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Single tree felling gaps and regeneration in Tanzania montane forests

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SINGLE TREE FELLING GAPS AND REGENERATION IN TANZANIA MONTANE FORESTS

By

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ABSTRACT

Illegal exploitation of timber in Tanzania is rampant in montane forests. It is mostly done by pitsawyers. To assess the extent of destruction and propose corrective measures, an experiment was laid down in the Machame, Chome and Rongai Forest Reserves from October 1998 to February 2000. The regeneration potentials of *Ocotea usambarensis, Fagaropsis angolensis, Podocarpus falcatus, P. latifolius* and *Ficalhoa laurifolia* were assessed and monitored.. Illegal logging was carefully simulated (particularly by reducing felling damage) by felling a single tree in selected experimental plots and subsequent regeneration response monitored. Growth of advance regeneration was also monitored. Litter and soil tillage treatments were applied to selected plots. Canopy closure and the associated light environment in both felled and non-felled plots were quantified quarterly with hemispherical photography. The canopy closure was reduced and the quantity of solar radiation reaching the forest floor was increased by the single tree felling from 0 to 40% and from 15.1 to 127.8% respectively. Initial results of the experiment after 18 months of observations showed that *Fagaropsis angolensis, Podocarpus falcatus, Podocarpus latifolius* and *Ocotea usambarensis* had the potential of regenerating in situ. In general, single tree felling had moderate influence on regeneration of the studied species. A combination of felling and litter/tillage significantly ($F = 11.58$, $\rho < 0.05$) influenced regeneration of *Ocotea usambarensis* at Machame. Chome *Ocotea usambarensis* new regeneration was significantly affected by tree removal ($t_{0.05} = -3.02$, $\rho = 0.0051$). *Ficalhoa laurifolia* neither responded to applied treatments nor had advance regeneration. Neither litter nor tilling had significant effects on the regeneration of any target species. Height growth of advance regeneration was influenced to a different extent by the applied treatments and time of application. In most cases, advance regeneration in felled plots grew faster than in un-felled plots. There was a significant effect for *Ocotea usambarensis* ($F = 2.04$, $\rho = 0.048$) at Machame, *Podocarpus latifolius* ($F = 3.45$, $\rho = 0.002$) at Chome and *Fagaropsis angolensis* ($F = 94.78$, $\rho = 0.000$) at Rongai. Increased direct light due to single tree felling had positive influence on *Ocotea usambarensis* advance regeneration at Machame in March 1999 - May 1999 and September 1999 - February 2000 growth phases ($F = 4.72$, $\rho = 0.031$ and $F = 10.31$, $\rho = 0.002$ respectively). It has been shown that height increment in *Ocotea usambarensis* at Chome and Machame and *Podocarpus latifolius* at Chome depends on the initial advance regeneration height ($F = 13.41$, $\rho = 0.015$; $F = 4.49$, $\rho = 0.035$; and $F = 4.02$, $\rho = 0.049$ respectively). In almost all sites advanced regeneration growth differed significantly between growth phases. The significance levels ranged from $\rho = 0.007$ to $\rho = 0.000$. It is suggested that the state of knowledge uncovered by this study should be extended and studies on the regeneration potential of economic tree species in other natural forests in Tanzania be conducted.

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CHAPTER ONE : INTRODUCTION

This thesis reports the effect of single tree felling on the regeneration of *Ocotea usambarensis*, *Fagaropsis angolensis* (Engl.) Dale, *Ficalhoa laurifolia* Hiern, *Podocarpus latifolius* (Thunb.) Mirb. and *P. falcatus* (Thunb.) Mirb. (alternative name is *Afrocarpus falcatus* (Thunb.) C. N. Page) in the Chome, Machame and Rongai forests in Tanzania. Since *Afrocarpus falcatus* is not in common use and has not been adopted for recent African flora (Beentje, 1994), *P. falcatus* will be used throughout this thesis. *Ocotea usambarensis* and *Fagaropsis angolensis* are among the timber species preferentially pitsawn in Kilimanjaro montane forests. The montane forests in Kilimanjaro (and in Tanzania as a whole) have been given protected area status for protection of water catchment, environment and biodiversity. In this multiple-use management, the role of these forests as sources of timber has been neglected. Multiple-use forest management including timber out-turn, has been reported to work well in many parts of the world (Franklin *et al.*, 1997; Clearwater, 1997). Although sometimes it is difficult to accommodate conflicting objectives in multiple-use forests (Erdle, 1999), if carried out properly these forests can be good sources of fine hardwood timbers - for which demand is ever-increasing. Further, tropical forests are more resilient to disturbance than previously thought (Leslie, 1987; Lugo, 1999). When the goal of natural forest management is to maintain the biodiversity and ecological integrity of the forest, while the silvicultural systems employed must promote timber production, negative impacts on non-timber resources must be minimized (Pinard *et al.*, 1999). Single-tree felling could satisfy these conditions.

Forests in Tanzania can broadly be classed as mangroves, woodlands and forests other than mangroves (MLNRT, 1989; MNRT, 1998). The proportions of these are shown in Table 1.1. Other than mangroves, Tanzania's closed forest consist of forest plantations and natural forests, mostly montane. Forest plantations are planted mainly with exotic conifers especially *Pinus patula* Schiede & Deppe and *Cupressus lusitanica* Mill. (Forest Division, 1982). Other species include *Pinus elliottii* Engelm. and *Pinus caribaea* Morelet. These exotic conifer plantations (Figure 1.1) are currently the main sources of industrial wood in the country. There are also a few exotic hardwood plantations mostly planted with Teak, *Tectona grandis* L.f. (Forest Division, 1982). Lately, *Pinus patula* and *Cupressus lusitanica* have been attacked by Pinus fungus, *Dothistroma septospora* (Dorog.) Morelet and Cypress aphid (*Cinara cupressi*) respectively. These attacks have greatly reduced the area of successful plantations in the country and in eastern African area as a whole (Forest Division, 1982). The most recent figures for Tanzania forest plantations stand at 135,000 ha (FAO, 2001).

Tanzania's montane forests occur especially in the Eastern Arc mountains (Usambara, Pare, Uluguru, Udzungwa ranges) and on Kilimanjaro (Lovett, 1992, 1993; Wasser and Lovett, 1993). Montane natural forests are estimated to occupy 1.6 million hectares (Mbwana, 1990; MNRT, 1998). FAO (1993) estimated this figure to be 3,035,000 ha which is 9% of total forest area of 33,555,000 ha. Recently Tanzania's total forest area has been estimated to be 38,811,000 ha (FAO, 2001). These forests are the main sources of hardwood for the domestic and export timber markets (Forest Division, 1982). The recent estimates of forest area (Table 1.1) suggest a decline from 1989 to 1998.

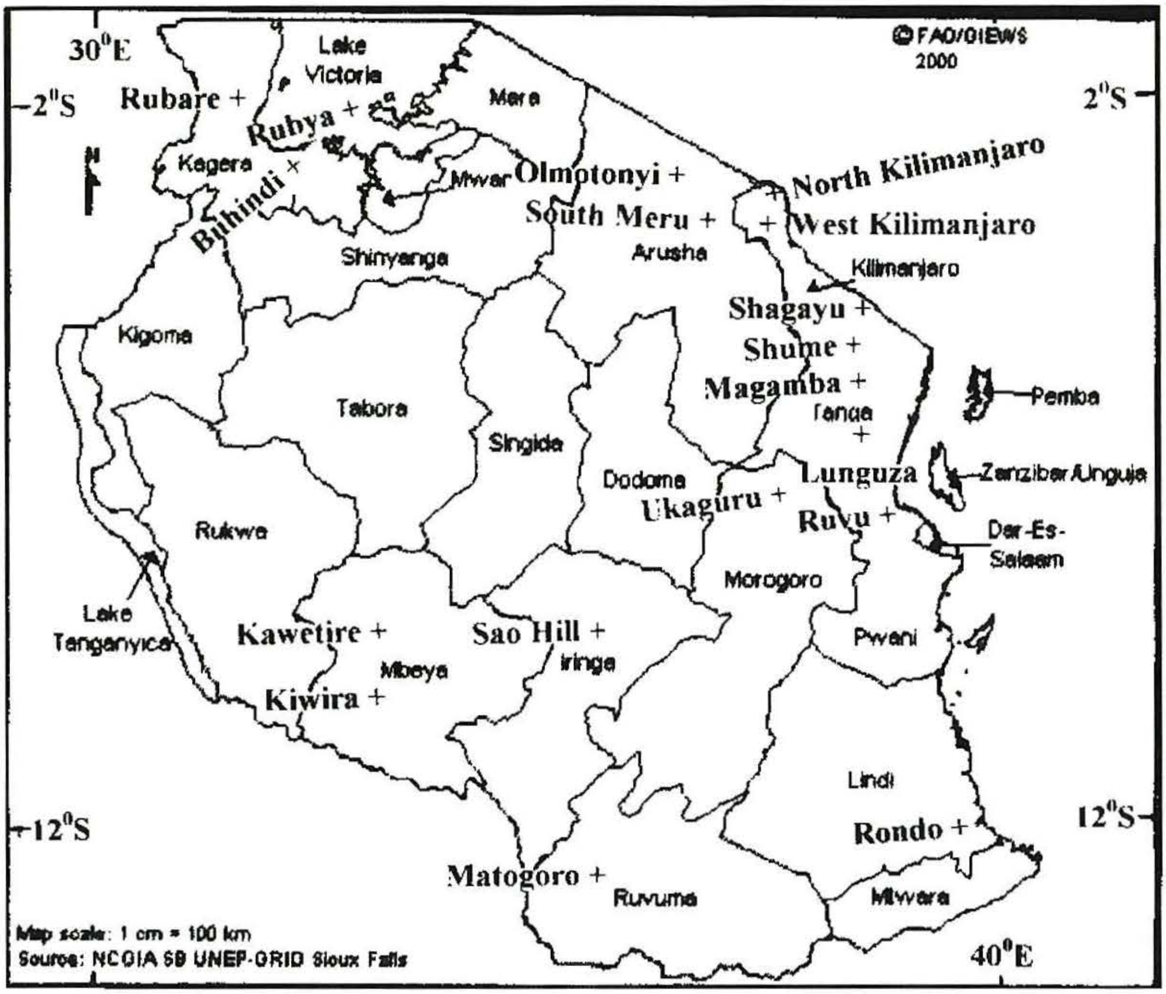


Figure 1.1 Softwood plantation locations (+) in Tanzania (Source: FAO/GIEWS 2001)

Table 1.1: Tanzania forest and woodland cover estimates

Forest Type	Hectares in 1989	Hectares in 1998
Closed canopy forests (other than mangroves)	1,400,000	1,141,000
Mangrove forest	80,000	115,000
Woodlands (miombo and savanna)	42,891,000	32,299,000
Total	**44,371,000**	**33,555,000**

Source: MLNRT (1989), FAO (1993), MNRT (1998)

It is accepted that the forested area of Tanzania, including montane forests, is declining (Lamprey *et al.*, 1991; Bjorndalen *et al.*, 1992; MNRT, 1998). The deforestation rate is estimated to be between 130,000 and 500,000 hectares per annum (MNRT, 1998). FAO (1993) gives an annual deforestation estimate for natural forests alone between 1981 and

1990 of 438,000 ha. The deforestation rate for the hill and montane zones stands at 38,800 hectares per annum (FAO, 1993). Although FAO estimates are still in use, their reliability is said to be questionable in terms of the model of deforestation adopted and in the quality and timeliness of the raw data (Gale, 1998). Nevertheless, with a lack of other reliable data, they form an important starting point in gauging the deforestation rate in Tanzania. Exploitation pressure of these forests mostly comes from illegal timber exploitation (pit-sawing), firewood collection, non-wood forest products collection (e.g. fruits, fodder), and illegal encroachment. Legal exploitation ended in 1984 (Mbegu, 1996; Seddon *et al.*, 1999). IDRC (1999) describes illegal timber exploitation and ways of curbing the problem. Currently the greatest threat to Tanzania's natural forests is pit-sawing, which is widespread in most forest reserves. Besides reducing the hectarage of the forest and causing environmental deterioration, illegal exploitation changes the forest structure, and hence the ecosystem structure and its biotic composition (Dinesen *et al.*, 1995, Seddon *et al.*, 1999). White (1978) and Lovett and Pocs (1993) studies have shown that forest patches around Mount Kilimanjaro which were once dominated by *Ocotea usambarensis* are now invaded by pioneer species *Macaranga capensis* and *Polyscias fulva*.

Laws and regulations in Tanzania have for many years restricted people from entering the forests for forest products (Holmes, 1995a; Wanitzek *et al.*, 1998; Conte, 1999; IDRC, 1999; McCarthy, 2000). Though these forests theoretically have been closed to exploitation by law still people find their way into them (Newmark *et al.*, 1993). Before the 1984 exploitation ban, while these forests were legally exploited (Mbegu, 1996), logging permits were issued to private and public logging, sawmilling and plywood companies and individuals. This process involved allocating forested areas for logging and allowing individuals to buy individual trees. While private and public companies had either mobile sawmills in the forest or hauled logs to mills located outside the forests, individuals sawed logs within the forest manually, using hand saws (pitsawing). Thus, before the Second World War, there was only small scale cutting of *Ocotea usambarensis* Engl. in Kilimanjaro. However, the war led to a tremendous demand for timber mainly for sleepers

(Wood, 1965) and out turn of *Ocotea* timber rose from 141.5 m^3 in 1941 to 16,499 m^3 in 1942 (Misana, 1991).

Government estimates for round wood production stand at 533,000 m^3 per annum (380,000 m^3 from sawmills and 153,000 m^3 from pitsawing) producing 215,000 m^3 of sawn timber (160,000 m^3 from sawmills and 55,000 m^3 from pitsawing) (Tanzania, 1998). Thus, pitsawing plays an important role in production of sawn timber in Tanzania. Pitsawing if is not carried out careful may result into enormous residual forest destruction (Howard, 1991). But if carried out careful specially with regard to felling direction and platform making, has little if any environmental impact (Dykstra and Heinrich, 1996). With the exception of the *Ocotea usambarensis* stands, very little was done to residual stands in terms of silvicultural treatments. Current management operations in these forests and other natural forests are effectively limited to gap planting. Gap management, however, can be a very successful mode of natural forest management if carried out properly (Coates and Burton, 1997).

During the colonial era and in the years soon after independence, leases were issued to loggers to exploit the montane and other natural forests (Tanzania 1951, 1958, 1960; Conte, 1999). Depending on the region in the country, the main logged species were *Cephalosphaera usambarensis* (Warb.) Warb., *Juniperus procera* Endl., *Ocotea usambarensis* and *Podocarpus* in the mountains (Tanga and Kilimanjaro), *Milicia excelsa* (Welw.) C. C. Berg in the coastal areas (Tanga, Morogoro, Lindi and Mtwara) and *Pterocarpus angolensis* DC. in the miombo (Morogoro and Tabora) (Kileo, 1972). Among these species, *Ocotea usambarensis* is the most logged and studied timber species in the country (Willan, 1961; Kimaryo, 1971; Borota, 1975; Mugasha, 1978, 1980; Holmes, 1995b). The distribution, ecology, silviculture and management of this tree species is relatively well known in Tanzania (Borota, 1975; White, 1978; Holmes, 1995b). Although *Ficalhoa laurifolia* has been reported to have been logged in West Usambara (Pitt-Schenkel, 1938), very little information has been reported of its silviculture and management. The other species of interest in the present study (*Fagaropsis angolensis*) was not thought to be marketable in the past and has also received very little attention. In fact *Fagaropsis angolensis* was reluctantly accepted by sawmillers in the past (Tanzania, 1957a). The importance of these secondary timber species has been rising progressively over the years as they have become accepted in the timber trade and increasing exploitation pressure has resulted (Tanzania, 1957b; 1980; 1992; 1993; 1995).

As mentioned above, a total exploitation ban in montane forests came into effect in 1984 (Mbegu, 1996). Such a ban can only be successful where peasants and other people concerned with exploitation are mobilised and relied upon (ISTF, 1996). A really successful outcome is reafforestation action. Reafforestation is most effective when local people see such activities as in their own interests (Wily and Haule, 1995). Although there are some improvements, in general these conditions have not emerged in Tanzania and people still illegally exploit forest reserves though it is forbidden by law. Against this background of persistent deterioration of reserved montane forests, this study, located in Kilimanjaro Region, investigates the regenerative potential of selected key timber species. Only a few areas of the forests in Kilimanjaro Region have remained unlogged to the present day. The logged montane forests of the wetter parts of the largest closed forest reserve in the Region, Kilimanjaro Forest Reserve, once dominated by *Ocotea usambarensis,* are now dominated by pioneer species particularly *Albizia gummifera* (J. F. Gmel.) C. A. Sm., *Macaranga capensis* (Baill.) Sim and *Polyscias fulva* (Hiern) Harms (White, 1978; Lovett and Pocs, 1993; Holmes, 1995b).

The present study was carried out in three forest reserves in Kilimanjaro Region: namely Machame, Chome and Rongai. The four timber species studied were *Ocotea usambarensis*, *Podocarpus falcatus*, *Podocarpus latifolius* and *Fagaropsis angolensis*, currently the most exploited timber species in this part of the country. Although *Ficalhoa laurifolia* is not preferred at the moment, it is likely to be routinely exploited in the future following depletion of supplies of other timber species. In fact, the stocking of this species in Magamba has been greatly reduced already (S. Hoza, personal communication). Other studies which were carried out in the past (particularly for *Ocotea usambarensis* Kimariyo, 1971; Mugasha, 1978, 1980) did not evaluate the environment under the canopy but were limited to increment studies after thinning and poisoning treatments. This study uses hemispherical photography to quantify light under forest canopy. The study also imitated pitsawing, neglected in research terms as a major threat to the existence of natural forests in Tanzania, by a single tree felling gap creation strategy.

This study therefore has a general objective of studying timber exploitation effects in these forests and the regenerative potential of the most logged montane timber tree species with the following specific objectives :

- to study the effect of soil treatment on induction of regeneration of the studied tree species
- to study the influence of forest floor litter on recruitment of new seedlings and suckers of the studied tree species
- to study the influence of changing light environment on newly germinated and advance regeneration of the studied tree species

The central question of this study is: Are Tanzania montane forests able to regenerate after moderate timber exploitation? To answer this question the following six hypotheses were formulated:

1. The light environment in the forest understorey is changed by single tree felling
2. Single tree felling does affect the overall seedling density of the principle timber tree species present at the site
3. Single tree felling does affect the growth of advance regeneration of the principle timber tree species present at the site
4. Litter and soil tillage affect the overall seedling density of the principle timber tree species present at the site
5. The growth of advance regeneration of the principle timber tree species present at the site depends on the initial height
6. There are variations in growth of advance regeneration of the principle timber tree species present at the site in different growth phases

CHAPTER TWO : LITERATURE REVIEW

This chapter is in two parts. The first part is concerned with the general ecological effects of tree removals in the forest ecosystem (Section 2.1). Subsections within Section 2.1 relate to ecological effects of felling single trees in the forest (2.1.1), impacts on the genepool of the residual forest (2.1.2), damage to non-targeted forest components due to tree removals (2.1.3) and facilitation and catalytic effects (2.1.4 and 2.1.5, respectively). The second section (2.2) briefly reviews knowledge of light penetration of the forest canopy. This is subdivided into comments on how entry of light is modified as a result of the loss or removal of trees in the canopy (2.2.1) and on the use of hemispherical photography to estimate closure levels (2.2.2).

2.1 Ecological effects of tree removals

There is an enormous volume of literature concerned with the ecological effects of tree removals in tropical forests. The practice of reduced impact logging has been receiving increasing attention (Jonkers, 1987; Hendrison, 1990; Pinard *et al.*, 1995; Whitmore, 1995; Andel *et al.*, 1996; Lageson, 1996; Clearwater, 1997; Magnusson *et al.*, 1999) as a means of minimizing wastage from avoidable damage and excessive site alteration. It is not intended to review the entire picture in this chapter because informative and stimulating treatments of the subject are already available (Jonkers, 1987; FAO, 1989; Hendrison, 1990; Appanah and Weinland, 1990; Whitmore, 1992, 1995; FAO, 1997, 1998; Magnusson *et al.*, 1999). Attention here is restricted to the most relevant aspects where Tanzanian montane forest is concerned.

Covered here, therefore, are five key ecological issues arising from tree removal in ecosystem conditions comparable with the present study area - Afromontane conditions.

There is much use of single-tree felling in montane terrain. This is an exploitation method suited to terrain inaccessible for mechanized equipment - terrain frequently present in mountain habitats. It is equally a technique used in illegal exploitation, a major problem in Tanzania's mountain forests. The second issue is that of genepool impact, since economic species native to mountain ecosystems remain neglected in terms of established silvicultural systems providing for increased regulation to offset harvested trees. A third issue, damage and change below the main canopy in montane forests, needs to be addressed because felling events are taking place in much more sensitive environmental and ecosystem conditions than in most lowland forest. Facilitation impacts, issue 4, link exploitation to social conflicts about access to forest areas for products utilized at village level. In Tanzania, mountain ranges are associated with rainfall regimes which offer better crop-growing conditions than most of the nearby lowlands. Demands for forest products and the impact of collecting them, have risen with population increases in mountain communities (Gamassa, 1991). Rising expectations in terms of living standards have also encouraged entrepreneurial initiatives using forest areas for livestock and harvesting timber for sale to other places in the country. Logging activity improves access and increases opportunities for these additional activities to take place whether or not they are officially permitted. The final issue recognizes that the ecology and biology of the constituent species of montane forest often differ from those of lowland tropical forest species.

The most important ecological functions of forest are identified by WWF (1991) and Gale (1998) as the role in the maintenance of plant and animal biodiversity. Gale describes tropical rainforests as important for the maintenance of biodiversity because they contain approximately half of all the earth's species. Tree removals from the forest canopy modify the ecological conditions under the canopy (Coates and Burton, 1997). Changes affect the regimes of light, moisture, wind speed and temperature. Due to these changes, faunal and floral species composition may change, adapting to the modified conditions (Bjorndalen *et al.*, 1992; Dinesen *et al.*, 1995; Whitmore and Burslem, 1996; Seddon *et al.*, 1999; Myers *et al.*, 2000a). Such changes are associated with the disappearance of species previously present and the appearance of new species which take advantage of released resources. The growth environment of the undergrowth may either be enhanced or impaired depending on the adaptation of the plant species in question. According to their response to environmental conditions, plants are broadly placed in two main categories namely pioneer and non-pioneer species (Swaine and Whitmore, 1988; Whitmore, 1990; Mabberley, 1992). It is widely accepted that pioneer species benefit in terms of establishment from the conditions associated with tree removal (Schutz, 1998; Tabarelli and Mantovani, 1999). On the other hand, seedlings of the non-pioneer species which are already established under the forest canopy benefit in terms of enhanced growth from its opening (Nwoboshi, 1987; Tang, 1987; Appanah and Weinland, 1990; Leslie, 1994; Tappeiner *et al.*, 1997; Franklin *et al.*, 1997 and Clearwater, 1997). Existing non-pioneer species, often have an advance regeneration bank of seedlings which responds with enhanced growth if the canopy is opened (Primack and Lee, 1991). Further, seeds of the most typical pioneer species seeds retain viability over long periods in forest soil and contribute to a soil seed bank but there is no evidence that typical non-pioneer species do this. Instead, non-pioneer species disperse seeds which can only germinate within a short period of dispersing or falling from the mother plant (Binggeli *et al.*, 1989; Demel and Granstrom, 1995; Chang *et al.*, 1998).

Although gaps thus play an important part in the regeneration and survival success of many species, they also represent a changed forest structure and this type of change has indirect effects on numerous forest organisms. Loggers opt for well-formed trees which normally are emergents and the removal of these will change dramatically the forest structure into that of secondary forest (logged over and left) in the long run, with various consequences (Fuhr and Delegue, 1999; Murphy *et al.*, 1999). Emergent trees usually are important habitats for tree climbers like primates and for birds. Their removal may reduce the population sizes of these in a forest reducing its biodiversity value (Dinesen *et al.*, 1995; Seddon *et al.*, 1999). Tree removal may also impair the activities of soil fauna for which continual humidity and moderate temperatures favour optimal activity (Drift, 1963; Anderson, 1995; Parmelee, 1995). On the other hand, the increased temperatures and periods of reduced soil moisture associated with tree removal will increase the activities of other types of animal, such as termites, which speed up litter decomposition (Lekha *et al.*, 1991).

