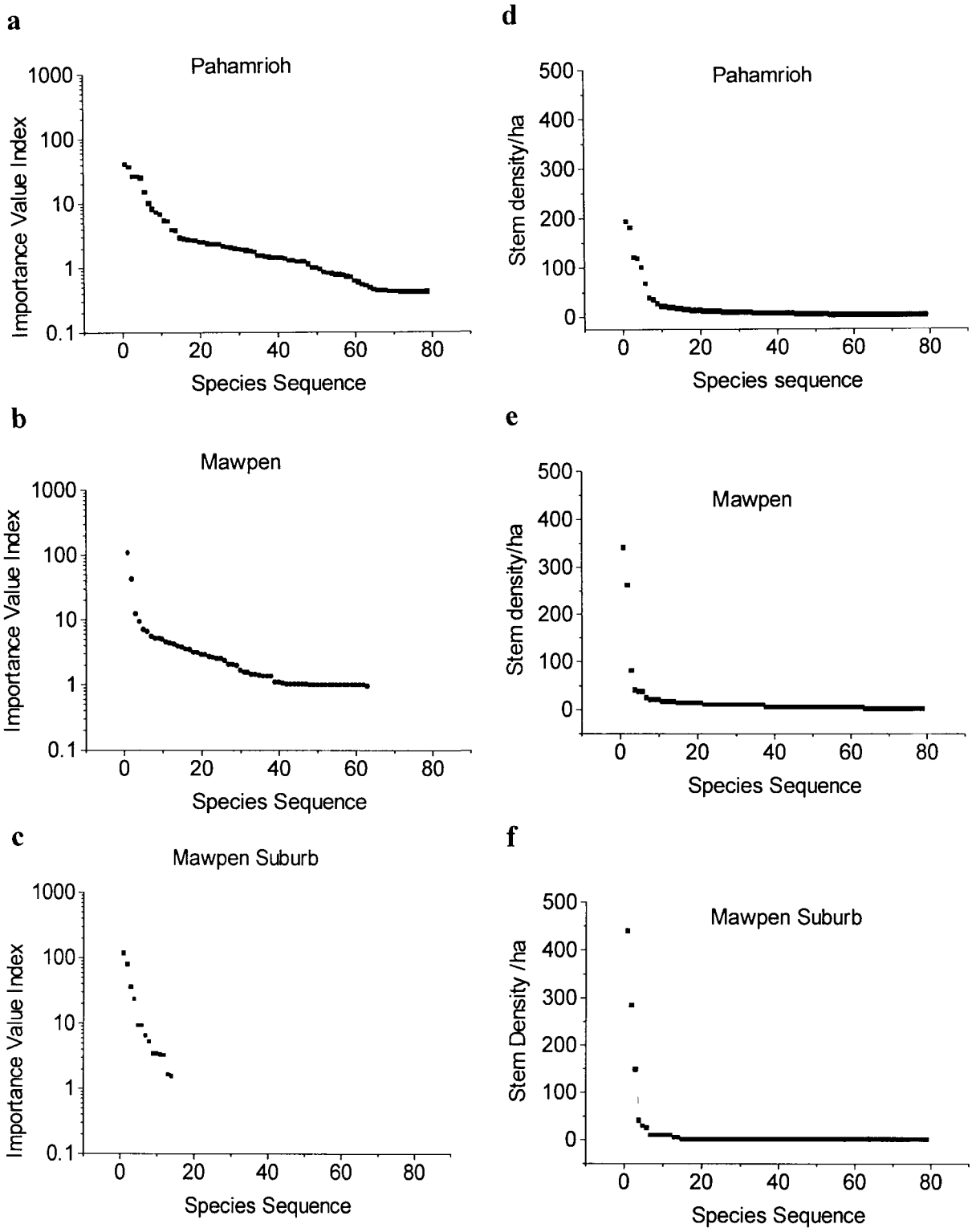


Figure 4.2. Dominance-diversity (a, b, c) and density-diversity (d, e, f) curves at three study sites.

Dispersion pattern

Most species (>69%) were concentrated in Raunkiaer's frequency class 'A' at all sites (Table 4.4). None of the sites had all five classes represented. Class 'E' was absent at Pahamrioh, class 'D' at Mawpen and class 'C' at Mawpen Suburb. Most species at Pahamrioh and all species at Mawpen and Mawpen Suburb exhibited clumped dispersion according to Whitford's index (Table 4.5). At Pahamrioh, 3% species were randomly distributed. No species exhibited regular dispersion at any of the study sites.

Table 4.4. Species distribution (%) in Raunkiaer's frequency classes at study sites.

Raunkiaer's Frequency Class	Study site		
	Pahamrioh	Mawpen	Mawpen Suburb
A	90.4	92.5	69.2
B	1.4	3.1	7.7
C	1.4	1.3	0
D	6.8	0	7.7
E	0	3.1	15.4

Table 4.5. Species distribution (%) in dispersion classes at three study sites.

Dispersion class based on Whitford's Index	Study site		
	Pahamrioh	Mawpen	Mawpen Suburb
Regular	0	0	0
Random	3	0	0
Clumped	97	100	100

Density

The density of stems ≥10 cm girth was 1,314 ha^{-1} at Pahamrioh, 1,256 ha^{-1} at Mawpen and 1,020 ha^{-1} at Mawpen Suburb (Table 4.6).

Table 4.6. Density (ha^{-1}), basal area ($cm^2\ ha^{-1}$) and importance value index (IVI) of species (for stems ≥10 cm) at three study sites.

Species	Family	Habit	Pahamrioh			Mawpen			Mawpen Suburb		
			Density	Basal area	IVI	Density	Basal area	IVI	Density	Basal area	IVI
Acacia dealbata Link	Mimosaceae	LT	2	194 9	0 48	-	-	-	-	-	-
Actinodaphnae obovata (Nees) Bl	Lauraceae	LT	8	2710 8	2 48	-	-	-	-	-	-
Albizia lebbeck (L) Benth	Mimosaceae	ST	12	983 0	2 31	-	-	-	-	-	-
Alchornea tiliaefolia Muell	Euphorbiaceae	ST	-	-	-	36	776 1	6 45	-	-	-
Antidesma acidum Retz	Euphorbiaceae	ST	-	-	-	12	2720 5	3 86	-	-	-
Aporusa aurea Hook f	Euphorbiaceae	LT	-	-	-	8	110 1	1 33	-	-	-
Aporusa oblonga Muell	Euphorbiaceae	ST	4	2181 0	1 46	-	-	-	-	-	-
Aporusa roxburghii Baill	Euphorbiaceae	LT	8	2622 6	2 69	-	-	-	-	-	-
Aralia armata (G Don) Seem	Araliaceae	ST	34	7351 9	7 13	12	384 4	3 05	-	-	-
Areca catechu Linn	Arecaceae	LT	-	-	-	-	-	-	148	9217 7	35 98
Artocarpus heterophyllus Roxb	Moraceae	LT	120	18893 5	24 66	20	7474 1	9 26	40	26435 2	23 24
Bauhinia purpurea Linn	Caesalpiniaceae	MT	118	18473 4	25 56	12	254 5	2 35	-	-	-
Beilschmiedia roxburghiana Nees	Lauraceae	ST	6	481 3	1 40	-	-	-	-	-	-
Bischofia javanica Bl	Bischofiaceae	LT	-	-	-	24	248 4	5 17	-	-	-
Bursera serrata Colebr	Burseraceae	LT	2	77 0	0 43	-	-	-	-	-	-
Callicarpa arborea Roxb	Verbenaceae	MT	2	894 9	0 77	4	53 8	0 97	-	-	-

Callophyllum polyanthum Choisy	Clusiaceae	MT	6	537 3	1 42	-	-	-	-	-	-
Capparis acutifolia Sweet	Capparaceae	ST	2	15 9	0 41	-	-	-	-	-	-
Capparis olacifolia Hook f	Capparaceae	ST	-	-	-	4	237 1	1 08	-	-	-
Carica papaya Linn	Caricaceae	SH	6	54 7	1 22	-	-	-	-	-	-
Caryota urens Linn	Arecaceae	LT	4	5015 4	2 89	-	-	-	-	-	-
Castanopsis kurzii Hance	Fagaceae	LT	6	1096 8	1 41	-	-	-	-	-	-
Castanopsis tribuloides (Sm) DC	Fagaceae	LT	2	280 6	0 52	8	978 1	2 48	-	-	-
Chisocheton paniculatus Roxb	Meliaceae	LT	-	-	-	8	277 4	1 43	-	-	-
Cinnamomum tamala Fr Nees	Lauraceae	MT	192	41201	40 42	340	107243	106 8	284	147420	115 96
Citrus aurantiifolia (Christm) Swingle	Rutaceae	ST	12	358 3	2 30	-	-	-	440	21479 5	78 74
Citrus decumasia Linn	Rutaceae	ST	-	-	-	40	780 8	5 52	-	-	-
Citrus sp	Rutaceae	ST	10	202 7	2 08	-	-	-	24	2815 9	9 03
Cleidion spiciflorum (Burm) Merr	Euphorbiaceae	MT	-	-	-	36	542 8	6 92	-	-	-
Cleistanthus chartaceus Muell -Arg	Euphorbiaceae	ST	8	756 3	1 91	-	-	-	-	-	-
Clerodendron wallichii Merr	Verbenaceae	SH	14	193 5	2 13	4	38 5	0 96	-	-	-
Cordia grandis Roxb	Boraginaceae	LT	100	24552 9	25 99	-	-	-	-	-	-
Croton joufra Roxb	Euphorbiaceae	MT	8	654 5	1 87	4	53 8	0 97	-	-	-
Cryptocarya andersonii King ex Hook f	Lauraceae	LT	2	35 8	0 41	-	-	-	-	-	-
Desmos longiflorus (Roxb) Safford	Annonaceae	ST	2	70 2	0 43	-	-	-	-	-	-
Dillenia scabrella (D Don) Roxb ex Wall	Dilleniaceae	LT	6	957 4	1 35	-	-	-	-	-	-
Dimocarpus logan Lour	Sapindaceae	MT	10	777 3	1 83	-	-	-	-	-	-
Diospyros discolor Willd	Ebenaceae	ST	-	-	-	8	91 6	1 31	-	-	-
Diospyros montana Roxb	Ebenaceae	ST	-	-	-	8	162 9	1 36	-	-	-

Diospyros variegata Kurz	Ebenaceae	ST	2	871 2	0 76	-	-	-	-	-	-
Dombeya mastersii Hook f	Sterculiaceae	ST	8	502 1	1 81	-	-	-	-	-	-
Dysoxylum gobara (Buch -Ham) Merr	Meliaceae	LT	-	-	-	8	215 1	2 01	-	-	-
Eleocarpus lancifolius Roxb	Eleocarpaceae	MT	-	-	-	1	62 4	0 98	-	-	-
Eleocarpus prunifolius (C Muell) Masters	Eleocarpaceae	MT	4	148 3	0 61	-	-	-	-	-	-
Eriobotrya bengalensis Hook f	Rosaceae	LT	2	894 9	0 77	-	-	-	-	-	-
Erythrina stricta Roxb	Fabaceae	LT	4	424 6	0 98	-	-	-	-	-	-
Erythroxylum kunthianum Wall ex Kurz	Erythroxylaceae	ST	10	1916 7	2 30	4	62 4	0 98	-	-	-
Euonymus bullatus Wall ex Laws	Celastraceae	MT	2	779 5	0 72	4	62 4	0 98	-	-	-
Eurya acuminata DC	Theaceae	LT	4	1145 5	1 28	8	186 4	1 99	-	-	-
Ficus curtipes Corner	Moraceae	LT	8	2819 7	2 77	-	-	-	-	-	-
Ficus drupacea Thunb	Moraceae	LT	4	795 5	1 13	-	-	-	-	-	-
Ficus fistulosa Reinwdt	Moraceae	ST	-	-	-	-	-	-	8	636 4	3 24
Ficus hirta Vahl	Moraceae	LT	-	-	-	-	-	-	8	990 8	3 40
Ficus hispida L f	Moraceae	ST	6	795 3	1 53	-	-	-	-	-	-
Garcinia tinctoria (DC) W F Wight	Clusiaceae	MT	2	15 9	0 41	-	-	-	-	-	-
Glochidion acuminatum Muell -Arg	Euphorbiaceae	MT	-	-	-	4	81 4	0 99	-	-	-
Glochidion assamicum Hook f	Euphorbiaceae	LT	2	19 3	0 41	-	-	-	-	-	-
Glochidion lanceolarium (Roxb) Voigt	Euphorbiaceae	ST	-	-	-	4	81 4	0 99	-	-	-
Glochidion sphaerogynum Kurz	Euphorbiaceae	MT	-	-	-	1	127 3	1 02	-	-	-
Grewia elastica Royle	Tiliaceae	LT	16	2174 5	3 85	-	-	-	-	-	-
Grewia multiflora Juss	Tiliaceae	MT	2	45 9	0 42	4	140 3	1 03	-	-	-
Gynocardia odorata R Br	Flacourtiaceae	MT	2	757 4	0 71	-	-	-	-	-	-

Horsfieldia amygdalina (Wall) Warb	Myristicaceae	LT	2	15 9	0 41	-	-	-	-	-	-
Ixora subsessilis Wall	Rubiaceae	ST	-	-	-	4	198 9	1 06	-	-	-
Jasminium subglandulosum Kurz	Oleaceae	SH	-	-	-	4	91 9	1 00	-	-	-
Lannea coromandelica (Houtt) Merr	Annacardiaceae	LT	-	-	-	4	62 4	0 98	-	-	-
Leea alata Edgew	Leeaceae	SH	-	-	-	4	14 8	0 95	-	-	-
Leea compactiflora Kurz	Leeaceae	ST	2	51 5	0 42	-	-	-	-	-	-
Lindera latifolia Hook f	Lauraceae	LT	8	1061 0	2 04	20	332 8	4 28	-	-	-
Litchi chinensis Sonner	Sapindaceae	MT	2	322 2	0 53	12	453 4	2 47	-	-	
Lithocarpus dealbatus Hk f & Th	Fagaceae	ST	-	-	-	20	660 2	4 48	-	-	-
Lithocarpus elegans Bl Hatus ex Soep	Fagaceae	LT	-	-	-	4	35 1	0 96	-	-	-
Litsea glutinosa (Lour) C B Robins	Lauraceae	ST	2	2485 8	1 43	-	-	-	-	-	-
Litsea laeta Wall ex Nees	Lauraceae	LT	-	-	-	8	5019 0	4 94	-	-	-
Litsea lancifolia Roxb ex Nees	Lauraceae	SH	-	-	-	4	31 8	0 96	-	-	-
Litsea salicifolia Roxb ex Nees	Lauraceae	ST	6	61 4	0 98	-	-	-	-	-	-
Litsea sebifera Pers	Lauraceae	MT	6	1316 6	1 75	-	-	-	-	-	-
Macaranga denticulata Muell -Arg	Euphorbiaceae	MT	66	10377 6	14 78	-	-	-	-	-	-
Maesa indica (Roxb) Wall	Myrsinaceae	ST	2	133 8	0 45	8	1597 6	2 85	-	-	-
Mallotus phillipensis (Lam) Muell -Arg	Euphorbiaceae	MT	16	587 5	2 45	4	31 8	0 96	-	-	-
Mangifera indica Linn	Anacardiaceae	LT	38	8097 1	9 97	12	1471 2	3 72	8	5014 6	5 18
Melastoma nepalensis Lodd	Melastomaceae	SH	-	-	-	4	71 6	0 98	-	-	-
Meliosma pinnata (Roxb) Walp	Sabiaceae	ST	8	1019 6	1 53	-	-	-	-	-	-
Micromelum integerrimum (Roxb) Wt & Arr	Rutaceae	ST	20	1969 4	3 82	-	-	-	-	-	-
Musa paradisica Linn	Musaceae	ST*	26	1560 5	5 34	4	103 1	1 00	28	1953 3	9 04

Mussaenda roxburghii Hk f	Rubiaceae	SH	4	71 60	0 58	-	-	-	-	-	-
Olax acuminata Benth	Meliaceae	SH	2	26 88	0 41	-	-	-	-	-	-
Olea dentata Wall ex DC	Oleaceae	MT	4	78 4	0 83	-	-	-	-	-	-
Olea dioca Roxb	Oleaceae	MT	2	24 9	0 41	80	1171 5	12 05	-	-	-
Opuntia ficus-indica (L) Mill	Cactaceae	SH	4	614 9	0 81	-	-	-	-	-	-
Persea duthiei (King ex Hk f) Koster	Lauraceae	ST	-	-	-	16	558 1	3 48	-	-	-
Phoebe lanceolata (Nees) Nees	Lauraceae	MT	14	720 2	2 60	-	-	-	-	-	-
Phyllanthus emblica Linn	Euphorbiaceae	MT	10	502 6	1 96	8	1930 1	3 06	8	7921 4	6 47
Picrasma javanica Bl	Simaroubaceae	LT	-	-	-	-	-	-	4	103 1	1 52
Pittosporum napaulense (DC) Rehdr & Wils	Pittosporaceae	ST	6	95 5	1 24	-	-	-	-	-	-
Polyalthia reticulata Bl	Anonaceaea	SH	-	-	-	4	62 4	0 98	-	-	-
Premna latifolia Roxb	Verbenaceae	MT	2	40 7	0 42	16	175 9	2 62	-	-	-
Prunus undulata Buch -Ham ex D Don	Rosaceae	MT	6	190 4	1 28	-	-	-	-	-	-
Psychotria eractica Hook f	Rubiaceae	SH	-	-	-	8	119 9	1 95	-	-	-
Pueraria wallichii DC	Fabaceae	SH	-	-	-	4	62 3	0 98	-	-	-
Quercus incana Roxb	Fagaceae	LT	-	-	-	12	109 4	1 64	-	-	-
Quercus serrata Thunb	Fagaceae	LT	-	-	-	8	2576 6	3 45	-	-	-
Rhus acuminata DC	Anacardiaceae	MT	12	1108 4	2 61	-	-	-	4	267 6	1 60
Rhus chinensis Miller	Anacardiaceae	ST	-	-	-	16	2195 5	5 10	-	-	-
Sarcosperma griffithii CL	Sapotaceae	ST	-	-	-	8	433 0	1 52	-	-	-
Saurauia napulensis DC	Saurauiaceae	ST	-	-	-	4	71 6	0 98	-	-	-
Schima khasiana Dyer	Theaceae	MT	18	11832 4	8 03	8	125 4	1 33	-	-	-
Schima wallichii (DC) Korth	Theaceae	LT	180	33436 8	36 52	260	14238 7	42 43	8	580 7	3 22

Sterculia hamiltoni (O.Ktze) Adelb.	Sterculiaceae	ST	-	-	-	8	28.0	1.43	-	-	-
Sterculia versicolor Wall.	Sterculiaceae	LT	18	7842.2	6.61	-	-	-	-	-	-
Stereospermum chelonoides (Linn.f.) DC.	Bignoniaceae	LT	2	967.9	0.80	-	-	-	-	-	-
Syzygium macrocarpum (Roxb.) Balak	Myrtaceae	ST	-	-	-	8	3800.4	4.20	-	-	-
Syzygium praecoxum Roxb.	Myrtaceae	ST	-	-	-	4	927.8	1.51	-	-	-
Symplocos paniculata (Thunb.) Miq.	Symplocaceae	ST	-	-	-	4	81.4	0.99	-	-	-
Viburnum cotinifoilium D. Don	Caprifoliaceae	ST	-	-	-	16	591.2	2.88	-	-	-
Vitex canescens Kurz.	Verbenaceae	MT	10	2024.6	2.35	-	-	-	-	-	-
Vitex negundo Linn.	Verbenaceae	ST	20	4223.6	5.26	4	71.6	0.98	-	-	-
Vitex quinata (Lour) F. N. William	Verbenaceae	LT	2	1288.6	0.94	-	-	-	-	-	-
Zanthoxylum armatum DC.	Rutaceae	ST	2	15.9	0.41	-	-	-	-	-	-
Unidentified	Undetermined	ST	6	95.5	1.24	-	-	-	-	-	-
Unidentified	Undetermined	ST	2	84.2	0.43	-	-	-	-	-	-
Unidentified	Undetermined	ST	-	-	-	12	668.2	2.6	-	-	-
Unidentified	Undetermined	MT	-	-	-	-	-	-	8	959.6	1.2
Total			1,314	240,077	300.0	1,256	163,882	300.0	1,020	225,796	300.0

Abbreviations: LT = Large tree, MT = Medium tree, ST = Small tree, SH = Shrub.

* *Musa paradisica* is treated as a Small Tree (ST) for the purpose of IVI calculation.

The large tree species comprised 41.2%, 32.8% and 21.2%, medium tree species 40.6%, 42.4% and 29.8% and small tree and shrub species 18.2%, 24.8% and 49% individuals respectively at Pahamrioh, Mawpen and Mawpen Suburb. The most individual rich family was Lauraceae at Pahamrioh and Mawpen and Rutaceae at Mawpen Suburb. Only a few species concentrated most individuals at all sites. *C. tamala* and *Schima wallichii* contributed 15% and 14% individuals respectively at Pahamrioh, 27% and 20% individuals at Mawpen, and *Citrus aurantifolia* and *C. tamala* contributed 43% and 27.8% individuals respectively at Mawpen Suburb.

Basal area

The basal area (m^2 ha^{-1}) of stems ≥10 cm girth was 24.01 at Pahamrioh, 16.39 at Mawpen and 22.58 at Mawpen Suburb (Table 4.6). The large tree species contributed 48.2%, 18% and 18.7%, medium tree species 39.1%, 71.0% and 69.3% and small tree and shrub species 12.7%, 11% and 12% of the stand basal area respectively at Pahamrioh, Mawpen and Mawpen Suburb. The top contributor to stand basal area was *C. tamala* at Pahamrioh (17.3%), Mawpen (65.7%) and Mawpen Suburb (65.9%). The maximum girth attained was 170 cm by *Cordia grandis* at Pahamrioh, 125 cm by *Litsea laeta* at Mawpen and 160 cm by *Artocarpus heterophyllus* at Mawpen Suburb.

Importance Value Index (IVI)

The large tree species added 43.9%, 28.7% and 24.4%, medium tree species 38.3%, 48.5% and 41.0% and small tree and shrub species 17.8%, 22.8% and 34.6% to importance value index respectively at Pahamrioh, Mawpen and Mawpen suburb (Table 4.6). *C. tamala* was the top contributor to importance value index at Pahamrioh (13.5%), Mawpen (35.6%) and Mawpen Suburb (38.6%).

Horizontal structure

Most stems were concentrated in 10-30 cm girth class with 46% at Pahamrioh, 83% at Mawpen and 42% at Mawpen Suburb (Figure 4.3). Concentration of stems decreased with increase in girth size, resulting in a reverse J-shaped curve at all sites. Most basal area was concentrated in the middle resulting in a unimodal distribution (Figure 4.4). The distribution of basal area in girth classes did not corroborate the distribution of stems.

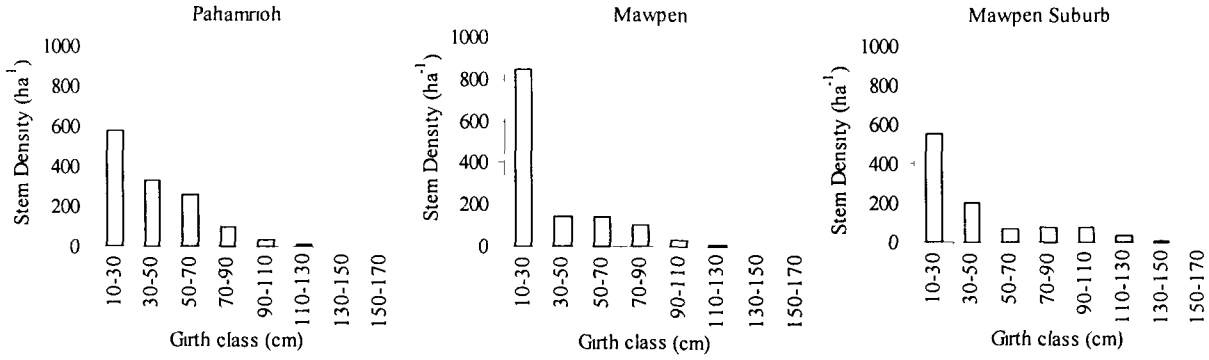


Figure 4.3. Density-diameter distribution at three sites.

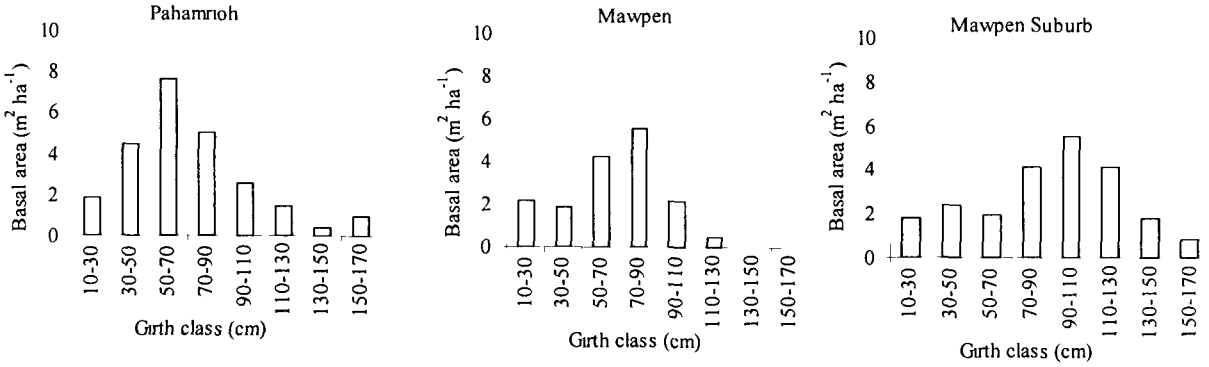


Figure 4.4. Basal area-diameter distribution at three sites.

Vertical structure

The mean tree height increased with increase in girth size at all sites (Figure 4.5). This increase was at a faster rate up to 80 cm girth size and slowed down subsequently. The only exception was 130-150 cm girth class at Pahamrioh. In all girth classes, the differences in mean tree height were insignificant among the three sites. At Mawpen, none of the trees attained a height of 15 m.

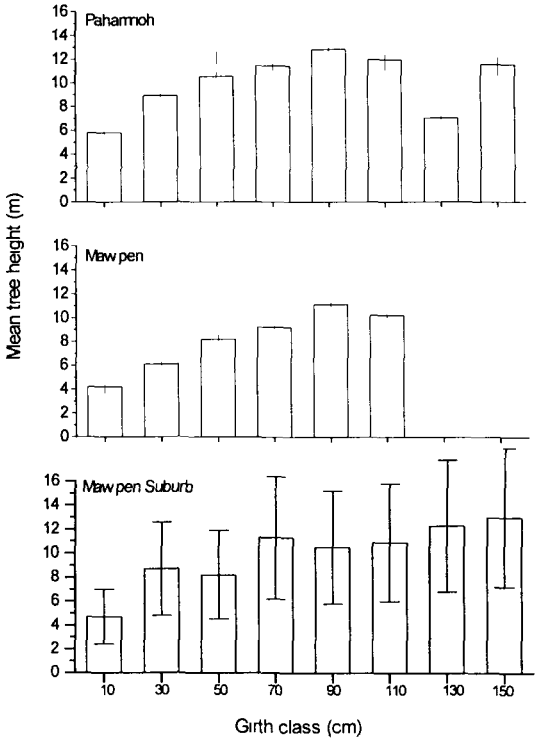


Figure 4.5. Tree height-diameter distribution at three sites.

Low strature of the forest was evident at all sites. Most stems and species were restricted to subcanopy and understorey at all sites (Table 4.7). Only 8 species in 23 individuals at Pahamrioh and 2 species in 3 individuals at Mawpen Suburb were present in canopy (individuals>15 m height). Overall, the number of stems increased from upper to lower stratum at all sites.

Table 4.7. Vertical structure of *C. tamala* communities at three sites. The values shown are the number of stems (≥10 cm) in a sampling area of 0.5 ha at Pahamrioh and 0.25 ha each at Mawpen and Mawpen Suburb. A superscript indicates number of species, if more than one. Stem height is ≥15 m for Canopy (C), 8 to <15 m for Subcanopy (SC) and <8 m for Understorey (US).