2.1.1 Single tree felling situations

The extent of disturbance (in this case single tree removal) depends on the scale, time and intensity (Eddy, 1993). The scale of disturbance deals with whether it is at community level e.g. forest fire or is a localized effect e.g. gap creation (Goldammer, 1993). Single tree removal can be put in the latter group where its effect is more localized. The death of single canopy trees by falling whether naturally or due to artificial removal, leads to the formation of small gaps while localized windthrow resulting from multiple tree-falls leads to the creation of relatively large gaps (Manokaran and Swaine, 1994). Chance plays a part in determining the size and position of gaps. But also, to some extent the size of a gap to be created depends on the size of the falling tree, particularly its crown diameter. The larger the crown diameter, the larger the gap created by the fall or removal of a single tree. The size of the gap determines the extent of change in the ecological conditions at the forest floor and hence the plant species which will establish there (Whitmore, 1990; Mabberley, 1992; D'Oliveira, 2000). Kennedy *et al.* (1992) reported that diversity of colonizing vegetation at the end of two years appeared to be negatively related to gap size. In the same study, seedling mortality was less both at larger gap size and in the absence of competition from advance regeneration, whereas the opposite appeared true for seedling growth. In extremely large gaps heat and drought injuries may cause seedling mortality while in the forest seedlings have poor vigour and quickly succumb to pathogens, herbivores, and rain splash (Haeussler *et al.*, 1995). Chapman and Chapman (1997) found that growth rates were consistently slower and mortality was higher in the heavily logged areas than in unlogged forest. Many deaths occurred when healthy trees were knocked over by neighbouring treefalls. The level of canopy opening created during logging, the lack of aggressive colonizing tree species, elephant activity that is concentrated in logged areas, and an aggressive herb community, all combined to delay vegetation recovery in Kibale Forest (Chapman and Chapman, 1997; Chapman *et al.*, 1999).

The time dimension deals with the frequency of the disturbance whether regular (systematic) or irregular. The former group normally is more organised and carried out after a specified time or when certain signs are revealed. On the other hand, the latter group of disturbances are unexpected e.g. hurricanes or cyclones. These may cause tremendous damage to the forest ecosystem. The frequency of disturbance regimes influences the regeneration and stand dynamics. Kneeshaw and Bergeron (1996) reported boreal forest disturbance regimes to have changed the regeneration and stand dynamics of these forests. In their study they found that time since fire was positively correlated with seedling abundance for late successional species, whereas it was not related to the abundance of early successional species. Differences exist between species in photosynthetic and growth responses to the high-light environment, competition for light in canopy gaps is highly asymmetrical and tends to reinforce any pre-existing dominance hierarchy (Brown *et al.*, 1999). Thus if the disturbance is more frequent, it denies the ecosystem time to recover from last disturbance which may lead to its degradation.

Single tree removal is characteristic of pitsawing (Howard, 1991) and of some selective forest management systems used in African and dipterocarp (South east Asian) forests (Parren and De Graaf, 1995; Clearwater, 1997). Selective management systems are polycyclic and aim to maintain mixed size, mixed species and mixed-aged stands of trees through selective felling, occasionally enhanced by limited silvicultural treatment. They are systems involving removal of a certain amount of exploitable-sized timber in shorter cycles than with a strictly monocyclic system designed to produce a fairly uniform crop of trees through intensive harvesting and/or extensive silvicultural treatment (Gale, 1998). Selective management systems are preferred in multipurpose forests such as conservation and protection forests. Selective logging remains the most commonly used practice for harvesting tropical timber. Variants of these systems are in use in South-eastern Asia (Malaysian Selective Management System; Philippines Selective Logging System - Clearwater, 1997; Gale, 1998). The characteristics of selective forest management systems as practised in Indonesia, the Philippines and Malaysia are shown in Table

2.1. The sustainability of selective forest management systems is questionable, however, due to the lack of loggers' adherence to the stipulated regulations (Clearwater, 1997; Ibrahim, 1997; Gale, 1998).

The selective logging method has been considered appropriate for tropical rainforests because of the sensitivity of such forests to clearcutting and because only logs large enough to make processing profitable are suitable for harvesting (FAO, 1992). Single tree removal is clearly relevant in such situations. Tree fall, especially of a canopy tree, tends to create gaps in which competition among newly establishing light demanding plants and advance regeneration is stimulated. This effect is thought to be brought about mostly by the changed light environment in the forest understorey. Nevertheless, conditions become harsher in extra large gaps where desiccation may occur, with resultant deaths of establishing plants (Turner, 1990; Akira, 1995). This is especially true in tropical forests in seasonal climates. Also, in certain instances, canopy opening may not enhance the regeneration of the intended species (Johnson *et al.*, 1997; Tognetti, *et al.*, 1997). In other instances, it does (Finegan and Camacho, 1999; Fuhr and Delegue, 1999).

Table 2.1 Characteristics of Selective Management Systems in Indonesia, Philippines and Malaysia

Country	Minimum cut diameter (cm)	Minimum number (trees/ha) or proportion (%) to be left	Dimensions (dbh) of left stock (cm)	Harvesting cycle (years)
Indonesia	50	25 trees	>35	35
Philippines	70	40%	65-75	30-40
Peninsular Malaysia	50	18 trees	30-45	30
Peninsular Malaysia	48	25 trees	35-40	25

Source : Gale (1998); FAO (1989)

2.1.2 Economic tree genepool impacts

Since pitsawyers and other single-tree exploiters seek well-formed individuals of a particular species, there is a danger of genepool erosion. Future seed trees will be those rejected by the exploiter, usually because of poor quality. If this lower quality has a genetic basis, it will affect the quality of future crops of that species (Gale, 1998). The situation is worsened by the fact that most of the economic tree species in East African montane forests are present only at low density (stocking) and have poor and erratic regeneration (Njunge, 1996). The removal of potential seed trees may increase significantly the distances from residual seed bearers giving greater chances for secondary species to occupy exploited areas (De Graaf, 1986; Parren and De Graaf, 1995). For instance, with *Swietenia macrophylla* King (mahogany) in the Bolivian Amazon where the harvestable density is as low as 0.12 trees/ha, sheer existence is threatened if control measures are not taken (Gullison and Hardner, 1993). A similar situation has been reported for Congo (former Zaire) in the cases of *Entandrophragma cylindricum* (Sprague) Sprague, *E. utile* (Dawe & Sprague) Sprague and *Triplochiton scleroxylon* K. Schum of which 1-2 trees/ha are removed in exploitation but for which regeneration is very sparse (Fickinger, 1992). Similarly, the selective removal of *Ocotea usambarensis* in West Usambara, Tanzania has greatly impoverished the forest of this species (Conte, 1999). In such circumstances even the seed trees become targets for loggers hampering seed production programmes and efforts to promote their future regeneration (Njunge, 1996). In Budongo forest, Uganda, *Khaya anthotheca* (Welw.) C. DC., *Entandrophragma angolense* (Welw.) C. DC., *E. cylindricum* and *E. utile* were found to have very few seedlings (Plumptre, 1995; D'Oliveira, 2000) and *Swietenia* in South America (D'Oliveira, 2000). More than that, many forest tree species do not become reproductively effective until reaching the canopy and it is generally individuals of good form that are the main sources of propagules (De Graaf, 1986). If a species is attractive for timber quality and distributed as widely separated single individuals through the forests, the "creaming" process (a single species is selectively intensively exploited) can lead to local elimination not just a reduction in germplasm quality, as with the trend of mahogany exploitation in Amazonia (CEDI, 1993; Verissimo *et al.*, 1995) and exploitation in dipterocarp forests in Indonesia (McCarthy, 2000). An extreme case is the removal of all seed trees of *Swietenia macrophylla* (Mahogany) in Amazonia which has greatly hampered regeneration of this species (Howard, 1991; Verissimo *et al.*, 1995). Pitsawyers, like other exploiters, usually are very selective in their choice of trees

(Howard, 1991). They normally select well-formed, straight trees which could well be future seed trees. They also use an enormous amount of pole-sized individuals as rollers for moving logs, levers, props and for platform construction (Hall and Rodgers, 1986). Such a process therefore has a creaming effect on the forests (Moad and Whitmore, 1994). Moreover, it endangers the recruitment of smaller individuals into mature stages thus affecting the future population of the exploited species (Hall and Rodgers, 1986). In Tanzania camphor is a tree species creamed from most of the country's montane forests (Pocs and Lovett, 1993; Holmes, 1995b). Thus, most former camphor forests in Tanzania are now dominated by pioneer species like *Macaranga capensis, Albizia gummifera* and *Polyscias fulva.* The genepool erosion will be immense for species which occur as individual sexes in different plants (dioecious). Uncontrolled exploitation may lead to imbalance in population structure between the two sexes hence threaten reproduction of the species. This is so depending on the bole-form, one sex may be preferred by the exploiters than the other. When these human activities are not controlled, change in forest structure and species composition may results (Smiet, 1992; Grodzinska *et al.*, 1998).

2.1.3 Damage and change below the main canopy

An unexploited forest as an ecological system is self-sustaining. Forest exploitation for timber or other products shifts this balance. In Africa, large tree exploitation has been going on mostly for less than 100 years (Conte, 1999). Forests have been exploited for building poles and wood for implements since time immemorial, however. It is virtually impossible to carry out any tree removal operations in a highly complex plant community such as the tropical moist forest without changing its original ecological condition (FAO, 1979; Seymour, 1993). Forest damage can be categorized into three main groups: damage to residual vegetation; reduction in quality as wildlife habitat and impact at ground/soil level (Sist *et al.*, 1998).

2.1.3.1 Damage to residual vegetation

Damage to residual vegetation takes the form of crown damage, broken trees, fallen trees, bark and stem injury and root and buttress injury (FAO, 1998). This affects canopy, middle storey and forest floor strata. In the conceptual model, the crown zone (area where the falling tree crown is envisaged to fall) represents the zone of maximum damage to existing vegetation, maximum organic matter input, and least soil disturbance (Clark, 1990). The bole zone is characterized by high admission of light, low organic matter input, little soil disturbance and intermediate damage to existing vegetation. The root zone, where nutrient-poor sub-surface soil is lifted to the surface, has high soil and vegetation disturbance but no organic matter input from crown or bole debris.

The most destructive operations in logging are felling and skidding (Durrieu *et al.*, 1998). Damage is most severe for smaller-sized individuals where it is irreversible (FAO, 1992, 1998; Fuhr and Delegue, 1999). Uncontrolled exploitation destroys and even kills a proportion of the growing stock (Fox, 1976; Jonkers, 1987; Anane, 1988). It has been shown that felling damage is restricted to the gap created, where most trees are completely destroyed, and its immediate surroundings where many trees are injured (Jonkers, 1987; Hendrison, 1990). Jonkers quantified almost 100% mortality of trees in gaps and on skid trails (caused by extraction) and frequent injury to trees close to them, but negligible damage further away. Fuhr and Delegue (1999) reported a mean of 23.5% of the initial tree population damaged in uncontrolled logging. Out of this felling damaged more trees (14.3%) than skidding (9.2%). Tay (1999) quotes a crown damage to 12% of the residual stand and the death of another 62% of residual stand for a felling intensity of 8-15 trees/ha of trees above 60 cm dbh which yields 80-150 m^3 ha^{-1}. Martins *et al.* (1997) reported logging damage of on average 98 trees/ha which is about 22.9% of the total number of trees/ha most of it occurring during tree felling. Hall and Rodgers (1986) reported destruction of 0.25 ha for a removal of about 30 m^3 of wood in Tanzania forests through pit sawing. Felling damage severity depends on plant size, felling intensity and felling method (Durrieu *et al.*, 1998). Small trees are much more vulnerable to destruction and very severe injury than larger individuals, but less severe injury was more common among larger trees (Jonkers, 1987; Preuhsler and Jakobi, 1996; Ruel *et al.*, 1995). Normally felling damage increases as felling intensity increases (Jonkers, 1987; Hendrison, 1990; Sundkvist, 1993; Bertault and Sist, 1997) and some felling methods are more destructive than others.. But this has been reported not to directly relate to exploited wood volume (Martins *et al.*, 1997). The extent of damage is directly correlated with the forest density (stocking) (Grove *et al.*, 2000).

2.1.3.2 Reduction in quality as wildlife habitat

Animals as components of forest ecosystems are also affected by exploitation. Many species of tropical forest wildlife suffer progressive population decline in commercially logged forests (Frumhoff, 1995). It has been reported that almost 80% of primate species inhabit tropical forests where communities of 6-15 sympatric species are found (Tutin and White, 1996). Primate infants suffered high mortality after logging in Peninsular Malaysia (Johns and Johns, 1995); mousedeer densities were negatively correlated with the proportion of severely disturbed forest in Malaysian northern Borneo (Heydon and Bulloh, 1997) and many components of the butterfly community in Brazilian Amazon were lost (Brown, 1997). Generally, it has also been found that as understorey density increases and overstorey density decreases, the abundance, richness, and diversity of the terrestrial small mammal fauna increases (Malcolm *et al.*, 1995). If selective logging is carried out carelessly, it may have adverse effects on wildlife by destroying both their habitat and food source (Tutin and White, 1996). Apart from animals obtaining shelter and food in the forest (Tutin and White, 1996), they also play important roles as plant pollinators (Renner, 1996), seed dispersers (Forget *et al.*, 1996) and in recycling plant and animal residues. Thus the decline or extinction of these animals may greatly affect proper functioning of these important plant processes.

2.1.3.3 Impact at ground / soil level

The soil properties which are affected by tree removal include: bulk density, aeration, infiltration, hydraulic conductivity, permeability, water retention and availability (Lacey, 1993). Soil damage comes in the form of forest floor exposure after litter removal, exposure of subsoil and burying fertile top soil, and soil compaction (Killer, 1994). Soil compaction is greatest in soils of high air and water content especially when heavy machinery is used (Lacey, 1993). There is no clear relationship between volume of timber removed and soil disturbance (Williamson, 1990). Similarly, in selective logging operations in tropical forests the number of trees removed per hectare has little bearing on the Area of Exposed Mineral Soil (AEMS) (Lacey, 1993). Soil damage is however, influenced by the method of logging. Aerial methods cause 5%, cable yarding 10-20% while ground-based methods cause 20-40% soil disturbance (Lacey, 1993). If carried out carefully, selective logging does not affect waterflow significantly in catchment forests (Nik, 1990). The structural impact on soil physical character indirectly mineralization and eventually soil fertility and site fertility because the soil fauna changes (Forest Service, 1998). Soil nutrient loss can be enormous when a large amount of biomass is removed from the forest ecosystem (De Graaf, 1986). Hendrison (1990) recommended that in order to minimize loss of nutrients, a logging intensity of 30 m^3 ha^{-1} should preferably not be exceeded. This should not be adhered to strictly but local stand conditions such as stocking should be considered. Similarly, the forest floor constitutes the seed bank from which new trees are recruited and it takes little imagination to picture the consequences of soil disturbance for seedling survival. In the undisturbed situation the litter on the soil surface plays a vital role in preventing splash erosion from the rain drops falling from the canopy (Bruijnzeel and Critch, 1994). Removal of this through logging accelerates soil degradation.

Besides these direct impacts on soil properties, single tree removals affect the microclimate of ground and soil under canopy. Soil temperature may differ little from air temperature in the understorey, but may be much higher than air temperature in gaps and clearings (Bazzaz, 1991). The differences are most pronounced near the soil surface, where the germination and early seedling growth usually occurs. In a way, the light environment dictates the temperature of air, plants, and soil in tropical forests. Since this is reduced as incoming light passes through the canopy to the understorey and eventually soil level, the temperature is low at the forest floor. Tree removal also influences soil water balance (Bazzaz, 1991). Incoming radiation and the albedo are the most important controllers of evaporation; the latter is high in clearings with exposed soil surfaces or dry vegetation, lower in gaps, and lowest in intact forest. Low evaporation from soil and low air mixing in dense tropical forests lead to high relative humidity, which in turn reduces evapotranspiration. In gaps and large clearings, relative air humidity may be low and may limit the establishment and growth of some forest species. Close to the ground within the forest, carbon dioxide content of the air remains high all the time but up in the canopy it drops during the day due to uptake by photosynthesis (Whitmore, 1998).

2.1.4 Facilitation impacts

Tree removal can have detrimental (negative) effects on the stand by opening the vegetation enough for other factors to have intensified effects. Forest fire is an important such factor (Hawthorne, 1994), but encroachment, windthrow and illegal timber exploitation, accelerated soil erosion and nutrient depletion may also result, all leading to loss of site productivity (Bruijnzeel and Proctor, 1989; Kim, 1996). Wounded trees which result from logging activities are susceptible to infection (Smith *et al.*, 1994; Hadley, 1994).

Tree removals from forests facilitate fire outbreaks in two main ways Opening the forest increases air movement within it, speeding up the drying of left over wood (Abeli and Sawe, 1999). In addition, opening the forest through logging increases the accumulation of dead wood which acts as fire fuels (Rundel, 1981; Vickery, 1984; De Graaf, 1986). The occurrence of fires opens up the forests even more and destruction of the ecosystem progresses (Cochrane and Schulze, 1999). Although some plant species needs forest fires for regeneration (Vickery, 1984), forest fires are generally detrimental to forest plants in the tropics (Vickery, 1984; Bhatnagar and Kawdia, 1989). Sprouts and young seedlings are killed by the intense heat generated by these forest fires especially when there is deep litter layer or dead wood on the forest floor (Rundel, 1981; Vickery, 1984; Bhatnagar and Kawdia, 1989; Cochrane and Schulze, 1999). As well as increasing fire risks, increased wind speed in exploited areas facilitates windthrow by reducing wind-breaking capability of the forest (De Graaf, 1986).

Opening forest by tree removal also facilitates inward movement of large animals like elephants and buffaloes (Lamprey *et al.*, 1991). Elephants at Kibale, Uganda have also been reported to use heavily logged areas more than lightly logged and unlogged areas (Struhsaker *et al.*, 1996). Chapman *et al.*, 2000 reported that *Colobus guereza* appeared to do well in some disturbed habitats and were found at higher group densities in the logged areas than in the unlogged area. These animals further open the forest by knocking down standing trees and browsing on them. Man's activities in the forest in search of firewood, fruits, animals, honey and other forest products is also encouraged when the forest is comparatively open (Smiet, 1992). Enchroachment is made easier in such circumstances with a diminishing forested area resulting ultimately, there may be fragmentation and the eventual disappearance of continuous forest (Lamprey *et al.*, 1991).

2.1.5 Catalytic impacts

Among numerous factors contributing to seedling mortality in undisturbed forest, are the lack of suitable stimuli or conditions of light, nutrients and root space (Lawson, 1981). Thus canopy opening by tree removal reduces seedling mortality by improving the under-canopy environment for seedlings and saplings of many species catalyzing escape from a risky stage of the life cycle. Canopy closure reduction through logging or silvicultural activities is believed also to increase the growth rate of seedlings of many primary forest tree species (Manokaran and Swaine, 1994). The majority of seedlings in partially open and open environments of an area logged 3 months earlier were found to grow fast (Clearwater *et al.*, 1999). This shows how important canopy opening is to seedling growth. Seedlings present at the time of canopy opening "seedling bank" may grow with renewed vigour (Teketay and Granström, 1997).

Positive impacts of tree removal are therefore increased survival and growth of advance regeneration in the residual stand (Osunkoya *et al.*, 1993; Johnson *et al.*, 1997; Tognetti *et al.*, 1997; Franklin *et al.*, 1997; Clearwater, 1997). There is experimental evidence for this effect: moving dipterocarp seedlings from shade to light significantly increased their growth rates (Howe *et al.*, 1985; Popma and Bongers, 1991). However, light conditions (photosynthetic active radiation) have to be improved (increased) significantly to have noticeable effects (Osunkoya *et al.*, 1993). Tree removal reduces fungal infections which attack young seedlings in shade conditions (Augspurger, 1984a). Tree removal also encourages the establishment of newly germinating seedlings of pioneer species, increasing the plant density in gaps (Augspurger, 1983; 1984a; Mabberley, 1992).

2.2 Light penetration

2.2.1 Light levels

Light quantity and quality is changed as light rays pass through the forest canopy (Schutz, 1998; Kyereh *et al.*, 1999). Since the canopy is made up mostly of green biomass, on passing through the canopy much of the blue and red proportion of the light (Photosynthetically Active Radiation) is absorbed (selective filtering) by the canopy for its photosynthetic requirements and the red : far red ratio is reduced (Lavender, 1990; Whitmore, 1990; Poorter and Bongers, 1993). Thus, what light reaches the forest floor will be in the 'red' range of wavelengths. The rate of this change depends on canopy depth and density in terms of green leaf layers per unit volume and their arrangement (Lambers *et al.*, 1998). Incoming light can be divided into three parts: light absorbed by the atmosphere, direct sunlight and diffused light that has been variously scattered by particles and droplets in the atmosphere (Bannister, 1976; Flint and Caldwell, 1998).

The death of a single tree, or a minor windfall may allow the entry of too little light for pioneers to grow (Fox, 1976) but in larger gaps the germination of seeds of pioneer species already dispersed takes place and these compete with existing seedlings. The more light that reaches the undergrowth, the more intense this competition. The most successful species are those that can respond most rapidly to gap creation (Flores, 1992; Holmes, 1995b). In general, seedling growth increases with increase in light (Fox, 1976; Chazdon and Fetcher, 1984; Oberbauer and Strain, 1985; Ramos and Del Amo, 1992; Dale and Causton, 1992; Nilsson, 1993; Osunkoya *et al.*, 1994) and survival of seedlings is also enhanced by increased light condition (Augspurger, 1984b).

2.2.2 Light level assessment and monitoring with hemispherical photographs

The hemispherical photograph is an indirect method of light assessment used for studying the light environments in gaps and in the understorey. The hemiphotos can be analysed to compute either relative or, more usefully, absolute measures of solar radiation for a sample point, taking account of the contributions of direct (beam or sun), indirect (diffuse or sky) and reflected radiation (Mitchell and Whitmore, 1993). Thus, site factors quantify the proportions of unobstructed radiation (Becker *et al.*, 1989). Without knowledge of prevailing sky conditions (especially cloudiness) these predictions are unreliable (Clearwater, 1997). So the site factors are relative estimates rather than absolute values. But direct measurements of above canopy irradiance can be used to convert these estimates to absolute totals of photosynthetic photon flux density (PPFD) (Clearwater, 1997). Site factors estimated from photographs are good predictors of mean daily PPFD (Chazdon and Field, 1987; Turner, 1990; Turton, 1992; Clearwater, 1997; Myers *et al.*, 2000b). The global or total site factor can therefore be used as a direct substitute for the daily PPFD if no estimates of above canopy PPFD are available.

2.2.2.1 The theory

The method has progressed a long way from its manual inception to the present day computerized analysis (Hill, 1924; Evans and Coombe, 1959; Anderson, 1964; Chazdon and Field, 1987; Ter Steege 1997). The detailed theory is based on geometry and light behaviour (Pearcy, 1989; Ter Steege, 1997). The fish-eye (180^0) lens gives an equiangular projection, i.e. one in which radial distance is directly proportional to angular altitude. The advantage of the equidistant projection is that objects on the hemiphot can easily be located by their zenith and azimuth angles (Mitchell and Whitmore, 1993). The amount of radiation absorbed and scattered by the atmosphere depends on sky conditions while that which reaches the earth surface depends on the distance from the sun and its declination to the point on the earth surface (Stigter and Musabilha, 1982; Mitchell and Whitmore, 1993). Thus it is necessary to take into account the position of the sun relative to the point on the earth surface. To define the position of the sun (S) relative to a point on the earth's surface (P), two angles must be known (Anderson, 1971), the altitude $\beta = \angle$ SPR and the azimuth $\xi = \angle$ NPR, which is the angular distance in the horizontal plane between the sun and the north point N of the meridian plane NMZ (Figure 2.1). Altitude and azimuth can be calculated from the latitude, λ, of P on the earth's surface; the declination δ of P (the difference between the sun's altitude when it crosses the meridian plane near noon and the co-latitude, $\pi/2 - \lambda$) and the hour angle, h, proportional to the time elapsed since the sun crossed the meridian plane. The hour angle is measured along the circle of the solar track S_R to S_S via S (S_R, position at sunrise; S_S, position at sunset), while PQ is the line joining the observer, P with the celestial north pole, Q (Figure 2.1). However, the orbit of the earth around the sun is elliptical rather than circular and the sun is not directly in the centre of this ellipse (Ter Steege, 1997). Since the sun apparently moves through 2π in a day, it appears to move 15^0 in one hour. Altitude and azimuth are given respectively by:

$\sin \beta = \sin \lambda \sin \delta + \cos \lambda \cos \delta \cos h$ .... Equation 1

$\sin \xi = \sin h \cos \delta \sec \beta$ .... Equation 2

At the crossing of the meridian plane h = 0, and equation 1 reduces to $\beta = \lambda - \delta$. Calculations are often made using the complement of altitude $\angle$ SPZ, the zenith distance z (Anderson, 1971).

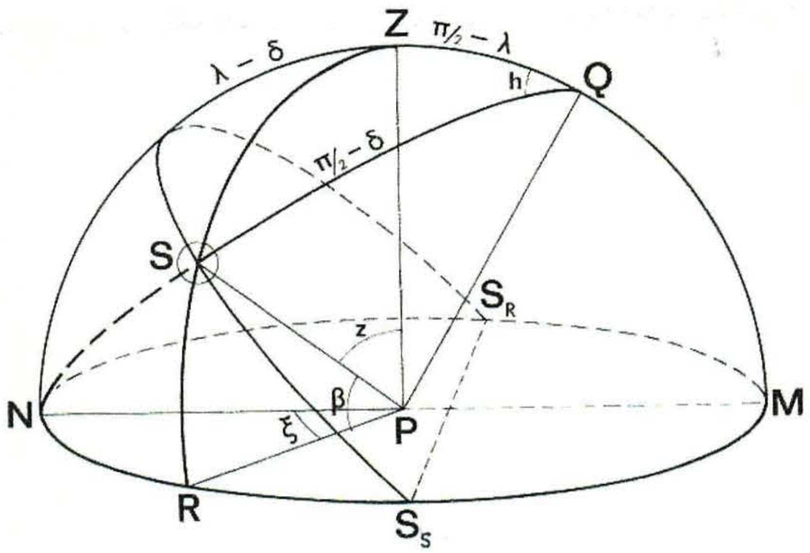
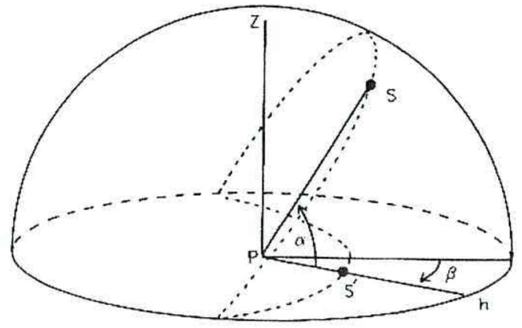
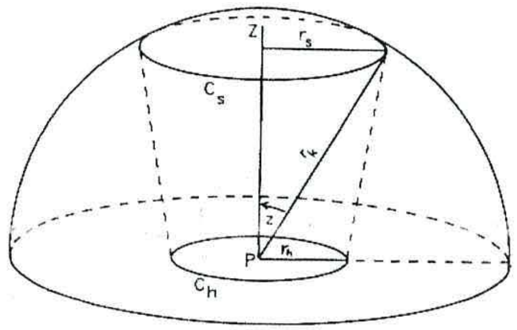


Figure 2.1 Sun positions relative to a point on the earth surface

Where S sun; Z zenith; NMZ meridian plane; P observer; β altitude (the angle between S, P and R); ξ azimuth; δ declination; λ latitude; Q the celestial north pole; z zenith distance; S_s sun position at sunset; S_R sun position at sunrise; R point on the earth's surface parallel to P; h hour angle which is proportional to the time elapsed since the sun crossed the meridian plane (Anderson, 1971).



a



b

Figure 2.2 Diagrams showing parameters used in deriving site indices

Legend for (a) The short dashed lines give the solar tracks.

S and S′ solar images on the hemisphere and Hill projection respectively

β azimuth; ∝ solar altitude; h distance from S′ to a point on the horizon of the Hill projection (is proportional to ∝); P observer; Z zenith

(b) Z zenith; C_s and r_s are the circumference and radius of slice across the hemisphere taken at a zenith angle z. The corresponding circumference and radius on the Hill projection are C_h and r_h. r_k is the radius of the hemisphere (Pearcy, 1989).

Thus the amount of direct light (S_{dir}) on a horizontal surface should be cosine correlated and is calculated as :

$S_{dir} = S_{no} \cdot \sin \propto$ where $S_{no} = S_{out} \cdot \tau^{M}$

S_{no} is amount of direct light on a surface normal to the beam

S_{out} is the radiation on the outer part of the atmosphere

τ is the transmissivity of the shortest atmospheric path length

M is the relative path length in number of optical airmasses or air with different densities the beam traverses

$\propto$ is the solar altitude (angle in degrees) as shown in Figure 2.2 (a).

This formula is based on Lambert's Cosine Law which states that "The irradiance at a surface depends on its orientation relative to the radiant beam" Jones (1992). This can be represented mathematically as :

$I = I_0 \cos \theta = I_0 \sin \beta$

Where I is the flux density at the surface; I_0 is the flux density normal to the beam; θ is the angle between the beam and the normal to the surface and β is the complement of θ as shown in Figure 2.3. The more the beam is at an angle to the surface, the larger the area it is spread over, so the irradiance decreases. The cosine relationship has no problem when the azimuth moves beyond 90^0 because the cosine function changes sign as it moves through 90^0 (Cos 0^0 = 1, Cos 90^0 = 0, cos 180^0 = -1) Mitchell and Whitmore (1993).

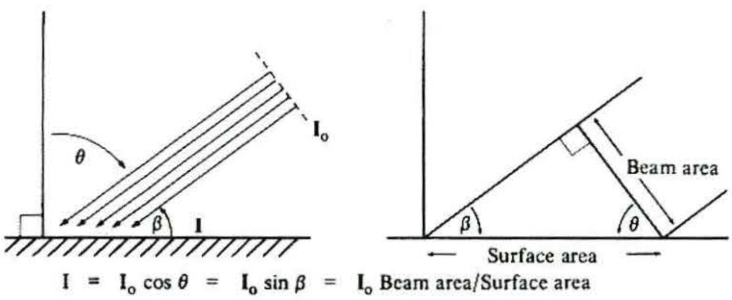


Figure 2.3 Lambert's Cosine Law (Source: Jones, 1992)

Diffuse light originates from direct light, scattered by the atmosphere. For most purposes, under clear sky conditions, the amount of diffuse light on a horizontal surface is estimated as 15% of the amount of direct light and then added to the amount of direct light on that same surface. However, at low solar altitudes the amount of diffuse light may be much larger (over 50%) and a more accurate (empirical) estimate of the diffuse light in a clear not dust-free sky is given by:

$$S_{dif} = S_{out} \,.\, (0.271 - 0.294.\ \tau^{M}).\sin\alpha$$

Where S_{dif} , diffuse light

S_{out}, radiation on the outer part of the atmosphere (W m^{-2}).

τ, transimissivity - expressed as a proportion of radiation received on the earth's surface after atmospheric absorption and scattering has been taken into account (Ter Steege, 1997).

Indirect (diffuse) site factor (ISF), direct site factor (DSF) and total site factor (TSF) are the fractions of direct, indirect or total radiation that will penetrate to a particular site relative to the amount of radiation above the canopy (Anderson, 1971; Mitchell and Whitmore, 1993; Ter Steege, 1997). These must each be calculated with appropriate weighting for the angular distribution of radiation (Mitchell and Whitmore, 1993).

A vertical cylinder in the field of view of the lens appears on a hemiphot tapered towards the zenith because successive points up from the base are farther from the camera and subtend smaller angles (Figure 2.2). The cylinder appears at the correct azimuth and points on it appear at the correct zenith angles as linearly transformed to the radius on the photograph (Mitchell and Whitmore, 1993). However, equal areas on the hemisphere are not represented by equal areas on the hemiphot because successive points up from the base in the field of view of the lens are farther from the camera and subtend smaller angles. This is the main reason for the distorted view of objects in a hemiphot (Mitchell and Whitmore, 1993).

2.2.2.2 The procedure

- Choice of equipment

Nowadays, cameras and lenses of different makes are available in the market and most give good quality pictures. Good cameras have focusing devices enabling good pictures. Either the camera or lens should have leveling and alignment devices which are also important for good quality images. A camera fitted with the 180^0 field of view lens, can be used to take hemispherical images. If a colour film is used, a red filter may be attached to filter red light and increase the contrast between sky and vegetation (Sizer and Tanner, 1999; Machado and Reich, 1999). Some researchers have used post-photographing contrasting as alternatives to red filters (Canham *et al.* 1990). In this case, negatives are exposed using a meter reading from a nearby open site. This helps to standardize the brightness of sky in the resulting image and effectively underexposes the foliage to enhance the contrast between foliage and sky. Black and white films are preferred to colour, since in the absence of filters or meter reading they give good contrast. Tripod or mono-pod camera stands may be used to position the camera. Mono-pod stands are especially useful when photographs are to be taken higher up in the canopy.

- Creating a suitable camera point

The camera point is preferred to be flat or gently sloping to facilitate camera and lens leveling and alignment. An area of one metre radius around the image point should be cleared of any obstructions in order to reduce interruptions.

- Photographing conditions

In equatorial latitudes the best pictures are obtained before 8.00 h or after 16.00 h as interference by direct sun rays is then avoided (Whitmore *et al.*, 1993; Oberbauer *et al.*, 1993). Sometimes, photographs are taken in overcast conditions to overcome the limitation imposed by timing (Whitmore *et al.*, 1993). The photographer should avoid taking pictures in the misty conditions common under the canopy because under these circumstances visibility is impaired and camera focusing imprecise. Photographs can be taken at any preferred height from the ground, such as 1.5 m (Canham *et al.*, 1990) and 1 m (Ter Steege *et al.*, 1994; Kabakoff and Chazdon, 1996; Nicotra *et al.*, 1999). Photographing height has insignificant effect on the results (Robison and McCarthy, 1999).

- Taking the photographs

The method involves taking vertical photographs from the forest floor upwards using a lens which views 180^0, hence the names "hemispherical" or "fisheye" canopy photographs (Mitchell and Whitmore, 1993). If the camera is mounted on a tripod this has a self leveling device. If a mono-pod stand is used the leveling device is attached to the fisheye lens.

- Photographs processing

Depending on the availability of equipment, films can be printed or digitized directly. Today it is normal for prints (Ter Steege *et al.*, 1994) or films (Becker *et al.*, 1989; Canham *et al.*, 1990) to digitize images using scanners. Measures taken off hemispherical photographs analysis are relative allowing straight forward comparison of different sites (Pearcy, 1989; Whitmore *et al.*, 1993). Digitized images are suitable for further analysis using image analysis computer programmes such as Canopy (Oberbauer *et al.*, 1993, Bellingham *et al.*, 1996), Solarcalc (Kabakoff and Chazdon 1996, Nicotra *et al.*, 1999), International Imaging Systems Model 75 image processor (Sizer and Tanner, 1999), Winphot (Ter Steege, 1997; Machado and Reich 1999) and Optimas 5.2, Optimas, Washington (Myers *et al.*, 2000b).

2.2.2.3 Advantages, disadvantages and alternatives

Advantages:

Hemispherical photographs are easy to capture and analyze: with little instruction it can be conducted by anybody. They are also suitable in situations were light quantification has to be done in different areas in a short time due to easy mobility of the methodology (Chan *et al.*, 1986). Versatility of the method in that it can be used in areas where other equipment may be difficult to use, e.g. in tree canopies or under closed forests or remote areas (Mitchell and Whitmore, 1993). Fieldwork is comparatively (compared to instrumental measurements) quick and cheap (Mitchell and Whitmore, 1993).

Disadvantages:

The method is limited by time in which best pictures are obtained. Best pictures are taken before 08.00 h and after 16.00 h when the sun angle is low (Whitmore *et al.*, 1993). There is angular distortion which requires correction (Pearcy, 1989). The values obtained are relative. In this study it was not a serious problem since the measurements were meant to monitor the changes in light conditions in created gaps and under-canopy. To determine absolute light values reaching the forest floor you need to measure the light in the open for calibration (Pearcy, 1989; Mitchell and Whitmore, 1993; Whitmore *et al.*, 1993; Akira, 1995; Clearwater *et al.*, 1999). These direct measurements are usually done using quantum sensors (Clearwater *et al.*, 1999). The values obtained depends on geographical positions, altitudes and sun hours (Clearwater, 1997; Ter Steege, 1997). Because of the relatively low precision of field measurements of radiation close agreement is not to be expected between computed and measured values (Mitchell and Whitmore, 1993). Wind speed may adversely affects the readings. Fast shutter speeds may counteract this effect (Pearcy, 1989). Significant seasonal canopy changes may result in differences in light measures (Pearcy, 1989). This is due to the fact that even the shedding of leaves has the potential in increasing the light reaching the forest floor which will be registered in hemispherical photographs. The problem is serious in deciduous forests which shed their leaves regularly. Thus consecutive photographs may yield different readings even though no tree removal has taken place.

Alternatives:

There are also methods for quantifying light in the open and under canopy which are direct methods, giving the required readings of required light property such as solar radiation, net and total radiation, photosynthetically active radiation immediately instead of involving an intermediate stage as in the case of hemispherical photography. Direct methods involve the use of light sensors which generate the direct readings of radiation. These sensors are of two kinds (Jones, 1992; Jones, 1993). One group uses thermoelectric properties (e.g. Kipp solarimeter or pyranometer) and the other is based on photoelectric (e.g. silicon cells, cadmium sulphide, photoresistive cells or selenium cells Ammer and Krotz, 1997) principles. As the groups suggest, the sensors react to either heat or photons in their operation. Sensors can alternatively be classified according to the type of radiation they measure, however, e.g.

- quantum sensors which measure photosynthetically active radiation (Torquebiau, 1988; Oberbauer, 1989; Pearcy, 1989; Thompson *et al.*, 1992).
- photosynthetically active photon flux density (PPFD) sensors (Lei *et al.*, 1998)
- ultraviolet-band sensors (Flint and Caldwell, 1998)
- solar radiation sensors (Pearcy, 1989)
- net and total radiation sensors (Pearcy, 1989)

Any sensor type can be used individually or as paired or larger sets of the same type linked to a data logger, enabling the measurement of light at different points simultaneously. Although individual sensors are relatively cheap compared with hemispherical photography equipment, data loggers are costly and need calibration and programming before use, as well as considerable operator familiarity. Besides the suitability of hemispherical photography in light quantification as describe earlier, it can be used as a management tool to estimate vegetative cover and stratifying reforestation units according to the severity of plant competition (Chan *et al.*, 1986). As a research tool, it provides an accurate, reproducible method of characterizing understorey light conditions, levels of competition, and canopy architecture.

CHAPTER THREE : STUDY FORESTS AND TARGET SPECIES

This chapter describes the forests which were studied and the characteristics of the target species. Section 3.1 concerns the forests: Chome (3.1.1), Machame (3.1.2) and Rongai (3.1.3). Subdivisions separate information on environmental setting, forest character, and management and logging history. The species covered are (Section 3.2): *Ocotea usambarensis* (3.2.1), *Podocarpus* spp. (3.2.2) and *Fagaropsis angolensis* and *Ficalhoa laurifolia* (combined in 3.2.3). In each case, the subdivisions under the species headings are general description, stocking levels, increment and reproduction.

3.1 Study forests

All three study forests (Chome, Machame, Rongai) are Afromontane forests in the terminology of White (1978, 1983). Locations are shown in Figure 3.1. There are a number of general accounts of Afromontane forests, White (1978, 1983) has provided the broadest coverage, recognizing seven separate systems, each associated with a particular mountain region, and describing the vegetation structurally and floristically. Donald and Theron (1983) outline forest management initiatives for these forests, although tending to emphasize activities in South Africa. Lovett (1992) and Holmes (1995b) have specifically addressed the Tanzanian situation, Lovett in terms of biogeographical aspects of the flora and Holmes from a management viewpoint. Case studies for areas comparable with the present study area are limited to an old account of the West Usambara forests (Pitt-Schenkel, 1938) and a more recent study of the Usambaras as a whole (Iversen, 1991a,b). Iversen provides details of floristics while Pitt-Schenkel's case study is of the Shume forest.

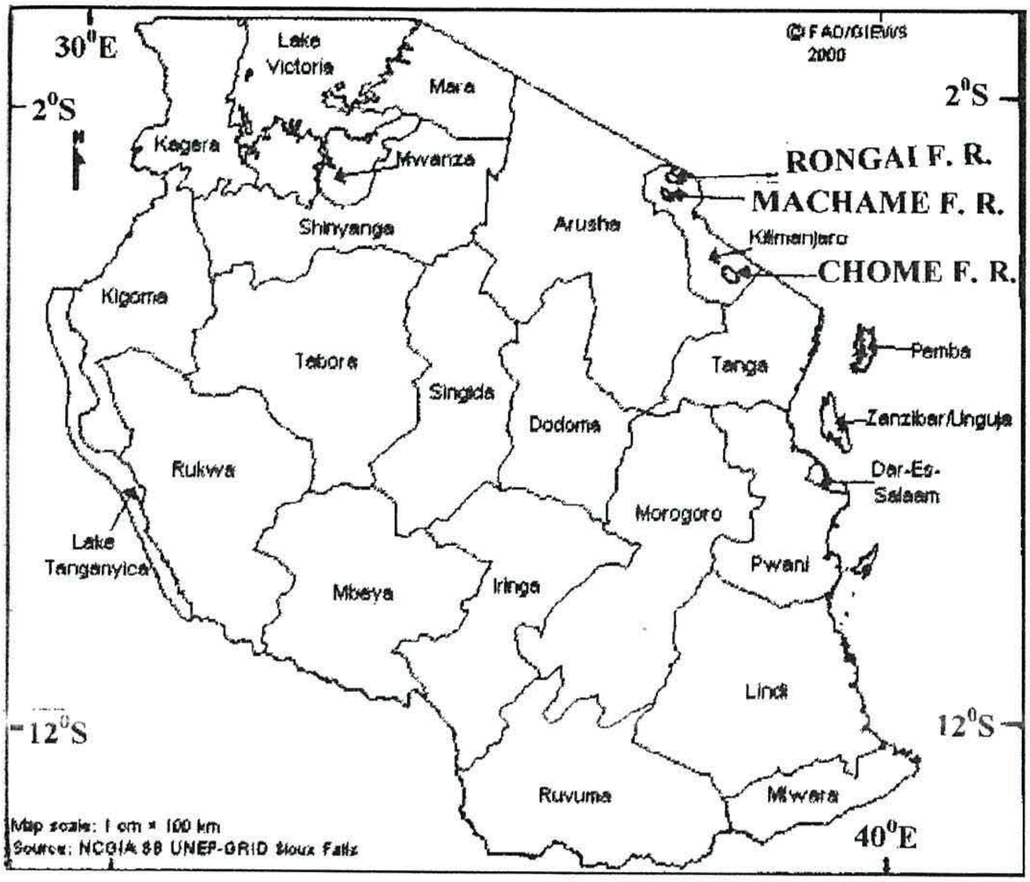


Figure 3.1 A map of Tanzania showing locations of studied forests
Source: Base map from FAO/GIEWS (2001)

3.1.1 Kilimanjaro - Machame ($3^0 00'$ S, $37^0 13'$ E; 1650 m)

3.1.1.1 Environmental setting

The forest is situated at the eastern foot of Mount Kilimanjaro. Kilimanjaro rises to 5890 m but the highest point sampled at Machame was 1850 m. The location of the forest in Tanzania and in Kilimanjaro Region is shown in Figure 3.1. The current montane forest on Mount Kilimanjaro, a remnant of a more extensive forest that has been steadily reduced by conversion to farmland, is now restricted to elevations of 1820-3050 m (Mwasaga, 1991). Mwasaga further reports that the surviving montane forest on Mount Kilimanjaro is being further degraded by cutting and fires. The nearest meteorological station to Machame is at Lyamungu (3^0 $14'$ S, $37^0 15'$ E; 1250 m). Figure 3.2 shows Mount Kilimanjaro. The eastern and southern slopes are wetter than the western and northern slopes. Thus, Machame forest has oceanic rainfall since it is situated on the southern windward side of the mountain (Figure 3.2). The mountain itself is of volcanic origin, thus its soils are deep and fertile with good drainage (Borota, 1975; Holmes, 1995b). The soils are andosols which are rich in nutrients developed from porphyry and basalt lava and hence are basic (Unesco, 1976; FAO, 1991; Lovett and Pocs, 1993). At lower elevation nitisols (FAO and Unesco, 1988; FAO, 1991) have also developed, while on the rocky ridges of higher elevation acidic lithosols occur. Parts of the area sampled in Machame were rocky while other parts were not.

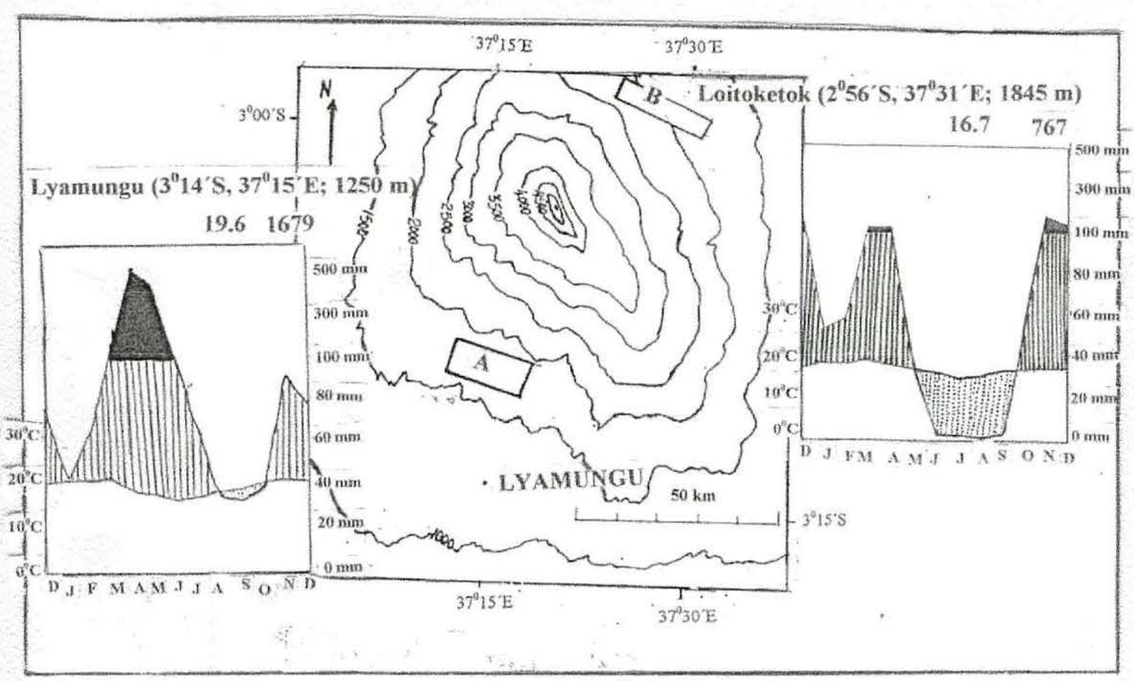


Figure 3.2 Relief map of Mount Kilimanjaro (with climatic diagram for Lyamungu and Loitoketok insets, Source: Pocs, 1991). Where A = Sampled area at Machame B = Sampled area at Rongai

3.1.1.2 Forest character

The vegetation in the forest varies with rainfall and altitude (Pleijel, 1997; Lovett, 1998,1999). This study was conducted in the belt between altitudes 1650 m and 1850 m. Although there were some areas with pure *Ocotea usambarensis*, this belt is dominated by *Albizia gummifera, Macaranga capensis* and *Polyscias fulva* among the pioneer tree species after past logging for *Ocotea usambarensis* (White, 1978; Lovett and Pocs, 1993).