Family	Pahamrioh				Mawpen				Mawpen Suburb			
	C	SC	US	Total	C	SC	US	Total	C	SC	US	Total
Anacardiaceae	-	13^2	12^2	25^2	-	1	7^3	8^3	-	2^2	1	3^2
Annonaceae	-	-	1	1	-	-	1	1	-	-	-	-
Araliaceae	2	11	4	17	-	1	2	3	-	-	-	-
Arecaceae	2	-	-	2	-	-	-	-	2	11	24	37
Bignoniaceae	-	1	-	1	-	-	-	-	-	-	-	-
Bischofiaceae	-	-	-	-	-	-	6	6	-	-	-	-
Boraginaceae	4	29	17	50	-	-	-	-	-	-	-	-
Burseraceae	-	-	1	1	-	-	-	-	-	-	-	-
Caesalpinaceae	6	36	17	59^2	-	2	1	3	-	-	-	-
Cactaceae	-	-	-	-	-	-	-	-	-	-	-	-
Capparaceae	-	-	1	1	-	-	1	1	-	-	-	-
Caprifoliaceae	-	-	-	-	-	-	4	4	-	-	-	-
Caricaceae	-	-	3	3	-	-	-	-	-	-	-	-
Cactaceae	-	-	2	2	-	-	-	-	-	-	-	-
Celastraceae	-	1	-	1	-	-	1	1	-	-	-	-

Clusiaceae	-	1	3	4^{2}	-	-	-	-	-	-	-	-
Dilleniaceae	-	3	-	3	-	-	-	-	-	-	-	-
Ebenaceae	-	1	-	1	-	-	4^{2}	4^{2}	-	-	-	-
Eleocarpaceae	-	-	2	2	-	-	1	1	-	-	-	-
Erythroxylaceae	-	4	1	5	-	-	1	1	-	-	-	-
Euphorbiaceae	-	37^{7}	24^{7}	61^{8}	-	-	30^{10}	30^{10}	-	2		2
Fabaceae	-	-	2	2	-	-	1	1	-	-	-	-
Fagaceae	-	4^{2}	-	4^{2}	-	1	12^{5}	13^{5}	-	-	-	-
Flacourtiaceae	-	1	-	1	-	-	-	-	-	-	-	-
Lauraceae	-	88^{8}	34^{4}	122^{9}	-	45^{2}	52^{5}	97^{5}	-	49	22	71
Leeaceae	-	-	1	1	-	-	1	1	-	-	-	-
Melastomaceae	-	-	-	-	-	-	1	1	-	-	-	-
Meliaceae	-	-	-	-	-	1	3^{2}	4^{2}	-	-	-	-
Mimosaceae	-	5^{2}	2	7^{2}	-	-	-	-	-	-	-	-
Moraceae	1	36^{4}	32^{3}	69^{4}	-	4	1	5	1	9^{2}	4^{3}	14^{3}
Musaceae	-	-	13	13	-	-	1	1	-	-	7	7
Myristicaceae	-	-	1	1	-	-	-	-	-	-	-	-
Myrsinaceae	-	1	-	1	-	1	1	2	-	-	-	-
Myrtaceae	-	-	-	-	-		3^{2}	3^{2}	-	-	-	-
Oleaceae	-	1	3^{2}	4^{2}	-	2	19^{2}	21^{2}	-	-	-	-
Pittosporaceae	-	-	3	3	-	-	-	-	-	-	-	-
Rosaceae	-	2^{2}	2	4^{2}	-	-	-	-	-	-	-	-
Rubiaceae	-	-	2	2	-	-	3^{2}	3^{2}	-	-	-	-
Rutaceae	-	4^{2}	18^{4}	22^{4}	-	-	10	10		10^{2}	106^{2}	116^{2}
Sabiaceae	-	1	3	4	-	-	-	-	-	-	-	-

Sapindaceae	-	3^2	3	6^2	-	-	3	3	-	-	-	-
Sapotaceae	-	-	-	-	-	-	2	2	-	-	-	-
Saurauiaceae	-	-	-	-	-	-	1	1	-	-	-	-
Simarubaceae	-	-	-	-	-	-	-	-	-	-	1	1
Sterculiaceae	2	8^2	3^2	13^2	-	-	2	2	-	-	-	-
Symplocaceae	-	-	-	-	-	-	1	1	-	-	-	-
Theaceae	4	48^3	49^2	101^3	-	5	64^3	69^3	-	-	2	2
Tiliaceae	2	1	6^2	9^2	-	-	1	1	-	-	-	-
Verbenaceae	-	11^3	14^4	25^6	-	-	7^4	7^4	-	-	-	-
Undetermined	-	1	3^2	4^2	-	-	3	3	-	1	1	2
Total stems	**23**	**352**	**282**	**657**	**-**	**63**	**251**	**314**	**3**	**84**	**168**	**255**
Stem density (ha^{-1})	**46**	**704**	**564**	**1314**	**-**	**252**	**1004**	**1256**	**12**	**336**	**672**	**1020**
Species represented	**8**	**54**	**55**	**79**	**-**	**11**	**63**	**63**	**2**	**9**	**12**	**14**

Discussion

The community characteristics of Pahamrioh are typical of a subtropical forest. High species diversity, high evenness index and low dominance index along with a lognormal dominance-diversity curve suggest a complex community. The Shannon-Wiener diversity index of 3.39 is comparable to that of sacred groves of Meghalaya and is higher than the homegardens of Uttar Kanada, India (Table 4.8). Hence, the homegarden system at Pahamrioh is expected to be a stable system. High species diversity at Pahamrioh could be a function of homegarden agroforestry by enrichment of NTFP species such as *C. tamala*, *Citrus aurantifolia*, *Mangifera indica*, *Artocarpus heterophyllus* and others. The role of humans in facilitating species richness of the stand is evident from the high importance value indices of economically important species in study plots than in natural forest ecosystems and sacred groves studied in Meghalaya (Table 4.8).

Homegardens may exhibit very high species richness. Lamont *et al.* (1999) documented 104, 111 and 125 different species in homegardens of three villages in northeastern Peru. Padoch and De Jong (1991) recorded as many as 168 species in homegardens of another village of Peru. Ramakrishnan (1992) suggested a large number of species in homegardens of northeastern India where a single hectare may harbour 30 to 40 plant species. This study evinces 73 tree species in an area less than a hectare, representing a highly intensive system of farming in harmony with the natural floristic composition. Linked to this landuse is an animal husbandry system traditionally centered around pigs and poultry. Earlier workers described them as systems imitating natural forest ecosystem in their structure and function (Ramakrishnan 1992, Nair 1993).

Table 4.8. Comparision of community attributes of three study sites with other natural and managed tropical forests.

Site	Location (latitude/ longitude)	Altitude (m asl)	Area (ha^{-1})	Gbh (cm)	Number of species	Density (ha^{-1})	Basal area ($m^2 ha^{-1}$)	Diversity index (H')	Even-ness index (E)	Dominance index (D)	References
Pahamrioh	25° 45′ N 91° 53′ E	671	0.5	≥10	79	1,314	24.0	3.39	0.77	0.06	Present study
Mawpen	25° 18′ N 91° 35′ E	762	0.25	≥10	63	1,256	16.4	2.91	0.70	0.15	Present study
Mawpen Suburb	25° 18′ N 91° 35′ E	838	0.25	≥10	14	1,020	22.6	1.79	0.68	0.24	Present study
Homegraden, Barak Valley	24° 41′ N 92° 41′ E		3	>5	122	1,535	33.9	-	-	-	Das and Das (2005)
Homegarden, Uttar Kanada, Weatern Ghats	14°35′ N 74°48′ E	545-615	1.280	>10	68	525		3.21			Shastri *et al.* (2002)
Sacred groves, Urkhla, Ram Khloo Paiu Ram Pyrthai, Khloo Langdoh Meghalaya	25° 26′ N	1200	0.8	≥5	135	1,176-1,496		3.74-4.3	0.91-0.95	0.02-0.03	Jamir (2000)
Sacred grove, Jalong, Meghalaya	25° 28′ N	1350	0.5	≥5	82	1,476	57.5	3.42	0.53	0.07	Upadhaya *et al.* (2003)
Sacred grove, Raliang, Meghalaya	25° 30′ N	1300	0.5	≥5	80	938	71.4	3.5	0.56	0.05	Upadhaya *et al.* (2003)

Sacred grove, Swer, Meghalaya	25° 25′ N 91° 47′ E	-	15	≥15	168	26.9 -1.7	-	2.2	0.4	0.1	Mishra *et al.* (2004)
Montane forest, Nokrek BR, Meghalaya	25° 29′ N 25° 20′ E	1050-1414	0.3	≥5	128	2,210	41.9	4.18	0.86	0.03	Prabhu (2004)
Montane forest, Nokrek Biosphere Reserve, Meghalaya	25° 29′ N 25° 20′ E	915-968	0.2	≥5	86	11,802	28.0	4.19	0.94	0.02	Prabhu (2004)
High-altitude, humid tropical forest, Tamil Nadu, India.	8° 29′ N 77° 15′ E	1000-1150	10	>10	96	971	64.3	2.45	1.66	0.13	Swamy *et al.* (2000)
Mid-altitude, humid tropical forest, Tamil Nadu, India.	8° 29′ N 77° 15′ E	500-700	10	>10	142	873	67.4	2.76	1.69	0.14	Swamy *et al.* (2000)
Low-altitude, humid tropical forest, Tamil Nadu, India.	8° 29′ N 77° 15′ E	250-400	10	>10	82	436	28.4	2.46	1.72	0.15	Swamy *et al.* (2000)
Dry evergreen forest, South India	12° 03′ N	-	0.2	≥2	-	1,130	36.0	1.47-1.56	-	-	Visalakshi (1995)
Sal forest, Mahananda Sanctuary	26° 46′ N 26° 56′ E	100-700	2	≥10	87	484	26.3	3.59	0.80	-	Uma Shankar (2001)
Tropical rain forest, Mt. Kinabalu, Borneo	6° 05′ N	1560	0.5	≥5	121	1,730	-	4.18	0.88	-	Aiba (1999)

The clumped distribution of majority species in Raunkiaer's frequency class A with absence in class E suggests a heterogeneous and patchy dispersion at Pahamrioh. Such a pattern is evident in tropical moist forests especially for trees with passive seed dispersal mode (Richards 1996).

On the other hand, Mawpen Suburb with low species richness exhibited low species diversity index, low evenness index, but a high dominance index. The broken-stick dominance-diversity curve indicates that the community is primarily ordered with respect to a single dominating element (*C. tamala*). At Mawpen Suburb, the clumped dispersion of most species in Raunkiaer's frequency class A with high percentage of species in class E depicts a more homogeneous community. This is uncommon in the mixed broadleaved subtropical forests of Meghalaya. The low species diversity and a homogeneous community at Mawpen Suburb could therefore be an outcome of human manipulation of the system in form of enrichment of selective NTFP species. The dominant (*C. tamala*) and co-dominant (*C. aurantifolia*) species at Mawpen Suburb reveal low abundance in natural forests. Hence, their high IVI value at Mawpen Suburb is an avowal of their enrichment as an economic species. Interestingly, these economic species do not show a regular dispersion as could be expected in a managed forestry system.

Mawpen represents intermediate values of community indices such as species richness index, Shannon-Weiner diversity index and Simpson's dominance index which are lower than Pahamrioh but higher than Mawpen Suburb (Table 4.8). The clumped dispersion of majority the species in Raunkiaer's frequency class A with a low representation of species in class E suggests a patchy and moderately homogeneous community. Here too, the species richness is attributed to enrichment of dominant (*C. tamala*) and co-dominant (*Schima wallichii)* species in the stand.

The most speciose family at Pahamrioh is Lauraceae with a basal area of 2.5 m^2 ha^{-1}. Most species in Lauraceae are evergreen and distributed in high proportions in all the three strata imparting the stand an evergreen physiognomy. Notwithstanding, the deciduous members like *Macaranga denticulata* (Euphorbiaceae) with basal area 0.9 m^2 ha^{-1} are well distributed in different strata of the community adding a mixed-evergreen look to the stand.

At Mawpen, Euphorbiaceae with deciduous members like *Emblica officinalis* is the most speciose family with a basal area of 0.2 m^2 ha^{-1}. However, the higher density of stems of Lauraceae with a basal area of 2.8 m^2 ha^{-1} is instrumental in maintaining the mixed- evergreen physiognomy of the stand.

At Mawpen Suburb, Moraceae is more speciose. But the deciduousness is overshadowed by the evergreen members of Lauraceae (e.g., *C. tamala*) with high basal area of 3.7 m^2 ha^{-1}. Although the stem density of deciduous members of Rutaceae (*Citrus aurantifolia*) is high, yet their basal area accounts for only 0.6 m^2 ha^{-1}. Hence, Mawpen Suburb also represents a mixed-evergreen broadleaved subtropical forest.

The species similarity index is very low between the three sites suggesting a wide variation from each other in floristic composition. The species area curve reached an asymptote at all three sites suggesting that the sampling intensity was adequate. At all sites, most species are less frequent and a few are more frequent suggesting the rarity of species. Populations of these rare species are vulnerable to disturbances.

Most stems were concentrated in 10-30 cm girth class at Pahamrioh (46%), Mawpen (83%) and Mawpen Suburb (42%). The frequency of individuals of different sizes in a population provides vital clues to the precedent factors and their effects on the extant population structure (Ogden 1985). Concentration of stems decreased with increase in

girth size, resulting in a reverse J-shaped curve at all sties. This suggests that all stands had good regeneration, especially of *C. tamala*. However, the high concentration of individuals in lower girth class at Mawpen Suburb was also influenced by the shrub habit of *Citrus aurantifolia*.

Basal area was concentrated the most in the intermediate girth classes suggesting that the stems in these classes dominate. Tree height was the least at Mawpen, where none of the trees had reached 15 m. Interestingly, *C. tamala*, a subcanopy or shade-tolerant species occurred profusely in open, sparse canopy. The absence of emergent trees in the canopy at Mawpen could be due to its high disturbance index. Small and large scale disturbances, such as treefall and clear cutting alter forest microclimate and microsite heterogeneity significantly, that influence the plant community dynamics (McCarthy and Facelli 1990).

The high density of stems in subcanopy at Pahamrioh is probably due to the dominance of medium-sized trees such as *C. tamala*. The high stem density in understorey at Mawpen could be due to treefall gaps in the canopy facilitating faster recruitment of small tree species. The favourable micro-environmental conditions for growth created by the tree fall gaps result in high species diversity in the understorey (Brokaw 1985)

The dominance of *C. tamala* was high at all sites and was in the order Mawpen>Mawpen Suburb>Pahamrioh. This highlights the efficient management of agroforestry systems in maintaining the species richness and community structure even after incorporation of NTFP species for livelihoods. The species richness of the three study sites could largely be influenced by the forestry systems practiced as well as the prevailing edaphic factors. It is possible that the farmers selected the species for enrichment in tune with the prevailing climate and physical conditions besides their

livelihood needs. *C. tamala* was at the centrestage of all the three communities and was capable of existing in high as well as low species diversity conditions. *C. tamala* greatly influenced the community structure of the study stands in terms of vertical and horizontal stratification. Though the impact of enrichment of three sites is evident from the high IVI indices of the economic species, none of the sites exhibited regular dispersion of any species, especially the dominant and co-dominant ones as could easily be expected in a managed community. This suggests that the sites are by and large natural systems.

Conclusions

The enriched natural forest systems studied at Pahamrioh, Mawpen and Mawpen Suburb exhibit *C. tamala* at the centerstage. The bay leaf harvested from *C. tamala* trees is a revenue churner to the farmers and hence the community structure of these systems is a result of the agroforestry management around *C. tamala*. However, the floristic composition, community organization and diversity indices affirm that these systems have undergone enrichment, but have succeeded to maintain the typical community characteristics of humid tropical forests. Hence, the farmers have paid adequate attention to maintain a harmony between natural diversity and management of cultivated resources.

Chapter V

Population Structure of *Cinnamomum tamala*

The forests of Meghalaya have been subjected to varying degree of disturbances and human interventions in recent years. The ownership of forested areas is with the people since most forested lands are with the communities and not with the governments as is the case in other states of India. The majority of the indigenous tribes of Meghalaya are dependent on the forests and their products for subsistence and income. Hence, the population structure and regeneration response of non-timber forest species in these community forests needs to be studied carefully to understand their sustainability.

One such tree species in close association with human livelihoods is bay leaf (*Cinnamomum tamala*). In forests under the protected area network of Meghalaya including the sacred groves, the population of *C. tamala* is reported to be small. For instance, the density of *C. tamala* was only 4 stems ha^{-1} at Raliang sacred grove (Upadhaya *et al.* 2003), 3 stems ha^{-1} in Nokrek Biosphere Reserve (Prabhu 2004) and 10 stems ha^{-1} at Urkhla sacred grove (Jamir 2000). At Swer sacred grove, *C. tamala* had an IVI of 0.9 in undisturbed forest patches and 1.4 in moderately disturbed patches (Mishra *et al.* 2004). However, Meghalaya is rich in managed forest systems in which bay leaf (*C. tamala*) population is maintained in much higher densities than in the natural forests. These systems are similar to homegardens or agroforestry systems found elsewhere.

The frequency distribution of stem girth has conventionally been used to describe the population structure of a species (Anonymous 1978, Saxena *et al.* 1984a, b, Newton

and Smith 1988, Uma Shankar 2001). These studies have often found differences in the density-diameter curves with change in forest types. Anonymous (1978) and West *et al.* (1981) had reviewed the population structure of trees based on their density-diameter distribution in tropical and temperate forests respectively. In this Chapter, the population structure of *C. tamala* in three enriched natural forest systems at Pahamrioh, Mawpen and Mawpen Suburb is studied to analyse among-site differences in population structure of *C. tamala*.

Methodology

Density-diameter distribution of stems of *C. tamala* and other dominant species was analysed within the continuous grids of 10 m x 10 m at each study site. The sampling area was 0.5 ha at Pahamrioh and 0.25 ha at Mawpen as well as Mawpen Suburb. The stems ≥10 cm gbh were labeled with aluminium tags. Girth at breast height (gbh) and height were measured for each individual. The seedlings of *C. tamala* (<10 cm) were counted in 1 m x 1 m plots, with one plot within each grid. The seedling density was estimated at the onset of winter (November) and again in spring (March). As seedling density fluctuated with seasons, the data on seedlings were used to study only the regeneration potential. Saplings (≥10 to <30 cm) and adults (≥30 cm) were considered as more established cut-off stages for studying other aspects of the population. The variance-to-mean ratio was calculated following Greig-Smith (1983) to study dispersion. A ratio of 1 indicates random dispersion, <1 uniform and >1 an increasingly clumped dispersion. The variance-to-mean ratio was calculated as:

$$V/M = \Sigma (x-\bar{x})^2 / (n-1) / x$$

Where,

x = number of individuals of a species in a quadrat

$\bar{x}$ = mean of individuals of a species per quadrat

n = total number of quadrats of occurrence

The locations of *C. tamala* individuals ≥10 cm were spatially mapped within the study plots by measuring x and y coordinates. The x and y values were used for plotting their dispersion pattern within the sampled area. Dispersion with vertical stratification was plotted in a three dimensional diagram by taking into account the position and height of the mapped individuals. To study conspecific effects on regeneration a two dimensional dispersion pattern was derived taking into account the position and girth of the juveniles (<30 cm) and adults (≥30 cm).

Results

Population structure of *C. tamala*

The population structure of *C. tamala* was analysed in two seasons, viz., autumn (November) when most of the seeds of the current year crop had fallen and germinated, and in spring (March) when newly germinated seeds have either grown into seedlings or have died. At all sites, the density of seedlings was high in autumn which sharply declined in spring. In autumn, the seedling density was highest at Pahamrioh (1,200 ha^{-1}), followed by Mawpen Suburb (896 ha^{-1}) and Mawpen (480 ha^{-1}).

By ensuing spring, the seedling density declined by 98% at Pahamrioh and 95% at Mawpen Suburb and 100% at Mawpen. The population structure was characterized by a reverse J-shaped pattern with a small hump in the middle at Pahamrioh and Mawpen and without hump at Mawpen Suburb when the population was sampled in November (Figure 5.1 a, b, c). The density of individuals in girth classes was of the order of seedlings>saplings <adults.

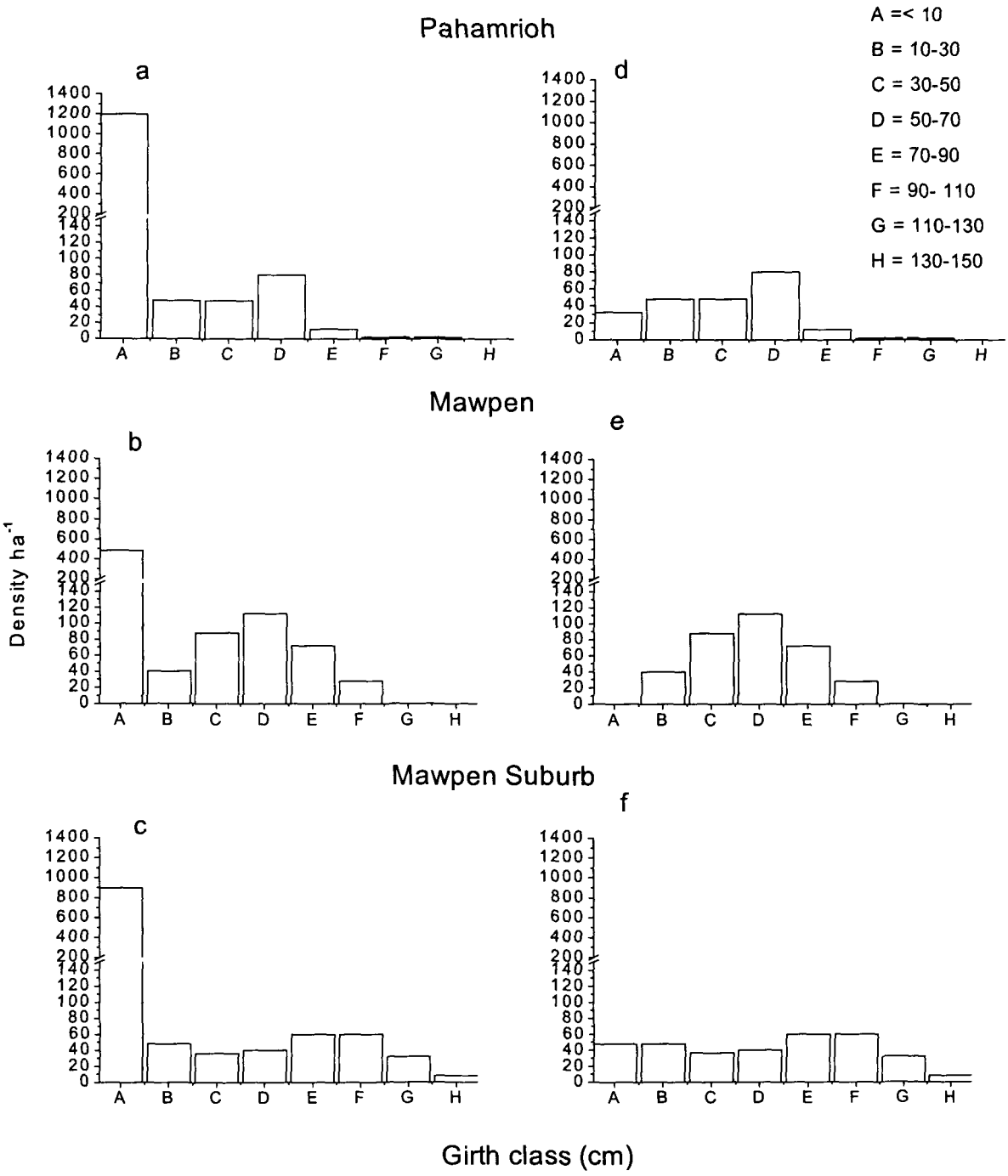


Figure 5.1. Population structure of *C. tamala* in November (a, b, c) and in March (d, e, f) at the three study sites. Girth class 0-10 cm represents seedlings, 10-30 cm represents saplings and those beyond 30 cm represent adult individuals or trees.

However, the population structure changed when sampled in March and exhibited varied distributions at different sites (Figure 5.1 d, e, f). The density of individuals in girth classes in March was of the order of seedlings<saplings<adults.

Population structure of dominant associates of *C. tamala*

Schima wallichii is a dominant species at Pahamrioh with an IVI of 36.5 and at Mawpen with an IVI of 42.4 and *Citrus aurantifolia* is dominant at Mawpen Suburb with an IVI of 78.7. These dominant species showed a reverse J-shaped curve with preponderance of individuals in lower girth class (Figure 5.2 a, b, c).

At Pahamrioh, *Cordia grandis* with an IVI of 25.6 exhibited a reverse J-shaped curve with a decline in stem density in the higher girth classes (Figure 5.2 d). *Olea dioica* at Mawpen with IVI of 12.1 exhibited a negative exponential type curve. The individuals of the species were present only in the 10-30 cm girth class (Figure 5.2 e). At Mawpen Suburb, *Areca catechue* with an IVI of 35.9 exhibited a negative exponential type curve (Figure 5.2 f).

Stem density, basal area and height of *C. tamala*

The IVI of *C. tamala* was 40.2 at Pahamrioh, 106.8 at Mawpen and 115.96 at Mawpen Suburb. The density of *C. tamala* stems≥10 cm gbh was 192 ha^{-1} at Pahamrioh, 340 ha^{-1} at Mawpen and 284 ha^{-1} at Mawpen Suburb. The basal area of *C. tamala* stems≥10 cm gbh was 4.1 m^2 ha^{-1} at Pahamrioh, 10.7 m^2 ha^{-1} at Mawpen and 14.7 m^2 ha^{-1} at Mawpen Suburb. The contribution of *C. tamala* to stand density was 15% at Pahamrioh, 28% at Mawpen and 29% at Mawpen Suburb (Figure 5.3).

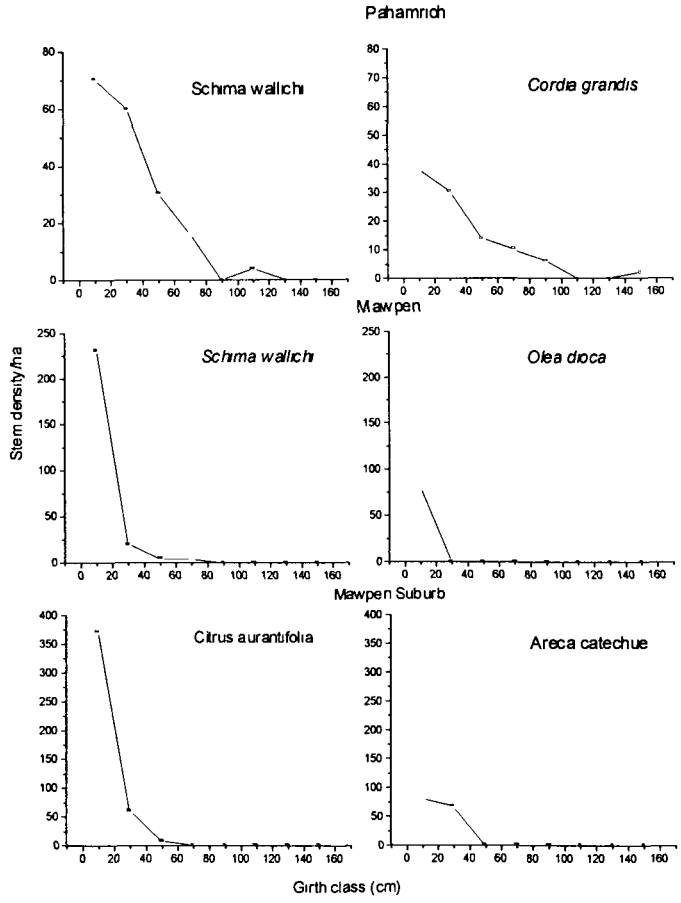


Figure 5.2. Population structure of dominant associates of *C. tamala* at three sites.

The contribution to stand basal area was 17.3% at Pahamrioh, 65.7% at Mawpen and 65.9% at Mawpen Suburb (Figure 5.3). *C tamala* attained a maximum girth of 144 cm at Mawpen Suburb, 130 cm at Pahamrioh and 110 cm at Mawpen.