Good regeneration of *Ocotea usambarensis, Macaranga capensis, Polyscias fulva* and *Albizia gummifera* can be observed at most places. Most of the plots (20 out of 24) were located on the upper bank of a seasonal stream where some areas were rocky and others had deep volcanic soils.

After reconnaissance, the plots in Machame were laid on both sides of the forest access road which was used during exploitation in the past. The area was chosen for ease of accessibility. Three plots were located South of the seasonal stream and 21 plots were located North of this stream. The plots were laid out in areas where there was at least a single tree per square metre of the target species in this case *Ocotea usambarensis*. This was not difficult in Machame since the great proportion of woody plants in this site was made up of *Ocotea usambarensis* with sparse undergrowth vegetation.

3.1.1.3 Management and logging history

Machame forest reserve has been managed as a source of camphor (*Ocotea usambarensis*) which was logged until the late 1970s. The detailed management regime for *Ocotea usambarensis* can be found in Donald and Theron, (1983) and Holmes (1995b). A complete silvicultural regime for *Ocotea usambarensis* is shown in Table 3.1. Couping involves dividing the forest into areas which have more or less uniform timber stocks. The silvicultural treatments involved poisoning of defective camphor and unwanted tree species, thinning, climber (brambles) cutting, slashing, liberation of suckers and gap planting with rooted camphor suckers (Holmes, 1995b). The final felling is at 75 years of age when the average diameter at breast height is 60 cm (Donald and Theron, 1983; Holmes, 1995b).

Table 3.1 Tending schedule for *Ocotea usambarensis* in Magamba Forest ($4^0 48'$ S, $38^0 30'$ E; 1500 m)

Year	Operation
F - 1	One year before felling, couping, demarcation, selection and enumeration by numbering all utilisable trees, takes place
F	Felling of marked trees - exploitation
F + 1	One year after felling - sanitary cleaning - thinning of Camphor coppice and root suckers to two or three per stump
F + 5	Assessment to determine the regeneration progress
F + 10	Second sampling to assess if regeneration is sufficient
F + 15	1st Thinning
F + 20	2nd Thinning
F + 40	3rd Thinning
F + 60	4th Thinning
F + 70 - 75	Final felling

Source: Holmes (1995b)

When legal logging activities ended in 1984 (Mbegu, 1996), except for existing experimental plots, silvicultural treatment of the main forest ceased. Management now is protective and under the control of the central government. There are patrols which try to stop people going into the forest, monitor and maintain the boundaries, and undertake gap planting (with other tree species e.g. *Croton macrostachys*) and fire fighting. Gap planting species are selected based on their easy colonisation of the area.

3.1.2 Kilimanjaro - Rongai ($2^0 58'$ S, $37^0 28'$ E; 1950 m)

3.1.2.1 Environmental setting

Rongai is on the northern side of Mount Kilimanjaro (and is also known as Northern Kilimanjaro Forest Reserve). This part of the mountain is quite dry being on the leeward aspect relative to the path of moisture-laden winds from the Indian Ocean coast (Figure 3.2). The dry season is long, from May to October. The nearest meteorological station is Loitoketok ($2^0 56'$S, $37^0 31'$E; 1845 m). The soils are andosols.

3.1.2.2 Forest character

This forest is an example of the dry transitional montane forest of White (1983). Lovett and Pocs (1993) classified the same type of forest as dry montane forest which occurs below 1800 metres. Dry montane forest covers most of the northern slopes between 1800 and 2000-2200 metres altitude and extends to the upper forest limit on dry ridges and slopes. The belt which was sampled in this study was from 1950 m to 2150 m (Figure 3.2). As in the case of Machame, the plots were sampled after initial reconnaissance. The plots were on the upper bank (right) of the River Kimengelia, a perennial stream enventually flowing into the River Pangani. On the uninhabited western and northern slopes of Mount Kilimanjaro buffalo and elephant migration has resulted in forests with an open canopy and thick tangles of climbers. According to Lovett and Pocs (1993) in dry montane forest with canopy height of about 10-20 metres, larger trees include: *Calodendrum capense* (L. f.) Thunb., *Clausena anisata* (Willd.) Benth., *Cussonia holstii* Engl., *Croton macrostachyus* Del., *C. megalocarpus* Hutch., *Euphorbia candelabrum* Kotschy (only up to 2000 metres), *Olea capensis* L. and *Teclea simplicifolia* (Engl.) Verdoorn (rarely with *Podocarpus latifolius*). In drier areas this forest with emergents to 40-50 metres is dominated by *Cassipourea congoensis* DC. and *Casearia battiscombei* R. E. Fries with *Bersama abyssinica* Fres., *Diospyros abyssinica* (Hiern) F. White, *Ekebergia capensis* Sparrman, *Entandrophragma excelsum* (Dawe & Sprague) Sprague, *Fagaropsis angolensis*, *Olea capensis* L., *Nuxia congesta* Fresen., *Podocarpus falcatus*, *Prunus africana* (Hook. f.) Kalkman, *Syzygium guineense* (Willd.) DC. subsp. *afromontana* F. White, *Tabernaemontana pachysiphon* Stapf, *Teclea nobilis* Del. and *Xymalos monospora* (Harv.) Baillon. Other species are *Juniperus procera*, *Dombeya torrida* and *Trichocladus ellipticus* Eckl. & Zeyh.

3.1.2.3 Management and logging history

Under the colonial governments (German and British), the Kilimanjaro Forest Reserve (including Rongai) was managed both for water catchment protection and for forest products (Kivumbi and Newmark, 1991). Forest products could only be collected with a valid forest licence which meant that much of the traditional use of the forest by the Chagga (indigenous people around Mount Kilimanjaro) was restricted. In 1941, a belt of forest above the lower forest boundary and approximately 800 m wide was set aside as buffer forest to provide the local people with forest products to reduce pressure on the reserved forest (Kivumbi and Newmark, 1991). Although organized logging activities took place in the past, no silvicultural treatments were applied in this forest. *Juniperus procera*, *Podocarpus* spp., *Fagaropsis angolensis* and *Hagenia abyssinica* were exploited and some natural forest was clear-felled for the establishment of softwood plantations of *Pinus patula* and *Cupressus lusitanica* (Lamprey *et al.*, 1991; Mwasaga, 1991; Holmes, 1995b). Since logging has stopped, management activity focuses on field patrols, boundary maintenance and gap planting with indigenous tree species (particularly *Croton macrostachys*) and occasionally surveying of unreserved areas for expansion of the forest reserve. *Croton macrostachys* is preferred in gap planting because is fast site coloniser.

3.1.3 Chome ($4^0 00'$ S, $38^0 00'$E; 1900-1950 m)

3.1.3.1 Environmental setting

Chome forest is on North Tanzania in Kilimanjaro region on the South Pare mountains ($4^0 00'$S, $38^0 00'$E; 1900-1950 m). The forest has oceanic rainfall with oceanic temperatures. Climatic conditions in Chome resemble those at Shume in the Usambara Mountains in terms of elevation and orientation (apect). The relief features of Chome are shown in Figure 3.3. The soils are probably humic nitosols, as at Shume.

3.1.3.2 Forest character

A forest description for Chome Forest Reserve has been given by Lovett and Pocs (1993). The present study was carried out in a belt at 1900-1950 m elevation on the southern side of Mount Shengena along the road from Chome to Suji. According to Lovett and Pocs (1993), montane forests occur above 1500 m with a drier type on the lower slopes and rainshadow areas. Heath occurs along rocky ridges in shallow, acidic soil as natural vegetation. Secondary heaths and grassland follow fire in drier montane forest and now occupy large areas at 1600-2000 m with scattered patches in the east and north and a continuous belt between the forest edge and cultivation in the drier west.

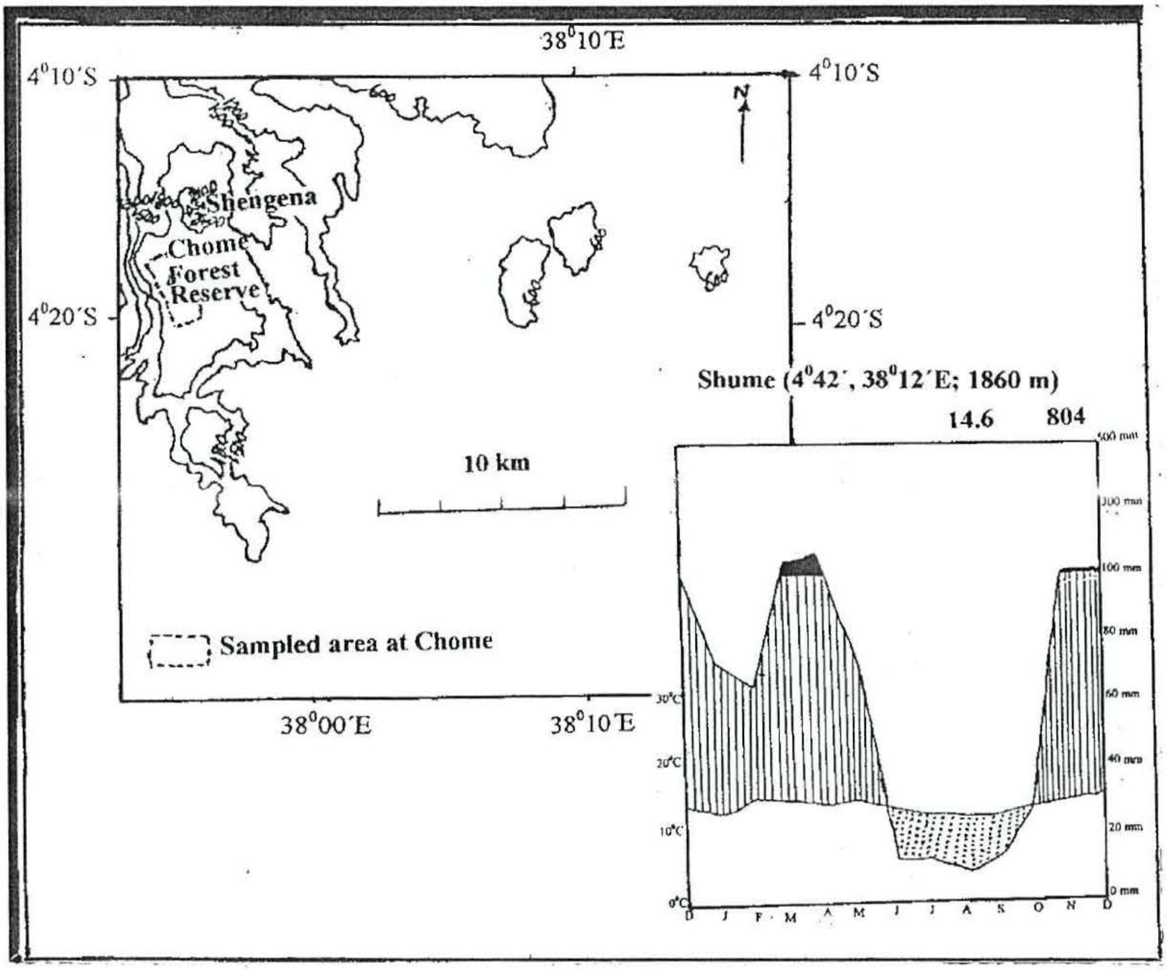


Figure 3.3 Relief map of Chome (with climatic diagram for Shume inset, Source: Survey Division, 1960).

According to Lovett and Pocs, (1993), the submontane forest below 1600 m is dominated by *Parinari excelsa* Sabine. The drier montane forest has a single high canopy and few epiphytes. Large trees include *Albizia gummifera, Ficalhoa laurifolia, Macaranga capensis, Teclea nobilis* and *Xymalos monospora*. Associated species are *Aningeria adolfi-friedericii* (Engl.) Robyns & Gilbert, *Chrysophyllum gorongosanum* Engl. and *Podocarpus latifolius*. In exploited areas secondary stands include *Macaranga capensis* and *Polyscias fulva*. Smaller trees include *Aphloia theiformis* (Vahl) Benn., *Balthasaria* *schliebenii* (Melchior) Verdc., *Cornus volkensii* Harms, *Ekebergia capensis, Halleria lucida* L., *Memecylon deminutum* Brenan, *Maesa lanceolata* Forssk and *Rapanea melanophloeos* (L.) Mez. *Ocotea usambarensis* does not occur or is rare in the North Pare mountains, whereas in the South Pare it is the dominant tree in primary montane forests and together with *Podocarpus latifolius*, has very good regeneration. This study was conducted in South Pare.

3.1.3.3 Management and logging history

Since this forest reserve also contains abundant camphor (*Ocotea usambarensis*), the management regime is as described for Machame (Section 3.1.2.3). In the past this forest received silvicultural treatments, especially those aimed at liberating existing camphor suckers, induction of new suckers and enhancing the growth of saplings and pole-sized individuals (Holmes, 1995b; Conte, 1999). Silvicultural treatments also included climber cutting, thinning and sucker transplanting. The tending schedule at Magamba is shown in Table 3.1. Hand in hand with silvicultural treatment, logging (particularly for *Ocotea usambarensis*) was carried out. For various reasons, but particularly lack of funds, silvicultural treatments were discontinued in the 1970s. Management currently concentrates on fire line and boundary cleaning, forest patrols and surveying new areas for reserve expansion. The forests are now managed as water catchments, and for biodiversity and environmental protection.

3.2 Species of interest

3.2.1 *Ocotea usambarensis* Engl. (Lauraceae)

3.2.1.1 Description

Ocotea usambarensis is a tree with a mature height range of 25 m to 45 m (Beentje, 1994). It is evergreen, with a massive straight slightly fluted bole up to 10 m high, buttressed at the base, and a spreading (dense) crown (Lind and Morrison, 1974; Beentje, 1994; Pope, 1997). The bark is reddish brown, rough when old and flaking in small rounded or rectangular scales (Beentje, 1994; Pope, 1997). The young branches and twigs are slender, angular and finely longitudinally striate towards the ends, ± densely fulvous-pubescent or tomentose, sometimes glabrescent (Pope, 1997). The leaves are often subopposite, strongly discolorous, glaucous-whitish, ovate or elliptic, base rounded or cuneate, apex acute or shortly acuminate, margin often inrolled, 5-10 cm by 3-5.5 cm (to 14 x 8 cm on sucker shoots), often puberulous beneath and camphor-scented when crushed (Beentje, 1994). The inflorescence is a panicle of cymes in the axils of subterminal leaves, these panicles being 3-13 cm long, ± lax, few to many flowered and densely yellowish-brown pubescent. The peduncle is 2-8 cm long; the bracts minute, ovate to ovate-lanceolate and soon falling (Pope, 1997). The flowers are greenish in 10-25-flowered puberulous panicles, 1.5-6 cm long. The corolla is about 3 mm long (Beentje, 1994). The fruit is ovoid, to 6 mm x 5 mm, located in a cup 2.5 mm high. Natural seedlings are rare in *Ocotea* forests due to seed predation by insects, and large creatures (Lind and Morrison, 1974; Backeus, 1982). Reproduction is mostly through root suckers and coppicing (sprouts).

Ocotea usambarensis is present in the montane forests of Kilimanjaro, Usambaras, Pares, Nguru, Uluguru, Mufindi, Usagara and Dabaga (Lovett, 1992; Holmes, 1995b). *Ocotea usambarensis* requires well-drained sites (Backeus, 1982; Holmes, 1995b) and is common on the wetter south and east-facing slopes of the mountain areas of Kilimanjaro, Pare and Usambaras at altitudes 1200-2250 m (Kimariyo, 1971). *Ocotea usambarensis* in its large-sapling (≥ 5 cm dbh), pole and tree stages is essentially a light demander, even if its seedling and small-sapling (≤ 5 cm dbh) stages are especially intolerant of direct light (Abraham, 1958). *Ocotea usambarensis* is usually gregarious and in the elevation range 1700-2400 m is often associated with *Podocarpus latifolius* in what are termed *Ocotea-Podocarpus* forests (Pitt-Schenkel, 1938).

3.2.1.2 Stocking levels

The stocking level as reported from Mazumbai in West Usambara for an area of 8.5 ha is shown in Figure 3.4.

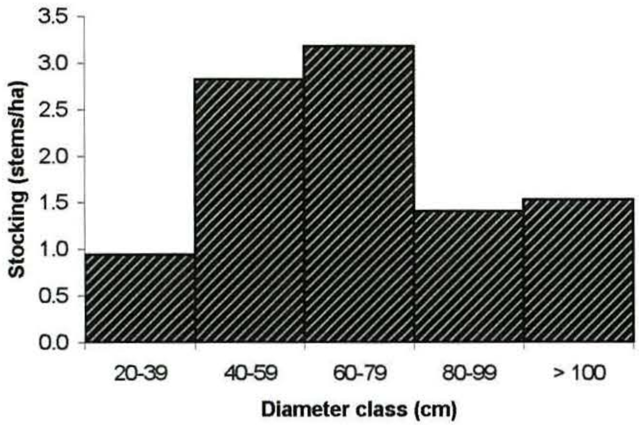


Figure 3.4 *Ocotea usambarensis* **stocking levels in 8.5 ha Mazumbai forest, Tanzania ($4^0 48'$ S, $38^0 30'$ E; 1500 m) (Source: Hall (1985)**

In undisturbed forest the stocking of *Ocotea usambarensis* ranges as high as 25 to 50 mature trees per hectare amongst 124 to 250 stems (all species) per hectare (Holmes, 1995b).

3.2.1.3 Increment

The best height growth is obtained by felling the camphor trees without further treatment (Kimariyo, 1971). Through this treatment the next generation of trees attain an average height of 3.8 m in eight years, with an increase of almost 0.48 cm dbh per year. An increment of 0.9 cm dbh and 0.92 m height per annum for well tended trees has been reported (Holmes, 1995b). In the West Usambara, Tanzania, more root suckers and coppice shoots are obtained when tree felling is done in December, the middle of the main rainy season (Kimariyo, 1971). Diameter growth of this species is enhanced by thinning

(Mugasha, 1978). In a 10 years experiment in a camphor stand it was found that on the final assessment, mean dbh was 40.3 cm, maximum was 53.2 cm and minimum was 16.9 cm on a thinned plot and mean dbh was 31.7 cm, with a maximum of 56.7 cm and a minimum 7.3 cm in an unthinned plot. The thinned stand was superior by 9 cm in terms of mean dbh (Mugasha, 1978).

3.2.1.4 Reproduction

Ocotea usambarensis does not appear to have well-defined seasons for flowering and fruiting but may produce flowers, fruits and foliage-shoots in any month of the year. It has also been reported that naturally the species produces good seeds every third or fourth year and seed longevity is about three months (Borota, 1975). The seeds, however, tend to be predated by insects and large creatures instead of being dispersed and natural seedlings are rare in *Ocotea* forests (Lind and Morrison, 1974; Backeus, 1982). The seedlings of this species have nevertheless been reported to be successfully raised in a nursery with moderately good (60%) germination (Msanga, 1998). Msanga has described the germination (epigeal), the seed handling, and the pre-sowing seed treatment for good germination. The treatment involves complete removal of the woody seed coat, by light hammering or cracking in a table vice (Msanga, 1998). Regeneration by root suckers is very common in *Ocotea* forests and is reported to be the best mode of reproduction in this species. Suckers are produced profusely (Kimariyo, 1971; Backeus, 1982; Holmes, 1995b; Njunge, 1996) but although regeneration of camphor by root suckers is abundant, few suckers develop into poles (Pitt-Schenkel, 1938; Holmes, 1995b). This is mainly due to root suckers competition for space and light.

3.2.2 *Podocarpus* spp. (Podocarpaceae)

3.2.2.1 Description

There are three species of *Podocarpus* in Tanzania: *Podocarpus falcatus*, *P. henkelii* and *P. latifolius*. *Podocarpus latifolius* and *P. falcatus* are widespread above 1200 m the former extending to 2700 m elevation and latter to as high as 3300 m. *P. henkelii* has been reported from the Usambara and Uluguru Mountain ranges. Van-Daalen and Van-Daalen (1993) have classified *P. falcatus* as a later successional species, while Midgley *et al.*, (1995) classify it as shade tolerant. This study deals with *Podocarpus falcatus* and *P. latifolius* only.

Podocarpus falcatus (Thunb.) Mirbel is an evergreen tree up to 36 m in height and 2 m dbh (Beentje, 1994). The bark is pale grey or brown, and flakes in long irregular rectangles (Palmer, 1977; Palgrave, 1988; Beentje, 1994; Wyk and Wyk, 1997). The crown is often festooned with the old man's beard lichen, *Usnea,* and of ridged branchlets squarish in cross-section. The leaves are restricted to the ends of the branchlets and are linear, with a cuneate base and an acute tapering apex. In size the leaves are 2-4 cm by 0.2-0.4 cm in mature trees but up to 18 cm by 1.6 cm in juvenile trees. Stomata are present on both surfaces. The male cones are in groups of 1-3, and are yellow-brown in colour and, 10-23 mm long. The female cones are single, green to grey- or yellow green, and later purple in colour. The seed and fleshy receptacle at maturity ("fruit") is ellipsoid or globose and 14-23 mm by 11-21 mm, with a woody shell 1-2 mm thick. The species is found in upland forest and drier forests with *Juniperus*, in often riverine sites. It is sometimes locally dominant, or may even form a pure stand.

Podocarpus latifolius (Thunb.) Mirbel is an evergreen tree 5-25 m or more in height when mature (Beentje, 1994). Its bark is pale brown or dark brown, peeling in long narrow strips. The leaves are aromatic, and linear in shape, with a cuneate base and a gradually tapered acute apex. In size they are 6-15 cm by 0.5-1.2 cm. They bear stomata only on the lower surface. The male cones appear singly or in pairs and are pinkish in colour and 1.5-5 cm long. The female cones are solitary, with the seed (fruit) (sub-)globose and 6-12 mm across, supported on a red fleshy swollen receptacle. This species is normally found in upland forest, in wetter zones, often forming almost pure stands above 2600 m and associated with bamboo, *Hagenia, Ocotea, Juniperus* and *Olea.*

3.2.2.2 Stocking levels

Stocking by diameter classes in different locations is shown in Figure 3.5. *Podocarpus latifolius* and *P. falcatus* are found in the moist montane forests of Meru, Kilimanjaro, South Pare and West Usambara mountains (Borota, 1975; Holmes, 1995b).

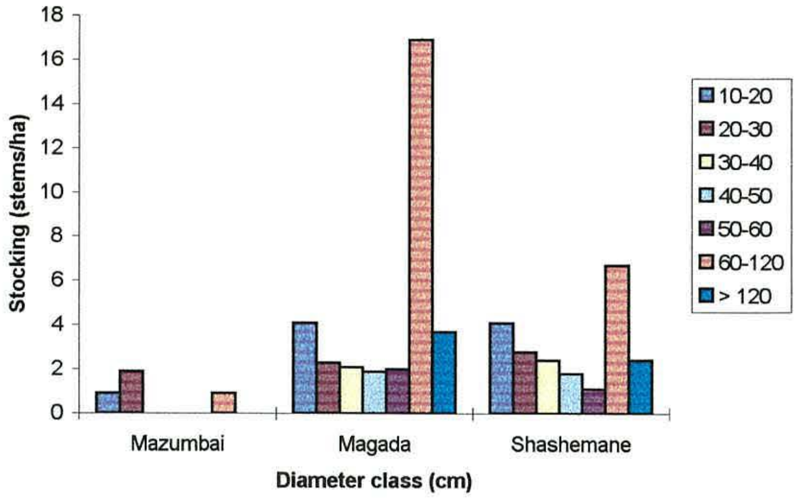


Figure 3.5 ***Podocarpus falcatus*** **stocking by diameter classes at different sites**
Source: Kabera (1990)

3.2.2.3 Increment

Though the recruitment of these two *Podocarpus* species is high (high seedling density), the growth rate is low (Borota, 1975; Backeus, 1982; Kabera, 1990; Geldenhuys, 1993; Holmes, 1995b; Njunge, 1996). The mean annual height and diameter growth of these two species is shown in Table 3.2. Mean increment data for *Podocarpus falcatus* from Kenya is shown in Table 3.3 in which the mean growth rate decreases with size (diameter class) and hence age. The species responds well to heavy canopy opening (Geldenhuys, 1993; Holmes, 1995b). Although growth appears slow, the possibility of using this spontaneous (fast) growth resulting from canopy opening for the establishment of *P. latifolius* stands under *Acacia melanoxylon* is considered interesting (Seagrief, 1965).

Table 3.2 Mean diameter and height increments for mature trees of *Podocarpus latifolius* and *Podocarpus falcatus*

Species	Diameter at breast height mean annual increment (cm)	Height mean annual increment (cm)	Location
Podocarpus latifolius	0.75	0.71	Lushoto (4°47′, 38°17′E; 1396 m)
Podocarpus falcatus	-	30	Minziro (1°S, 31°30′ E; 1500 m)

- figure not given

Source: Holmes (1995b)

Table 3.3 Periodic mean annual dbh increment (cm) of *Podocarpus falcatus* in natural forest at Kaptagat, Kenya (0°30′N, 35°30′E; 3000 m)

Periods	Diameter class (cm)					
	16-25	25-35	36-45	46-55	56-65	66-75
1946-1961	0.38	0.36	0.34	0.31	0.31	0.29
1961-1973	0.34	0.32	0.31	0.30	0.29	0.28
1946-1978	0.35	0.33	0.31	0.30	0.29	0.28

Source: Kigomo (1985) in Kabera (1990).

3.2.2.4 Reproduction

In South Africa *Podocarpus latifolius* flowers in July-September and fruits in December-February while *P. falcatus* fruits in September-May annually (Palmer, 1977; Palgrave, 1988; Kabera, 1990; Wyk and Wyk, 1997). Pollination has been reported to be performed by wind, birds, insects and climbing small animals (Kabera, 1990). Both species reproduce through seeds dispersed by birds and baboons attracted by the large, red, fleshly receptacle to which 2 green berry-like seeds (fruits) are attached (Battiscombe, 1936; Seagrief, 1965). Seed dispersal in *Podocarpus falcatus* seems to be inefficient since most of the seeds germinate near the mother tree (Table 3.4). The stony sclerotesta has been reported to delay germination up to a year (Geldenhuys, 1993). This hindrance can be overcome by complete removal of the woody seed coat, by light hammering or by cracking in a table vice, all treatments speed up germination to within 30 days (Msanga, 1998). Germination is epigeal, the seedling having, at first, a reverse-U shape which straightens after the fall of the outer seed shell (Kabera, 1990). Kabera describes the first leaves as opposite and the subsequent ones as spirally arranged.

Table 3.4 Distribution of *Podocarpus falcatus* seedlings at Ruhande (Rwanda)

Stocking (seedlings/ha^{-1})	Distance from seed sources (m)
4500	at seed source
600	50
100	200

Source : Kabera (1990)

Though germination success is good (50-80%) there are heavy seedling losses to browsing by bush-buck and environmental factors e.g. temperature, rainfall (Kabera, 1990). *Podocarpus latifolius* is widespread and common at high density and has a high recruitment rate (Palgrave, 1988; Geldenhuys, 1993). The species can regenerate and become established even under the canopy of another species (Geldenhuys, 1996). Nevertheless, the seedlings respond well when grown without shade (Van-Daalen, 1981).

3.2.3 Other species: *Fagaropsis angolensis* (Engl.) Dale (Rutaceae) and *Ficalhoa laurifolia* Hiern (Theaceae)

3.2.3.1 Descriptions

Fagaropsis angolensis is a deciduous tree 10-24 m high when mature (Beentje, 1994). Its bark is pinkish-grey, slightly rough and sometimes covered with corky outgrowths. The branchlets are purple-brown, dotted with pale elliptical lenticels and cinereous-pubescent while older branches are glabrous (Kokwaro, 1982). The leaves have 5-11 glabrous but for the midrib, elliptic leaflets 4-9 cm by 2-5 cm with gland-dots near the margin. The flowers are yellowish and in panicles 3-12 cm long. On individual flowers petals are 3.5-6 mm long (Beentje, 1994). In the male flowers the stamen number is variable even on the same plant (4-8). Each stamen is 2.5-4 mm long, and usually shorter than the petals. The anthers are ±1 mm long and the glabrous vestigial pistil 1-1.5 mm long, (Kokwaro, 1982). In the female flowers, staminodes are present but rudimentary. There is an annular disk; and a slightly 4-lobed ovary with a very short style (Kokwaro, 1982). Palgrave (1988) reports the sexes separate on the same tree (monoecious) but Wyk and Wyk (1997) report separate sexes on different plants (dioecious)! The fruit is purple, round, globose, grandular-foveolate 6-8 mm in diameter and mucronate (Kokwaro, 1982; Beentje, 1994). The species occurs in rain-forests, especially the edges, and more often in drier evergreen forests at elevation 1000-2250 m (Kokwaro, 1982).

Ficalhoa laurifolia is an evergreen tree 24-36 m tall when mature, much branched, with rough fissured bark and copious white latex (Verdcourt, 1962). The branches are at first sparsely pilose but eventually anything from glabrous to densely pilose. The leaves are somewhat leathery, oblong or lanceolate, acuminate at the apex and cuneate or rounded at the base. They are 7-12.4 cm long and 2-4.3 cm wide, with the margins bluntly serrulate, glabrous or sparsely pilose. The petiole is 3-9 mm long. The flowers are white, yellowish or greenish and develop in solitary or paired cymes. The peduncle is 2-6 mm long and pubescent or pilose. The pedicels are short and pubescent. The sepals are rounded, sparsely to densely pubescent and about 1 mm long. The petals are oblong and rounded, and 3 mm long. The ovary is densely adpressed-pilose with the styles pilose at the base. The fruit is a capsule about 3 mm in diameter with widely spreading valves. The seeds are about 0.5 mm long. This species is normally found in upland rain-forest, riverine forest and bushland, at streamsides and on cultivated ground in areas cleared of forest; at altitudes 1350-2400 m.

3.2.3.2 Stocking levels

Stocking levels for *Fagaropsis angolensis* in Bugoma forest, Uganda (Osmaston, 1959) and Kiraragua catchment forest, Tanzania (Mwasaga, 1984) are shown in Figure 3.6. The figure shows the typically very low stocking levels of this species. Figure 3.7 shows stocking levels for *Ficalhoa laurifolia* in Mount Kahusi, Kigogo and Nyawaronga in Congo (Pierlot, 1966). The figures show that the populations of this species differ in the three forests with Kigogo having the highest population density which is more or less "balanced" (has more individuals in small size classes).

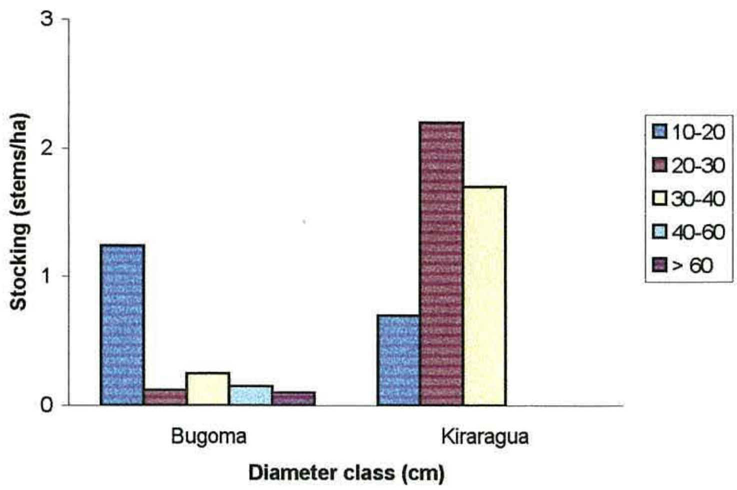


Figure 3.6 ***Fagaropsis angolensis*** **stocking at Bugoma forest, Uganda 1° 15′N, 31° 00′; 1067 m (232 ha of drier peripheral Evergreen Guineo- Congolian Rain Forest) and at Kiraragua catchment forest, Mount Kilimanjaro Tanzania (3° 05′S, 37°05′E; 1500-2000 m)**
Sources: Osmaston (1959); Mwasaga (1984)

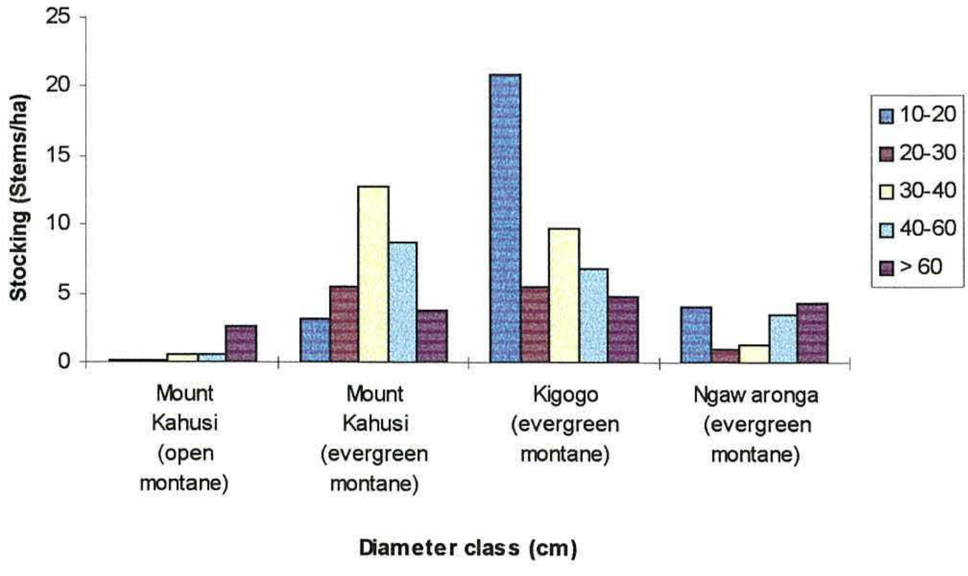


Figure 3.7 ***Ficalhoa laurifolia*** **stocking at Mount Kahusi, Congo (2°16′S, 28°37′E; 2200 m), Kigogo, Congo (3°02′S, 28°36′E; 2200 m) and Ngawaronga, Congo (2°02′S, 28°46′E; 2200 m).**
Source: Pierlot (1966).

3.2.3.3 Increment

Data are not available.

3.2.3.4 Reproduction

Fagaropsis angolensis reproduces sexually by seeds (Njunge, 1996). The young fruits are green but turn purple with maturation. At South Nandi forest in Kenya the species has been reported to flower from October to March and to fruit from December to August (Njunge, 1996). Natural regeneration of *Fagaropsis angolensis* is erratic even when there is a mature individual nearby (Mwasaga, 1984; Njunge, 1996). Njunge also found that even though very few seedlings were found in the forest, some seed of *Fagaropsis angolensis* was present in a soil seed bank.

Ficalhoa laurifolia reproduces by seeds (Pitt-Schenkel, 1938). The fruiting has been described as synchronized with fruiting of other mature trees of *Ficalhoa* for five months (Sun *et al.*, 1996). Pitt-Schenkel (1938) also reported seedlings of this species in Magamba forest reserve.

CHAPTER FOUR : METHODS

There are four major parts to this chapter: the experimental approach (4.1), the target species (4.2), data summarization (4.3) and data analysis (4.4). The opening part describes how the study forests were sampled, the experimental design that was used and how the single tree gaps were created and monitored (4.1.1). Subsection 4.1.2 describes the sample site characterization. In Subsection 4.1.3 the determination of forest floor light exposure is explained. Section 4.2 describes the collection of information about the species studied. Section 4.3 describes how data were summarized before analysis and Section 4.4 describes how the summarized data were analysed - involving the application of descriptive statistics (4.4.1), data transformation and statistical analysis procedures (4.4.2) and diagrammatic and graphical procedures (4.4.3).

4.1 Experimental approach

4.1.1 Design

This study adopted a split plot design. The number of plots was decided on the basis of the total number of trees (36) which could be felled, as approved by the Tanzania Forest Authority. These were divided equally (12 each) between the three study sites. Thus a total of 72 (36 felled and 36 unfelled) plots was involved for the whole study. The plots were located in pairs (felled and unfelled) which reduced the time spent moving from one plot to another while taking hemispherical photographs. The sampling strategy is shown in Figure 4.1. The plots were rectangular in shape extending a distance equal to the target tree height to one side and a distance equal to crown radius plus 20 m on the opposite side (Figure 4.2), demarcated by manilla strings. The width of the plots also differed, being made equal to target tree crown diameter. Plot areas ranged from 319.6 m^2 to 2052.1 m^2.

The plot width was subdivided into eight strips (sub-plots) of equal width to which litter and tillage treatments were applied. These treatments were:

- litter removed, no soil tillage
- litter removed and soil tilled
- litter removed, soil tilled
- control, with no litter removal and no soil tillage.

Each litter and tillage treatment was represented twice in each plot (two-fold replication). This reduces the actual study forest area which would otherwise be needed if the replications would be applied in different plots. The new recruits in the replicates had to be pooled for statistical analysis because they were very few in sub-plots considering that they had to be standardized to 10 m^2 area. The treatment allocations were made systematically in every plot as shown in Figure 4.2. The figure shows that the direction of tree felling was determined according to the plot's longest side in either direction. The felling was done using a powered (chain) saw. The felled trees were cross-cut and where possible removed from the plot otherwise were left on the plot. The treatments were not allocated strictly randomly to the plots but those of each phase were in proximity for logistic reasons (speed of access, separation from either - sometime illicit-activity in the forest and monitoring efficiency). For each site and phase, every second tree was felled.

4.1.2 Sample site characterization

Sample site characterization was done at Machame, Chome and Rongai from October 1998 to February 1999. Target species in the sites were not taken as criteria for plot sampling since their stocking was very variable in each site. While Chome was dominated by *Ficalhoa laurifolia*, the dominant species at Machame was *Ocotea usambarensis*. On the other hand, both *Podocarpus falcatus* and *Fagaropsis angolensis* were in small numbers at Rongai forest (Appendix 23). As a result of this variation, a balanced sampling of the study species could not be achieved instead local forest and understorey conditions were used as plot location criteria. Criteria set for sample site selection were closed canopy, woody understorey and terrain level or gently sloping over an extensive area. Twenty four plots were demarcated in each forest reserve studied, to make a total of 72 plots for the whole study. The locations of individual plots were not farther than 200 m from each other but a minimum separation distance of 50 m was applied. In Machame three plots were located south of a seasonal stream while the other 21 were located north of this stream. These areas were chosen because the tree populations are dominated by *Ocotea usambarensis* (one of the economic tree species of this study). Further, the areas were easily accessible by motor car. In Chome, there were eight plots to the south and 16 to the north of the road which passes through the forest towards Suji. These forest areas were dominated by either *Ocotea usambarensis, Podocarpus latifolius, Ficalhoa laurifolia* or a mix of all three and were easily accessible. At Rongai, 19 plots were located on a ridge between the road to Kamwanga and the road to the lower end of the Rongai trail to Mount Kilimanjaro. There were nine plots on the south side and 10 plots on the north side of the ridge.

A further plot was located north of the road towards Kamwanga and the remaining four plots were located about 500 m east of the other group of the plots. All the plots in Rongai Forest Reserve were located to the west after crossing the River Kimengelia. These areas were chosen based on criterion that they had at least one mature *Fagaropsis angolensis* or *Podocarpus falcatus* tree or both species. Each plot was established around a target tree. The target tree was the centrepoint of the plot and was a canopy or emergent individual. A single plot was established at every target tree.

In each plot litter depth was determined by measurement at four randomly sampled points within its boundary of each plot. Measurements were made using a tape measure by insertion into the litter layer up to the top soil layer. The general forest basal area was estimated with a relascope (point sampling) from the centre of each plot using a relascope factor of one. In each plot altitude above sea level was determined using an altimeter. Each plot was cleared of all vegetation except large trees (≥ 2 cm dbh) and their (all tree seedlings) regeneration (≤ 2 cm dbh), including the seedlings of the studied species. The clearance minimized weed competition suppressing tree regeneration. It also made regeneration assessment easier. Treatments were applied in three phases: in March 1999, in May 1999 and in September 1999. This was to allow comparison of the effects of gap creation in different seasons. Treatments at Rongai were applied in May 1999 and September 1999 since there was heavy rainfall in March 1999 which prevented the researcher visiting the experimental site. In this case, the treatments which were meant to be applied in March 1999 were applied in May 1999 together with those which were due for May 1999 (a double May treatment application). Assessments of increment of marked seedlings, regeneration response and under-canopy light environment were periodically carried out until February 2000. In each treatment phase, four plots received treatments and four were left as controls. The control with respect to the felling factor refers to the plots where the target tree was not felled.

REQUIREMENTS

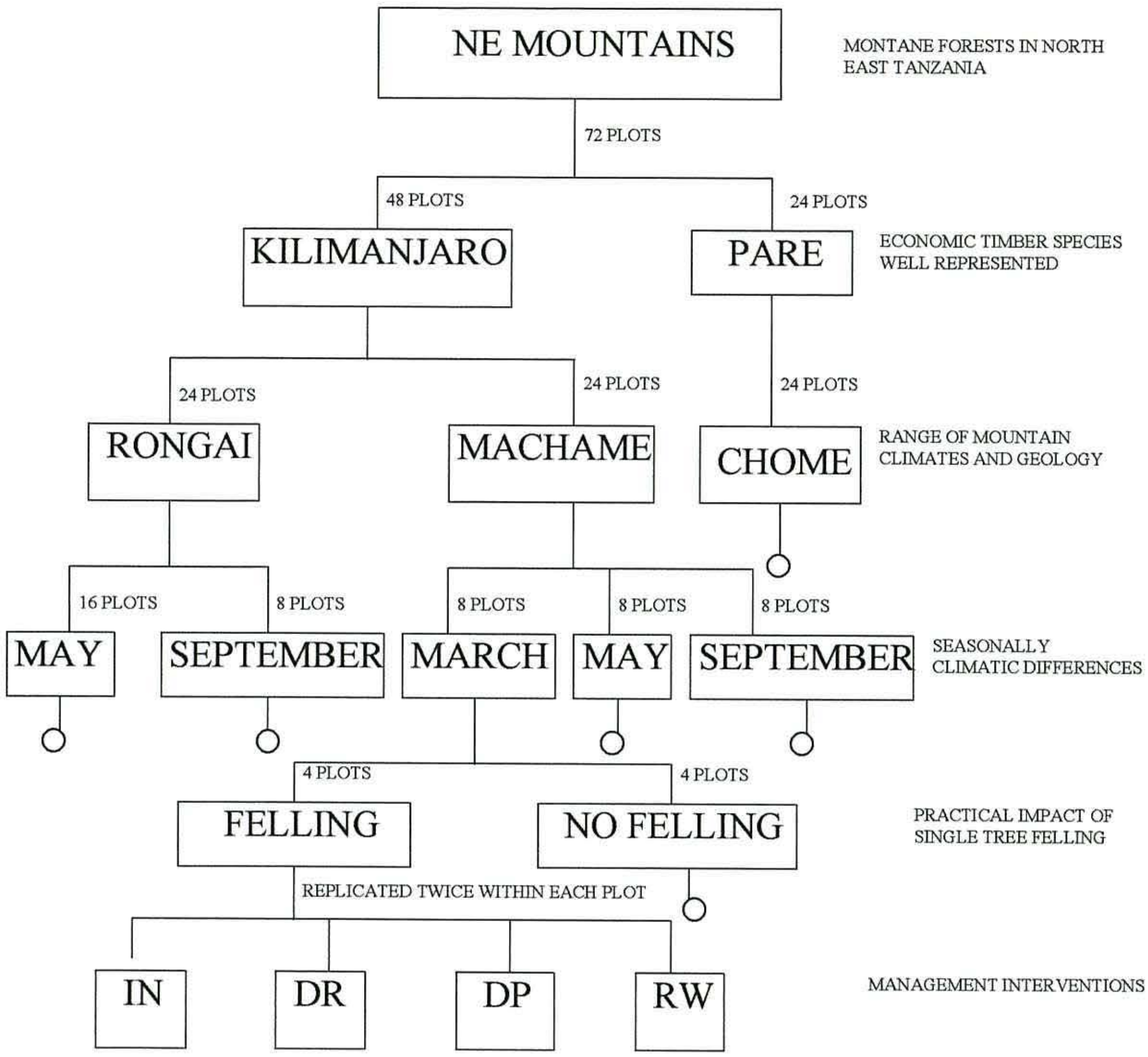


Figure 4.1 A flow chart of the sampling strategy
DP, soil tilled with litter in place; DR, soil tilled with litter removed; IN, intact; RW, no soil tillage with the litter removed
○ : represents that the same structure as for the equivalent Machame March plots

CONSTRAINTS : - Climatic conditions (Rongai could be visited only in May and September
- Limited number of trees (12) which were allowed to be felled in each forest

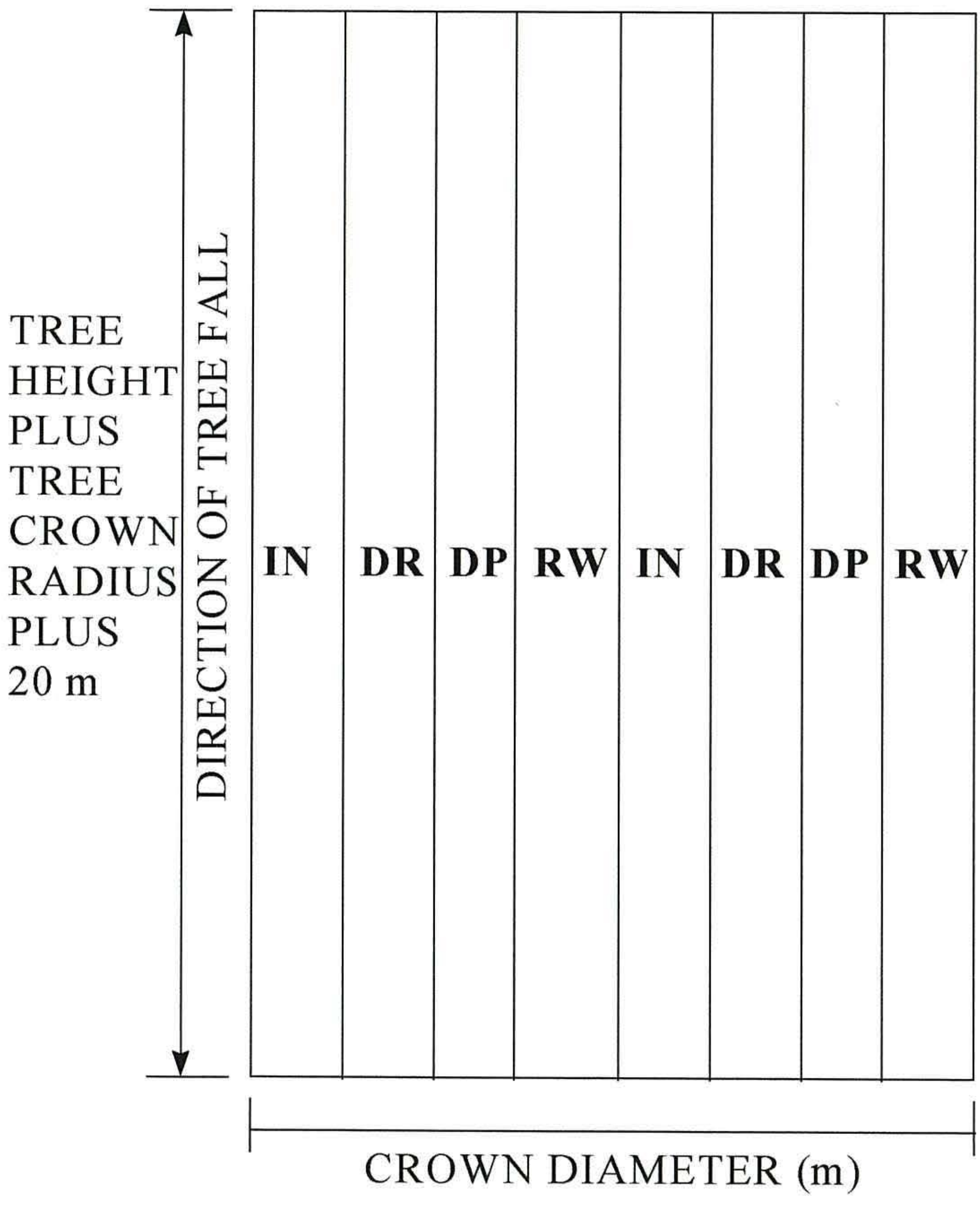


Figure 4.2 Diagram showing single plot subdivision

DP, soil tilled with litter in place; DR, soil tilled with litter removed; IN, intact; RW, no soil tillage with the litter removed

The control with respect to the tillage/litter factor refers to a strip in which neither tillage nor litter removal was carried out. In each of the three treatment phases, eight new plots were added to the study at each location (apart from Rongai in March / May 1999 as mentioned above).