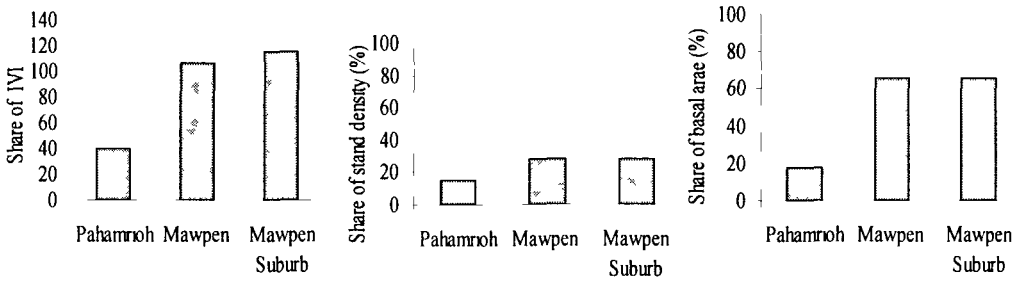


Figure 5.3. Share of *C. tamala* in the (a) IVI, (b) stand density (ha^{-1}) and (c) basal area (m^2 ha^{-1}) at the three study sites.

The average height of *C. tamala* individuals ≥10 cm increased with an increase in girth size at all sites up to about 100 cm girth and then attained a plateau (Figure 5.4). The highest tree height was 15 m at Pahamrioh in 90-110 cm girth class, 14 m in 90-110 cm girth class at Mawpen and 15 m in 70-90 cm and 130-150 cm girth classes at Mawpen Suburb. The average tree height did not differ significantly between the three sites and was 9 m at Pahamrioh and Mawpen Suburb and 8 m at Mawpen.

Spatial mapping of *C. tamala* in stands

C. tamala populations at three study sites showed variable dispersion patterns in understorey (<8 m height) and subcanopy (8-15 m height). The density of *C. tamala* stems was 27% in understorey and 73% in subcanopy at Pahamrioh, 49% in understorey and 51% in subcanopy at Mawpen and 31% in understorey and 69% in subcanopy at Mawpen Suburb.

The basal area of individuals was 40% in understorey and 60% in subcanopy at Pahamrioh, 38% in understorey and 62% in subcanopy at Mawpen and 18% in understorey and 82% in subcanopy at Mawpen Suburb.

The mean tree height of *C. tamala* individuals was 6 m in understorey and 10 m in subcanopy at Pahamrioh and Mawpen and 6 m in understorey and 11 m in subcanopy at Mawpen Suburb (Figure 5.5).

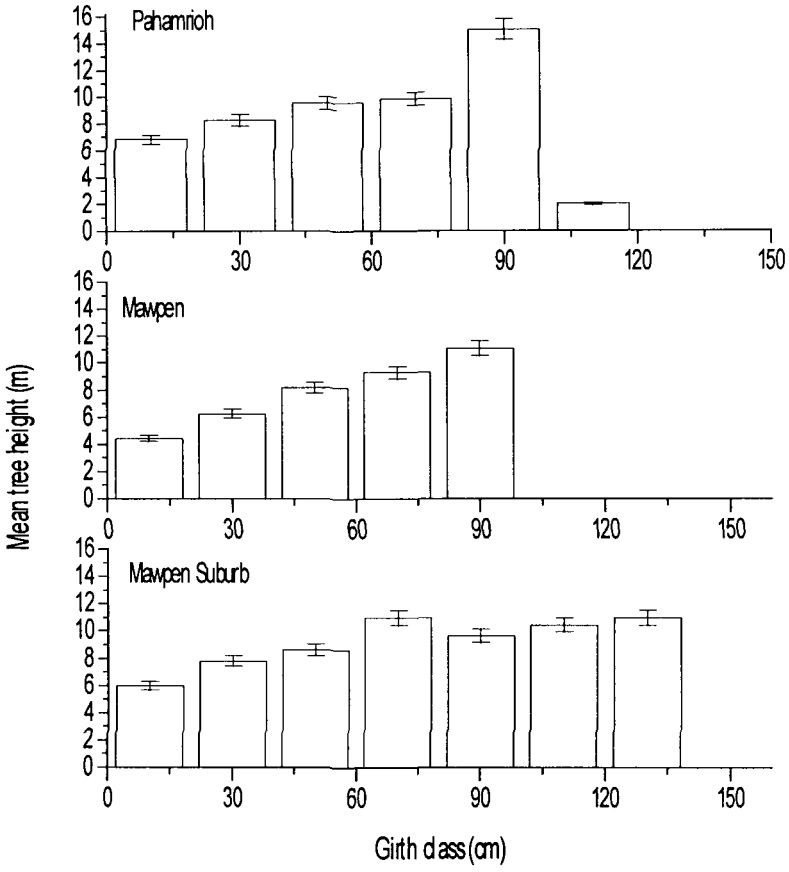


Figure 5.4. Mean height of *C. tamala* trees in different girth classes at three sites.

At Pahamrioh, adult *C. tamala* individuals were in two clumps (Figure 5.5 a, b). At Mawpen, adult individuals were randomly dispersed in two halves of the stand (Figure 5.5 c, d) due to presence of a footpath in the middle. At Pahamrioh, the individuals of *C. tamala* were randomly dispersed. Mawpen Suburb the species was more concentrated within one-half of the stand (Figure 5.5 e, f).

Whitford's index revealed a clumped dispersion at Pahamrioh (0.08), Mawpen (0.16) and Mawpen Suburb (0.16). The variance-to-mean ratio was 1.12 at Pahamrioh, 1.11 at Mawpen and 1.88 at Mawpen Suburb. Thus the latter indicated a near-random pattern at Pahamrioh and Mawpen and clumped pattern at Mawpen Suburb. The two

dimensional view of *C. tamala* population showed that the saplings were distributed in close proximity to the conspecific adults (≥30 cm girth) at all the three sites (Figure 5.5).

Discussion

The high density of *C. tamala* in study plots as compared to natural forests suggests that the sites have been enriched with *C. tamala* to maintain the agroforestry system and to generate revenues from the sale of the bay leaf. Since *C. tamala* is an important NTFP tree species, the farmers prefer this tree. The high contribution of *C. tamala* to stem density and basal area at Mawpen and Mawpen Suburb compared to Pahamrioh indicates greater stand age and better performance of *C. tamala*. At Pahamrioh, *C. tamala* represents a younger population due to recent intensification. Enrichment of homegardens with *C. tamala* is a response to the changing socioeconomic milieu of the region. Although *C. tamala* was dominant at all sites, the significant difference in basal area among sites was influenced by the stems in the higher girth classes.

The population structure of *C. tamala* in autumn suggests an abundance of regeneration through seeds. This is in conformity of the typical population structure of trees in undisturbed forests in Meghalaya (Rao *et al.* 1990). A significant reduction in seedling density in ensuing spring suggests that even though the reproductive potential of the species is good, recruitment is poor. This could be due to environmental and anthropogenic factors operating at the study sites.

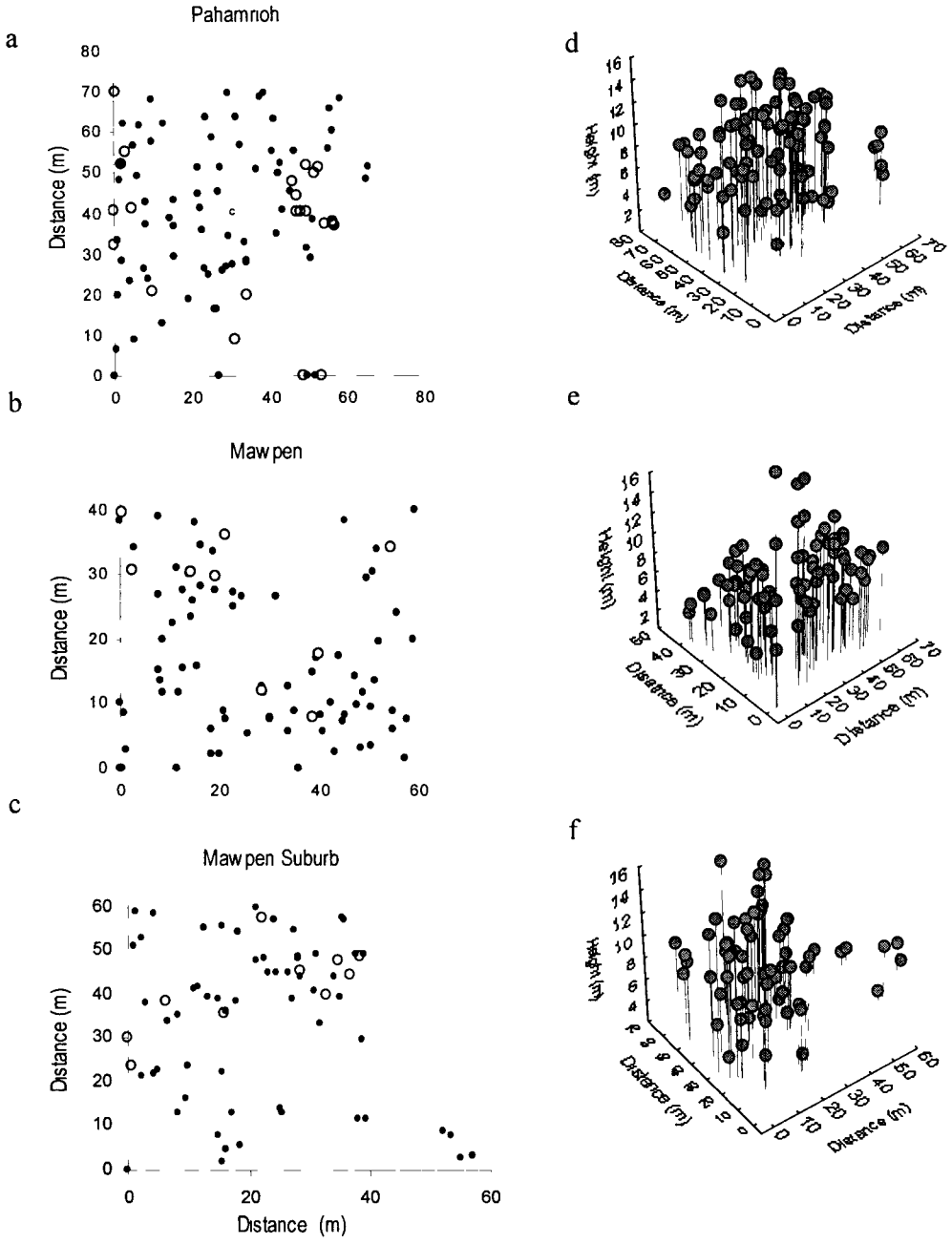


Figure 5.5. Spatial mapping of individuals of *C. tamala* at three study sites. Figures a, b and c represent two-dimensional view and d, e and f represent three-dimensional view. Individuals <30 cm are represented as empty circles and those ≥30 cm by filled circles.

The preponderance of individuals in intermediate girth classes at Pahamrioh and Mawpen may be shaped by infrequent recruitment of younger individuals and selective felling or senescence of trees in larger girth classes. The recruitment of younger individuals is slow but the exit of adult individuals is balanced since *C. tamala* trees are not harvested for timber. The older trees get eliminated due to disease or senescence. Rao *et al.* (1990) found occurrence of bimodal curves as a result of selective cutting of trees in some girth classes and it was species dependent in the disturbed forest stands in Meghalaya.

The dominant associate species (with high IVI value) at Pahamrioh, viz., *Schima wallichii* and *Cordia grandis* exhibited a reverse J-shaped curve suggesting fair regeneration. The absence of individuals of *S. wallichii* in higher girth classes suggests its ongoing logging for timber at Mawpen. The logging of *S. wallichii* is also largely responsible for higher disturbance index of the stand. The absence of individuals of *Olea dioca* in higher girth classes could also be due to its extraction as a timber. However, *Citrus aurantifolia* at Mawpen Suburb showing preponderance of individuals in lower girth classes was primarily due to its shrubby habit. *Areca catechu* is a relatively new entry into the system at Mawpen Suburb and therefore is restricted to smaller girth classes. The introduction of *Areca catechue* and *Piper betle* (a climber cultivated for chewable leaves) indicates increasing awareness among the people of Meghalaya for creating livelihood resources by enrichment of natural forests with economically important species.

The basal area of *C. tamala* populations was significantly higher compared to the basal area of the most dominant associate species at all sites. At Pahamrioh, *C. tamala* had a basal area of 4.12 m^2 ha^{-1} accommodated by 192 stems ha^{-1} as compared to *Schima wallichii* with a basal area of 3.34 m^2 ha^{-1} accommodated by 180 stems ha^{-1}.

At Mawpen, *C. tamala* had a basal area of 10.72 m^2 ha^{-1} accommodated by 340 stems ha^{-1} as compared to *Schima wallichii* with 1.42 m^2 ha^{-1} accommodated by 260 stems ha^{-1}. At Mawpen Suburb, *C. tamala* had a basal area of 14.74 m^2 ha^{-1} accommodated by 284 stems ha^{-1} which was far greater than 2.15 m^2 ha^{-1} basal area of *Citrus aurantifolia* accommodated by 440 stems ha^{-1}.

The dispersion of *C. tamala* varied from near-random (less clumped) at Pahamrioh and Mawpen to clumped at Mawpen Suburb as expressed by the spatial mapping of *C. tamala* in study stands and by calculating variance-to-mean ratio. Most of the Lauraceae members have been reposted to exhibit clumped dispersion in natural sal forests of Eastern Himalaya (Uma Shankar 2001). At the study sites, the farmers seem to have a tendency to distribute evenly the *C. tamala* trees throughout the plots to achieve higher degree of randomization. Nevertheless, the dispersion of *C. tamala* may potentially be influenced by the study site factors such as slope, aspect and cultivable space available for the crops.

The two dimensional spatial dispersion of *C. tamala* suggests that the young trees are situated close to the adult trees, suggesting that negative adult conspecific effect on the juveniles is not operational. Hence, it can be said that the dispersion of *C. tamala* species could be clumped in undisturbed conditions. However, there are examples where species show clumped dispersion in the juveniles, while adults show random dispersion (Toshinori *et al.* 1997).

The close dispersion of juveniles to the adult suggests that the dispersal distance of the seeds is small. A passive dispersal results in a seedling carpet under the parent tree. The seedlings here are likely to compete for resources and face density-dependent mortality. Janzen (1971) and Connell (1971) suggested that in such cases seedlings would perform better by escape mechanism with increase in dispersal

distance naturally or artificially. The present results do not support the theory as *C. tamala* population are seen to perform equally well in terms of their density and basal area accommodation in both randomly (Mawpen) and clumped (Mawpen Suburb) dispersed populations.

Conclusions

The study suggests that the seed production and germination of *C. tamala* contribute substantially to the appearance of seedlings at the end of rainy season as reflected in ≤10 girth class. Most seedlings face mortality during winter due to a variety of reasons. Thus, succession of seedlings in higher girth classes is limited or recruitment of *C. tamala* is poor in these systems. Anthropogenic activities especially farm management practices are the most important factors affecting recruitment. The infrequent recruitment of the younger members results in the poor demography of *C. tamala* population at the three sites. Nonetheless, the densities of *C. tamala* are higher at study sites than can be found in natural forests. The abundance of *C. tamala* in species rich (Pahamrioh) as well as species poor (Mawpen Suburb) stands suggests its wider adaptability. The abundance of *C. tamala* at the study sites suggests early stages of domestication. The popular belief that large quantities of bay leaf are harvested from wild populations of *C. tamala* is not therefore true. Hence, enrichment of *C. tamala* in agroforestry systems is responsible for commercial supply of bay leaf from Meghalaya. Excessive enrichment of homegardens and agroforestry systems with *C. tamala* may however run a risk of reducing diversity and heterogeneity.

Chapter VI

Regeneration Ecology of *Cinnamomum tamala*

The dynamic process of tree regeneration through seeds starts with the onset of flowering and passes through several stages such as pollination, fertilization, fruit and seed development, dispersal of fruits and/or seeds to safe sites, seed germination, seedling emergence and finally the establishment of seedlings. Seeds are physically independent entities responsible for the perpetuation of a species in time and space. Establishment of species is predominantly through seeds rather than the vegetative propagules, especially in early successional communities (Bazzaz *et al.* 2000). Many workers have predicted that seed production may be limited by extrinsic factors such as resource availability, pollination failure, predation on flower, fruits and leaves and hostile environments, as well as intrinsic factors such as the age and size of the plant and genetic constitution (Stephenson 1981, Winn and Werner 1987, Khan *et al.* 2005).

The knowledge of reproductive potential of constituent tree populations in a forest community is necessary for an understanding of the dynamics of recruitment process. The importance of the study of the regeneration of a species increases if the species is economically important and subjected to harvest of a plant part or the whole plant. Reproductive vigor of a harvested population may be reduced due to removal of leaves or branches since resources are diverted from the reproductive processes to regeneration of leaves and branches (Dayanandan *et al.* 1990, Hall and Bawa 1993). Year-wise variations in seed production and occurrence of mast fruiting events have been viewed as an adaptation strategy to protect offsprings from herbivores through predator satiation (Janzen 1971, Howe and Smallwood 1982). The patterns of seed

production also differ among populations of the same species that have become locally adapted to different environments.

Many authors have demonstrated seedling establishment to be positively correlated with the seed mass (Tripathi and Khan 1990, Khan and Uma Shankar 2001, 2004, Khan 2004). However, germination may be independent of seed size in some species (Gross and Kromer 1986, Perez-Garcia *et al.* 1995). Uma Shankar (2006) demonstrated that seed weight is a better indicator of germination success and seedling establishment than seed size in tropical tree species. Apparantly, larger seeds possess greater food energy to ensure better seedling survival until the seedlings become capable of photosynthesis and fit to survive independently (Fenner 2000). Therefore, the number of successful seedlings will depend both on the size/weight and the number of seeds produced.

The regeneration of plant communities depends on seeds being in good physiological state to germinate in the right place at the right time. Hence, dispersal of seeds to favorable sites is an important event for successful regeneration of a species. Leishman and Westoby (1994) and Leishman *et al.* (1995) found animal-dispersed seeds significantly larger than unassisted-, wind- or adhesion-dispersed seeds. In species where dispersal is passive, regeneration is facilitated by quick germination of seeds after dispersal. Most tropical species germinate immediately after seed shed and do not experience a dormancy period as conditions are mostly favorable for growth (Bisht and Ahlawat 1999). Such phenomenon induces low viability in storage of recalcitrant seeds. The final success of regeneration depends on successful establishment of the seedlings. The survivorship curves of the seedlings are an important tool for studying the regeneration success of a species.

Information on reproductive potential and seed regeneration of *C. tamala* is not readily available. We do not know if *C. tamala* populations flower gregariously or

sparsely, or what age group individuals flower and yield fruits and seeds most. We also lack information if seed size determines germination success and seedling establishments, if seedling mortality is exogenous or endogenous, and if seed size varies with time (between study years) and space (between the study sites). This chapter describes the results of field observations on phenology, reproductive potential, seed characteristics, germination and seedling establishment of *C. tamala*.

Methodology

Phenology and reproductive potential

The activity of flowering, fruiting, seed shed, dispersal, germination, seedling establishment in *C. tamala* population was monitored at the three study sites during 2003 and 2004. Leaf flushing was monitored throughout the year and the time of leaf harvest was recorded.

To study the production of flowers, fruits and seeds, 10 flowering individuals were tagged in 2003 at Mawpen and Mawpen Suburb. No trees were selected at Pahamrioh in 2003 due to absence of flowering activity in entire population. At Mawpen and Mawpen Suburb, a few individuals among those selected in 2003 failed to flower in 2004. Hence, additional flowering individuals were selected in 2004 to maintain the sample size.

Trees were climbed up by ladders and fifty inflorescences were tagged on each selected tree to record the phenophases. The number of flowers, number of healthy matured fruits, number of aborted fruits and number of fruits lost due to early fall were recorded on the tagged inflorescences. The total number of main branches, number of inflorescence per sub-branch, number of branchlet per sub-branch, number of inflorescence per branchlet and number of flowers per inflorescence, and number of healthy fruits per inflorescence were counted on each marked tree for estimating

flower and fruit production. Since fruit is a drupe with a single seed, seed production was considered to be equivalent to fruit production. Variation in flower and fruit production between sites and between the years was also analyzed statistically.

Seed dispersal and predation

Ten flowering trees that were relatively isolated with non-flowering neighbors were selected for studying seed dispersal pattern. Seed traps of 1 m x 1 m were laid in concentric circles up to 7 m at 1 m increments from the select tree trunk. Seeds collected in the traps were counted and their physical status was recorded at 15 d intervals at all sites during the months of July, August and September. The seeds collected from the traps were sorted into three categories, i.e., healthy, aborted and diseased. To monitor the fate of the shed seeds consequent upon predation, 10 seeds were painted red and left in each trap and monitored subsequently.

Seed characteristics

Ripe drupes that could be recognized by purplish-black color were collected from the marked trees. The seeds were extracted by scrapping the fruit cover, labeled, weighed and stored individually in paper bags until sowing. Viability of seeds was tested at 5 d interval from the collection date. Ten seeds were presoaked overnight in distilled water and later soaked in 1% solution of 2, 3, 5-triphenyl tetrazolium chloride (TTC) in petriplates. The petriplates were moulded in silver foil and kept at 48^0 C for 5 hr in an oven. Embryos that stained dark red and pink were counted as viable.

Seed germination

Seed germination was recorded both in the field and the laboratory during 2003 and 2004. The phenomenon of seed germination on the soil surface in the field conditions was mimicked in the laboratory. Most seeds from the three study sites were sown on the soil surface in the laboratory. A set of 50 seeds were sown at 5 cm from the soil surface and another set of 50 seeds were sown in the BOD at 25^0 C. Ripe seeds were directly sown in the field.

Seed germination was recorded for a month, i.e., until germination ceased to occur. A seed was considered germinated when plumule/radicle or both as observed in this species, were visibly emerged from the seeds. Two month old seedlings were transferred to the nethouse and watered at regular interval.

Histogram of germinated seeds, non-germinated seeds and seeds that germinated and survived as seedlings at three months from germination was drawn to examine their frequency class distribution in different seed weight class.

Seedling mortality and establishment

Seedlings of *C. tamala* were tagged in 1 m x 1 m plots in each of the 100 m^2 grids of 0.5 ha, 0.25 ha and 0.25 ha study plots at Pahamrioh, Mawpen and Mawpen Suburb, respectively. Seedlings already present in the field during November 2002, were tagged as cohort I, seedlings from the seed batch produced in July 2003 were tagged as cohort II and seedlings from seed batch produced during July 2004 were tagged as cohort III. At the end of the study period, cohort I were 27 months old seedlings, cohort II were 19 months old and cohort III were 8 months old seedlings. Survival of seedlings was monitored on monthly basis till the end of the study period in February 2005. The age specific mortality rate (q_x) of each cohort was calculated on monthly basis as given below by following Poole's (1974) method:

q_x (seedling mortality) = d_x / ln,

Where, q_x is the age specific mortality, ln is the number of seedlings at the beginning of a month and d_x is the number of seedlings in the time interval of one month. Seedling mortality in the nethouse calculated at 6 months interval.

One-way analysis of variance was done to analyze if there was any significant influence of the prevailing environmental factors and the age specific seedling mortality rate (q_x) in the field conditions.

Seedling density was also counted in adjacent 1 m x 1 m herbaceous (not cleared) and non-herbaceous (cleared) plots to study the influence of herbaceous cover on seedling establishment.

Seedling vigour

Seedling vigour was measured by estimating the following growth attributes: root length (cm), shoot length (cm), collar diameter (mm), number of leaf per shoot and leaf area per shoot (cm^2). Since, most seedlings were dead at the age of six months after germination in the field conditions, data presented on seedling vigour is for five months only. Seedling vigour was measured for seedlings in the field and the nethouse. Growth attributes were compared for seedlings within each seed weight class. The growth attributes were regressed against the seed weight to examine the relationship between seed weight and seedling vigour using Statistica 6.0.

Comparison of mean leaf area and mean height of the seedlings was used as an essential indicator of seedling vigour at the three study sites and the nethouse. Microenvironmental variables in the field and in the nethouse were monitored to examine the influence of microenvironment on seedling vigour. One way analysis of variance was performed between the microenvironmental variables of the study area and the nethouse during the early growth period of the seedlings.

Since, sampling of the reproductive population was skewed at all sites a scatter plot for seed weight and girth size of the parent trees was plotted to study if there existed a linear relationship between the two. Histograms were drawn to examine the frequency distribution of seeds in different seed weight classes. One way analysis of variance was conducted to examine if there was any significant difference in the seed weight between the three sites.

Results

Phenology

C. tamala trees began flowering in April and were in full bloom by May at Mawpen and Mawpen Suburb. At Pahamrioh, flowering lagged behind by 10-15 days. There was an additional episode of leaf flush during July and August. Also, sporadic leaf flushing was present throughout the year (Figure 6.1). Fruit maturation started from June and continued till September. Seed shedding occurred during July to September. Seed germination coincided with the timing of seed shedding. Seedling establishment started from August and continued till October. Seedlings showed mortality between October and February with a peak during December. The timing of bay leaf harvest overlapped with that of seedling mortality.

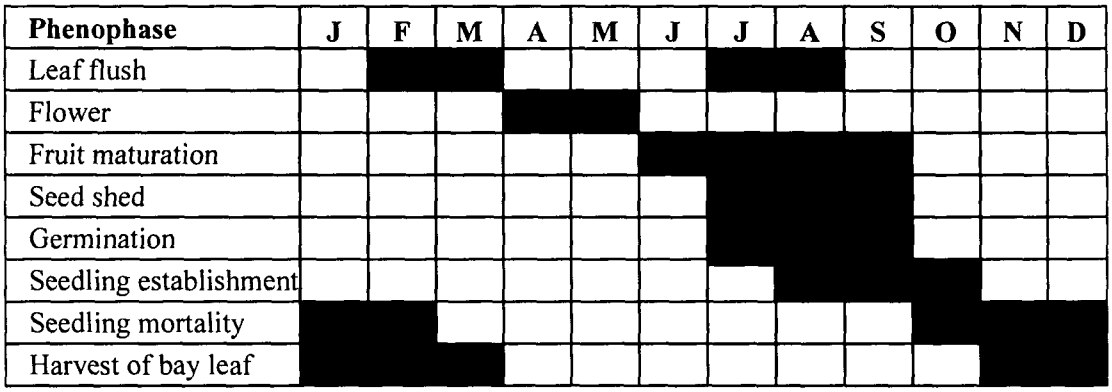


Figure 6.1. Phenology of *C. tamala* based on pooled observations in 2003 and 2004.

Flowering incidence

Flowering was observed on a sample of reproductive trees at the three study sites. The mean girth of the trees was the least at Pahamrioh (mean 20.3 cm with a range from 12 to 35 cm), more at Mawpen (mean 92.3 cm with a range from 32 to 110 cm) and the most at Mawpen Suburb (mean 107.3 cm with a range from 71 cm to 144 cm) (Table 6.1).

Table 6.1. Girth characteristics of trees selected for studying reproductive potential of *C. tamala* at three sites.

Site	Number of trees	Minimum tree girth (cm)	Maximum tree girth (cm)	Mean tree girth (cm ± sd)
Pahamrioh	10	12.0	35.0	20.3 ± 8.2
Mawpen	10	32.0	110.0	92.3 ± 19.3
Mawpen Suburb	10	71.0	144.0	107.3 ± 20.6

Flowering incidence varied in different years. In 2003, about 46% trees flowered at Mawpen and 66% at Mawpen Suburb, but no trees flowered at Pahamrioh (Figure 6.2). In 2004, as much as 82% trees flowered at Pahamrioh, 35% at Mawpen and 17% at Mawpen Suburb. Of the trees that flowered in 2003 and were subjected to bay leaf harvest, only 31% trees repeated flowering at Mawpen and 21% trees at Mawpen Suburb in 2004 (Figure. 6.3).

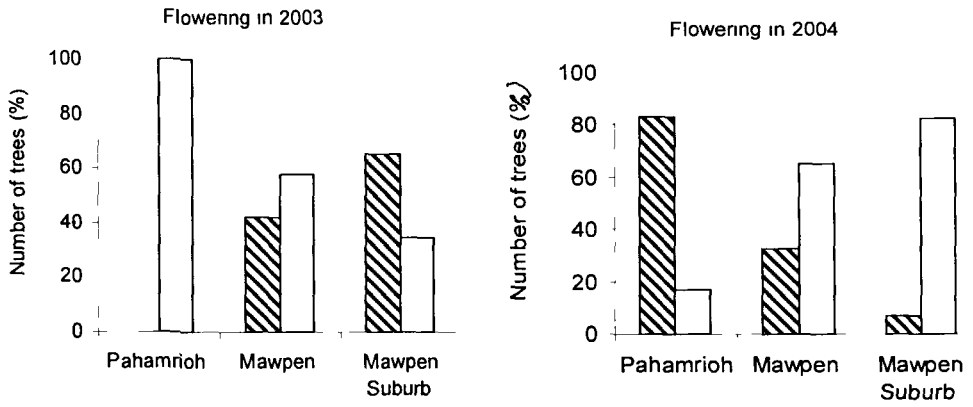


Figure 6.2. Percentage of flowering (hatched bar) and non-flowering (blank bar) trees of *C. tamala* at the three study sites in 2003 and 2004.

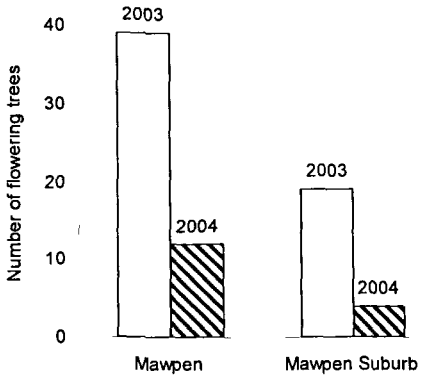


Figure 6.3. Recurrence of flowering of *C. tamala* trees in 2004 out of those flowered and harvested during 2003.

Flowering incidence in different girth classes varied at the three study sites (Figure 6.4). At Pahamrioh, flowering was restricted to <70 cm girth class in 2004. At Mawpen, flowering was recorded in 30-110 cm girth classes only, during 2003 and 2004.

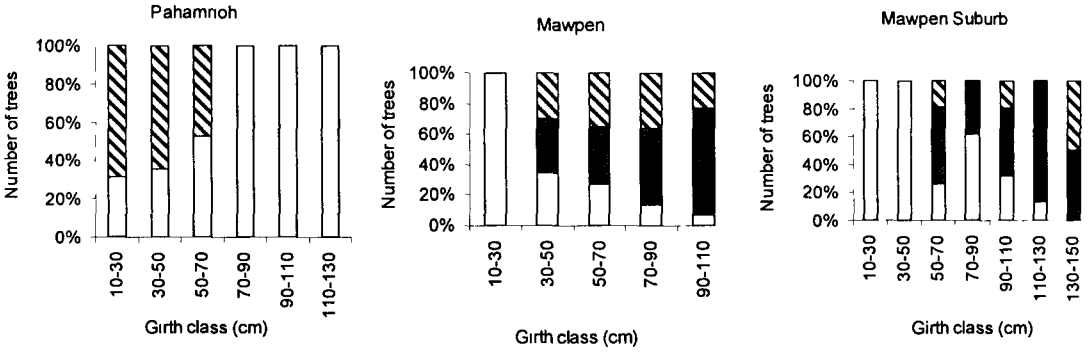
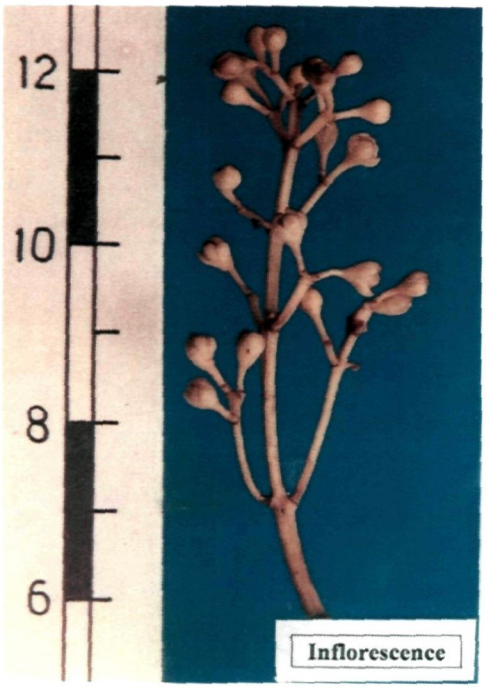


Figure 6.4. Percentage of *C. tamala* trees that flowered in different girth classes in 2003 (black bar) and 2004 (hatched bar).

At Mawpen Suburb, flowering was restricted to individuals >50 cm girth class in 2003, and in 2004, flowering was observed in alternate girth classes within the same range. Maximum flowering was observed in 10-30 cm girth class at Pahamrioh, 90-110 cm girth class at Mawpen and 130-150 cm girth class at Mawpen.

Flower, fruit and seed production

The inflorescence in *C. tamala* is a greenish pubescent panicle of 8-15 cm length (Plate 6.1). The flowers are bisexual and 0.5-0.8 cm across (Plate 6.2). The perianth is 3+3, silky pubescent on both surfaces, longitudinally brown ribbed, elliptic-ovate-lanceolate, sub-equal, outer 2.5 mm long, inner 2-2.5 mm long. Stamens are 3+3+3, 1.5-2 mm long with tetralocular anthers. Pollen dehiscence occurs through the opening of valve in introrse manner, but extrorse in whorl III. Glands of whorl III are attached to 1/3 of the base of the filaments. Glands and anther are pale yellow in colour, filaments are silky tomentose and pale yellow and head is sagittate.



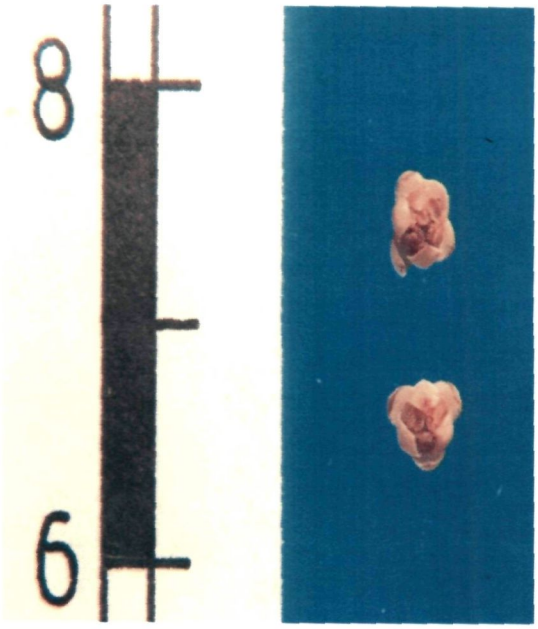


Plate 6.1. An inflorescence of *C. tamala*. **Plate 6.2. Flower of *C. tamala*.**

Average flower production per tree in 2003 did not vary significantly between Mawpen (800 flowers tree^{-1}) and Mawpen Suburb (920 flowers tree^{-1}) and was absent at Pahamrioh (Table 6.2). In 2004, average flower production was significantly higher at Pahamrioh (427 flowers tree^{-1}) than at Mawpen (224 flowers tree^{-1}) and Mawpen Suburb (236 flowers tree^{-1}), but did not vary between the latter two sites. Flower production differed significantly with the girth (p >0.05) and the height (p >0.05) of the tree at the sites, except for Mawpen Suburb in 2004.

Average fruit production per tree was more at Mawpen Suburb than at Mawpen in 2003 (Table 6.2). In 2004, average fruit production was maximum at Pahamrioh followed by Mawpen and Mawpen Suburb.

Table 6.2. Yearly variation in reproductive potential of *C. tamala* trees at three sites.

Site	Flowers tree^{-1} (Mean ± SE)	Fruits tree^{-1} (Mean ± SE)	Reproductive success (%)	Abortion of flowers/fruits (%)
		2003		
Pahamrioh	0	0	0	0
Mawpen	800 ± 115	666 ± 90	83	17
Mawpen Suburb	920 ± 174	859 ± 176	93	7
		2004		
Pahamrioh	427 ± 48	303 ± 39	71	29
Mawpen	224 ± 30	111 ± 18	50	50
Mawpen Suburb	236 ± 41	67 ± 14	29	71

The fruit of *C. tamala* is a drupe harbouring a single seed (Plate 6.3). The fruits are 0.8-1.5 cm across, ovoid, globose and purplish black when ripe. Fruit is devoid of pulp and fruit wall is 1-1.5 mm thick, closely attached to the seed coat. Fruit wall is easily removed by applying pressure between the fingers. The seeds are 7 to 12 mm across, ovoid and brown in color (Plate 6.4). Seed coat is thin (<1 mm), continuous and one layered enclosing two whitish cotyledons. Endosperms are 3-5 mm across, whitish in color, papery in texture and horseshoe shaped. Of the total fruit weight, 95% is contributed by the seed. Henceforth, the fruit shall be considered as seed in this study.

Plate 6.3 Fruits of *C. tamala*.

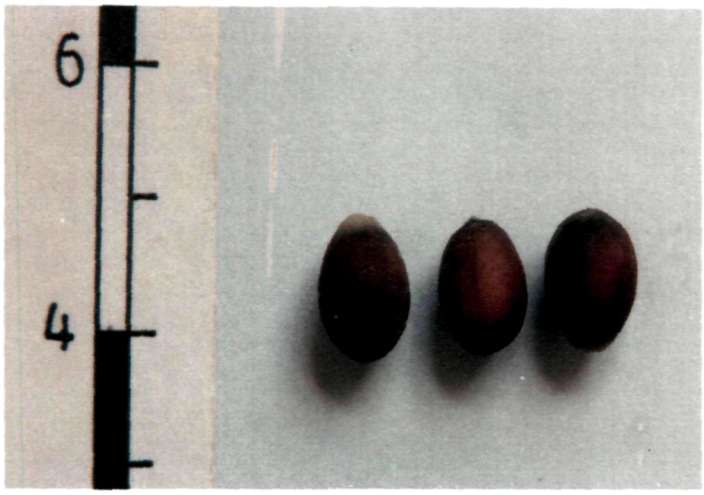


Plate 6.4. Seeds of *C. tamala*.

Seed dispersal and predation

Seed dispersal was gravity-driven or unassisted. The seed fall peaked in August at the three sites (Figure 6.5). At all sites, seeds generally dispersed up to 4 m from the parent tree trunk and most seeds remained within 2 m radius (Figure 6.6). The number of dispersed seeds decreased with distance from the parent tree.

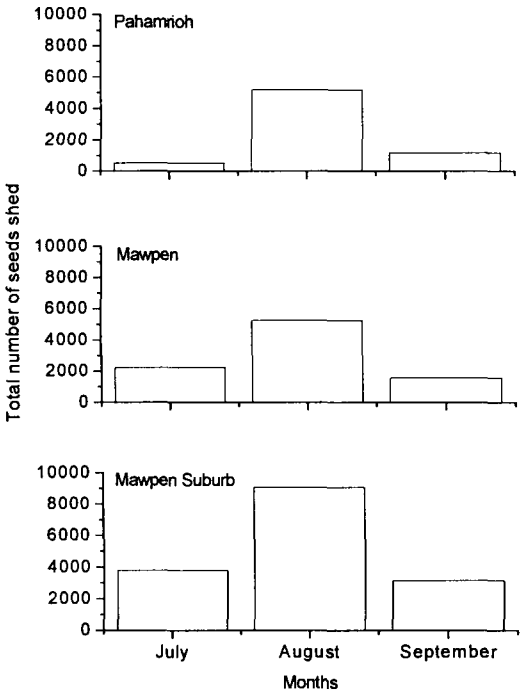


Figure 6.5. Seasonality in seed fall pattern of *C. tamala* at three study sites.

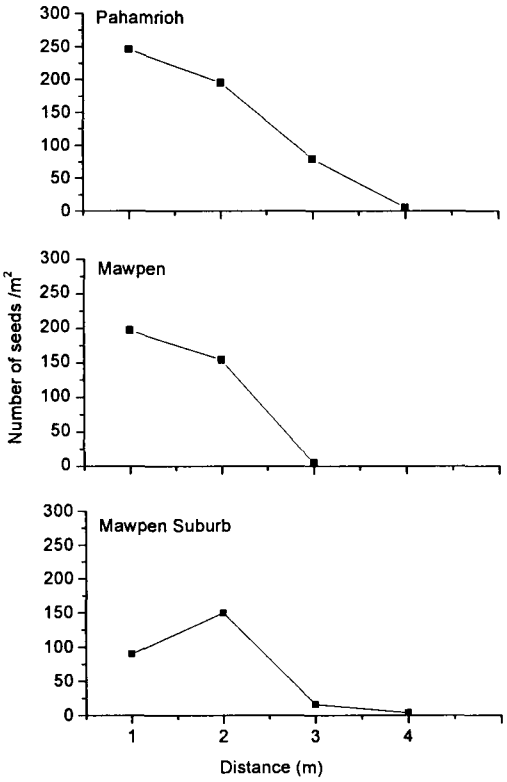


Figure 6.6. Dispersal of seeds of *C. tamala* with increasing radius from the parent tree trunk at three study sites.

Seed production was measured through collection in seed traps. Of total seeds collected in seed traps in 2003, as much as 81% at Mawpen and 77% at Mawpen Suburb were healthy. Only 11% seeds at Mawpen and 10% seeds at Mawpen Suburb were diseased. The rest 8% seeds at Mawpen and 13% at Mawpen Suburb suffered abortion (Figure 6.7).

Of total seeds collected in seed traps in 2004, as much as 79% at Pahamrioh, 66% at Mawpen and 62% at Mawpen Suburb were healthy, 13% at Pahamrioh, 9% at Mawpen and 5% at Mawpen Suburb were diseased, and 7% at Pahamrioh, 24% at Mawpen, and 33% at Mawpen Suburb suffered abortion (Figure 6.7). Seeds after paint-marking were left on the ground in the seed traps to quantify seed predation. No loss of marked seeds was observed.

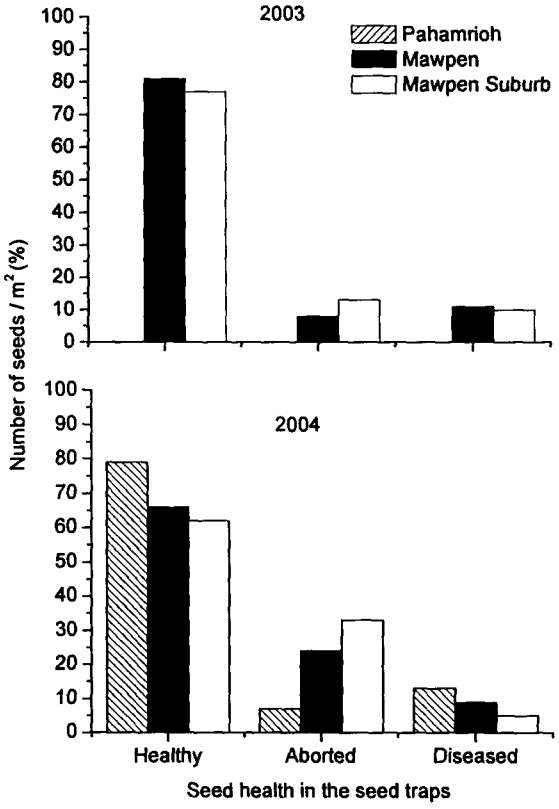


Figure 6.7. Seed production at three study sites in 2003 and 2004.

Seed weight characteristics

Seed weight varied among sites in 2003 as well as in 2004 (Table 6.3). In 2003, mean seed weight was more at Mawpen Suburb than at Mawpen. There were no seeds produced at Pahamrioh. Across sites, seed weight ranged between 99 and 751 mg, i.e., by more than seven-fold. In 2004, Pahamrioh exhibited significantly higher mean seed weight than Mawpen and Mawpen Suburb. The mean seed weight for a pool of all sites did not differ significantly between 2003 and 2004.

Table 6.3. Variability in seed weight characteristics of *C. tamala* at three sites.

Site	Number of seeds	Minimum seed weight (mg)	Maximum seed weight (mg)	Mean (±sd) seed weight (mg)	Variation in seed weight (LSD test)
			2003		
Pahamrioh	-	-	-	-	-
Mawpen	212	99	544	275 ± 71	3
Mawpen Suburb	205	127	751	298 ± 85	2
All sites	417	99	751	287 ± 79	-
	F				8.7
ANOVA	df				415
	p				0.003
			2004		
Pahamrioh	569	28	509	286 ± 73	2, 3
Mawpen	54	100	355	200 ± 54	1
Mawpen Suburb	41	65	364	201 ± 72	1
All sites	664	28	509	273 ± 78	-
	F				98.8
ANOVA	df				662
	p				0.001

A scatter plot for seed weight and girth class of the parent trees did not exhibit any linear relationship between seed weight and girth size of the parent trees (Figure 6.8). However, seed weight showed significant variation within tree with few outliers.

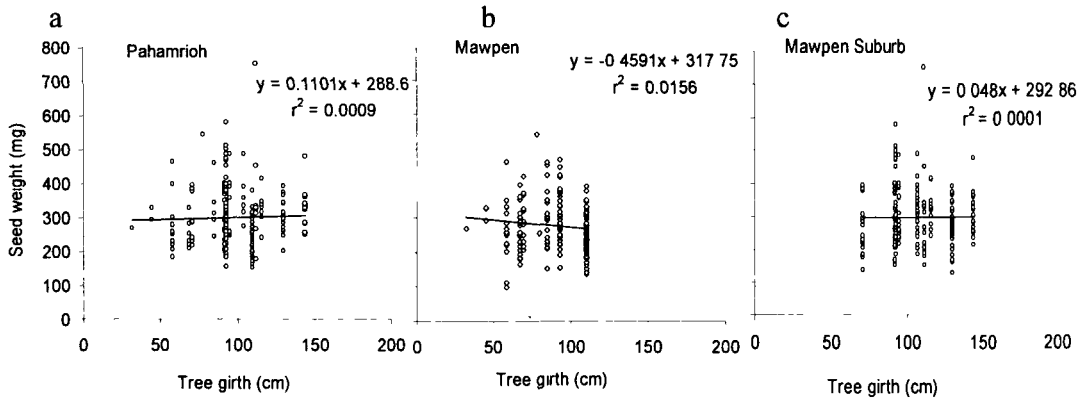


Figure 6.8. A scatterplot for relationship between seed weight and girth of the parent tree at three sites.

A frequency distribution of seed population at Pahamrioh exhibited 48% seeds in 200 to 300 mg and 34% in 300-400 mg seed weight class (Figure 6.9). At Mawpen 55% seeds were distributed in 200 to 300 mg and 29% in 300-400 mg seed weight class. At Mawpen Suburb, 47% of the seeds were distributed in 200 to 300 mg and 35% in 300-400 mg seed weight class. Rests of the seeds were distributed in varying percentages in other seed weight classes (Figure 6.9). The seeds seem to follow a normal frequency distribution at all sites.

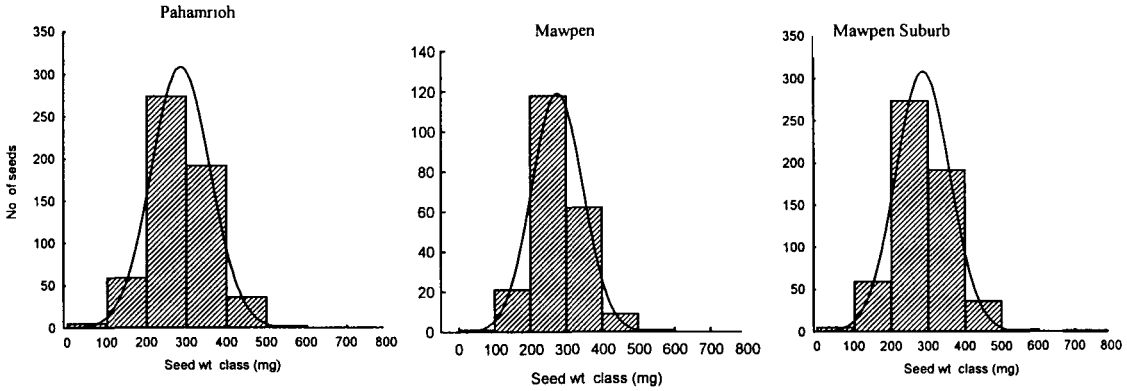


Figure 6.9. Frequency distribution of seeds in seed weight classes at three sites.

Seed germination

Seed viability declined rapidly after collection of seeds from the trees (Table 6.4). By 25th day, all seeds lost viability. Seed storage in moist conditions is difficult since seeds would germinate or get infected by the fungi. Dry storage without fruit coat resulted in loss of viability within 25 days.

Table 6.4. Seed viability of *C. tamala* at periodic intervals from the date of collection.

Days from collection	No. of seeds	No. of stained seeds	No. of unstained seeds	Seed viability (%)
5th	10	10	0	100
10th	10	10	0	100
15th	10	7	3	70
20th	8	2	6	25
25th	8	0	8	0

Seed germination in *C. tamala* was hypogeal (Plate 6.5). Seeds began germinating 15 days after sowing. In the field seed germination was abundant and resulted in a carpet of seedlings under the parent tree (Plate 6.6).

Of 150 seeds placed in the field, 60% germinated at Mawpen and 67% at Mawpen Suburb (Table 6.5). In 2004, germination in the field was 65% at Pahamrioh of 150 seeds sown, 23% at Mawpen of 70 seeds sown and 25% at Mawpen Suburb of 60 seeds sown.

In 2003, 212 seeds collected from Mawpen and 205 seeds from Mawpen Suburb were sown in greenhouse. Of these, 91.9% from Mawpen and 78% from Mawpen Suburb germinated. In 2004, 569 seeds from Pahamrioh resulted in 65% germination, 54 seeds from Mawpen resulted in 17% germination and 41 seeds from Mawpen Suburb resulted in 22% germination (Table 6.5).

Plate 6.5. Hypogeal germination in *C. tamala.*

Plate 6.6. *Ex-situ* germination and seedling carpet of *C. tamala*.

Table 6.5. Seed germination and seedling survival in natural and control conditions for *C. tamala* population at the three sites.

Sites	Germination (%)				Survival (%)			
	2003		2004		2003		2004	
	Field	Green-house	Field	Green-house	Field	Green-house	Field	Green-house
Pahamrioh	0	0	65.0	57.6	0	0	20.0	42.2
Mawpen	60.0	91.9	23.0	17.0	7.8	52.8	12.5	11.0
Mawpen Suburb	66.7	78.1	25.0	22.0	0	65.6	20.0	11.0

Seedling survival in the field was 8% for seeds from Mawpen and nil for seeds from Mawpen Suburb in 2003. In 2004, seedling survival in the field was 20% at Pahamrioh, 12.5% at Mawpen and 20% at Mawpen Suburb (Table 6.5). Seedling survival in greenhouse was 53% at Mawpen and 66% at Mawpen Suburb in 2003 until after 180 days of sowing. In 2004, seedling survival was 42% for Pahamrioh and 11% for Mawpen as well as Mawpen Suburb (Table 6.5).

Germination was nil when seeds were sown at 10 cm below the soil surface in greenhouse laboratory. Germination was only 2% for the seeds sown in the BOD.

Most germinated seeds were from intermediate seed weight classes (200-400 mg) at all sites (Figure 6.10). On the other hand, most underminated seeds were from small seed weight class (Figure 6.11). Percentage of non-germinated seeds was 41% at Pahamrioh, 52% at Mawpen and 53% at Mawpen Suburb in 200-300 mg seed weight class (Figure 6.11). The percentage of seeds that germinated and survived as seedlings after six months from germination was 40% at Pahamrioh, 58% at Mawpen and 50% at Mawpen Suburb in 200-300 mg seed weight class (Figure 6.12).

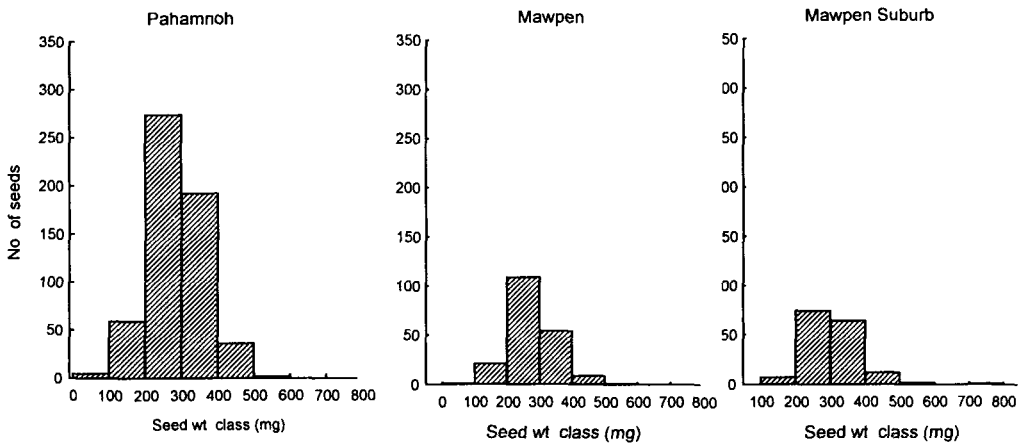


Figure 6.10. Frequency distribution of germinated seeds in different seed weight classes (mg) at three sites.

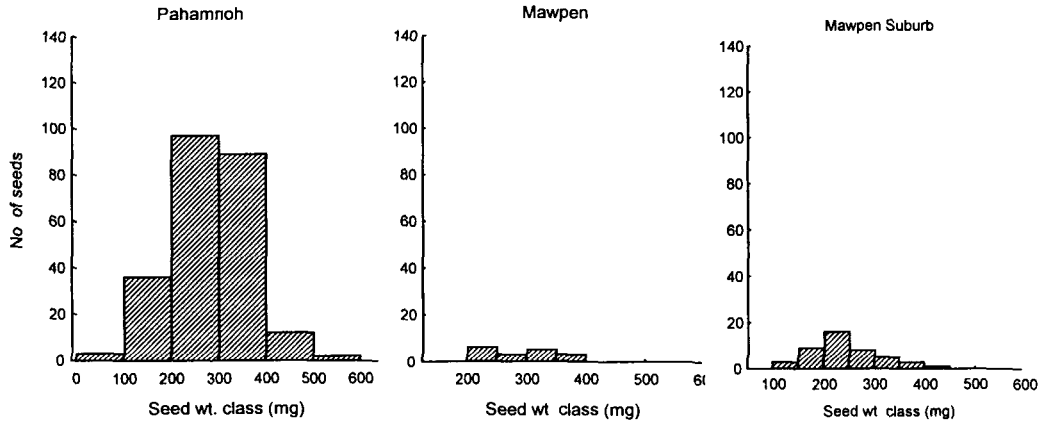


Figure 6.11. Frequency distribution of ungerminated seeds in different seed weight classes (mg) at three sites.

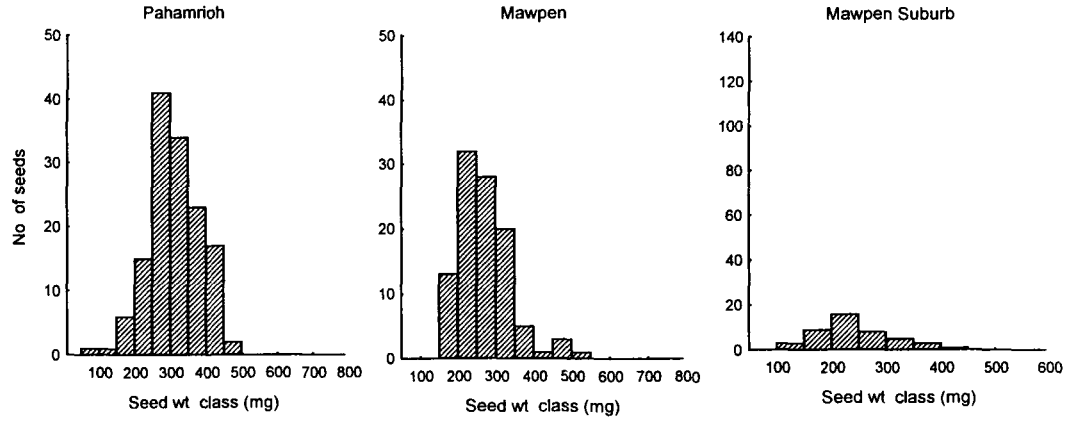


Figure 6.12. Frequency distribution of seeds in different seed weight classes (mg) that germinated and survived as seedlings after six months in the greenhouse.

Seedling survival and mortality

Survivorship curves of *C. tamala* seedlings in field exhibited a rapid decline in seedling density in December at all sites (Figure 6.13). Seedling density stabilized in subsequent months. The survived seedlings suffered further decline in density during next winter.