During each treatment phase four target trees were felled at each site, and litter removal and soil tillage treatments applied to the plots which resulted. Thus, overall, a total of 12 trees out of 24 were felled at each site, making 12 created gaps per forest reserve. The felling operations were carried out such that felling damage was minimized by directional felling (Dykstra and Heinrich, 1996). The felled trees were directed toward existing gaps or where there were fewer seedlings or saplings of desired species. The care taken during felling was meant to reduce felling damage to the residual forest in contrast to that done by pitsawyers in practice (Hall and Rodgers, 1986). Trees to be felled in each phase were selected so that attention to a felled plot was followed by attention to a non-felled plot, reducing time between taking "before felling" and "after felling" hemispherical photographs. The felled trees were cross-cut and where possible were removed from the plot area. The plots were allocated to phases according to their distance from the first plot i.e. nearby plots were treated first. Litter removal was by collecting the litter using a steel rake and transferring it from the plot area. Tillage was done with a hoe, by shallow digging within the boundary of the strip which was allocated tillage treatment. The depth of the tillage was approximately 10 cm in every plot.

4.1.3 Determination of forest floor light

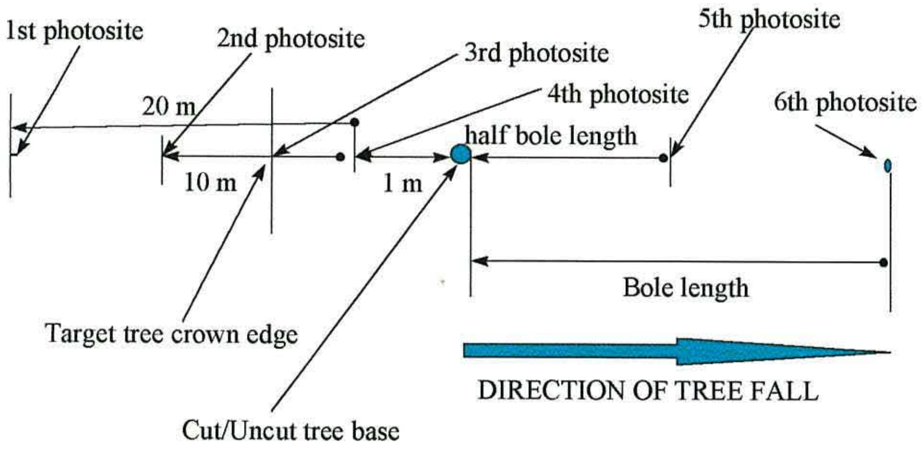
The effective size of each gap was determined from hemispherical photographs as canopy openness. Each time the plots were visited hemispherical photographs were taken. Before any felling was carried out, canopy openness was determined by taking hemispherical photographs to gauge the extent of opening resulting from the felling. The extent was determined by openness values from "before- and after-felling" hemispherical photographs. After each felling, felling damage was determined by counting the number of mature and pole-sized trees whose crowns were broken and injured. Injured trees were classified as those which had part of their crown or bark removed while the broken crown trees had their whole crown broken or cut. The assessments were meant to gauge the initial damage soon after felling since the affected individuals may re-sprout later. Except for Rongai forest reserve where felling was carried out in May and September, 1999, the felling was done in three phases as mentioned earlier (Subsection 4.1.1).

Variation in the light environment under the forest canopy before canopy opening was assessed by taking hemispherical photographs in six pre-selected photosites along a line passing through the centre of the tree base along the axis in the direction in which the tree would be felled (i.e. that was determined first) (Figure 4.3). The obtained light values were not absolute since no measurements were done in the open due to lack of equipment. Despite this shortcoming, the values obtained were enough to monitor relative under-canopy light changes. The photosites were marked in advance with treated wooden pegs. The six photosite positions were :

- 20 m from crown edge,
- 10 m from crown edge,
- at crown edge,
- one metre from target tree base,
- half bole length and
- bole length (the point where the tree crown was envisaged to fall).

For non-felled plots the orientation followed the same procedure as for the felled plots. The sites were selected to represent the varying effects of the different parts of the tree on striking the ground. A falling tree causes much damage to the area where the crown falls and little damage if any on the opposite side (Orians, 1982; Clark, 1990).

Photographs were taken at a height of 2.5 m above the forest floor using a Nikon FM2 camera fitted with a Sigma fisheye lens with a built-in compass for north/south alignment and LED image markers used to align hemiphots. The photographing height was chosen so that the photographer could work at that height easily. The camera was appropriately rotated to ensure the North reference was in the correct position on every image. The first set of pictures were taken using Colf /10 colour 35 mm films which were supplied free by the manufacturer. In order to reduce image variations, later pictures were taken using colour Konica VX 100 films.



NB. The photosites are similar for both cut and uncut plots

Figure 4.3 A schematic diagram showing six photosites in a plot

4.2 The target species

The information collected was to ascertain whether or not the applied treatments affected the regeneration of the target species. The effects investigated were numbers of seedlings appearing (all un-marked individuals $\leq$ 2 cm height), re-iteration in the form of new shoots from individuals already established in the plots, and height increment values. In the forest, seedlings, saplings and suckers which could be reached (up to 2.6 m tall) by the assessor were monitored. Seedlings were defined as plants which developed directly from seeds both before and during the study. Suckers were defined as shoots originating directly from the root system, emerging from the soil surface away from any existing aerial shoot. A sample of stem coppices (sprouts off aerial shoots), particularly of camphor was also monitored. On very few occasions *Podocarpus falcatus*, *Podocarpus latifolius* and *Fagaropsis angolensis* saplings developed coppice shoots after their aerial shoots were cut. These sprouts were not monitored. Seedlings of *Fagaropsis angolensis* and *Podocarpus* spp. were easily recognized as these species do not produce root suckers. For *Ocotea usambarensis*, it was sometimes necessary to ascertain the origin of a shoot by excavating soil around it to reveal any connection to a pre-existing root from an established tree.

Crown diameter and diameter at breast height were measured for each target tree where a plot was established. Crown diameter was measured with a measuring tape. Diameter at breast height (dbh) was measured using calipers or a diameter tape, depending on the size of the tree. The crown diameters were taken as the projected ground distance in metres direct from a point on one edge of the crown to the point opposite, passing through the target tree stem base. For uneven crowns, two measurements perpendicular to each other were taken and averaged. The same principle was applied for non-cylindrical boles when diameter at breast height was measured with calipers. Before felling at least 10 seedlings (except *Ocotea* because none were recorded), 10 saplings and 10 suckers (*Ocotea*) of each studied tree species were identified, marked using aluminium tags and measured for initial height using a tape measure, in each strip. These individuals were sampled randomly. All unmarked individuals were marked with paint so that they would not confuse counts of recruited individuals.

After felling field seedling assessment was conducted four times (March 1999, May 1999, September 1999 and February 2000). The assessment procedure involved counting the number of newly germinating or newly sprouting seedlings or suckers and measuring the height of each marked (tagged) seedling or sucker on each occasion. Newly encountered seedlings and suckers were marked with oil paint to ensure recognition during subsequent assessments and to separate them from seedlings or shoots which appeared later.

4.3 Data summarization

The summarized data were categorized into gap characteristics, light data and species data.

Gap characteristics

Target tree environment's range, mean and standard deviation were calculated for plot areas, basal area and litter depth. Values for canopy openness were obtained directly from hemispherical photograph analysis. Canopy closure percentage was obtained by subtracting canopy openness percentage from 100 i.e. (100 - canopy openness percentage). Felling damage was expressed as numbers of broken crowns and injured mature trees, poles or saplings in each plot subjected to the felling treatment in each forest reserve.

Light data

The whole study produced a total of 1824 hemispherical photographs: March 1999 - 144 photographs (Chome, 72; Machame, 72; Rongai, 0); May 1999 - 384 photographs (Chome, 96; Machame, 96; Rongai, 192); September 1999 - 864 photographs (Chome, 288; Machame, 288; Rongai, 288); February 2000 - 432 photographs (Chome, 144; Machame, 144; Rongai, 144). For further analysis, 864 hemiphotos were analysed (Table 4.1). The photographs were selected in such a way as to represent seasonal and spatial variation and progressive recovery after felling. For control plots, photographs were chosen to show estimated light variations in March 1999 to February 2000, May 1999 to February 2000 and September 1999 to February 2000 periods. A set of pre- and post-felling photographs was selected for March 1999, May 1999 and September 1999 fellings for each site. Thus the hemiphot selection was done systematically in order to achieve the pre-set objective. In March 1999 no canopy photographs were taken at Rongai.

Treatments were first applied at Rongai in May 1999 due to adverse weather conditions at this site in March 1999.

Table 4.1 Number of hemiphotos which were analysed further

Forest	March 1999	May 1999	September 1999	February 2000	Totals
Chome	72	78	114	96	360
Machame	66	78	90	60	294
Rongai		72	90	48	210
					864

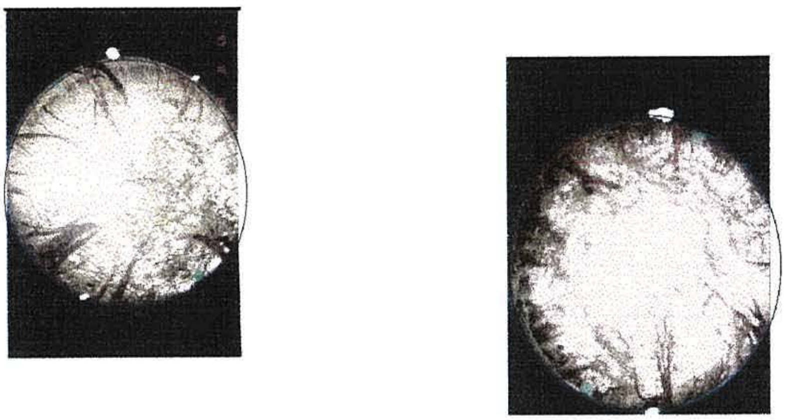
The selected photographs were first prepared for analysis using the WINPHOT computer program (Ter Steege, 1997). The image limit on the selected photographs were first marked using white marker pen. This simplified the work of delimiting the gaps later. Sometimes it is difficult to identify the image limit on a photograph which is not pre-marked. An example of a marked photograph is shown in Figure 4.4.

Figure 4.4 A sample of pre-marked hemispherical photograph Where the two white line marks represent the image limit

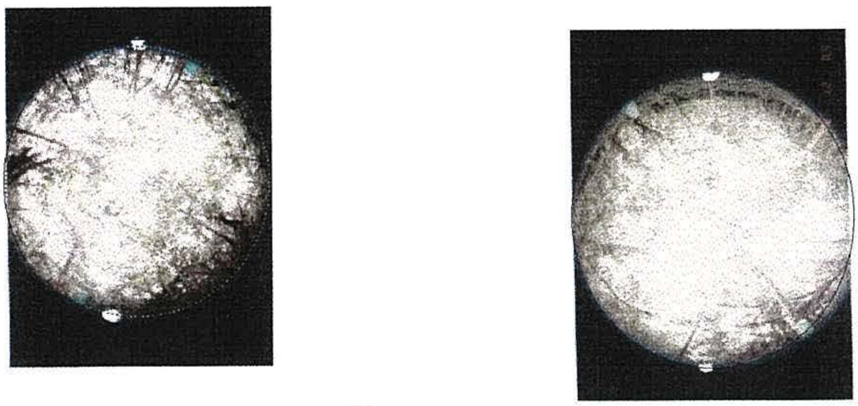
Preparation of the photographs before analysis involved scanning to obtain digitized images. Photographs were scanned using a Scan Jet 2100C scanner. Grey shades were handled by setting a standard threshold level for all photographs i.e. threshold level was constant. This made the scanning process easier considering the number of photographs to be processed. The individual digitized images were saved as .PCX files which were later used as input data to the WINPHOT hemispherical photographs analysing program. The limits of the canopy were delimited by marking the area covered with its boundary on the pre-marked marks using a mouse. This was marked as the circular area covered by the canopy. Samples of delimited images are shown in Figure 4.5 for the photosite 1 (A) and the photosite 5 (B) before- and after-felling situations respectively. Since the ideal canopy and even the created gap are irregular, the figures obtained from the analyses are approximations.

In addition to digitized images, the WINPHOT program requires input data for percentage of sunshine per hour at the sites where the photographs were taken, the elevation (altitude) above sea level, latitudes and longitudes (geographic co-ordinates). Site altitude and geographic co-ordinates were specified for each digitized image analysed. Altitudes were recorded in each plot while the geographical co-ordinates were taken as site averages from maps. All the days when photographs were taken were assumed to be sky overcast (SOC) since the photographs were taken before eight o'clock in the morning or after four o'clock in the afternoon. In this study almost all photographs were taken in the morning so there was no significant sky conditions. Other parameters required such as percentage of sunshine per hour, time zone, transmission of red, transmission of far red, red-far red ratio (RFR), diffuse part, Tau and magnetic correlation were taken as the program default values (100, 0.00, 0.05, 0.45, 1.20, 0.15, 0.60 and 0.00 respectively). With these inputs, it was possible to determine the parameters relevant to this study - canopy openness and under-canopy light conditions. The input data thus include digitized images as .PCX files, geographic co-ordinates and altitude. The output includes canopy openness (percent) and above- and below-canopy photosynthetic photon flux density (PPFD) as direct, diffuse and total radiation. In addition, direct site factor (DSF), indirect site factor (ISF) and total site factor (TSF) were also output. Since no light data in the open, the obtained values are only meant for comparison (relative) purposes and should not taken as obsulute values. If light readings will be available in the future these relative values can be converted into obsolute values. The light environment under the forest canopy before and after felling treatment was shown in terms of the amount of direct light in mol m^{-2} day^{-1}. A day here represents the portion of a day where there is daylight. This was specified before analysis. Canopy change was represented as percentage closure of canopy, obtained from:

$$\text{Canopy closure \%} = 100 - \text{Canopy openness \%}.$$



A



B

Figure 4.5 Samples of delimited hemispherical photographs for photosites 1 (A) and 5 (B) in each case (left to right) before and after felling. Where the dotted circular area (emphasized in B before felling) is the estimated limit of the image. Left photographs show before felling canopy openness while right side photographs show after felling canopy openness.

Species data

Target trees were the trees at the centres of the plots. Target tree variables (dbh, crown diameter and, for trees which were felled, total height) were taken as values for individual trees. The set of 12 felled trees at each location was analysed in terms of correlations between felled tree variables (height, dbh and crown diameter) and felling impact on associated trees. Tree basal area was presented for each plot in each site. Means, ranges and standard deviations were calculated for plot area, basal area, litter depth and numbers of trees killed and injured by the felling treatment for each site.

A regeneration data set was recorded for each time phase of the study (March-May 1999, May-September 1999, September 1999-February 2000) and for each site (Chome, Machame, Rongai). Regenerating individuals were categorized into height classes for each species and site. Within the data sets, observations from replicate felled and unfelled target trees were kept separate. For each target tree, observations were recorded separately for each till/litter level combination, the records from replicate strips being pooled and standardized for a unit area of 10 m^2 . Separate data sets were used for newly appearing suckers, newly appearing seedlings and pre-existing shoots. Shoots monitored for increment were grouped by site and treatment (felling x litter x tillage combination), by origin (reiteration or direct from seed) and when first recorded (pre-existing in March 1999, appearing between March 1999 and May 1999, appearing between May 1999 and September 1999, appearing between September 1999 and February 2000). The absolute growth (increment) was obtained by subtracting the heights of the marked seedlings or suckers in successive assessment (measurement) times.

4.4 Data analysis

4.4.1 Descriptive statistics

Descriptive statistics were used to characterize the plots incorporating the target trees. Means and standard errors were calculated by site for litter depth, forest basal area in the vicinity, and plot size. Gap micro-environments and the regeneration response to the applied treatments were characterized by strip as described in 4.1.3 and Figure 4.2.

4.4.2 Data transformation and statistical analysis procedures

Rongai *Podocarpus falcatus* regeneration response data had to be tranformed, by logarithmic transformation (base ten), of the raw data. Regeneration count data were standardized to an area of 10 m^2 for purposes of comparisons across plots.

For comparison of experimental treatments, data sets were checked for normality. If non-normal situations arose, logarithmic transformations were applied where these enabled more satisfactory analysis, failing which a non-parametric approach was taken.

From the digitised images, canopy openness and direct, diffuse and total light above and below canopy were calculated automatically by the WINPHOT computer program. Direct, diffuse and total site factors (direct beam light from the sun, diffuse light from the sky and total light, respectively) were also automatically calculated by the program. These were presented as direct light values, for each of the six photosites in a plot, for the three study phases.

Statistical analysis was performed for comparison of recruited regeneration of *Ocotea usambarensis* with *Ocotea usambarensis* basal area in the vicinity using analysis of variance (ANOVA). A two-way ANOVA was used to check whether there were differences in regeneration recruited between species for felled and unfelled plots. The general linear model - simple factorial was used to check the influence of tillage, litter and their interaction on the recruited regeneration of the studied species. The Chi-squared test was also used to check if *Ocotea usambarensis* sucker numbers were associated with felling treatments at Chome and Machame. Analysis of variance was applied to the recruited regeneration of *Ocotea usambarensis*, *Podocarpus latifolius*, *Podocarpus falcatus* and *Fagaropsis angolensis* in relation to treatments. Analysis of variance was applied to test the effect of applied treatments and time on height increment of advance regeneration of studied species. T-tests were used to compare increment between species and to compare light levels between photosite positions. T-tests were also used to compare recruited regeneration in felled and un-felled plots. Regression analysis was used the check the relationship between monthly increments and direct light, monthly increments and advance regeneration intial height and monthly increments in successive growth phases for both felled and non-felled plots. All statistical tests were performed using the Minitab Release 12.1 and SPSS Version 7.5 statistical packages.

All the tests were performed using default setting by selecting an appropriate test and specifying the parameters to be tested. This was done since all the input data used were normal or had been transformed to an acceptably normal state. The tests were conducted at five percent significance level. The data from individual forest reserves and study phases were analysed separately.

4.4.3 Diagrammatic and graphical procedures

Diagrammatic summaries were used to show how felled tree variables were related to felling damage indicators (broken crowns and injured trees), supporting a non-parametric summary (Spearman's rank correlation coefficient) of the relationship.

Graphs showing plot area distribution for each site were drawn. Litter depth distribution for each site was also shown graphically. Direct light variations between assessment periods for each site for "not felled" plots, were shown graphically. Diagrammatic summaries were also used to show the extent of changes observed with time in regeneration and seedling increment. Graphs were used to show regeneration in felled and unfelled plots for each regenerating species. In addition, variation in increment for each studied species in each site for the three assessment periods i.e. March-May 1999, May-September 1999 and September-February 2000 were presented graphically. Height increments between assessment occasions by species, treatment and site were compared graphically. Lastly, scatter plots for regression and fitted lines showing the relationship between direct light and monthly height increments of the advance regeneration were drawn for each site, species and growth period. All diagrams and graphs were prepared using Excel, Minitab and SPSS computer programs.

CHAPTER FIVE : RESULTS

This chapter describes the results obtained in the following order: data collection points and immediate felling impacts (5.1), canopy cover from hemispherical photographs (5.2), assessment and monitoring of the amount of regeneration (5.3) and assessment and monitoring of increment (5.4). Within each section, results are reported separately for each research site.

5.1 Data collection points and immediate felling impacts

5.1.1 Chome

5.1.1.1 Target tree environment

The environment of the target trees varied between plots in altitude, plot size, basal area per hectare and litter depth (Table 5.1). The sampled area was between 1900 and 1960 m altitude. The plot areas depend on the size of the plot's central target tree. They are defined as the rectangular area around the target tree with target tree's crown diameter as the width and 20 m + target tree crown radius + target tree height as the length. The areas varied from 387.2 to 1823.8 m^2 with a mean of 987.7 m^2 and a standard error of 71.5 m^2 (Figure 5.1). Figure 5.1 shows that plot areas in Chome were more or less normally distributed. The smooth curve is the normal curve for the calculated parameters, generated in the Minitab statistical program (this applies to histogram presentations throughout Chapter 5).

Currently Chome forest is illegally logged by pitsawyers for *Ocotea usambarensis* and *Podocarpus latifolius*. In nearly every sampled plot in this study there was a sawing pit within 20 metres. Cattle, sheep and goats are left to graze freely in this forest. Thus disturbance and frequency of tree felling are at high levels. Some areas of the forest have been affected by forest fires but none of the sampled plots were located in these parts of the forest. All these disturbances have been and are still affecting *Ocotea usambarensis* and *Podocarpus latifolius* regeneration. The understorey in the sampled areas was mainly made of small trees, shrubs and herbs. These were slashed during plot dermacation.

Table 5.1 Target trees' environment at Chome

Plot number	Species	Date when included in the study (month, year)	Altitude (m)	Plot area (m^2)	Local forest basal area (m^2/ha)	Mean litter depth (cm)
1	*Ocotea usambarensis*	March'99	1900	1044.0	24	7.5
2	*Podocarpus latifolius*	March'99	1900	387.2	18	6.5
3	*Ocotea usambarensis*	March'99	1925	1034.0	37	5.8
4	*Ficalhoa laurifolia*	March'99	1950	1533.4	30	6.5
5	*Ocotea usambarensis*	March'99	1950	766.3	31	5.8
6	*Ocotea usambarensis*	March'99	1950	1823.8	17	5.8
7	*Ocotea usambarensis*	March'99	1950	966.4	36	9.5
8	*Ficalhoa laurifolia*	March'99	1950	792.1	31	9.4
9	*Ocotea usambarensis*	May'99	1950	1621.7	30	10.2
10	*Ocotea usambarensis*	May'99	1960	833.5	30	9.2
11	*Podocarpus latifolius*	May'99	1950	623.0	32	6.3
12	*Ocotea usambarensis*	May'99	1950	873.3	36	6.3
13	*Ocotea usambarensis*	May'99	1940	909.5	35	8.5
14	*Podocarpus latifolius*	May'99	1950	731.4	33	8.0
15	*Ficalhoa laurifolia*	May'99	1950	1173.1	36	9.0
16	*Ficalhoa laurifolia*	May'99	1950	658.7	36	9.5
17	*Ocotea usambarensis*	September'99	1925	1351.7	37	9.3
18	*Ocotea usambarensis*	September'99	1930	813.3	54	12.8
19	*Ficalhoa laurifolia*	September'99	1950	617.5	48	10.5
20	*Ocotea usambarensis*	September'99	1950	897.0	32	9.5
21	*Ocotea usambarensis*	September'99	1940	1298.7	29	7.0
22	*Ocotea usambarensis*	September'99	1950	1127.8	38	8.0
23	*Ocotea usambarensis*	September'99	1950	1186.6	35	8.0
24	*Ocotea usambarensis*	September'99	1950	640.1	35	10.5

The basal area per hectare of the forest in and around each plot ranged from 17 to 54 m^2/ha (mean 33.3 m^2/ha; standard error 1.6 m^2/ha). The greatest proportion of woody plants in Chome is made up of *Ocotea usambarensis* (mean = 3.9 m^2/ha; standard error 0.7 m^2/ha) followed by *Ficalhoa laurifolia* (mean = 3.8 m^2/ha; standard error 1.0 m^2/ha). *Podocarpus latifolius* has a low basal area per hectare (mean = 0.7 m^2/ha; standard error 0.2 m^2/ha). A complete inventory of the forest in and around each plot is shown in appendix 23. The overall litter depth differed between plots, ranging from 5.8 to 12.8 cm (mean 8.5 cm, standard error 0.3 cm). The distribution of litter depth is shown in Figure 5.2.