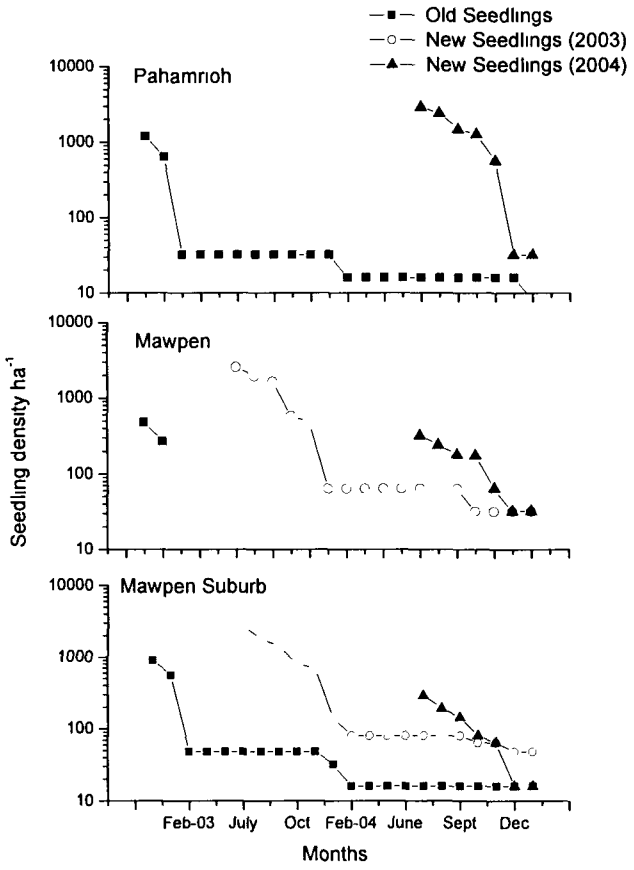


Figure 6.13. Seedling survivorship curves from November 2002 to February 2005.

The annual seedling mortality rate from November 2002 to November 2003 was 97%, 98% and 95% at Pahamrioh, Mawpen and Mawpen Suburb (Table 6.6). In the second year of study, from November 2003 to November 2004, the annual seedling mortality rate was nearly 50% at all sites.

Table 6.6. Annual seedling mortality rate (%) during November 2002 to November 2004 at three sites.

Site	Nov. 02 to Oct. 03	Nov. 03 to Oct. 04
Pahamrioh	97	50
Mawpen	98	50
Mawpen Suburb	95	50

Seedling mortality at the end of the study period was 99%, 100% and 98% in cohort I at Pahamrioh, Mawpen and Mawpen Suburb. In cohort II seedling mortality was 99%, and 98% at Mawpen and Mawpen Suburb. There were no seedlings in cohort II at Pahamrioh. Seedling mortality was 99%, 90% and 94% in cohort III at the end of the study period (Table 6.7).

Table 6.7. Seedling mortality (%) in different cohorts at three sites.

Site	Cohort I	Cohort II	Cohort III
Pahamrioh	99	-	99
Mawpen	100	99	90
Mawpen Suburb	98	98	94

In greenhouse, seedling mortality of *C. tamala* six months after germination was 47% at Pahamrioh, 34% at Mawpen and 40% at Mawpen Suburb. About 12 months after germination, mortality increased to 55% at Pahamrioh, 64% at Mawpen and 50% at Mawpen Suburb. More than 70% of seedlings in the nethouse died due to fungal infection of the shoot tip.

Seedling establishment decreased with distance from the parent tree at all sites (Figure 6.14). Mean seedling density in cleared plots was 59 m^2 at Pahamrioh, 62 m^2 at

Mawpen and 51 m^2 at Mawpen Suburb and in non-cleared plots was 5 m^2 at Pahamrioh, 3 m^2 at Mawpen and 6 m^2 at Mawpen Suburb. Hence, the density of *C tamala* seedlings was significantly higher in cleared plots than in uncleared plots at the three study sites.

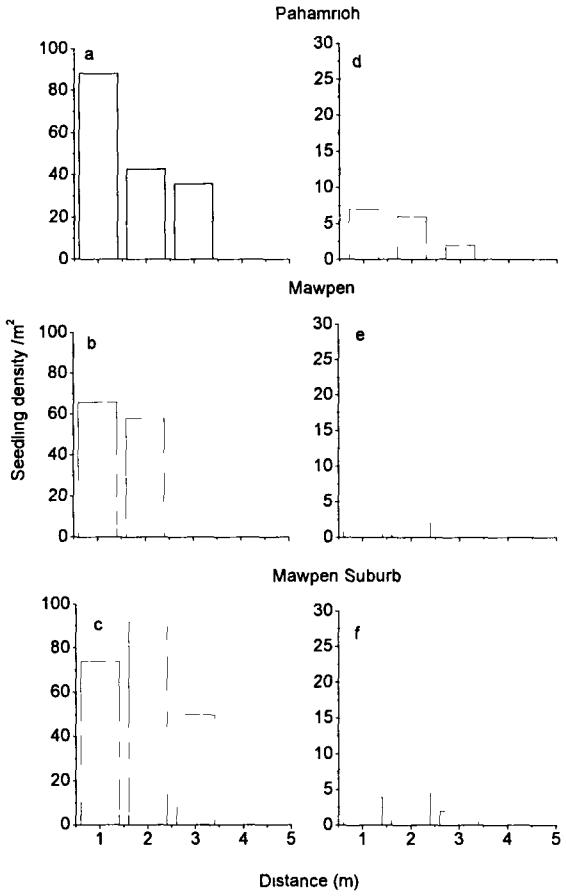


Figure 6.14. Seedling density (m^2) at different distances from the parent tree in cleared plots (a, b, c) and non-cleared plots (d, e, f) during autumn at three sites.

Seedling vigour

The growth attributes of seedlings such as root length, shoot length, number of leaf and leaf area between the three sites did not show a common trend in relation to seed weight (Figure 6.15).

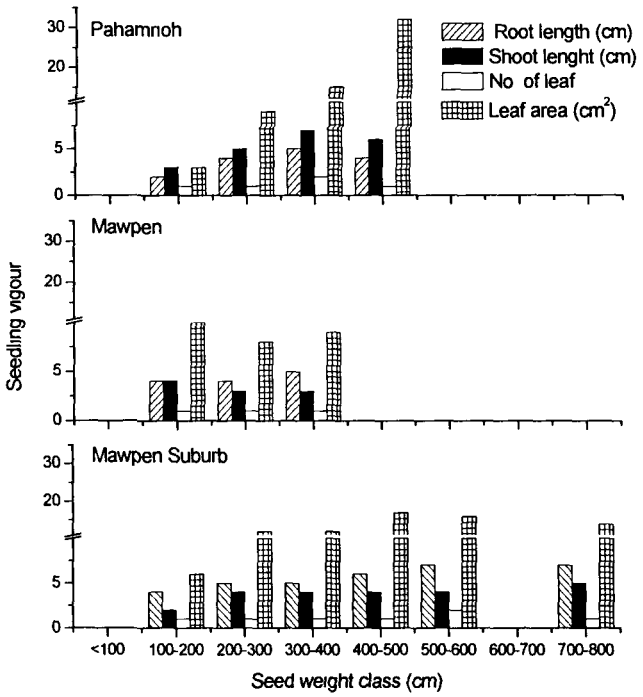


Figure 6.15. Seedling vigour in different with seed weight classes a six months from germination for the three study sites.

Seedling vigour parameters such as root length, shoot length, collar diameter, number of leaves and leaf area showed greater values for Mawpen Suburb than Mawpen both in 2003 and 2004 (Figure 6.16).

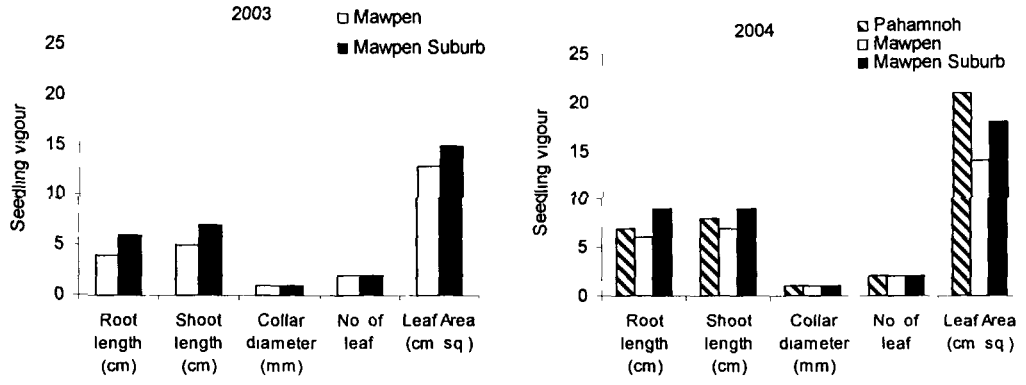


Figure 6.16. Seedling vigor parameters at six months after germination for the three sites in 2003 and 2004.

In 2004, the seedling vigour was higher at both Mawpen Suburb and Pahamrioh to that of Mawpen. Seedling vigour was significantly higher (p =0.05) in field than in greenhouse conditions, both in 2003 and 2004 (Figure 6.17).

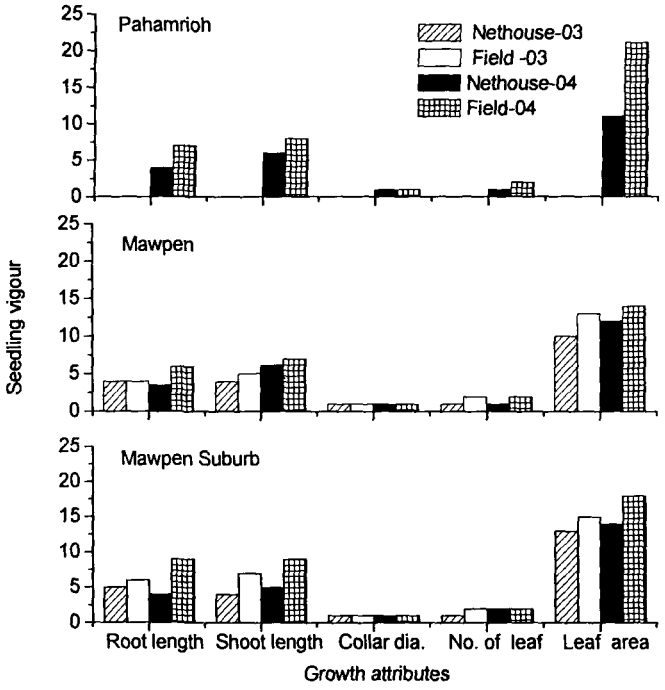


Figure 6.17. Seedling vigor in field and greenhouse three months after germination for three sites in 2003 and 2004.

Discussion

C. tamala reproduces sexually between April and October. The flowering activity shows a distinct peak in May and the fruit maturation peaks in August. These activities are temporally synchronous with the second leaf flush. The allocation of resources to fruit as well as leaf production at the same time during rainy season suggests the efficiency of the species in resource utilization during rainy season (Van Schaik *et al.* 1993). However, it could be that the second phase of leaf flush is devised as a strategy for supporting the reproductive process by increasing the photosynthetic

area for resource production. However, such a the process could also be responsible for the poor regeneration of the species by diverting the resources for reproductive process to vegetative process (Hall and Bawa 1993)

The individuals harvested for bay leaf expressed a significant decline (<35%) in recurrence of flowering in the subsequent year at Mawpen and Mawpen suburb. The inflorescence predominantly occurs in sub-terminal position in *C. tamala* following Rauh's model of tree architecture (Richards 1996). Hence, removal of the 2^{nd}, 3^{rd} and 4^{th} order branches for harvest of bay leaf results in severe loss of the reproductive sites. The magnitude of reduction in recurrence of flowering however depends on the method of harvest and the quantities of harvest.

Flowering of *C. tamala* was sporadic, i.e., not all trees flowered every year at any of the sites. Tropical trees are known to produce mast fruiting events at regular intervals with lower reproductive activity in intermittent years. In the present study, reduction in flowering is due to the impact of bay leaf harvest. However, the harvested trees tend to show improved flowering at least one year after harvest. The incidence of flowering was skewed towards the younger individuals at Pahamrioh and towards the mature individuals at Mawpen and Mawpen Suburb.

In 2003, the reproductive success was high at Mawpen Suburb (93%) as well as at Mawpen (83%). The reproductive output declined in 2004 due to the harvest of bay leaf. It was observed that 50% to 70% of immature fruits aborted due to the incidences of heavy rainfall in 2004. At Pahamrioh, reproductive success was high (71%) in 2004. Janzen (1971) considered abundant seed production and mast fruiting at long and irregular intervals as a means to escape and satiate predators in many rainforest species. In the present study, predation was absent and most seeds were healthy on the forest floor at the three sites and in both the study years. Hence, the sporadic and significantly variable flowering and fruiting activity in *C. tamala* is

probably not because of mast fruiting, but due to bay leaf harvest. The presence of secondary compounds such as lauric acid in the seeds could result in warding off the predators (Anonymous 1950).

Flower and fruit production was positively correlated with the girth and the height of trees. With an increase in girth, the number of branches increases which results in an increase in reproductive sites. Barik *et al.* (1996) have reported an increased seed production with increasing age of the trees as well as with increasing intensity of disturbance in subtropical humid forests of Meghalaya. Khan *et al.* (2005) have also reported similar results for rudraksh (*Eleaocarpus ganitrus*) from Arunachal Pradesh.

The mean weight of *C. tamala* seeds varied significantly between the sites and between the study years, but it remained within a range of 200 to 300 mg per seed. Although the flower and fruit production was correlated with the girth of the parent tree, seed weight was independent of girth size of the parent tree.

Nonetheless, there was a significant variation in seed weight within the trees. Most within species variation in seed weight occurs within plants rather than among plants or populations indicating environmental effects rather than genetic differences between mothers play an important role in varying seed size (Obeso 1993, Vaughton and Ramsey 1998). Within species, seed size typically spans less than four-fold (Micheals *et al.* 1988). Uma Shankar (2006) reported more than five-fold variation in seed weight and less than two-fold variation in diameter in *Dipterocarpus macrocarpus*. *C. tamala* showed seven-fold variation in seed weight with the highest value of 751mg produced by an adult tree at Mawpen Suburb and the lowest value of 28 mg produced by a young tree at Pahamrioh.

Given the architecture of *C. tamala* trees, small crown and absence of efficient dispersal mechanism, most seeds were shed under the canopy and within a distance of 4 m from the tree trunk. The regeneration of a tree species is largely influenced by the

gap phase as well as the dispersal mechanism of the species in forests (Watt 1947, Runkle 1990). *C. tamala* produces most seeds with small variation in weight and disperses seeds within small distances of parent tree in moisture laden rainy season which results in the formation of a seedling carpet under the tree canopy. Germination success was as high as 91% in greenhouse as compared to 70% in the field. Likewise, survival was >50% in greenhouse as compared to 10% in the field during the first year of study.

Interestingly, the germination potential was highest in the 200-300 mg seed weight class at all sites. Most seeds that germinated and survived belonged to this class. Hence, it can be said that the reproductive strategy in *C. tamala* follows the prediction of Smith and Fretwell (1974). A key prediction of the model is if a mother plant is in a position to allocate more resources to seed output, it should produce more seeds of same size to maximize the chances of seedling establishment. The significance of such a reproductive strategy is that the seedling survival would be due to a chance factor and not because of selection of the fittest, i.e., each seed would have an equal chance of germination and survival depending on acquisition of favorable niches. The influence of chance factor on the survival of the seedlings is further strengthened by the significantly higher germination and survival of seedlings in greenhouse than in field conditions. Growth parameters of seedlings grown in the greenhouse exhibited a positive relationship with the seed weight. This is in conformity with many tree species such as oaks (Tripathi and Khan 1990), *Mesua ferrea* (Khan *et al.* 1999), *D. macrocarpus* (Uma Shankar 2006).

Mass mortality of seedlings (>90%) coincided with the onset of winter at the three study sites and during both the years of study. Seedling mortality was higher during the first year as compared to the second year exhibiting a stair-step survivorship curve. It is a characteristic feature in tropical forests where seedling abundance varies

from one time of the year to the other (Richards 1996, Ng 1978). The survival of tree seedlings depends principally on moisture, temperature, light regimes, microsite heterogeneity, nature of soil and competition from established species in the surrounding vegetation (Bazzaz and Pickett 1980, Schultz and Marshall 1983, Gunatilleke and Gunatilleke 1998). Jamir (2000) reported high seedling mortality of *C. tamala* from a subtropical scared grove of Urkhla, Meghalaya due to soil moisture stress and low ambient temperature. Burdon and Chilvers (1976) have opined that crowded seedlings suffer disproportionately greater seedling mortality. Veenendaal *et al.* (1996) have stressed that aboitic stress factors such as shade, excess light, heat, water stress, flooding and drought may not kill seedlings immediately, but lower their tolerance to biotic mortality agents such as herbivores and pathogens. In *Litsea cubeba* Pers., Baruah and Nath (1998) observed high germination percentage (91.3%), low viability (3-4 weeks) and high seedling mortality due to soil moisture stress in winter.

The seedling density was higher in the cleared plots as compared to the non-cleared plots at the three sites, suggesting that they suffer from resource competition from the herbaceous associates. Tripathi and Khan (1990) have reported similar results where the emergence, survival and growth of seedlings were highest in the plots devoid of litter and herbaceous cover, and were lowest in the control plots that were not cleared. Jain (1996) showed an improvement in natural regeneration in *Pterocarpus santalinus* by removing *Cymbopogon coloratus* grass which was the main herbaceous competitor and enhancer of ground fire.

C. tamala seeds failed to germinate undersurface in greenhouse suggesting that seed burial is an abiotic stress in this species. Large seeds are considered to be better equipped to overcome such stress (Seiwa and Kikuzawa 1996, Grubb and Metcalfe 1996). Although some small seed species (<1 mg) in rainforests are very shade-

tolerant, large seeded species are consistently associated with shaded habitats (Grubb and Metcalfe 1996). Hence, it is possible that *C. tamala* seeds suffer from restricted illumination under soil surface. Khan and Tripathi (1989) observed that the interacting influence of light and soil moisture plays a crucial role in regeneration and population growth of *Alnus nepalensis, Quercus griffithii* and *Schima khasiana* in forests of Meghalaya.

Seedling vigor was higher in the field than in the greenhouse for all three sites. Barik *et al.* (1996) have reported that an alteration in the forest microclimate and microsite characteristics, consequent upon exposure of the forest floor to insolation, favours both seed production and germination in the shade-intolerant *Schima khasiana. C. tamala* being a sub-canopy or moderate shade tolerant species shows light dependency for germination and early growth. In absence of a canopy at Mawpen, *C. tamala* also exists as an adult stage in full illumination. Hence, it is possible that *C. tamala* belongs to the guild of 'cryptic pioneers' that require full light for germination, establishment and early growth, but can continue to grow below canopy shade (Hawthorne 1993, Oldeman and Dijk 1991).

Conclusions

The phenology of *C. tamala* exhibited a single peak for flowering and fruiting, but an additional peak for leaf flush. The fruits and seeds mature in the rainy season when moisture is abundant in the soil. The seeds show a recalcitrant behaviour and germinate quickly after dispersal. Germination of seeds is very good. Although the mean seed weight varies with the site and within the study years, a lower mean seed weight was observed in the year after harvest of bay leaf from *C. tamala* trees, indicating a possibility that the harvest could impact mean seed weight. An increase in mean seed weight showed an increase in seedling vigour. However, most seedlings in

the field died soon after germination during the ensuing winter. The death of the seedlings was mainly due to moisture stress in the soil during winter months. Besides, cultural practices such as sweeping the forest floor for drying of harvested bay leaf and hoeing for cultivation of other associated agricultural crops, were responsible for the mortality of recruited *C. tamala* seedlings. Also, density-dependent mortality of seedlings is a possibility as most seeds fall under the canopy of the parent tree and form a carpet of seedlings. Light could be the limiting factor under parent canopy affecting seedling survival. Hence, the seed production and seed germination is good in *C. tamala*, but seedling establishment is poor due to mortality induced by both environmental and anthropogenic factors.

Chapter VII

Sustainability of current harvest practices and trade of bay leaf

The role of non-timber forest products (NTFPs) in enhancing rural income and conserving biodiversity has been reported from many quarters of the world (May 1991, Gillis 1992, Bawa and Gadgil 1997, Hegde *et al.* 1996, Uma Shankar *et al.* 1996, Ros-Tonen 2000, Zuidema and Boot 2002, Rai 2004). Most workers have expressed their concern for the sustainability of harvest practices that adversely affect the population structure and yield of the produce (Murali *et al.* 1996, Uma Shankar *et al.* 1996, 1998 a, b, Ganeshaiah *et al.* 1998, Ticktin 2004, Endress *et al.* 2003, 2004).

In Meghalaya, bay leaf is an important NTFP harvested from *C. tamala* trees. However, there are no studies to suggest that if the quantities of bay leaf harvested are sustainable and if the sustainable harvests can continue in future. A decline in *C. tamala* populations (low risk-near threatened category) in natural forests is often talked about. It is also not clear if the market demand of bay leaf is instrumental in decline of the populations in natural forests. It is therefore imperative to engender the knowledge of the sustainability of harvest practices of bay leaf.

The harvest levels of an NTFP are largely determined by its demand in the market and efficiency of marketing channels (Pinedo-Vasquez *et al.* 1990, Uma Shankar *et al.* 1998 a, b, Te-Velde *et al.* 2006, Viet Quang and Namanh 2006). The market demand often leads to un-sustainable harvests in quest of earning more money. To assess the sustainability of bay leaf harvest, it is equally important to study the trends of bay leaf

collection and trade, seasonal fluctuations in prices, marketing channels and agencies networking the trade.

Methodology

Sustainability of bay leaf harvest practices

The harvest practices prevalent at the three sites were recorded during the harvest seasons in 2003 and 2004. Processing of bay leaf following harvest and the procedures for packaging were obtained from ten collectors at each site through a questionnaire.

For determining sustainability of bay leaf harvest, leaf area index (LAI) of the trees that were subjected to harvest was measured twice, i.e., prior to the harvest and following harvest. The change in leaf area index indicated the intensity of harvest. These trees were observed throughout the ensuing growth seasons until the next harvest. The development of the canopy and increase in leaf area index during this period indicated recovery. Leaf area index was determined again prior to harvest and following harvest. It is argued that the leaf area index of a tree is considered restored if it attains pre-harvest levels before the next harvest and these harvest levels may be considered sustainable (Godoy and Bawa 1993, Ticktin 2004). Hence, if harvest is annual, pre-harvest levels should be restored in a year's time.

The impact of harvest practices on *C. tamala* population was measured by recording the change in foliage of tagged trees after harvest in 2003 and 2004 at all three sites. A total of 12 trees were measured at Pahamrioh, 20 trees at Mawpen and 21 trees at Mawpen Suburb. The measurements 'before harvest' were taken in November and those 'after harvest' in December of 2003 and 2004. The leaf area index was measured by a Plant Canopy Analyzer Model LAI-2000 from LICOR. Measurements were taken under individual trees at four cardinal points at a distance of 1 m from the tree bole. LAI-2000

uses fisheye light sensor that measures diffuse radiation simultaneously in five distinct angular bands about the zenith point. Readings were taken in mornings to avoid increase in the sensors' below canopy readings due to scattering of light from sunlight foliage. For making the reference readings a narrow view cap of 45° was used at the three sites. The sensor consists of five photodiodes whose active surfaces are arranged in concentric rings. The image of its hemispheric view is projected onto these rings, allowing each to measure the radiation in a band at a known zenith angle. An optical filter restricts transmitted radiation to below 490 nm, minimizing the contribution of light that has been scattered by foliage. Though LAI nominally means 'leaf area index', it is to be noted that the LAI-2000 measures all light blocking objects, so it is more appropriate to consider the measurements as 'foliage area index'. The mean values represent the foliage cover per unit ground area and is expressed as m^2 foliage/ m^2 ground area.

Branching pattern and damage

Damage of branches due to harvest of leaf, flower, fruit may seriously impact regeneration and growth of NTFP species (Ticktin 2004). Hence, an attempt was made to quantify the damage of branches due to harvest practices at three sites. Further, the branching pattern of trees was studied to establish whether there was any variation in branching pattern as a result of the harvest procedures at the three sites. To study the branching pattern and branch damage of *C. tamala* trees, six trees were tagged at each site. The gbh (cm) and height (m) of the tagged trees were measured and their architectures were drawn on scaled dimensions. The number of main branches (first order), second order branches and third order branches (branchlets) were counted. The smaller branches of 4^{th} and 5^{th} order (usually less than 10 cm girth) were excluded from

the count. The number of cut branches for each tree was recorded. The sum of intact branches and cut branches represented total branches. A relationship between the girth and the numbers of branches of sampled trees was worked out using regression analysis for three sites. The percentage damage of a tree was calculated as a proportion of cut branches to total branches.

Trade of bay leaf

The market channel of bay leaf was followed from the point of origin to the end-consumer. All possible routes involved in the network were monitored. At each point of collection and/or trade, information on selling price and costs incurred was obtained from 5-10 resource persons through a questionnaire (Marshall and Newton 2003). The outgoing quantities from meghalaya were recorded at Burnihat check gate. A flow chart was developed to depict the marketing network of bay leaf. Quantities of collection of bay leaf from 1996 to 2005 were recorded from trade registers of the Mecofed Regulated Market, Mawoing, East Khasi Hills, Shillong. The mean monthly minimum and maximum selling price of bay leaf was also recorded from Mecofed and other markets for two years, i.e., from September 2003 to September 2005. The average revenue generated from bay leaf sale was calculated as a product of the average price (in Rs. kg^{-1}) and the quantities of bay leaf collection for each month.

Results

Bay leaf harvest practices

Bay leaf harvest begins in November and continues up to February. However, in some villages harvest begins as late as in January.

The pattern of bay leaf harvest varied at the three sites (Table 7.1). At Pahamrioh, few branches from almost all trees are harvested in alternate years. At Mawpen, many branches are harvested from many trees every year. At Mawpen Suburb, many branches are harvested from only selective trees every year.

Table 7.1. Bay leaf harvest practices at three sites.

Site	Frequency of harvest	Method of harvest
Pahamrioh	Alternate year	Many trees, few branches
Mawpen	Every year	Many trees, many branches
Mawpen Suburb	Every year	Few trees, many branches

In general, lower order branches are cut from the trees and left on the ground for 2 to 3 days for moisture loss (Plate 7.1). The colour of the leaves turns whitish-green during drying (Plate 7.2). Sometimes, higher order branches are also cut and this is most frequent at Mawpen where the main trunk of many trees has been cut at about 8-10 m height (Plate 7.3). The leaves are plucked manually from branches by hand with the help of a cloth that is run along the length of the branch (Plate 7.1). The plucked leaves are packed either in cane baskets as at Pahamrioh or in jute sack as at Mawpen and Mawpen Suburb. The leaves are compress-packed to save space. The farmers have developed skills for rapid compression of leaves within the sacks (Plate 7.4). At Mawpen and Mawpen Suburb, a square frame of wood logs is erected and a sack is hung such that it is located at the center of the frame with its open-end upright. The leaves are filled in the sack and compressed by stick beats. The sacks are sealed with cane sliver. About 40 to 42 kg leaves are packed in each sack. The farmers keep an account of the quantities collected. The collected quantities of bay leaf are ready for transport and sale.

Plate 7.1. Bay leaf harvest.

Plate 7.2. Air drying of bay leaf.

Plate 7.3. A heavily harvested *C. tamala* tree.

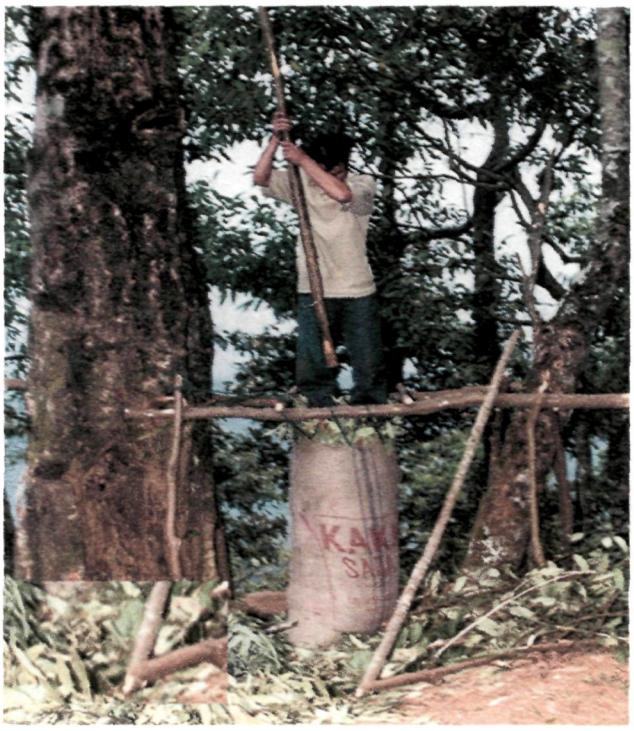


Plate 7.4. Packing bay leaf in the field.

Impact of bay leaf harvest

The impact of bay leaf harvest was quantified on *C. tamala* trees. A total of 12 trees at Pahamrioh, 20 trees at Mawpen and 21 trees at Mawpen Suburb could be selected (Table 7.2). The leaf area index (LAI) of individual trees was a strong indicator of the impact of leaf harvest. Leaf area index was measured before harvest in November 2003 and following harvest in December 2003. The decline in LAI from November to December indicated the impact of bay leaf harvest. The harvested trees recuperated in the ensuing growth season and regained vigour. The period between December, 2003 and November 2004 indicated the growth or recovery period. Hence LAI was measured in November 2004 just prior to the harvest season and in December 2004 after bay leaf harvest.

Table 7.2. Leaf area index (m^2 foliage / m^2 ground area) of trees before and after bay leaf harvest in 2003 and 2004.

Tree number	Before harvest (November 2003)	Without harvest (December 2003)	Before harvest (November 2004)	After harvest (December 2004)
		Pahamrioh		
1	6.16 ± 0.34	6.41 ± 0.42	8.32 ± 0.42	4.23 ± 0.55
2	6.79 ± 0.74	6.98 ± 0.94	8.45 ± 0.75	5.33 ± 0.71
3	4.56 ± 0.38	5.11 ± 0.74	7.44 ± 0.26	3.21 ± 0.68
4	5.44 ± 0.80	5.56 ± 0.82	6.99 ± 0.68	3.33 ± 0.46
5	6.66 ± 0.69	6.86 ± 0.73	8.21 ± 0.67	4.23 ± 0.26
6	1.91 ± 0.32	2.10 ± 0.15	3.84 ± 0.46	2.33 ± 0.29
7	2.89 ± 0.80	3.23 ± 0.33	1.98 ± 0.34	3.50 ± 0.40
8	2.36 ± 0.90	2.63 ± 0.61	4.63 ± 0.26	3.96 ± 0.80
9	1.93 ± 0.68	2.14 ± 0.62	3.76 ± 0.45	2.13 ± 0.79
10	1.34 ± 0.44	1.56 ± 0.96	2.63 ± 1.35	2.81 ± 0.87
11	0.99 ± 0.92	1.22 ± 0.98	3.72 ± 0.52	2.04 ± 0.93
12	2.27 ± 0.64	2.46 ± 0.74	3.88 ± 0.49	2.65 ± 0.72
		Mawpen		
1	4.30 ± 0.61	4.32 ± 0.69	4.82 ± 1.14	3.52 ± 0.56
2	12.34 ± 0.79	8.72 ± 0.73	8.80 ± 0.69	7.90 ± 0.96

3	9.15 ± 1.01	3.30 ± 0.66	4.30 ± 1.40	3.00 ± 0.26
4	3.81 ± 0.63	2.30 ± 0.83	2.40 ± 0.17	2.50 ± 0.24
5	7.26 ± 0.17	4.60 ± 1.11	5.60 ± 0.63	2.25 ± 0.33
6	6.33 ± 0.79	4.64 ± 0.53	5.94 ± 1.16	3.94 ± 1.09
7	4.61 ± 0.49	2.00 ± 0.41	3.3 ± 0.66	3.35 ± 0.51
8	4.75 ± 0.50	4.84 ± 1.13	6.14 ± 0.43	4.64 ± 0.68
9	6.27 ± 0.74	5.90 ± 1.11	6.10 ± 0.16	4.60 ± 0.72
10	1.58 ± 0.36	1.34 ± 0.09	4.34 ± 1.20	3.04 ± 1.04
11	6.00 ± 0.91	5.39 ± 0.85	7.39 ± 1.05	3.89 ± 0.91
12	5.97 ± 0.66	4.16 ± 0.49	4.23 ± 0.68	4.16 ± 0.63
13	8.21 ± 0.91	5.25 ± 0.64	6.70 ± 0.94	1.50 ± 0.03
14	3.72 ± 0.48	2.51 ± 0.22	3.81 ± 0.16	2.31 ± 0.75
15	3.74 ± 0.45	0.82 ± 0.15	2.12 ± 0.13	2.22 ± 0.15
16	5.64 ± 0.36	3.51 ± 0.45	4.81 ± 1.11	3.71 ± 1.14
17	4.89 ± 0.95	1.92 ± 0.63	3.22 ± 0.39	1.82 ± 0.46
18	11.07 ± 0.62	6.99 ± 0.96	8.29 ± 0.69	5.79 ± 0.92
19	12.18 ± 0.83	2.92 ± 0.84	4.22 ± 1.40	3.02 ± 0.64
20	6.61 ± 0.86	4.67 ± 0.51	5.97 ± 0.72	3.87 ± 0.22
		Mawpen Suburb		
1	5.99 ± 0.84	3.99 ± 0.56	4.01 ± 0.23	4.06 ± 0.55
2	5.70 ± 0.66	3.70 ± 1.10	4.62 ± 1.01	4.72 ± 0.84
3	3.01 ± 1.02	3.01 ± 1.02	3.75 ± 0.55	3.81 ± 1.01
4	10.81 ± 0.81	4.81 ± 0.46	5.43 ± 0.31	5.50 ± 0.42
5	11.11 ± 0.45	6.11 ± 0.66	6.88 ± 1.06	3.56 ± 1.11
6	1.52 ± 0.19	1.58 ± 0.19	2.25 ± 0.92	2.35 ± 0.90
7	7.27 ± 0.49	7.32 ± 0.46	7.54 ± 0.86	3.22 ± 0.33
8	6.16 ± 0.34	6.06 ± 0.36	6.90 ± 0.96	3.43 ± 0.51
9	8.69 ± 0.47	4.09 ± 0.21	4.40 ± 0.32	4.46 ± 1.00
10	11.95 ± 0.87	7.95 ± 0.95	8.87 ± 0.37	4.87 ± 0.49
11	9.39 ± 0.65	3.39 ± 0.66	3.43 ± 0.92	3.53 ± 0.51
12	6.41 ± 0.53	4.41 ± 0.70	4.55 ± 1.00	4.46 ± 0.45
13	9.10 ± 0.62	4.06 ± 0.47	5.10 ± 0.33	3.10 ± 0.40
14	11.53 ± 1.20	5.53 ± 0.63	6.29 ± 0.78	4.29 ± 0.50
15	11.82 ± 0.87	5.32 ± 1.21	6.16 ± 0.63	3.93 ± 0.83
16	12.35 ± 0.89	4.35 ± 0.45	5.13 ± 0.33	3.02 ± 0.66

17	4.57 ± 0.63	3.87 ± 0.52	4.12 ± 0.62	4.19 ± 0.95
18	4.33 ± 0.45	4.33 ± 0.60	4.87 ± 0.40	4.93 ± 1.05
19	13.18 ± 0.66	13.25 ± 0.96	13.82 ± 0.94	4.82 ± 0.46
20	9.78 ± 0.40	5.78 ± 0.86	6.67 ± 0.77	4.67 ± 0.93
21	5.81 ± 0.62	5.87 ± 0.69	5.90 ± 0.74	6.01 ± 0.63

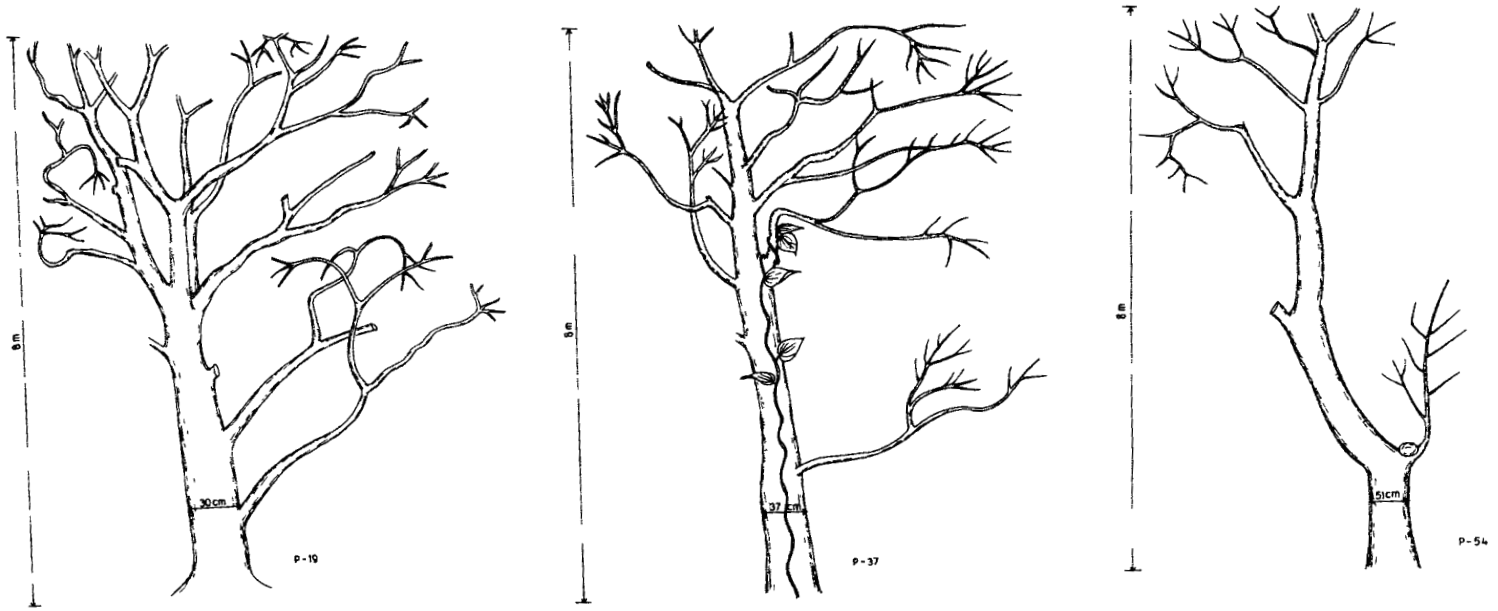
Bay leaf harvest was not carried out at Pahamrioh in 2003 resulting into a marginal increase in leaf area index (Table 7.3). At Mawpen and Mawpen Suburb, leaf area index declined by nearly 37% due to bay leaf harvest in 2003 (Table 7.3). The increase in foliage during growth period in 2004 varied markedly among three sites (Table 7.3). At Pahamrioh where bay leaf harvest was not done in 2003, the increase in leaf area index was maximum, i.e., about 36%. This was followed by Mawpen with 29% increase in leaf area index and Mawpen Suburb with only 12% increase in leaf area index (Table 7.3). In 2004, leaf harvest resulted in a decline in leaf area index at all sites (Table 7.3). Almost 38% leaf area index was lost at Pahamrioh, 31% at Mawpen and 28% at Mawpen Suburb.

Table 7.3. Mean leaf area index (m^2 foliage/ m^2 ground area) before and after bay leaf harvest in 2003 and 2004 at three sites.

Site	LAI in November 2003 (mean ±sd)	LAI in December 2003 (mean ±sd)	Change in LAI (%)	LAI in November 2004 (mean ±sd)	Change in LAI (%)	LAI in December 2004 (mean ±sd)	Change in LAI (%)
Pahamrioh	3.60 ± 2.16	3.90 ± 2.17	+8.3*	5.30 ± 2.38	35.5	3.30 ± 0.99	-37.7
Mawpen	6.10 ± 2.90	3.80 ± 1.96	-37.7	4.90 ± 1.82	28.9	3.40 ± 1.47	-30.6
Mawpen Suburb	8.12 ± 3.36	5.18 ± 2.35	-37.2	5.78 ± 2.40	11.6	4.14 ± 0.88	-28.4

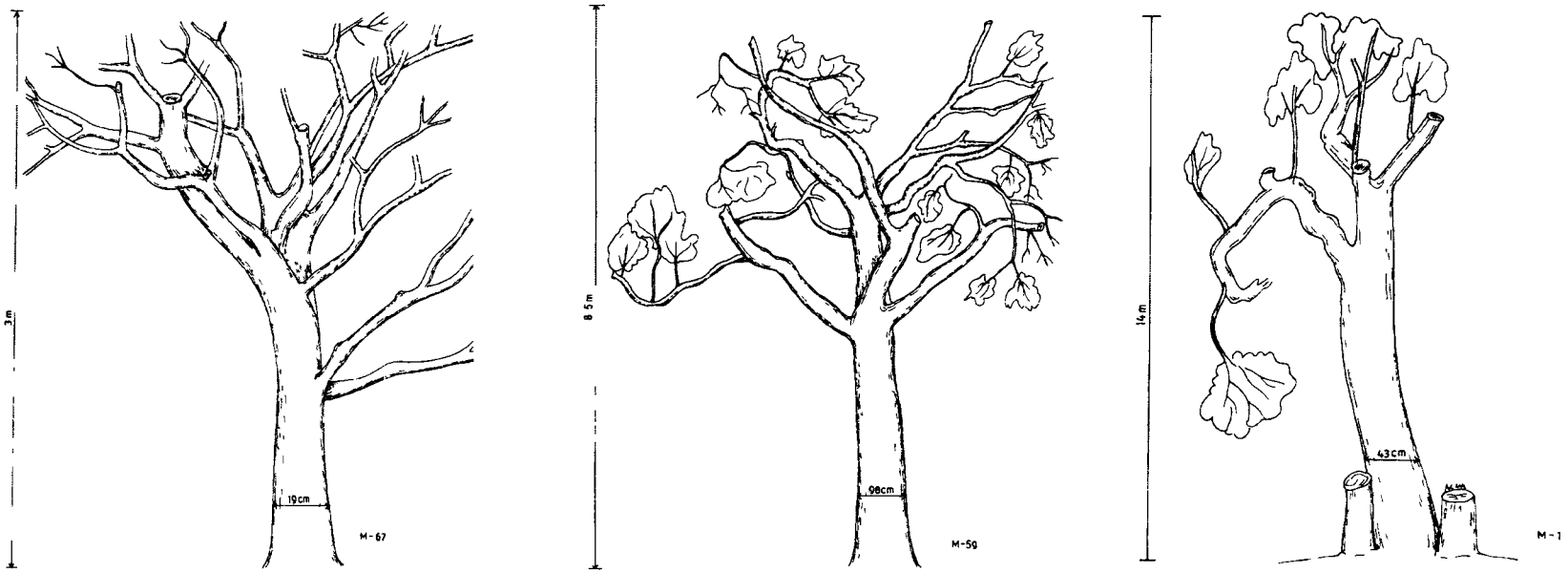
* Harvest of bay leaf was not done at Pahamrioh in 2003

The impact of different intensities of bay leaf harvest on tree architecture is shown at Pahamrioh (Figure 7.1), Mawpen (Figure 7.2) and Mawpen Suburb (Figure 7.3).



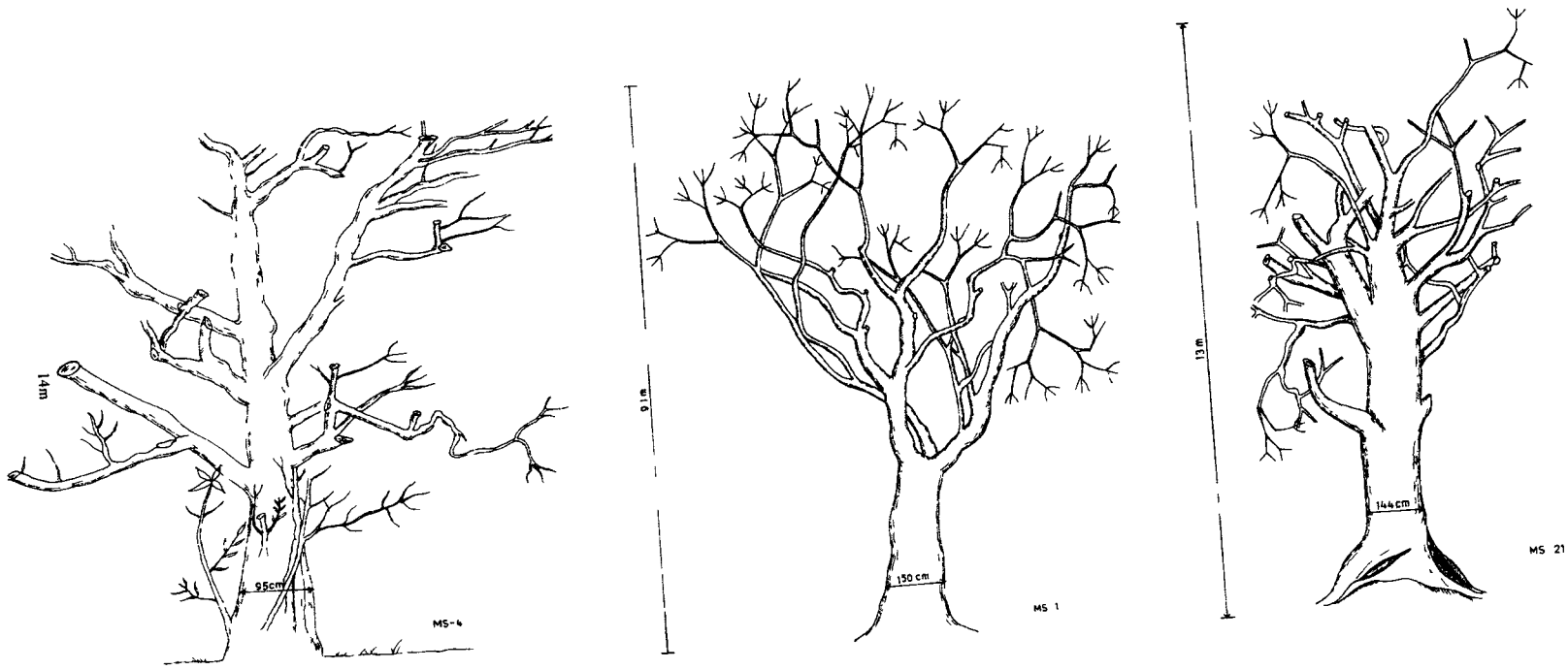
Low Moderate High

Figure 7.1. Impact of different intensities of bay leaf harvest on tree architecture at Pahamrioh.



Low Moderate High

Figure 7.2. Impact of different intensities of bay leaf harvest on tree architecture at Mawpen.



Low Moderate High

Figure 7.3. Impact of different intensities of bay leaf harvest on tree architecture at Mawpen Suburb.

Branching pattern and damage

With the monopodial branching and sub-terminal position of the inflorescence, *C. tamala* trees resembled Rauh's model of tree architecture (Halle and Oldeman 1970). Younger trees at Pahamrioh (Plate 7.1) followed the Rauh's model more closely than adult trees at Mawpen (Plate 7.2) and Mawpen Suburb (Plate 7.3). A moderately harvested tree of 130 cm gbh and 8 m height at Mawpen Suburb (Table 7.4) was not characteristically monopodial in its branching pattern (Plate 7.3). However, the phenology of the tree was similar to the other trees in the population.

The mean girth of the tagged trees for studying the branching pattern increased from 29.8 ±14 cm at Pahamrioh to 82 ±36 cm at Mawpen and 110 ±26 cm Mawpen Suburb (Table 7.4). The mean height of these trees was 6.4 ±2 m at Pahamrioh, 5.9 ±3 m at Mawpen and 10.6 ±2 m at Mawpen Suburb (Table 7.4). The mean of total number of branches per tagged tree increased from 27 at Pahamrioh to 39 at Mawpen and 63 at Mawpen Suburb. Similarly, the mean number of cut branches increased from 2 at Pahamrioh to 8 at Mawpen and 12 at Mawpen Suburb. The percent damage of branches (ratio of cut branches to total branches) was maximum at Mawpen (21%), followed by Mawpen Suburb (19%) and Pahamrioh (8%). Most trees at all sites followed a pattern of branchlets (3^{rd} order) >sub-branch (2^{nd} order) >main branch (1^{st} order) (Table 7.4).

The tree girth did not show a significant relationship branches and branch damage at Pahamrioh (Table 7.5). At Mawpen, tree girth showed a significant negative correlation with all branches and branchlets. At Mawpen Suburb, tree girth had significant negative correlation with sub-branches (Table 7.5). However, the relationship of branch damage to tree girth was significantly positive only at Mawpen (Table 7.5).

Table 7.4. Branching pattern of *C. tamala* trees at three sites.

Number of trees	Girth (cm)	Height (m)	Main branch	Sub-branch	Branch-let	Cut branchlets
			Pahamrioh			
1	37	8	1	10	27	3
2	18	3	1	2	5	1
3	30	8	2	13	35	4
4	12	4	1	13	48	1
5	52	8	1	14	23	1
6	30	7.5	2	6	9	2
Total	179	38.5	10	58	147	12
Mean	29.8	6.4	1.7	9.7	24.5	2
SD	14	2	1	5	16	1
			Mawpen			
1	130	7.5	2	6	0	7
2	80	6	3	15	23	11
3	80	2	2	13	23	9
4	85	8.5	1	6	10	9
5	98	8.5	1	8	25	7
6	19	3	1	10	38	6
Total	492	35.5	10	58	119	49
Mean	82	6	2	10	20	8
SD	36	3	1	4	13	2
			Mawpen Suburb			
1	105	9.1	3	8	46	9
2	144	13	1	13	43	17
3	95	14	1	8	54	16
4	130	8	2	9	40	10
5	70	9	1	5	22	8
6	116	11	1	8	42	12
Total	660	64	9	51	247	72
Mean	110	11	2	9	41	12
SD	26	2	1	3	11	4

Table 7.5. Regression model, correlation coefficient (*r*), and significance level (*p*) explaining relationships between tree girth and branching pattern of *C. tamala* trees at three study sites.

Site	Independent variable (x)	Dependent variable (y)	Sample Size (n)	Regression model	*r*	*p*-level	Significance
Pahamrioh	Girth	All branches	6	y = 0.015x + 1.5529	0.163	<0.05	NS
		Main branch	6	y = 0.003x + 1.3234	0.223	<0.05	NS
		Sub-branch	6	y = 0.1296x + 5.8015	0.385	<0.05	NS
		Branchlet	6	y = -0.2043x + 30.596	0.180	<0.05	NS
		Cut branch	6	y = -0.1893x + 32.149	0.168	<0.05	NS
		Branch damage	6	y = -0.0718x + 12.308	0.156	<0.05	NS
Mawpen	Girth	All branches	6	y = -0.3375x + 67.005	0.776	<0.05	Significant
		Main branch	6	y = 0.0064x + 1.1405	0.120	<0.05	NS
		Sub-branch	6	y = - 0.0385x + 12.823	0.360	<0.05	NS
		Branchlet	6	y = - 0.3141x + 45.588	0.863	<0.01	Significant
		Cut branch	6	y = 0.0087x + 7.4526	0.172	<0.05	NS
		Branch damage	6	y = 0.2841x + 4.1702	0.768	<0.05	Significant
Mawpen Subrub	Girth	All branches	6	y = 0.3367x + 26.127	0.591	<0.05	NS
		Main branch	6	y = 0.0029x + 1.1804	0.091	<0.05	NS
		Sub-branch	6	y = 0.0901x – 1.407	0.913	<0.01	Significant
		Branchlet	6	y = 0.17626x + 22.184	0.427	<0.05	NS
		Cut branch	6	y = 0.071 2 x + 4.1702	0.499	<0.05	NS
		Branch damage	6	y = -0.0099x + 20.087	0.074	<0.05	NS

Trade of Bay leaf

The channel of bay leaf trade is rather straightforward (Figure 7.4). Marketing of bay leaf is predominantly in two ways: regulated marketing wherein the traded quantities are recorded and unregulated marketing wherein the traded quantities are unknown.

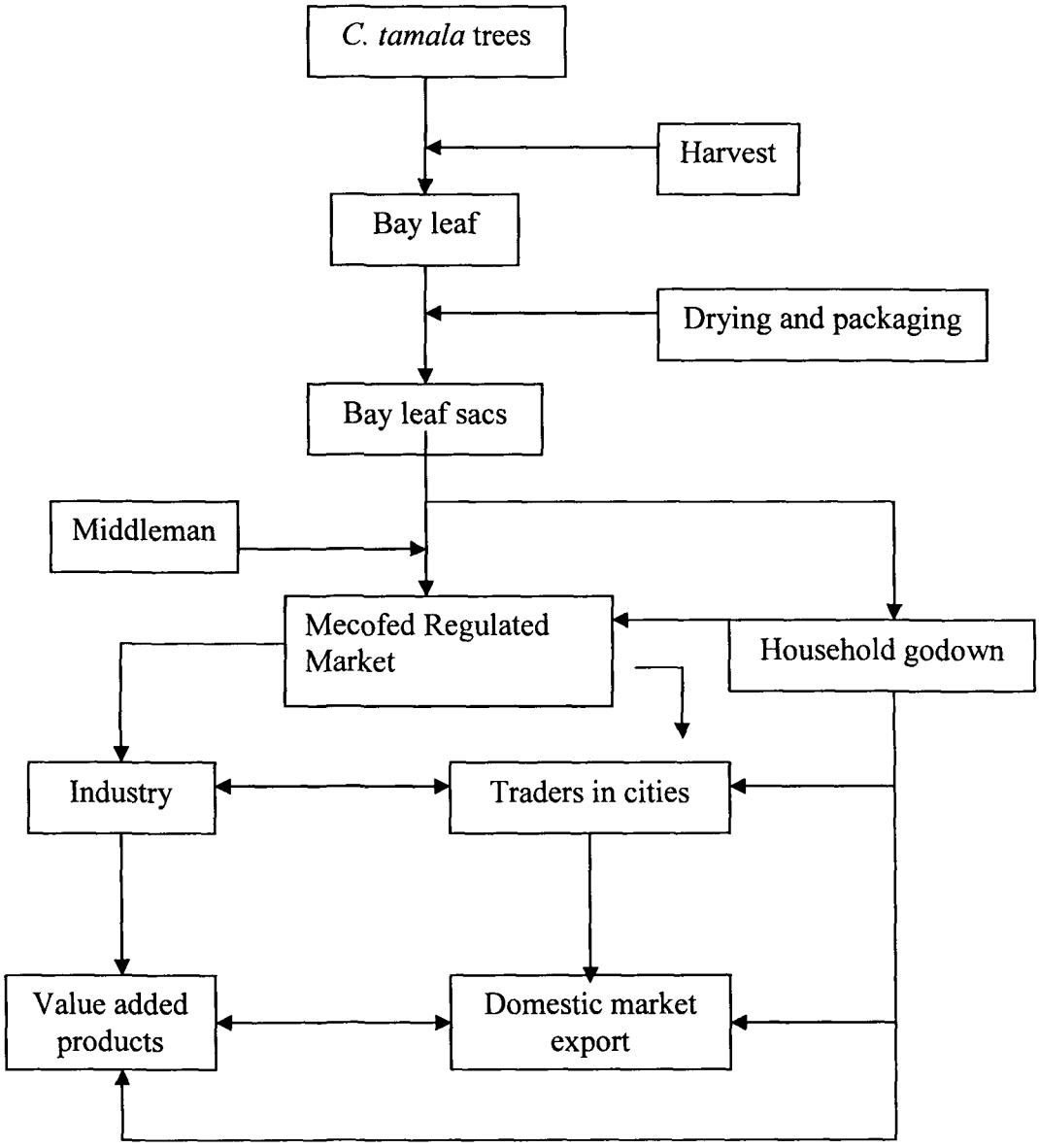


Figure 7.4. Flow route of bay leaf from field to consumer.

In Meghalaya, the State Government established two regulated markets in 1996, namely, Mawiong Regulated Market in Shillong and Garobada Regulated Market in Tura. Mawiong regulates the bay leaf trade in Khasi and Jaintia Hills and Garobada in Garo Hills. These markets were established to improve trade by building a bridge between the villagers and the traders, prevent malpractices of the middleman and extend transit storage facilities and provide a platform for auction of the agricultural and non-agricultural produce. The quantities of bay leaf traded through these regulated markets are officially recorded. In this channel, the farmers sell the collected quantities of bay leaf to the certified agents of the regulated markets (Figure 7.4). These agents then transport bay leaf from collection site to the transit storage facilities and from there to the go-downs of the Mawiong Regulated Market in Shillong. Hereafter, bay leaf is sold to traders outside Meghalaya. A variant of this route may occur when the farmers themselves transport and sell bay leaf to Mawiong Regulated Market in Shillong by-passing the agents. In this process, the sealed bay leaf sacks are brought home from the field and stored until they are sold.