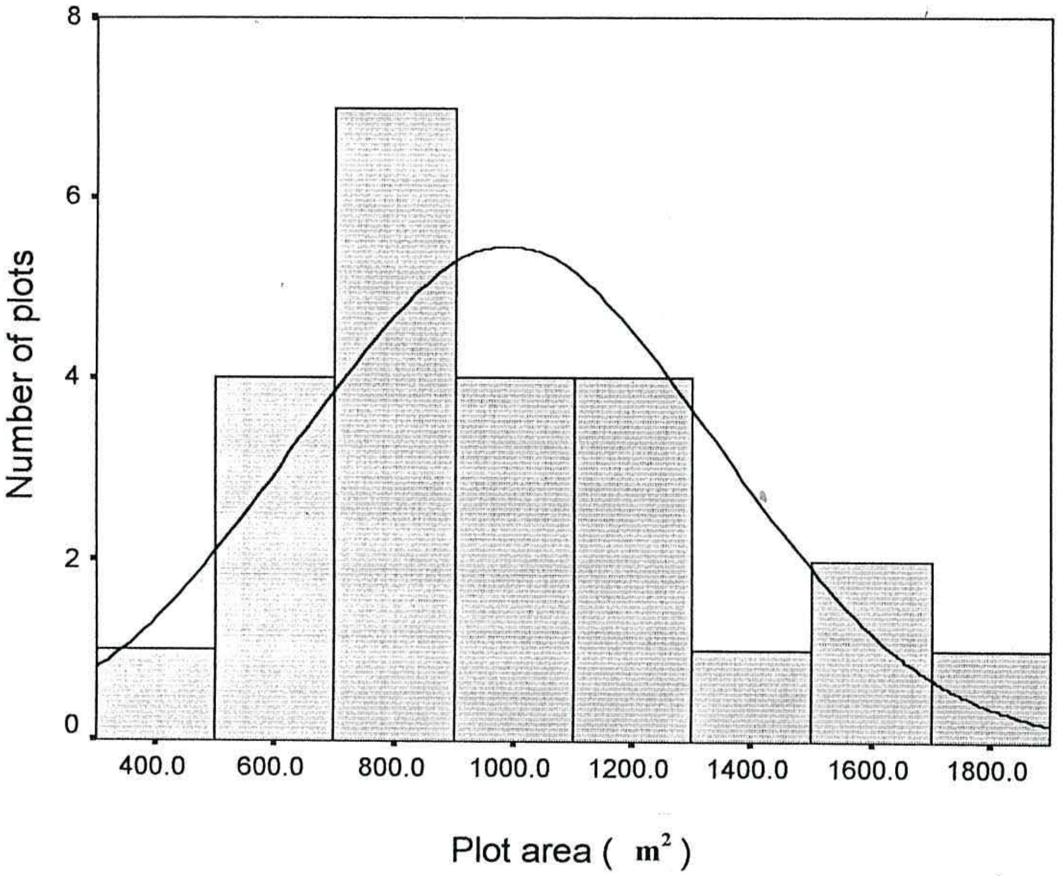


Figure 5.1 Chome plot area distribution

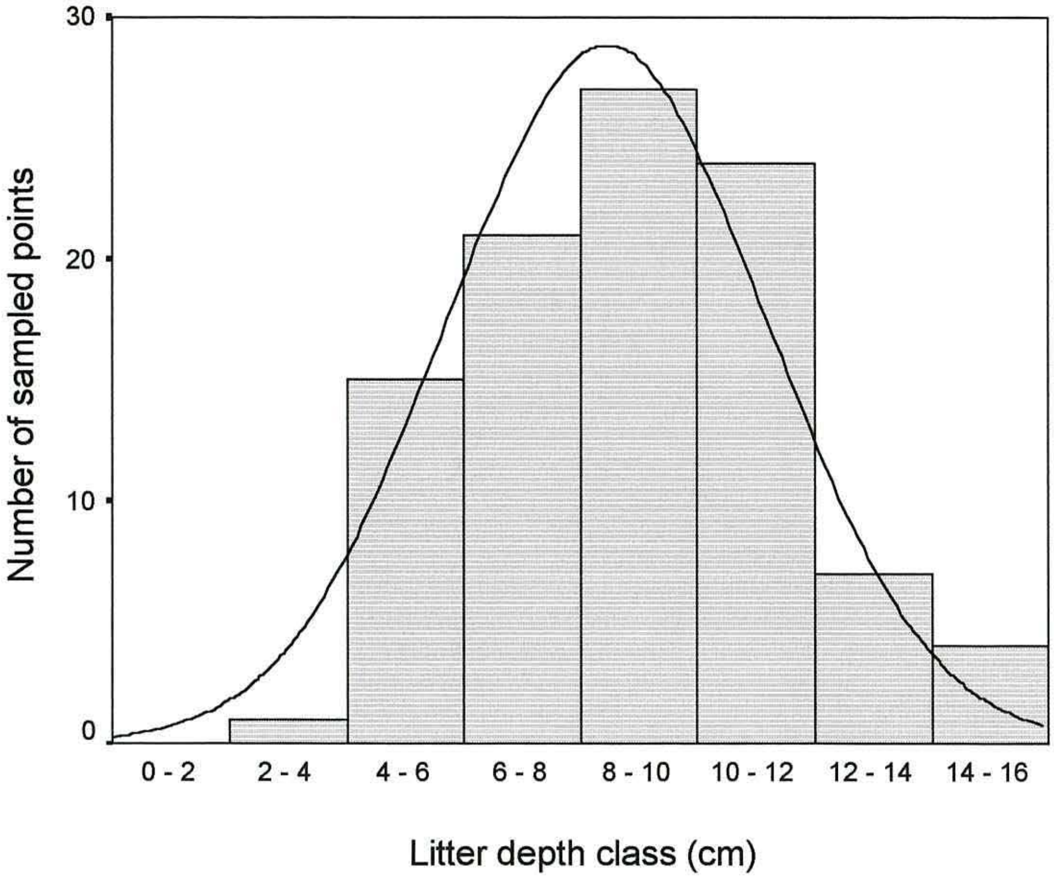


Figure 5.2 Chome litter depth distribution

5.1.1.2 Felling effects

The trees felled were of *Ocotea usambarensis*, *Ficalhoa laurifolia* and *Podocarpus latifolius*. The number of broken crown trees per felling varied from 3 to 13 (Table 5.2). The number of trees injured by the felling operation varied from 0 to 6 trees.

Table 5.2 Felling damage on surrounding trees (≥ 10 cm dbh) at Chome

Trees felled as target trees				Effect on surrounding tree population		
Species	**Height (m)**	**dbh (cm)**	**Mean crown diameter (m)**	**Broken crown**	**Injured**	**Total affected**
Ocotea usambarensis	23.42	88.50	21.8	6	4	10
Ocotea usambarensis	21.90	87.00	19.1	6	6	12
Ocotea usambarensis	34.21	78.00	17.5	7	3	10
Ocotea usambarensis	21.79	90.50	20.3	3	5	8
Ocotea usambarensis	19.40	57.00	16.8	3	3	6
Ficalhoa laurifolia	24.37	54.50	19.0	5	5	10
Ficalhoa laurifolia	26.20	53.00	16.9	3	3	6
Ocotea usambarensis	25.60	60.30	13.6	4	4	8
Ocotea usambarensis	26.20	60.00	17.4	6	0	6
Ocotea usambarensis	31.10	85.00	24.3	13	1	14
Ficalhoa laurifolia	32.90	98.50	18.2	4	3	7
Podocarpus latifolius	27.30	56.50	9.5	7	1	8

Twice as many trees had crowns broken by the felling operation as were injured. The number of trees injured during felling operation was negatively correlated (r_s) with the felled tree's height (Table 5.3). Total number of affected trees correlated statistically significantly ($\rho = 0.022$) with crown diameters of felled trees. Other felled tree variables had no significant correlation with the number of trees broken or injured.

Table 5.3 Spearman's rank correlations between tree variables and felling damage at Chome

Variables of felled (target) tree	Other trees affected		
	Injured	**Broken crown**	**Total affected**
Height	$r_s = -0.604$*	$r_s = 0.559$	$r_s = 0.93$
dbh	$r_s = 0.272$	$r_s = 0.092$	$r_s = 0.336$
Crown diameter	$r_s = 0.344$	$r_s = 0.252$	$r_s = 0.65$*

*** significant, $\rho \geq 0.01 < 0.05$**

5.1.2 Kilimanjaro - Machame

5.1.2.1 Target tree environment

The environment of the target trees varied between plots in altitude, plot size, basal area per hectare and litter depth (Table 5.4). The sampled area was between 1650 and 1850 m altitude. The plot areas varied from 319.6 to 1452.8 m^2 with a mean of 739.0 m^2 and standard error of 67.1 m^2. Plots area distribution is shown in Figure 5.3. This Figure shows that plot areas in Machame were bimodally distributed.

Although logging has stopped in this forest, fodder, firewood and building poles collection is still going on. Once in a while cattle are left to graze in this forest. Small scale hunting with dogs is also done. The sampled area understorey consists mainly of shrubs and herbs which were cut during plot dermacation.

Table 5.4 Target trees' environment at Machame

Plot number	Species	Date when included in the study (month, year)	Plot area (m^2)	Altitude (m)	Local forest basal area (m^2/ha)	Mean litter depth (cm)
1	*Ocotea usambarensis*	March'99	667.6	1650	13	4.0
2	*Ocotea usambarensis*	March'99	538.4	1700	28	5.0
3	*Ocotea usambarensis*	March'99	741.8	1675	33	7.8
4	*Ocotea usambarensis*	March'99	629.0	1720	22	4.5
5	*Ocotea usambarensis*	March'99	949.4	1750	24	7.5
6	*Ocotea usambarensis*	March'99	1240.3	1750	19	7.3
7	*Ocotea usambarensis*	March'99	588.2	1750	24	4.8
8	*Ocotea usambarensis*	March'99	702.3	1750	22	5.0
9	*Ocotea usambarensis*	May'99	609.5	1775	28	6.8
10	*Ocotea usambarensis*	May'99	748.5	1800	19	7.5
11	*Ocotea usambarensis*	May'99	1186.1	1850	19	6.3
12	*Ocotea usambarensis*	May'99	491.8	1680	24	5.0
13	*Macaranga capensis*	May'99	1316.5	1675	27	4.5
14	*Ocotea usambarensis*	May'99	337.6	1700	28	5.8
15	*Ocotea usambarensis*	May'99	396.2	1700	27	5.5
16	*Ocotea usambarensis*	May'99	564.0	1700	27	6.0
17	*Ocotea usambarensis*	September'99	1260.4	1750	16	7.0
18	*Ocotea usambarensis*	September'99	772.9	1750	16	4.3
19	*Ocotea usambarensis*	September'99	351.1	1750	19	4.7
20	*Ocotea usambarensis*	September'99	319.6	1750	30	5.5
21	*Ocotea usambarensis*	September'99	608.8	1775	21	6.0
22	*Ocotea usambarensis*	September'99	493.7	1800	17	4.3
23	*Ocotea usambarensis*	September'99	769.1	1700	24	7.0
24	*Ocotea usambarensis*	September'99	1452.8	1675	26	5.6

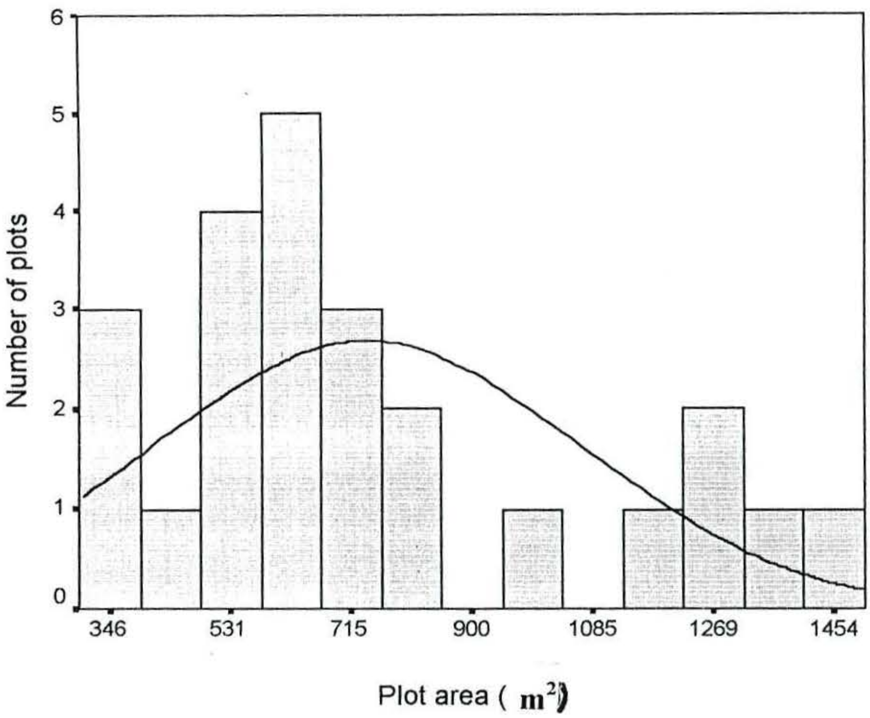


Figure 5.3 Machame plot area distribution

The basal area per hectare of the forest in and around each plot ranged from 13 to 33 m^2/ha (mean 23 m^2/ha; standard error 1.0 m^2/ha). The species contributing the highest proportion of the basal area in Machame was *Ocotea usambarensis* (mean = 10.0 m^2/ha; standard error 1.1 m^2/ha). A complete inventory of forest in and around each plot is shown in appendix 23. The overall litter depth differed between plots ranging from 4.0 to 7.8 cm (mean 6.9 cm, standard error 0.5 cm). The distribution of litter depth in Machame is shown in Figure 5.4.

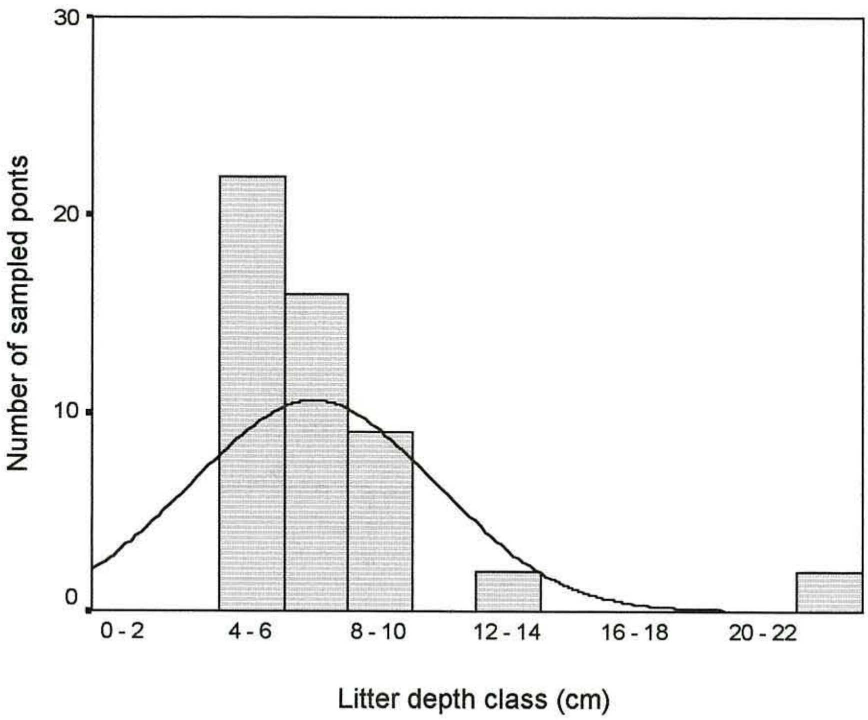


Figure 5.4 Machame litter depth distribution

5.1.2.2 Felling effects

Except for one *Macaranga capensis* tree all trees felled were of *Ocotea usambarensis* (camphor). The number of trees whose crowns were broken per felling ranged from 0 to 4 while those which were injured by the same operation ranged from 0 to 6 (Table 5.5). Thus a higher number of trees suffered crown breakage by the felling operation. The number of broken crown trees, injured or broken crown plus injured during felling was not correlated (r_s) with the felled tree dimensions (Table 5.6).

Table 5.5 Felling damage on surrounding trees (≥ 10 cm dbh) at Machame

Trees felled as target trees				Effect on surrounding tree population		
Species	Height (m)	dbh (cm)	Mean crown diameter (m)	broken crown	Injured	Total affected
Ocotea usambarensis	25.64	63.50	17.4	0	3	3
Ocotea usambarensis	24.90	71.00	16.5	1	1	2
Ocotea usambarensis	25.98	67.00	12.9	2	5	7
Ocotea usambarensis	25.69	58.00	11.5	2	3	5
Ocotea usambarensis	25.73	75.50	22.8	4	6	10
Macaranga capensis	14.58	78.50	23.5	4	1	5
Ocotea usambarensis	30.97	79.50	21.8	1	2	3
Ocotea usambarensis	26.73	64.50	11.6	0	0	0
Ocotea usambarensis	25.51	46.50	13.5	1	0	1
Ocotea usambarensis	28.30	67.50	17.3	4	3	7
Ocotea usambarensis	27.65	57.00	14.1	4	4	8
Ocotea usambarensis	24.74	58.50	14.9	1	1	2

Table 5.6 Spearman's rank correlations between tree variables and felling damage at Machame

Variables of felled	Other trees affected		
(target) tree	Injured	broken crown	Total affected
Height	$r_s = 0.401$	$r_s = 0.131$	$r_s = 0.338$
dbh	$r_s = 0.117$	$r_s = 0.197$	$r_s = 0.208$
Crown diameter	$r_s = 0.149$	$r_s = 0.284$	$r_s = 0.296$

5.1.3 Kilimanjaro - Rongai

5.1.3.1 Target tree environment

The environment of the target trees varied between plots in altitude, plot size, basal area per hectare and litter depth (Table 5.7). The sampled area was between 1950 and 2100 m altitude. The plot areas, varied from 459.9 to 2052.1 m^2 with a mean of 1203.8 m^2 with standard error of 87.2 m^2. Rongai plot area distribution is shown in Figure 5.5. Plot areas in Rongai were bimodally distributed.

Besides hunting, the sampled area of the forest was intact. Illegal pitsawing for *Fagaropsis angolensis* continues in other parts of the forest. The forest understorey consists of shrubs, herbs and sparse mountain grass.

Table 5.7 Target trees' environment at Rongai

Plot number	Species	Date when plot was incorporated in the study (month, year)	Altitude (m)	Plot area (m^2)	Local forest basal area (m^2/ha)	Mean litter depth (cm)
1	*Fagaropsis angolensis*	May'99	2050	1456.2	32	3.0
2	*Fagaropsis angolensis*	May'99	2050	674.6	45	3.0
3	*Fagaropsis angolensis*	May'99	2050	770.9	38	3.8
4	*Fagaropsis angolensis*	May'99	2075	1542.0	30	2.8
5	*Fagaropsis angolensis*	May'99	2100	1689.8	35	3.5
6	*Fagaropsis angolensis*	May'99	2100	1098.3	30	3.8
7	*Fagaropsis angolensis*	May'99	2100	2052.1	25	3.8
8	*Podocarpus falcatus*	May'99	2150	1060.8	37	5.8
9	*Podocarpus falcatus*	May'99	2100	777.6	29	5.0
10	*Fagaropsis angolensis*	May'99	1975	1027.0	23	3.3
11	*Fagaropsis angolensis*	May'99	1975	459.9	19	3.0
12	*Fagaropsis angolensis*	May'99	1975	1026.0	15	7.0
13	*Fagaropsis angolensis*	May'99	1975	733.2	21	5.3
14	*Fagaropsis angolensis*	May'99	1950	1910.2	16	4.3
15	*Fagaropsis angolensis*	May'99	2010	1603.3	27	4.0
16	*Fagaropsis angolensis*	May'99	2000	864.0	32	2.5
17	*Fagaropsis angolensis*	September'99	2000	1539.2	33	3.8
18	*Fagaropsis angolensis*	September'99	2050	1326.0	27	3.5
19	*Fagaropsis angolensis*	September'99	2025	1475.0	22	5.0
20	*Fagaropsis angolensis*	September'99	2025	652.5	28	4.0
21	*Fagaropsis angolensis*	September'99	2060	1535.1	35	5.8
22	*Fagaropsis angolensis*	September'99	2050	1500.0	34	5.8
23	*Fagaropsis angolensis*	September'99	2050	934.4	51	4.8
24	*Fagaropsis angolensis*	September'99	2075	1182.6	35	3.8

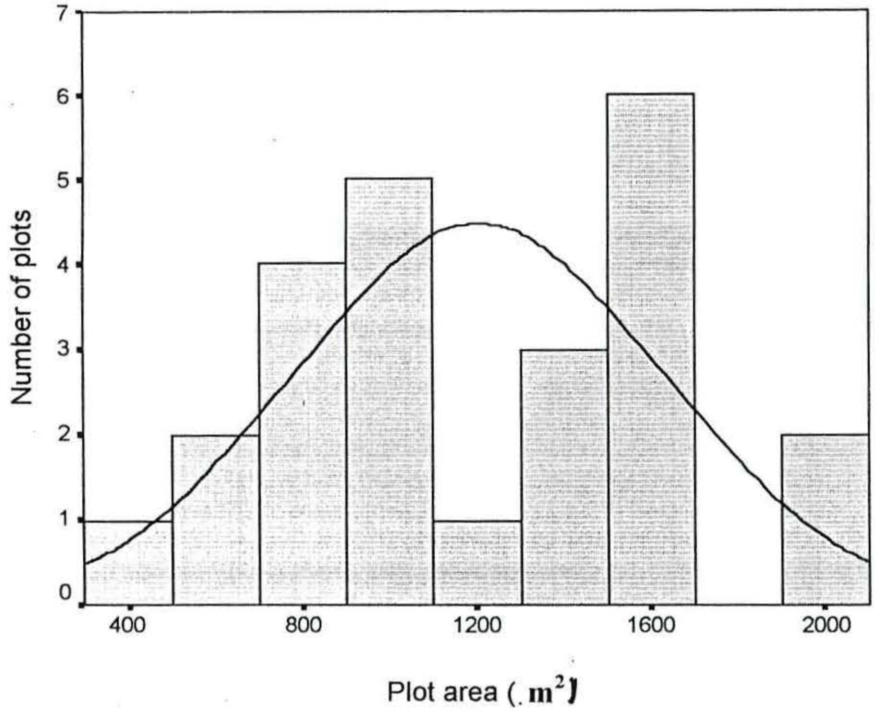


Figure 5.5 Rongai plot area distribution

The basal area per hectare of the forest in and around each plot ranged from 15 to 51 m^2/ha (mean 30 m^2/ha; standard error 1.7 m^2/ha) with more (2.4 m^2/ha; standard error 0.7 m^2/ha) contributed by *Podocarpus falcatus* than by *Fagaropsis angolensis* (1.7 m^2/ha; standard error 0.2 m^2/ha) although more target trees were of the latter species (a complete inventory is shown in Appendix 23). The overall litter depth differed between plots, ranging from 2.5 to 7.0 cm (mean 4.2 cm, standard error 0.2 cm). The distribution of litter depth is shown in Figure 5.6.