A large chunk of bay leaf is traded by-passing regulated markets (Figure 7.4). Wholesale traders of Shillong and those from outside Meghalaya operate through middlemen who purchase bay leaf from the field and straightaway transport it to the wholesalers. The wholesalers sell a part of the produce to retailers within Meghalaya and major quantities to the wholesale traders outside Meghalaya. A variant of this occurs when farmers directly sell the produce to the wholesalers. Yet another variant is observed when villagers sell bunches of 10-20 twigs of bay leaf to the retail stores or the end-user. The retailer stores sell these bunches to the consumers. Illegal (unregulated) trading of bay

leaf is also reported wherein the villages bordering Bangladesh export bay leaf directly to Bangladesh.

Whether through regulated or unregulated channel, most quantities of bay leaf finally proceed to different destinations in the country. Some important destinations are Delhi, Mumbai, Kanpur, Kolkata, Patna and Bhubneshwar. A part of these quantities is subsequently exported to different countries either as raw bay leaf or after its value addition.

A scientific grading standard for ascertaining the quality of bay leaf is not developed. Nonetheless, the traders have their own grading system based primarily on the origin point of the produce (i.e., geographical location). The bay leaf from high altitudes of East Khasi Hills district is considered the best in quality. The hub of bay leaf production is Mawpen village and its adjoining localities. Other important villages are Nongkhet, Nongjiri, Nongsken, Pahamrioh and Pynursla.

Generally, Grade I and Grade II are the two categories from the sale point of view. Grade II produce may be up to 10% cheaper in comparison to Grade I produce. In traders' parlance, Meghalaya is accredited with the purity of bay leaf quality. In other words, all the produce is derived from a single tree species called *C. tamala*. Other species of the genus such as *C. bejolghota, C. glanduliferum, C. glauscens, C. pauciflorum* are found in Meghalaya and have a chance of being mistaken for *C. tamala* inadvertently. However, the reports of intentional mixing of leaves of other species are not known. Hence, quality consciousness among the local people is a top priority.

Of late, bay leaf trade is improved to add value. Now, the leaves are sorted, packed, weighed and sealed in the regulated market as well as in go-downs of private wholesale

traders. This tenders an assurance of good quality to the purchasers outside Meghalaya and helps fetch better prices. Also, this generates employment to the local people.

Value addition is being achieved by selling small bunches of twigs directly to the end-users. A new trend has begun in which 20-50 g leaves are poly-packed and sold through reputed Departmental Stores in the town especially to target the tourists. A few entrepreneurs have started to add a greater value by exporting bay leaf powder. This is rather on a small scale, but has a vast potential. Blending bay leaf with tea is in experimental stage. Tea cultivation in Meghalaya has picked up especially during last 7-8 years. Some local tea growers are experimenting with development of 'bay leaf tea' with a reasonable shelf-life. Two principal industries consuming bay leaf include spice and condiment industry, and pharmaceutical and cosmetic industry. Every grocery shop in India sells bay leaf invariably as it is an indispensable ingredient in Indian kitchen. Most pharmaceutical laboratories primarily based on Ayurvedic system of medicine, such as Ayur, Baidyanath, Dabur, Hamdard, Vicco and Zandu use bay leaf in their medicinal and cosmetic products. Value addition to bay leaf is telescopic in these industries. Bay leaf harvest yields an important subsidiary product, i.e., the twigs and branches that are sold as fuel wood in the local village markets and the storehouse where leafs are sorted. Generally, a bundle of reasonably dried wood weighing about 30 kg fetches Rs. 15 despite the fact that the rates vary with the season and with the market location.

The quantities of bay leaf traded through Mawiong Regulated Market showed a steady increase from 1997 to 2005 (Table 7.6). This increase has been steep during 2004 and 2005. The traded quantities of bay leaf have grown more than three times, i.e., from 1,466 t in 1996-97 to 4,935 t in 2004-05.

Table 7.6. Quantities of bay leaf (in tones) traded through Mawiong Regulated Market in Shillong during 1997 to 2005.

Month	Year									Mean ± sd
	1997	1998	1999	2000	2001	2002	2003	2004	2005	
January	133.0	507.0	592.5	493.5	622.8	687.4	716.5	913.0	1,091.1	639.6 ± 270.4
February	261.0	426.0	482.5	517.0	645.4	365.1	438.7	743.0	515.2	488.2 ± 143.3
March	257.0	300.0	269.5	336.0	401.5	280.6	343.6	497.3	289.8	330.6 ± 76.9
April	233.0	213.0	159.0	285.0	241.0	231.1	229.0	174.8	183.5	216.6 ± 38.9
May	139.0	191.0	153.0	157.0	310.0	216.9	271.6	241.0	284.5	218.2 ± 62.5
June	132.0	116.0	123.0	141.0	266.3	173.6	203.6	289.0	348.3	199.2 ± 83.7
July	127.0	98.0	115.0	150.0	166.4	142.5	126.3	138.8	273.1	148.6 ± 50.8
August	31.0	71.0	48.5	155.0	106.5	92.7	77.5	151.2	174.7	100.9 ± 50.1
September	12.0	175.0	16.0	91.0	86.7	156.2	125.0	134.0	255.6	116.8 ± 76.9
October	18.7	127.0	14.5	76.0	57.8	87.0	78.0	199.0	264.1	102.5 ± 82.4
November	15.0	78.0	76.0	50.0	14.3	24.5	52.5	191.2	118.6	68.9 ± 57.1
December	117.0	359.0	422.0	363.0	329.0	574.3	551.5	1,065.4	1,136.1	546.4 ± 341.7
All months	1,465.7	2,661.0	2,471.5	2,814.5	3,247.4	3,031.9	3,213.8	4,737.7	4,934.6	
Mean annual for 9 years from 1997 to 2005										3,176.5 ± 1,082.6

There is a marked seasonality in collection quantities of bay leaf. The collection quantities are high during winter months (December to March) with a maximum quantity recorded during December or January (Figure 7.5). Subsequently, these quantities decline steadily with a minimum in November, i.e., just prior to the next year's harvest (Figure 7.5). The export of bay leaf through Burnihat Check Gate followed a similar pattern of seasonality as that of collection (Figure 7.6).

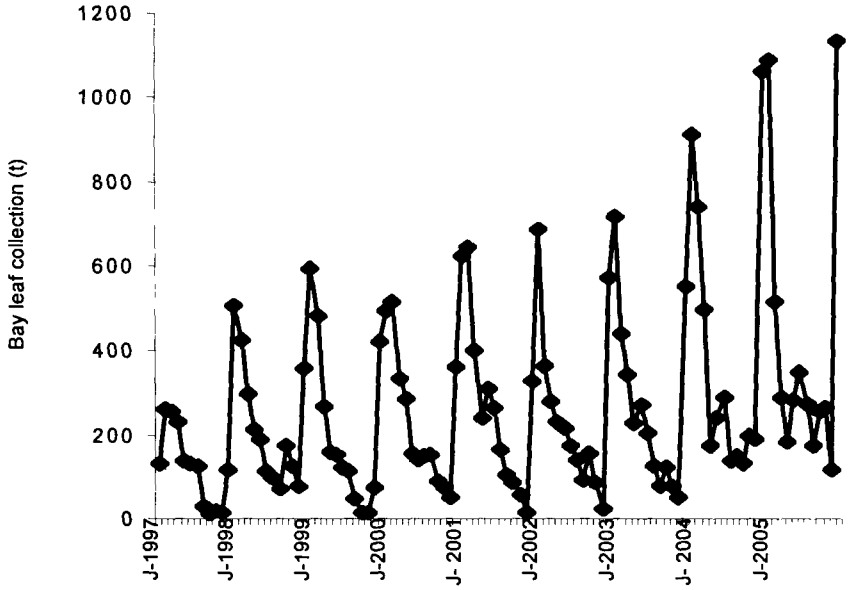


Figure 7.5. Monthly collection of bay leaf at Mecofed between 1997 and 2005.

The maximum selling price of bay leaf was markedly higher at Mecofed than at other markets (Table 7.7). The minimum selling price of bay leaf at Mecofed was lower than that at other markets. The gap between the minimum and the maximum selling price was wider at Mecofed than at other markets (Figure 7.7). The range of fluctuation of selling price for other markets remained within the range of selling price at Mecofed (Figure 7.7). The selling price experiences seasonality and goes down following current years' harvest during January to May and rises again from June to December.

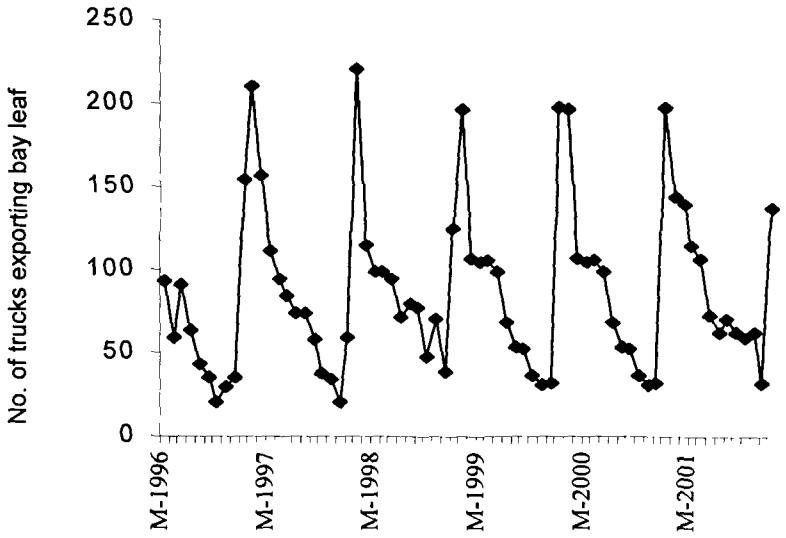


Figure 7.6. Monthly trade of bay leaf through between 1996 and 2001 as recorded at Burnihat Check Gate.

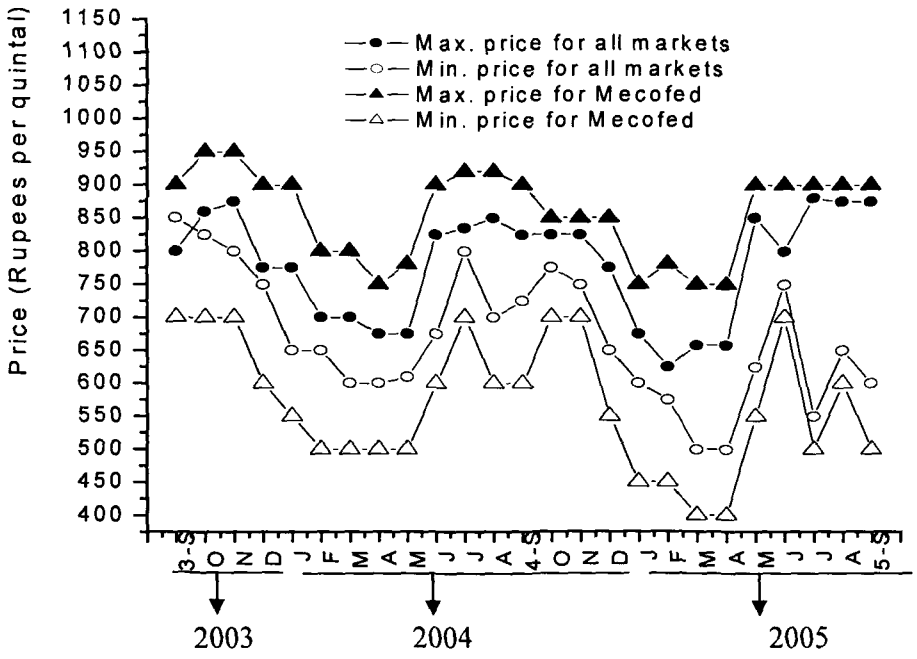


Figure 7.7. Temporal variation in selling price of bay leaf at Mecofed and other markets between 2003 and 2005.

Table 7.7. Mean minimum and maximum price of bay leaf (rupees per quintal) for Mecofed and other markets between 2003 and 2005.

Year / months	Mecofed		Other markets	
	Minimum	Maximum	Minimum	Maximum
September 2003	700	900	750	800
October	700	950	825	860
November	700	950	800	875
December	600	900	750	775
January 2004	550	900	650	775
February	500	800	650	700
March	500	800	600	700
April	500	750	600	675
May	500	780	610	675
June	600	900	675	825
July	700	920	800	835
August	600	920	700	850
September	600	900	725	825
October	700	850	775	825
November	700	850	750	825
December	550	850	650	775
January 2005	450	750	600	675
February	450	780	575	625
March	400	750	500	658
April	400	750	500	658
May	550	900	625	850
June	700	900	750	800
July	500	900	550	880
August	600	900	650	875
September	500	900	600	875

Source: www.megamb.nic.in

The annual trade of bay leaf from Meghalaya adds substantial income to the farmers as well as to the State. A precise estimate of quantities of bay leaf traded and the

revenues earned from the trade was difficult due to the absence of data from many parts of the State. Notwithstanding, the quantities traded and the selling price fixed by Mecofed provided an indication of the enormity of bay leaf trade in Meghalaya. Mecofed realized approximately 28 million rupees in 2003, 33 million rupees in 2004 and 40 million rupees in 2005 from bay leaf trade (Figure 7.8). The selling price has a clear seasonality (Figure 7.8). Every year, the selling price is lower during the harvest season (November to March) and rises post harvest (April to October). However, the trend does not differ between the years.

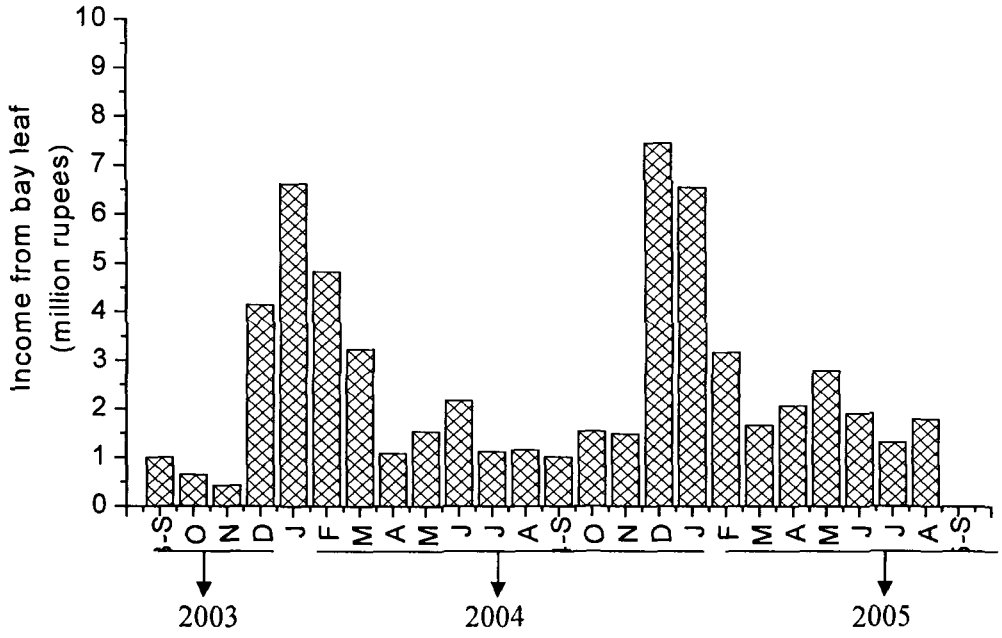


Figure 7.8. Seasonal variation in estimated monthly income (based on minimum of range for every month) from bay leaf trade during 2003-04 and 2004-05 at Mecofed.

Discussion

The season of bay leaf harvest was similar at the three study sites, i.e., November to January. This is despite the fact that the leaves may stay on the trees beyond harvest season and could be harvested in other months. Nevertheless, most harvests are synchronized during winter season. In some areas, harvests begin a bit late due to the common belief that the production of bay leaf would be good if harvest is done after Christmas celebrations. This may probably due to the reason that better drying of leaves is achieved in post-Christmas winter.

The harvest practices at the three sites differed depending on the framers' dependence on bay leaf as means of livelihood. The frequency of harvest was different at three sites, with yearly harvest at Mawpen and alternate year harvest at Pahamrioh. At Mawpen Suburb, the moderation of harvest on few trees could be appreciable income from fruits of *C. aurantifolia.* The distance from the human habitat to the nearest trading point, poor transportation facilities and lack of motorable roads result in exorbitant carrying charges and hence finish up in lower harvests. At Mawpen, repeated harvests of most individuals every year is most likely due to high dependence of farmers on bay leaf as a source of livelihood and close proximity of human settlement to the trading point.

Pinedo-Vasquez *et al.* (1990) observed that the use value of a specific NTFP for the tribes of Northern Peru depended on the presence or absence of trade market. Lawrence *et al.* (2005) reported contrasting results from Peru where 15 medicinal taxa of NTFPs having highest ranking in use value were not traded by the tribal community. The distance-dependent use of NTFPs does not explain the trends at Pahamrioh where human settlement is very close to the point of transport. Here, the agroforesty system is capable of providing livelihood through cash crops such as

ginger and pineapple. Such trends were observed in some villages within the Sinharaja Reserve Forest in Sri Lanka (Caron 1995).

The impact of bay leaf harvest was reflected by the leaf area index. The average reduction in leaf area index following harvest was about 37% in 2003 and 30% in 2004 at Mawpen and Mawpen Suburb. At Pahamrioh, leaf harvest was not done in 2003 and reduction in leaf area index was 38% in 2004. The similarity in the change in leaf area index due to bay leaf harvest at the three sites suggests that the harvest pressure is more or less similar during the study period. Several authors have stated that more than 50% reduction in the harvested products is unsustainable. Godoy and Bawa (1993) advocated that the sustainability could be determined by directly measuring the rate of extraction and comparing it to the rate of natural replacement.

The leaf area index failed to attain the pre-harvest levels in one year time at Mawpen and Mawpen Suburb. These sites would thus experience a continuous decline in leaf area index over time unless a break is given to the bay leaf harvest. The leaf area index at Pahamrioh recovers better in two year harvest cycle since leaf area index before harvest at Pahamrioh in 2004 was greater than in the previous year due to harvest in alternate years. It seems therefore that with one year break, bay leaf can be harvested more efficiently and probably on a sustained-yield basis.

Although the average leaf area index did not attain pre-harvest levels, some trees within the population did attain pre-harvest levels of leaf area index. This suggests the need for selective management of individual trees subjected to different intensities of bay leaf harvest. Ticktin (2004) highlighted that the permissible harvest level of leaf harvest is much lower than that of fruit and flower harvests. The estimate of leaf area index for individual trees suggests that the farmers do give a break to some individual trees to restore canopy cover at regular intervals.

The pattern of harvest has a considerable impact on regeneration ability of the canopy. The branching pattern of *C. tamala* individuals differed at the three sites. The variation was likely due to the different age groups of the populations. The number of branches increased with the girth of the tree at Mawpen Suburb, but not at Mawpen and Pahamrioh. The accumulation of cut branches (scars of cut branches) in the trees increased with the tree girth at the three sites. However, the percentage of branches that had been cut or damaged was significantly more at Mawpen and Mawpen Suburb as compared to that at Pahamrioh. This is in tune with the intensity of harvest which is yearly at Mawpen and Mawpen Suburb and is in alternate years at Pahamrioh.

The impact of harvest practices on branching pattern of C. *tamala* trees is visible in terms of crown diameter and health of the trees. The crown diameter determines the dispersal distance of passively dispersed seeds. In the long run, the severity of harvest may also reduce the seed weight of the harvested trees. Authors such as Vasquez and Gentry (1989), Cunningham (1993) and Sinha and Bawa (2002) have reported the damage of branches as the main reason for the demographic decline in of many species. Endress *et al.* (2003) have reported increased adult mortality and reduced fecundity as a result of leaf harvest in *Chamaedorea radicalis*, an understorey palm in the El Cielo Biosphere Reserve, Mexico. An experimental setup by Endress *et al.* (2004) following the existing leaf harvest regime of *Chamaedorea radicalis* showed that there was a modest initial increase in leaf production following harvest. However; leaves produced in the harvest treatments were significantly shorter than those in the control. This reduction in leaf length led to a 41–68% decline in yield after 2 years because many leaves produced were too short to be marketable. This response suggests that leaf harvesting is not a stable source of income for communities in El Cielo. Chalchat *et al.* (1995) have reported that the chemical composition and quality

of essential oils varies significantly with respect to harvest location, growth stage and part of plant being harvested. Hence, harvest techniques and intensity may have a significant impact on the active principle of an NTFP, affecting its marketability. Such responses to harvests may result in a decline in the income generation from NTFP sale. It is possible that the quality of essential oil of bay leaf may get affected due to harvest and this needs further research.

The trade of bay leaf has been rising consistently since 1996. This clearly spells out that the demand of bay leaf is high and is increasing. It is observed that although the harvest of bay leaf is limited to winter season, the produce is traded throughout the year. It could be reasoned that the regulated markets probably do not succeed in selling the produce at a rate at which it is collected during the peak harvest season. This results in storage of bay leaf in go-downs and subsequent sales when the price of bay leaf is significantly higher during the non-harvest periods. Therefore, the trade of bay leaf throughout the year signifies the tendency of traders to amass bay leaf in stores to fetch higher price during non-harvest months. Also, bay leaf being a product used throughout in the Indian culinary is in demand and consumption all along the year. Hence, bay leaf trade is triggered all-round the year. However, the main activity of bay leaf trade is concentrated to the harvest season during which the average selling price of bay leaf remains lower than the non-harvest period. But, average income from bay leaf trade is high, as the quantity of bay leaf traded remains high during harvest season.

The establishment of the regulated markets (e.g., Mecofed) exhibits as a profitable bridge between rural people and the traders. At Mecofed, the maximum price fetched from bay leaf is significantly higher than the price fetched from all other markets. While, the significantly lower price fetched at Mawpen could be due to the shortage

of storage space, which compels the farmers to sell the produce at lower prices. The lower price could also be due to the reputation of the point of origin among the traders. Tiwari *et al.* (2006) have observed that the determination of bay leaf prices is mostly at the discretion of the traders. Only affluent growers can afford to store bay leaf and bargain a relatively higher price in non-harvest months.

The magnitude of bay leaf trade in Meghalaya is difficult to quantify. The quantities reported in Table 7.6 are only those traded through Mawiong Regulated Market. Since, Garobada Regulated Market has remained non-functional during last several years, the quantities of bay leaf traded through Garo route remain unknown. The trade through the unregulated markets is also difficult to quantify. Hence, the traded quantities of bay leaf are certainly far more than presented in Table 7.6. A 'resource base inventory' approach has been suggested to estimate the production quantities of forest products such as fuelwood (Uma Shankar *et al.* 1998) and other NTFPs (Uma Shankar *et al.* 2003). However, estimation of bay leaf production in Meghalaya is difficult in the absence of the precise estimates of the populations of *C. tamala* trees.

A single tree of *C. tamala* may yield 9 to19 kg of bay leaf every year (Baruah and Nath 2004). If a density of a single tree per hectare is agreed, the geographical area of Meghalaya could potentially produce nearly 23,000 t of bay leaf per year. Further, the quantities can rise with domestication of *C. tamala* trees in home gardens. The yield estimates vary dramatically although the yield depends upon the age of the plant and canopy cover of the tree. In the present study, average yield from matured trees ranged between 10 and 24 kg $tree^{-1}$. Tiwari (2006) estimated the production from small trees between 30 and 40 kg $tree^{-1}$ $harvest^{-1}$ and from bigger trees between 55 and 65 kg $tree^{-1}$ $harvest^{-1}$. The average yield was estimated between 26 and 44 t ha^{-1} for the forests in low altitudes of Meghalaya. However, if the average yield, on the

lower side, is 26 t ha^{-1} and if total bay leaf in 2005 is 4,935 t (see Table 7.6), only about 190 ha area could have produced entire quantity of bay leaf traded in Meghalaya, which is certainly an unreal estimate. The area under bay leaf production is far more than this and there is probably no single hectare producing 26 t of bay leaf.

The production potential of bay leaf in Meghalaya could be very large. During the study period, the average income from bay leaf ranged from 28 to 33 million rupees per year. For a population of 2,306,069 in Meghalaya (as per 2001 census), per capita revenue from bay leaf would range from Rs 14 to Rs 16. Hence, bay leaf has the potential to become a major revenue earner for Meghalaya.

Conclusions

The harvest practices of bay leaf differed in time interval and management at the three sites. A harvest process that involved a one-year gap between consecutive harvests allowed the tress to attain higher levels of LAI than the harvest process with shorter time interval. It was observed that even consecutive yearly harvest can be considered as sustainable as the levels of reduction in LAI are much lower than standard limits. However, harvests could be more sustainable if an intermittent break is given to all harvested trees to attain pre-harvest levels of LAI .

The injury inflicted on *C. tamala* trees by cutting the higher order branches for bay leaf collection results in the loss of both reproductive and vegetative sites of the harvest trees. Such faulty harvest practices can reduce the economic output of the trees. This constraint can be overcome by employing more manpower to manually pick the leaves from the trees as in case of fruits. Also, biotechnologies can be

employed to design a geneotype of *C. tamala* that is shrub in habit. This would facilitate easy collection of leaf as in case of *Thea chinensis* (tea).

The trade of bay leaf has an enormous potential in alleviating rural livelihoods in Meghalaya. The contribution of bay leaf trade to rural livelihood of Meghalaya has been consistent over the past few years. The demand-supply relationship of bay leaf in the market, established trade links, regulated markets and consistency in average selling price of bay leaf over the years offer win-win situation to the farmers as well as traders of the state. The benefits from bay leaf trade can be further improved by increasing the population of *C. tamala* and adding value to the produce.

Chapter VIII

General Discussion

The leaf of *Cinnamomum tamala* or bay leaf, used in pharmaceutical and cosmetic industries and as spice, has been an important income-generating non-timber forest product (NTFP) of Meghalaya. Since the people of Meghalaya do not use it in traditional cuisine, cultivation of *C. tamala* in the state is primarily for trade. Meghalaya has been a major supply centre of the Indian bay leaf (Baruah 2004). The present study is of special interest as it brings out the earliest assessment of the ecology and economics of bay leaf harvest in Meghalaya.

It has been shown that NTFP extraction from natural populations even at moderate levels may change the floristic composition, erode species diversity and effect population structure (Daniels *et al.*1995, Murali *et al.* 1996, Uma Shankar *et al.* 1998a). This study assessed the population demography of *C tamala* and its role in determining the overall forest community structure. The trade of bay leaf was monitored to ascertain whether there was a rise in demand of bay leaf in the market and its impact on the sustainability of leaf harvest and regeneration of the species.

All the three study sites selected, viz., Pahamrioh, Mawpen and Mawpen Suburb represent subtropical wethill broadleaved forest where *C. tamala* grows abundantly. The density of *C. tamala* at the three study sites ranged between 192 and 340 stems ha^{-1}, which was much higher than that in the natural forests of Meghalaya (3 to 10 stems ha^{-1}) reported by earlier workers (Jamir 2000, Upadhaya *et al.* 2003 and Prabhu 2004). Hence, the dominance of *C. tamala* with IVI ranging from 40.8 to 115.9 in the forest communities at the study sites was the result of domestication of the species

through enrichment planting. However, except for the dominance pattern, all other community attributes of the forests such as species diversity, evenness index, dispersion pattern, stratification and tree density-diameter distribution were similar to that of adjacent natural forests, not interfered by any human activities. Thus, the community structure of the forest remained more or less unaltered inspite of the enrichment plantation with *C. tamala*. In contrast, the works of de Zoya *et al.* 1990, Guantilleke *et al.* 1993, have provided conclusive evidences of simplifying community structure due to the introduction of NTFP species.

The enrichment pattern of *C. tamala* or the intensiveness of intervention in the forest had an influence on the diversity of the stand that influenced the three types of forestry systems at three study sites. Pahamrioh forest (a home garden) which had least intervention was most species diverse with $\bar{H} = 3.39$, being close to the values obtained for several sacred groves of Meghalaya (Jamir 2000, Upadhayay *et al.* 2003). On the other hand, Mawpen (natural enriched forest) and Mawpen Suburb (semi wilds orchard), which were characterized by intensive intervention, had less Shannon's diversity index values i.e. 2.91 and 1.79, respectively. Similarly, the contribution of *C. tamala* to the total IVI was high at Mawpen Suburb (39%) and Mawpen (36%), but low at Pahamrioh (13%). The contribution of *C. tamala* to the total stand density and basal area also followed the same trend.

The tree populations in all the three communities exhibited a reverse J-shaped curve indicating favourable conditions for tree regeneration (Everard, D. A. *et al* 1995). However, the population structure of *C. tamala* did not yield a reverse J-shaped curve at any site, suggesting poor regeneration of the species. The regenerability of a species apparently depends on population size, reproductive potential, conducive microhabitat and anthropogenic pressures (Hall and Bawa 1993). The seedling density of *C. tamala* was high at Pahamrioh (1,200 ha^{-1}), Mawpen (480 ha^{-1}) and Mawpen

Suburb (896 ha^{-1}) during autumn (soon after monsoon is over) indicating good regeneration of the species. However, seedling census in ensuing winter showed a steady decline in seedling population size leaving only < 5% seedlings to survive at all the sites. This suggests that though conditions are conducive for germination of the seeds, the seedlings do not succeed in establishing themselves due to microenvironmental and/or anthropogenic filters.

It was observed that the small distance of unassisted dispersal of the *C. tamala* seeds results in negative con-specific effects on the seedlings and a clumped to near random distribution of the species at the three sites. The absence of regular distribution of this economically important NTFP species further strengthens the naturalness of the study systems. The clumped to near random distribution of this dominant species is also responsible for the maintaining the species diversity of the systems. It is believed by some authors (Janzens 1970, Hubbel and Foster 1990) that high species diversity of tropics is maintained by the random distribution of species due to negative conspecific effects or density dependent mortality. But many species rich tropical forests such as Pasoh Forest Reserve in Malaysia exhibited clumped distribution for majority of the species (Toshinori *et al.* 1997).

The phenology of *C. tamala* unraveled a more or less synchronous flowering and fruiting at the three sites The *C. tamala* trees attained reproductive maturity at a young age when gbh is about 10 cm. Nonetheless, flower production varied significantly between sites and between years within sites. The reproductive success measured in terms of proportion of flowers yielding fruits was as high as 83% at Mawpen and 93% at Mawpen Suburb during the first year, but declined significantly during the second year. At Pahamrioh, the reproductive activities were absent in the first year of study, but occurred with enhanced vigor in the second year. It may be

recalled that the bay leaf harvest occurred in the preceding year at Pahamrioh and in the first year of study at Mawpen and Mawpen Suburb. The lower order branches are cut during bay leaf harvest requiring a year's time or more for the trees to recover. The harvest practices at the three sites differed. At Pahamrioh, few branches from all trees are harvested in alternate years. At Mawpen, most branches are harvested from most trees every year. At Mawpen Suburb, many branches are harvested from only selective trees every year.

A decline in flowering and reproductive success after harvest was observed at all the sites, confirming the role of harvest in the reduction in reproductive success (Reining *et al.* 1991, Parameswarappa 1992, hall and Bawa 1993, Tewari and Campbell 1995, Marshall and Newton 2003). The quantity of harvested leaf from a tree and the method of harvest e.g. plucking the leaves vis-à-vis cutting the branches were the main reasons for decline in flowering and reproductive success. The over harvesting and faulty harvest techniques have been correlated with the market demand for several NTFP species by Pinedo-Vasquez *et al.* (1990) and Browder (1992), Uma Shankar *et al.* (1998 a, b), Te-Velde *et al.* (2006), Viet Quang and Namanh (2006).

In *C. tamala*, the fruits and seeds mature in the rainy season when moisture is abundant in the soil. Seeds show hypogeal germination on the soil surface and fail to germinate below ground. This suggests that though *C. tamala* is a sub canopy, shade tolerant species, it requires illumination at the early stages of regeneration. Hence, C. tamala can be grown in canopy gaps and moderately disturbed forests.

The seeds show a recalcitrant behaviour and germinate quickly after dispersal. Most of the tropical species exhibit this phenomenon as they synchronize the seed shed and germination with the monsoon season when conditions are mostly favorable for growth (Bisht and Ahlawat 1999). However, most seedlings in the field died soon

after germination during the ensuing winter due to moisture stress in the soil and cultural practices such as harvest of bay leaf and agricultural operations. Also, density-dependent mortality of seedlings is a possibility as most seeds fall under the canopy of the parent tree and form a carpet of seedlings.

Hence, the seed production and seed germination is good in *C. tamala*, but seedling establishment is poor due to mortality induced by both environmental and anthropogenic factors. It has been stated by (Hubbell 1979, Kohyama *et al.* 1994, Toshinori *et al.* 1997) that such strategy is followed by many tropical tree species to maintain stand diversity. They stated that if a single species with large recruitment, unregulated by density-dependent mortality factors, existed then such a species would have high potential to dominate entire parts of the forest and reduce its diversity. This also explains the low density of *C. tamala* individuals in undisturbed forests of Meghqalaya.

In view of the poor regeneration of the species in natural conditions it is important that the reproductive processes are not further impaired due to branch damage during bay leaf harvest. Interestingly, the parent *C. tamala* trees species has developed a strategy to maximize the chances of seed germination and seedling establishment by packing a standard amount of resources in each seed (Smith and Fretwell 1974). Thus, seed germination and survival was maximum around the mean seed weight of 200-300 mg. While most workers (Tripathi and Khan 1990, Uma Shankar 2006) have positively correlated seed germination and seedling establishment of a species to its seed mass, Perez Garcia *et al.* (1995) has shown that germination is independent of seed mass. Moreover, the seed weight of *C. tamala* had no direct relation to the parent tree girth at all sites. This suggests that *C. tamala* seeds collected from any reproductive individual have the equal potential of germination.

Table 8.1. Maximum sustainable harvest limits proposed for various non-timber forest products.

Plant part harvested*	Species	Life history[¥]	Environment[£]	Annual sustainable harvest rates (%)	Method used to obtain the rate[§]	Reference(s)
Leaves	*Cinnamomum tamala*	Tree, SC	TSE	<30%	MH	Present study
	Neodypsis decaryi	Palm, C	TE	25	MU	Ratsirarson, Silander and Richard (1996)
	Livingstonia rotundifolia	Palm, U	TE	<20	VE	O'Brien and Kinnaird (19960
	Geonoma deversa	Palm, U	TE	All leaves on 8-16 year rotation	MH	Zuidema (2000)
	Aechmea magdalenae	Herb	TE	75	MH	Ticktin *et al.* (2002)
	Rumohra adiantiformi	Fern	ME	50	VE	Geldenhuys and Van der Merwe (1988)
	Mattecuia struthiopteris	Fern	TD	<50	VE	Bergeron and Lapointe (2000)
Inflorescense	*Banksia hookeriana*	Shrub	H	20 %	VE	Witkowski, Lamont and Obbens (1994)
Seeds/fruits	*Phytelephas seemanii*	Palm, U	TE	86	MU	Bernal (1998)
	Neodypsis decary	Palm, C	TE	95	MU	Ratsirarson, Silander and Richard (1996)
	Brosiumum alicastrum	Tree, C	TE	95	MU	Peters (1992)
	Grias peruviana	Tree, U	TE	80	MU	Peter (1991)
	Bertholletia excelsa	Tree, C	TE	*c.* 93[¶]	MH	Zuidema and Boot (2002)

	Allium tricoccum	Herb	TD	0-16	MU	Nault and Gagnon (1993); Natel, Gagnon and Nault (1996)
	Panax quinquefolium	Herb	TD	5-15	MU	Charron and Gagnon (1991); Natel, Gagnon and Nault (1996)
	Hydrastis Canadensis	Herb	TD	<10	MH	D. Christensen and D. Gorchov, unpublished data
Whole plants	*Aechmea magdalenae*	Herb	TE	35	MH	Ticktin *et al.* (2002)
	Prunus africanus	Tree , C	TE	0 (on 8-10 yr rotation)	MH	Stewart (2001)
	Aquilaria malaccensis	Tree , C	TE	>10 cm dbh	MU	Soehartono and Newton (2001)
	Aquilaria microcarpa	Tree, C	TE	0 (>30 cm dbh every 15 year)	MU	Soehartono and Newton (2001)
	Thrinax radiate	Palm, C	TSE	40 ha^{-1}	MU	Olmsted and Alvarez-Buylla (1995)
	Coccothrinax readii	Palm, C	TSE	0	MU	Olmsted and Alvarez-Buylla (1995)
	Euterpe precatoria	Palm,SC	TE	0	MU	Zuidema (2000)

* Whole plants harvested for bark; resin in wood; leaves and wood; apical meristem.

¥ U, Understorey; C, canopy; SC, Subcanopy species.

£ TE, tropical evergreen; TSE, tropical semi-evergreen forest; TD, temperate deciduous forest; ME, montane evergreen forest; H, heathland.

§ Demographic method by which maximum annual sustainable harvest rate was obtained: MU, matrix model projections based on simulations of unharvested populations; MH, matrix model projections based on simulations of harvested populations; VE, effects of experimental harvest on vital rates.

¶ Maximum sustainable harvest rate was not estimated but populations harvested at this level were found to be stable.

Nevertheless, the mean seed weight varied with the site and within the study years. A lower mean seed weight was observed for the populations where harvesting was done every year in comparison to the population where the harvest was done at alternate years (Table 6.3), indicating the role of frequency and intensity of harvest in determining the mean seed weight.

The loss of LAI due to harvest at any point of time ranged between 28 and 37%, which is much less in comparison to the suggested level of sustainable harvest worked out by several workers (Table 8.1). Thus, the current harvest intensity of bay leaf in Meghalaya may be treated as sustainable. However, the leaf area index failed to attain the pre-harvest levels in one year's time as evident from the data for Mawpen and Mawpen Suburb, where harvest was done every consecutive year (Table 7.3). Only 11 to 28% of the original LAI could recover after one year of harvest at these sites. In contrast, at Pahamrioh, where harvesting is done in alternate years, the recovery rate was much higher at 35%, suggesting that the harvest of bay leaf should be undertaken every alternate year to ensure higher level of sustainability.

The variation in recovery of LAI between Mawpen, where most trees are harvested every year, and Mawpen Suburb where selected trees are harvested every year suggests the need of adopting the selective harvest technique. In fact, the farmers at the latter site select the trees for harvest considering the health of the tree, and provide a break from harvest for more than one year to selected trees to allow them to recover. Such a harvest technique also ensures the recurrence of flowering incidence every year. Hence, the sustainable harvest limits of bay leaf would be less than 30% at an alternate selective cycle of a minimum of one year for individual trees.

The importance of bay leaf as a revenue generator has been largely recognized by the farmers and the government of the State in the recent past. Hence, the trade of bay

leaf is mostly through an organized network of Mecofed (a public sector undertaking of Government of Meghalaya) Regulated Market in Shillong. This is primarily to protect farmers from exploitation by the middlemen. However, bay leaf is also traded through other routes where no record is kept. The quantities of bay leaf traded through Mecofed have increased exponentially (4 times) during the last decade and are on the rise every year. This indicates that the demand for bay leaf in the market is also rising. Also, the income from bay leaf has risen from Rs 20 to 30 million over the last 3-4 years. Undoubtedly, bay leaf has an enormous potential in improving rural livelihood of the state. However, considering the consistent rise in supply of bay leaf and the income from its trade, there was no evidence of recent inclusion of *C. tamala* individuals by the farmers in the population demography of the species at the three sites.

Hence, increasing resource base of bay leaf, i.e., more domestication of *C. tamala* trees, is inevitable, as in other NTFPS of economic importance (Browder 1992). Domestication could afford much greater densities and ensure high production of an NTFP (Uma Shankar *et al.* 1996). Low densities of an NTFP in natural habitat results in limited production per unit area that may often fail to fulfill market demand thereby increasing the harvest pressure. In addition, the assured supplies from domestication of NTFPs benefit the consumer by exercising a control on price rise (Homma 1992). On the whole, domestication curtails human interference in natural populations, thus minimizing disturbance-related losses of biodiversity.

This study unravels that the wild populations of *C. tamala* are scanty and the supply of most of bay leaf is a result of human manipulation of the forest communities. Since such manipulations neither alter the natural forest community structure nor affect the natural regeneration. Hence, *C. tamala* can safely be cultivated in the forest gaps without clearing forested areas. Such cultivation would not only enhance the bay leaf production but would also enhance the overall forest productivity and species diversity. Based on the findings of this study, it is recommended that in order to ensure the sustainable yield, the species may be cultivated and leaves may be harvested by maintaining periodic blocks as maintained under uniform shelterwood system of silviculture. Alternatively, harvesting may also be undertaken following selection system as practiced at Mawpen Suburb. However, faulty harvest methods involving branch damage could reduce the population size of a species considerably and make them susceptible to disease (Paoli *et al.* 2001, Sinha and Bawa 2002, Ticktin and Johns 2002, Tickting 2004, CARPE 2004). Hence, there is a need to adopt the hand-pick method of leaf collection in lieu of branch harvest technique, to ensure the sustainability of bay leaf production and conservation of the species in Meghalaya.

SUMMARY

The people residing in and around forest areas have utilized non-timber forest products (NTFPs) for subsistence for millennia. Of late, NTFPs have offered revenue generation potential to enhance rural income. Extraction of NTFPs has been debated since their sustainable harvest levels are not known in most cases. However, it is widely acknowledged that the sustainable harvests of NTFPs imply conservation of biodiversity. The studies on population ecology, regeneration, sustainability of harvest and trade are the prerequisites for evolving an effective conservation strategy for any NTFP while providing economic benefits to the rural people. The extraction of bay leaf from *C. tamala* trees offers a potential system for studying sustainability of leaf harvest in Meghalaya. Hence, the present study investigated the community organization of the systems that house *C. tamala* trees, regeneration of *C. tamala*, sustainability of bay leaf harvest and profitability of trade of bay leaf in Meghalaya.

The major findings of the study are summarized below.

- The study was conducted at three sites, viz., Pahamrioh (671 m, 25^0 54' N latitude and 91^0 53' E longitude) in Ri-Bhoi district, and Mawpen (762 m, 25^0 18' N latitude and 91^0 35' E longitude) and Mawpen Suburb (838 m, 25^0 18' N latitude and 91^0 35' E longitude) in East Khasi Hills district of the State of Meghalaya in India.
- The sites represent predominantly tropical mixed evergreen forest vegetation that has been enriched by the people especially with *C. tamala* trees and crops on the forest floor to render them as agroforestry systems.

- In all, 123 species occurred at three sites. Of these, Pahamrioh had 79 species (65 genera and 40 families), Mawpen had 63 species (54 genera and 33 families) and Mawpen Suburb 14 species (11 genera and 10 families). Only, 35.2% species were common between Pahamrioh and Mawpen, 17.2% between Pahamrioh and Mawpen Suburb and 18.2% between Mawpen and Mawpen Suburb.

- At Pahamrioh, Lauraceae was the most species rich family with 9 species followed by Euphorbiaceae (8 species) and Verbenaceae (6 species). At Mawpen, Euphorbiaceae was the most species rich family with 10 species followed by Lauraceae, and Fagaceae (each with 5 species). At Mawpen Suburb, Moraceae was the most species rich family with 3 species followed by Anacardiaceae and Rutaceae (each with 2 species).

- The species-area curve showed a rise with increase in sampling area at Pahamrioh and Mawpen. At Mawpen Suburb, the number of species increased in the first 10 sampling plots and stabilized thereafter.

- The Shannon's diversity index was maximum at Pahamrioh (3.39) followed by Mawpen (2.91) and Mawpen Suburb (1.79). The evenness index was maximum at Pahamrioh (0.77) followed by Mawpen (0.70) and Mawpen Suburb (0.68). On the contrary, the Simpson's dominance index was 0.24 at Mawpen Suburb, 0.15 at Mawpen and 0.06 at Pahamrioh.

- The dominance-diversity curve using IVI values followed a log-normal distribution at Pahamrioh and Mawpen, and a broken-stick model at Mawpen Suburb. *C. tamala* was the dominant species with an IVI of 40.8 at Pahamrioh and 106.7 at Mawpen and an IVI of 115.9 at Mawpen Suburb. *Schima wallichii* was the co-dominant species with an IVI of 36.5 at Pahamrioh and 42.4 at Mawpen. At Mawpen Suburb, Citrus *autrantifolia* was co-dominant with an IVI of 78.7.

- Most species (71-94%) were concentrated in Raunkiaer's frequency class 'A' at all sites. Whitford's index represented 97% species with clumped dispersion at Pahamrioh and 100% species with clumped dispersion at Mawpen and Mawpen Suburb. There was no regular dispersion at the three sites

- The density (ha^{-1}) of stems ≥10 cm girth was highest at Pahamrioh (1,314), followed by Mawpen (1256) and Mawpen Suburb (1,020). The contribution to stand density was highest by large tree species (41.2%) at Pahamrioh, by medium trees (42.4%) at Mawpen and by small tress (49%) at Mawpen Suburb.

- The stand basal area (m^2 ha^{-1}) for stems ≥10 cm girth was higher at Pahamrioh (24.01) and Mawpen Suburb (22.58) as compared to Mawpen (16.39). However, the contribution to stand basal area was highest by large trees (48.2%) at Pahamrioh and by medium trees at Mawpen (71.0%) and Mawpen Suburb (69.3%).

- The large tree species contributed 43.9%, 28.7% and 24.4%, medium tree species 38.3%, 48.5% and 41.0% and small tree and shrub species 17.8.1%, 22.8% and 34.6% to importance value index respectively at Pahamrioh, Mawpen and Mawpen Suburb.

- Most stems were concentrated in 10-30 cm girth class: 46% at Pahamrioh, 83% at Mawpen and 42% at Mawpen Suburb. Concentration of stems decreased with increase in girth size, resulting in a reverse J-shaped curve at all sites. The distribution of basal area in girth classes was skewed and did not corroborate the distribution of stems.

- Mean tree height increased with increase in girth class at all sites. Low stature of forest was evident at all sites, i.e., most trees were below 15 m height.

- The population structure of *C. tamala* exhibited a reverse –J at all the three sites before winter, but did not exhibit the same post winter. Pre-winter seedling density was highest at Pahamrioh (1200 ha^{-1}) followed by Mawpen Suburb (896 ha^{-1}) and Mawpen (480 ha^{-1}). The density of individuals was seedlings >saplings <adults. However, post winter the seedling density was reduced to 2% at Pahamrioh, 0% at Mawpen and 5% at Mawpen Suburb. The density of individuals was seedlings <saplings <adults.

- Highest stem density of *C. tamala* was at Mawpen (340 ha^{-1}), followed by Mawpen Suburb (284 ha^{-1}) and Pahamrioh (192 ha^{-1}). Whereas as highest basal area (m^2 ha^{-1}) of *C. tamala* population was 14.74 at Mawpen Suburb, 10.72 at Mawpen and 4.12 at Pahamrioh. However, the contribution of *C. tamala* to the total stand density was 28.6% at Mawpen Suburb, 28% at Mawpen and 15% at Pahamrioh. Its contribution to stand basal area was 65.9% at Mawpen Suburb, 65.7% at Mawpen and 17.3% at Pahamrioh.

- The dispersion pattern of *C. tamala* varied among the three sites. A variance-to-mean ratio of 1.12 at Pahamrioh and 1.11 at Mawpen suggested a near-random dispersion. At Mawpen Suburb, a value of 1.88 indicated a clumped dispersion. The saplings (≥10 to <30 cm girth) were distributed in close proximity to the conspecific adults (≥30 cm girth) at all sites.

- *C. tamala* trees begin flowering in April and are in full bloom in May. Leaf flushing occurs in February and March followed by a second flush in July and August. However, sporadic leaf flushing occurs throughout the year. Fruit maturation starts from June and continues till September. Seedling mortality peaked during December.

- In 2003, flowering incidence was 46% at Mawpen and 66% at Mawpen Suburb. No trees flowered at Pahamrioh. In 2004, 82% trees flowered at Pahamrioh, 35% at Mawpen and 17% at Mawpen Suburb. Of the trees that that flowered in 2003 and were harvested, only 31% repeated flowering in 2004 at Mawpen and 21% at Mawpen Suburb. Most flowering was observed in trees of 10-30 cm girth at Pahamrioh, 70-90 cm girth at Mawpen and 130-150 cm girth at Mawpen.

- Average flower production per tree was 800 at Mawpen and 920 at Mawpen Suburb in 2003. It was only 427 at Pahamrioh, 224 at Mawpen and 236 at Mawpen Suburb in 2004. Flower production differed significantly with girth size and height of parent tree at all sites.

- Average fruit production per tree was 666 at Mawpen and 859 Mawpen Suburb in 2003. It was only 303 at Pahamrioh, 111 at Mawpen and 67 Mawpen Suburb in 2004. The fruit of *C. tamala* is a drupe harbouring a single seed. Hence, the seed production is equivalent to the fruit production.

- The reproductive success was 83% at Mawpen and 93% at Mawpen Suburb in 2003. It was 71% at Pahamrioh, 50% at Mawpen and 29% Mawpen Suburb in 2004.

- Seed dispersal was gravity-driven. The seed fall peaked in August at the three sites. The number of seeds dispersed decreased with distance from parent tree. Most seeds were dispersed below the parent tree canopy at all sites.

- Seed production was measured through collection in seed traps. Of total seeds collected in seed traps in 2003, as much as 81% at Mawpen and 77% at Mawpen Suburb were healthy. Only 11% seeds at Mawpen and 10% seeds at Mawpen

Suburb were diseased. The rest 8% seeds at Mawpen and 13% at Mawpen Suburb suffered abortion.

- Of total seeds collected in seed traps in 2004, as much as 79% at Pahamrioh, 66% at Mawpen and 62% at Mawpen Suburb were healthy, 13% at Pahamrioh, 9% at Mawpen and 5% at Mawpen Suburb were diseased, and 7% at Pahamrioh, 24% at Mawpen, and 33% at Mawpen Suburb suffered abortion.
- Seeds after paint marking were left on the ground in the seed traps to quantify seed predation. No loss of marked seeds was observed.
- Seed weight varied among sites in 2003 as well as in 2004. In 2003, mean seed weight was more at Mawpen Suburb than at Mawpen. There were no seeds produced at Pahamrioh. Across sites, seed weight ranged between 99 and 751 mg, i.e., by more than seven-fold. In 2004, Pahamrioh exhibited significantly higher mean seed weight than Mawpen and Mawpen Suburb. Mean seed weight declined significantly at Mawpen and Mawpen Suburb after harvest of bay leaf, i.e., from 2003 to 2004
- The seed weight had no direct relationship to the girth of the parent tree at all sites.
- Seed viability declined rapidly after collection of seeds and was completely lost 25 days after detachment from the parent tree.
- Seed germination in *C. tamala* is hypogeal. Seeds germinated within 15 ± 3 days from sowing in the field. Germination was synchronous resulting in a seedling carpet under the parent canopy. Seeds fail to germinate belowground.

- In greenhouse, germination was 91.9% at Mawpen and 78% at Mawpen Suburb in 2003 and 65% at Pahamrioh, 17% at Mawpen and 22% at Mawpen Suburb in 2004.
- In the field, germination was 60% Mawpen and 67% at Mawpen Suburb in 2003. It was 65% at Pahamrioh, 23% at Mawpen and 25% at Mawpen Suburb.
- Seedling survival in greenhouse for seedlings of 2003 was 53% for Mawpen and 66% for Mawpen Suburb. It was 42% for Pahamrioh and 11% each for Mawpen and Mawpen Suburb for seedlings of 2004. Seedling survival in the field was <10% in 2003 and <20% in 2004 at all sites.
- Most germinated seeds were from intermediate seed weight classes (200-400 mg) at all sites. On the other hand, most ungerminated seeds were from small seed weight class. The percentage of seeds that germinated and survived as seedlings after six months from germination was 40% at Pahamrioh, 58% at Mawpen and 50% at Mawpen Suburb in 200-300 mg seed weight class.
- Seedling survival in the field was 8% for seeds from Mawpen and nil for seeds from Mawpen Suburb in 2003. In 2004, seedling survival in the field was 20% at Pahamrioh, 12.5% at Mawpen and 20% at Mawpen Suburb. Seedling survival in greenhouse was 53% for Mawpen and 66% for Mawpen Suburb in 2003 until after 180 days of sowing. In 2004, seedling survival was 42% for Pahamrioh and 11% for Mawpen as well as Mawpen Suburb. Seedling establishment decreased with distance from the parent tree at all sites.
- The growth attributes of seedlings such as root length, shoot length, number of leaf and leaf area did not show a common trend in relation to seed weight among the three sites.

- Seedling vigour parameters such as root length, shoot length, collar diameter, number of leaves and leaf area showed greater values for Mawpen Suburb than Mawpen both in 2003 and 2004. Seedling vigour was significantly higher in field than in greenhouse, both in 2003 and 2004.

- In Meghalaya, bay leaf harvest begins in November and continues up to February. The pattern of bay leaf harvest varied at the three sites. At Pahamrioh, few branches from almost all trees are harvested in alternate years. At Mawpen, many branches are harvested from many trees every year. At Mawpen Suburb, many branches are harvested from only selective trees every year.

- The impact of bay leaf harvest was quantified on *C. tamala* trees. The leaf area index (LAI) was measured before harvest in November 2003 and following harvest in December 2003. At Mawpen and Mawpen Suburb, leaf area index declined by nearly 37% due to bay leaf harvest in 2003. The increase in foliage during growth period in 2004 varied markedly among three sites. At Pahamrioh where bay leaf harvest was not done in 2003, the increase in leaf area index was maximum, i.e., about 36%. This was followed by Mawpen with 29% increase in leaf area index and Mawpen Suburb with only 12% increase in leaf area index. In 2004, leaf harvest resulted in a decline in leaf area index at all sites. Almost 38% leaf area index was lost at Pahamrioh, 31% at Mawpen and 28% at Mawpen Suburb.

- The collection of bay leaf harvest involved the cutting of higher order branches. The branch damage was significantly correlated to the tree girth at Mawpen

- The channel of bay leaf trade is rather straightforward. Marketing of bay leaf is predominantly in two ways: regulated marketing wherein the traded quantities are recorded and unregulated marketing wherein the traded quantities are unknown.

- The quantities of bay leaf traded through Mecofed Regulated Market, Shillong showed a steady increase from 1997 to 2005. This increase has been steep during 2004 and 2005. The traded quantities of bay leaf have grown more than three times, i.e., from 1466 t in 1996-97 to 4935 t in 2004-05.

- There is a marked seasonality in collection quantities of bay leaf. The collection quantities are high during winter months (December to March) with a maximum quantity recorded during December or January. Subsequently, these quantities decline steadily with a minimum in November, i.e., just prior to the next year's harvest. The export of bay leaf through Burnihat Check Gate followed a similar pattern of seasonality as that of collection.

- The maximum selling price of bay leaf was markedly higher at Mecofed than at other markets. The minimum selling price of bay leaf at Mecofed was lower than that at other markets. The gap between the minimum and the maximum selling price was wider at Mecofed than at other markets. The range of fluctuation of selling price for other markets remained within the range of selling price at Mecofed.

- The selling price experiences seasonality and goes down following current years' harvest during January to May and rises again from June to December. The average selling price of bay leaf remained higher during the harvest season as compared to the non- harvest seasons at all markets.

- The annual trade of bay leaf from Meghalaya adds substantial income to the farmers as well as to the State. Mecofed realized approximately 28 million rupees in 2003, 33 million rupees in 2004 and 40 million rupees in 2005 from bay leaf trade. The selling price has a clear seasonality. Every year, the selling price is

lower during the harvest season (November to March) and raises post harvest (April to October). However, the trend does not differ between the years.

It can be concluded that *C. tamala* evinces good regeneration through seeds, but high seedling mortality results in poor establishment. The people harvest bay leaf sustainably and provide harvested trees a break for recovery. However, the faulty harvest technique could hamper regeneration and productivity of the species. The indigenous people of Meghalaya have tapped the revenue generation potential of *C. tamala* trees by domesticating it in agroforestry systems with minimum alterations in the forest structure. This has been done by enriching *C. tamala* trees in suitable habitats and developing an organized network of bay leaf trade. Enormous possibilities exist for value addition of bay leaf at the point of origin.

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