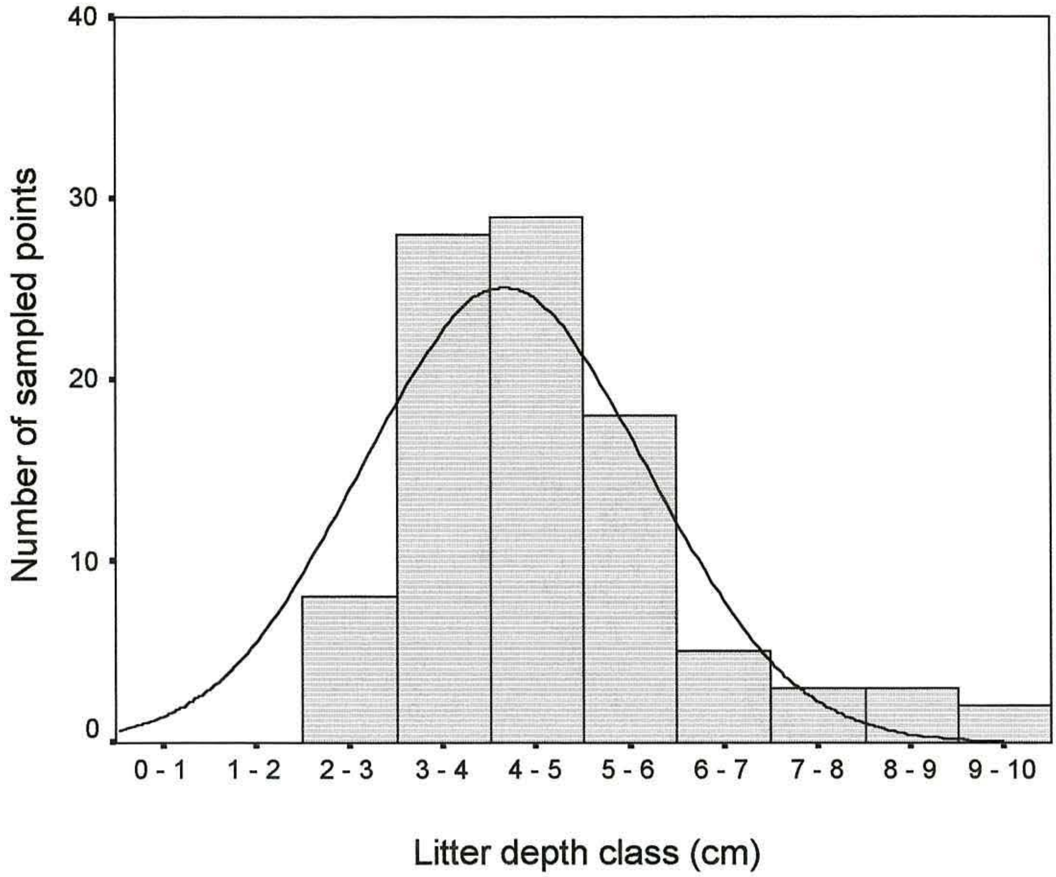


Figure 5.6 Rongai litter depth distribution

5.1.3.2 Felling effects

The trees felled were of *Fagaropsis angolensis* and *Podocarpus falcatus*. The number of trees whose crowns were broken per felling ranged from 0 to 6 (Table 5.8) while those injured ranged from 0 to 5, thus more trees had their crowns broken by the felling.

Table 5.8 Felling damage on surrounding trees (≥ 10 cm dbh) at Rongai

Trees felled as target trees				Effect on surrounding tree population		
Species	Height (m)	Dbh (cm)	Mean crown diameter (m)	Broken crown trees	Trees injured	Total affected
Fagaropsis angolensis	27.92	54.25	15.7	0	4	4
Fagaropsis angolensis	35.16	70.00	16.8	2	5	7
Fagaropsis angolensis	31.32	70.00	15.3	1	0	1
Fagaropsis angolensis	36.16	70.50	16.9	4	0	4
Fagaropsis angolensis	29.10	62.50	16.5	5	5	10
Fagaropsis angolensis	27.10	82.00	18.8	4	0	4
Fagaropsis angolensis	29.30	55.50	16.3	1	1	2
Podocarpus falcatus	21.57	58.50	14.5	3	2	5
Podocarpus falcatus	28.90	83.25	19.0	6	1	7
Fagaropsis angolensis	40.52	112.50	26.2	4	2	6
Fagaropsis angolensis	31.54	87.00	19.4	3	1	4
Fagaropsis angolensis	35.40	88.75	18.4	3	0	3

There was a significant positive correlation (r_s) between the number of trees killed and the crown diameter of the felled tree (Table 5.9). Other felled tree variables were not correlated with the number of trees which were broken, injured or total.

Table 5.9 Spearman's rank correlations between tree variables and felling damage at Rongai

Variables of felled (target) tree	Other trees affected		
	Broken crown	Injured	Total affected
Height	$r_s = 0.046$	$r_s = -0.162$	$r_s = -0.096$
dbh	$r_s = 0.525$	$r_s = -0.400$	$r_s = -0.077$
Crown diameter	$r_s = 0.583$*	$r_s = -0.180$	$r_s = 0.257$

*** significant, $\rho \geq 0.01 < 0.05$**

5.2 Canopy closure from hemispherical photographs

5.2.1 Chome

5.2.1.1 Seasonal changes

Table 5.10 lists the trees defining plots which received felling and those which did not receive the felling treatment. The species of trees defining plots were *Ocotea usambarensis*, *Podocarpus latifolius* and *Ficalhoa laurifolia*. Table 5.10 separates the three phases (March 1999, May 1999 and September 1999) and shows the dates when the first hemispherical photographs were taken.

Table 5.10 Trees defining plots and first dates for light readings at Chome

Phase	No felling treatment		Felling treatment		
	Plot (target tree)	**Date of first reading**	**Plot (target tree)**	**Date of pre-felling reading**	**Date of first post-felling reading**
Phase 1	**3** *Ocotea usambarensis*	(8/3/1999)	**2** *Podocarpus latifolius*	(8/3/1999)	(8/3/1999)
	5 *Ocotea usambarensis*	(8/3/1999)	**4** *Ficalhoa laurifolia*	(8/3/1999)	(8/3/1999)
	1 *Ocotea usambarensis*	(9/3/1999)	**6** *Ocotea usambarensis*	(9/3/1999)	(9/3/1999)
	8 *Ficalhoa laurifolia*	(9/3/1999)	**7** *Ocotea usambarensis*	(9/3/1999)	(9/3/1999)
Phase 2	**9** *Ocotea usambarensis*	(9/5/1999)	**10** *Ocotea usambarensis*	(9/5/1999)	(9/5/1999)
	11 *Podocarpus latifolius*	(9/5/1999)	**15** *Ficalhoa laurifolia*	(9/5/1999)	(9/5/1999)
	12 *Ocotea usambarensis*	(10/5/1999)	**16** *Ficalhoa laurifolia*	(10/5/1999)	(10/5/1999)
	13* *Ocotea usambarensis*	(10/5/1999)	**18*** *Ocotea usambarensis*	(10/5/1999)	(10/5/1999)
Phase 3	**14*** *Podocarpus latifolius*	(10/9/1999)	**20** *Ocotea usambarensis*	(10/9/1999)	(10/9/1999)
	17 *Ocotea usambarensis*	(11/9/1999)	**21** *Ocotea usambarensis*	(11/9/1999)	(11/9/1999)
	19 *Ficalhoa laurifolia*	(11/9/1999)	**22** *Ocotea usambarensis*	(11/9/1999)	(11/9/1999)
	24 *Ocotea usambarensis*	(12/9/1999)	**23*** *Ocotea usambarensis*	(12/9/1999)	(12/9/1999)

NB. * Hemispherical photographs which were not included in further analysis. The selection procedure is explained in 4.3 for light data.

Progressive canopy closure change may be a result of applied treatments or differences in seasons. In areas where there are well-defined dry and wet seasons we would expect seasonal variations in canopy closure. Table 5.11 shows the initial light readings and corresponding canopy closure percentages at the six photosite positions for ten plots which did not receive the felling treatment. Images from these felling control plots were used to seek indications of seasonal variation. The reported light figures are relative since light readings in the open and cloudiness conditions data were not available for calibration.

Table: 5.11 Trees defining non-felling plots and initial light readings (mol m^{-2} d^{-1}) and corresponding canopy closure values (%) by photosite position at Chome

Phase	Plot (target tree)	Photosite positions					
		Photosite 1: 20 m behind base of bole	Photosite 2: 10 m behind base of bole	Photosite 3: Below crown edge	Photosite 4: 1 m behind base of bole	Photosite 5: 0.5 m x bole length from base of bole	Photosite 6: 1 x bole length from base of bole
Phase 1	3 *Ocotea usambarensis*	13.2 (74)	9.8 (78)	15.7 (73) [8.7]	14.9 (73)	15.3 (68) [13.5]	13.5 (73) [27.0]
	5 *Ocotea usambarensis*	16.9 (74)	14.4 (96)	13.4 (89) [6.9]	13.6 (90)	14.3 (63) [11.0]	13.0 (81) [22.0]
	1 *Ocotea usambarensis*	28.6 (51)	34.2 (61)	33.5 (66) [9.5]	35.6 (73)	21.8 (46) [15.9]	23.4 (56) [31.8]
	8 *Ficalhoa laurifolia*	24.7 (54)	39.4 (18)	32.2 (54) [7.7]	34.7 (48)	23.3 (50) [12.3]	20.7 (55) [24.5 m]
Phase 2	9 *Ocotea usambarensis*	34.9 (44)	34.3 (50)	38.1 (33) [10.3]	33.1 (38)	34.6 (30) [20.2]	38.3 (30) [40.3]
	11 *Podocarpus latifolius*	37.6 (36)	29.8 (39)	34.5 (41) [3.6]	36.9 (41)	36.1 (44) [7.8]	37.0 (37) [15.5]
	12 *Ocotea usambarensis*	32.5 (36)	35.7 (40)	33.8 (34) [7.6]	39.7 (35)	28.0 (47) [9.4]	29.0 (46) [18.7]
Phase 3	17 *Ocotea usambarensis*	36.3 (54)	29.2 (54)	34.1 (51) [9.2]	24.9 (58)	30.0 (55) [10.6]	28.1 (39) [21.2]
	19 *Ficalhoa laurifolia*	32.4 (44)	31.8 (51)	31.7 (46) [5.0]	32.3 (47)	30.8 (46) [6.1]	37.7 (35) [12.2]
	24 *Ocotea usambarensis*	25.3 (53)	23.5 (51)	19.6 (56) [8.4]	31.6 (46)	21.7 (49) [17.8]	28.4 (48) [35.6]

NB. Figures in brackets ( ) show canopy closure percentages

Entries in parentheses [ ] represents distances in metres from bole base (Photosites 3, 5 and 6)

In Figures 5.8, 5.9 and 5.10 light data are plotted for time sequences (March 1999, May 1999 and September 1999) separately for representative trees in the unfelled plots. Examination of Figure 5.8 shows an increase over time of direct light reaching the forest under-canopy. Also Figure 5.9 shows that May 1999 had received higher direct light compared to September 1999. Figures 5.8 and 5.9 show that there is little difference between light data for May 1999 and September 1999. This period is within the dry season (Figure 3.3). The short rains season starts in October and end in January (Figure 3.3). Due to this, light levels in February 1999 were lower than those of September 1999 (Figures 5.8, 5.9 and 5.10) since it was soon after the rainy season when most trees are in leaf hence canopy closure is high and little direct light is received at the forest floor. Despite these visual observations, there was no statistical evidence of seasonal light differences ($F_{(3,3)} = 0.64$, $\rho = 0.637$ (4 seasons, for the plots sampled in March 1999, May 1999, September 1999 and February 2000); $F_{(2,6)} = 1.80$, $\rho = 0.244$ (3 seasons, for the plots sampled in May 1999, September 1999 and February 2000); $F_{(1,6)} = 2.53$, $\rho = 0.163$ (2 seasons, for the plots sampled in September 1999 and February 2000) respectively). The results are from combined information in Figures 5.8, 5.9 and 5.10. In all seasons light levels were between 30 to 40 mol m^{-2} d^{-1}.

5.2.1.2 Impact of felling

Table 5.12 shows the changes in canopy closure at each photosite position immediately following felling. In most cases the canopy closure was reduced following felling. Change was minimal at the positions least affected by the tree felling (20 m and 10 m from the bole base). The extent of canopy closure was increased in some instances by branch debris on the forest canopy. The extent of these changes differed according to the photosite position. The changes were most noticeable at the following photosites: at tree edge; one metre from bole base; half bole length and bole length distances. Typical reductions ranged from 0 to 29% canopy closure. These changes in canopy closure were the results of single tree removal as well as seasonal changes as explained in Table 5.11 and Figures 5.8, 5.9 and 5.10. Pre- and post-felling photographs were taken immediately before and after felling. As a result of canopy closure reduction following felling, incident light was increased (Figure 5.7). In cases where incident light is lower post-felling the cause is branch debris above the crown position which blocked incoming light. The mean increase was 24.5% and standard error of the mean of 3.7% of the original values. There was no statistically significant differences between the pre- and post-felling levels for all Chome fellings combined ($t_{0.05} = 0.05$, N = 18, $\rho = 0.96$, df = 18).

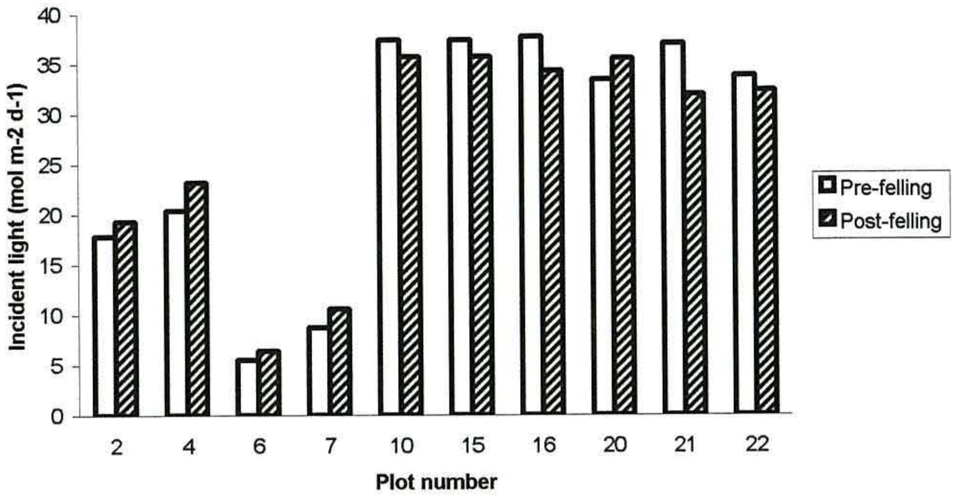


Figure 5.7 Incident light changes following single tree felling at Chome, Tanzania

NB. The plotted data are for photosite 4 (1 m from target tree base). Plots 2-7 were felled in March 1999, plots 10-16 were felled in May 1999 and plots 20-22 were felled in September 1999. Plots 18 and 23 hemispherical photographs were not further analysed as shown in Table 5.12.

5.2.1.3 Progressive recovery

Table 5.13 shows the recovery of canopy closure in the created gaps after single tree removal in plots which received felling treatments. The recovery rate varied between photosite positions and assessment periods. The initial effect of single tree removal is a reduction in canopy closure, accentuated by seasonal trends after the March 1999 fellings (Table 5.11). In most March 1999 cases canopy closure is further reduced by the time of the subsequent (May 1999) assessment. Afterwards the canopy closure proportion increased. Positive changes in canopy closure were frequent between the May 1999 post-felling assessment and the September 1999 assessment being in the dry season. Where trees had been felled in March 1999, the May - September 1999 period was also associated with increasing canopy closure. The increase was mainly due to broken branches hang-ups.

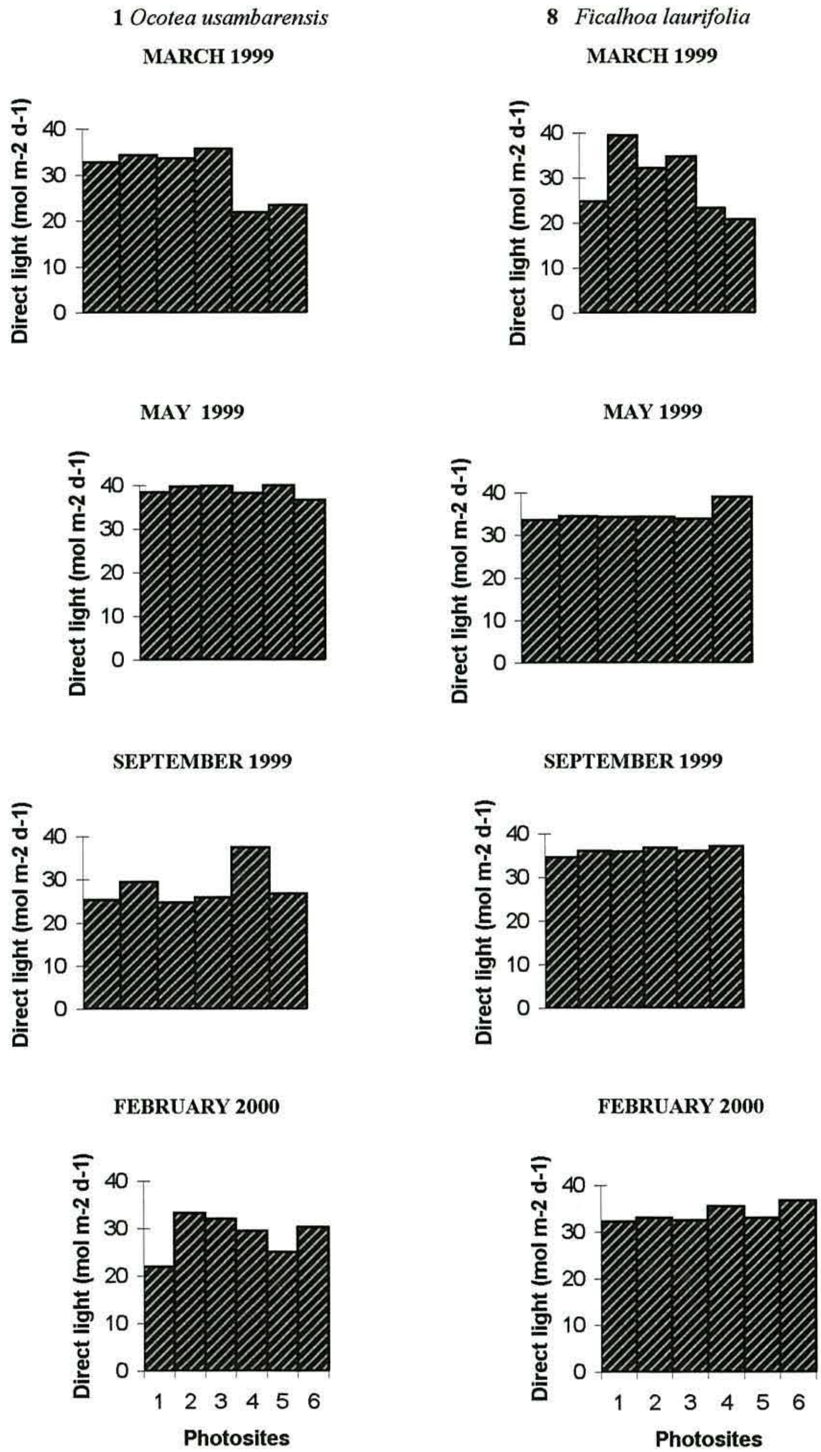


Figure 5.8 Seasonal changes of direct light between assessment periods at Chome for the two plots with four measurements (March 1999 - February 2000). Where photosites are 1 - 20 m behind base of bole; 2 - 10 m behind base of bole; 3 - below crown edge; 4 - 1 m behind base of bole; 5 - 0.5 x bole length from base of bole; 6 - 1 x bole length from base of bole. Each graph heading shows the plot number and target tree species.

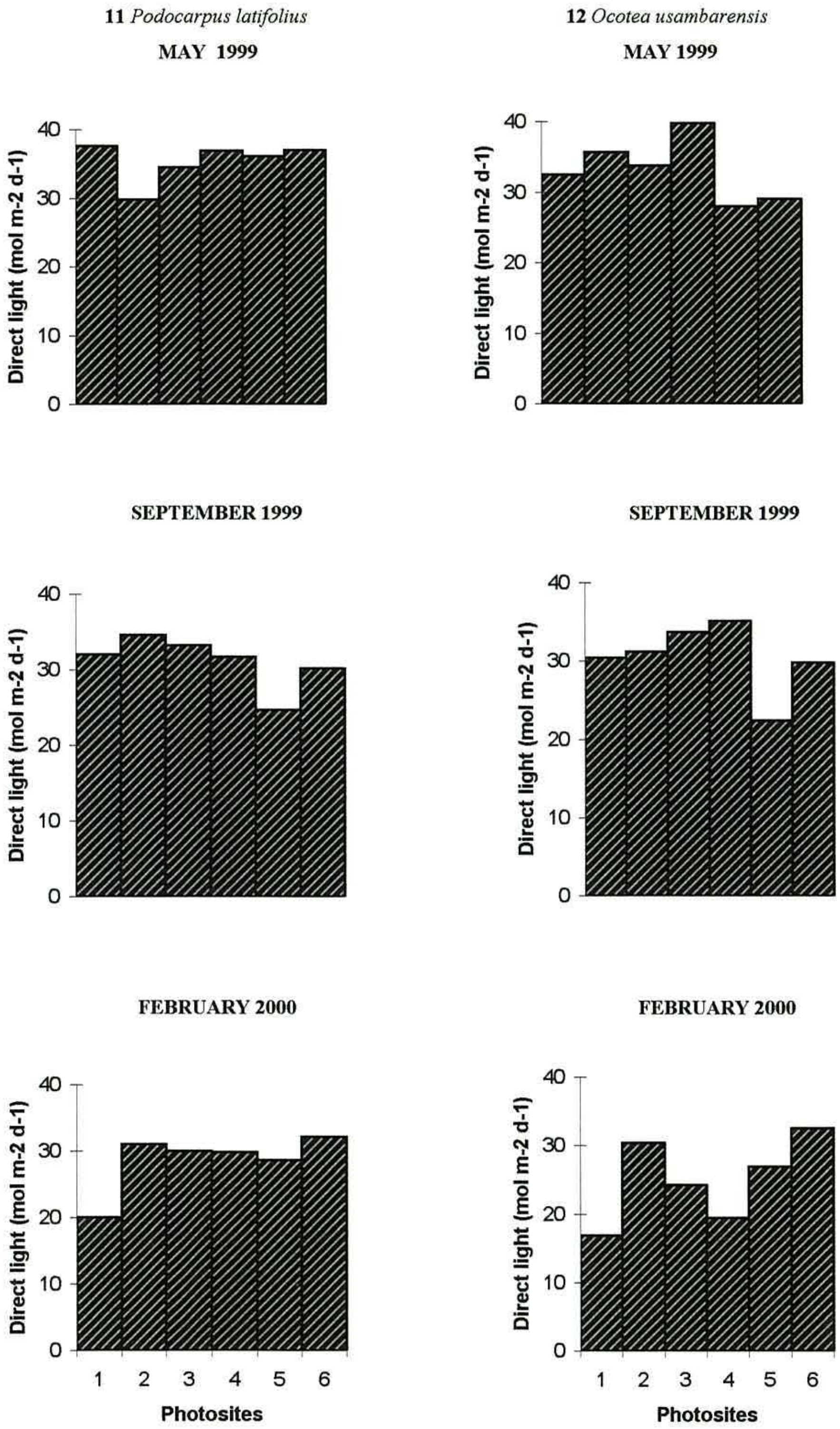


Figure 5.9 Seasonal changes of direct light between assessment periods at Chome for the two plots with three measurements (May 1999 - February 2000). Where photosites 1 - 20 m behind base of bole; 2 - 10 m behind base of bole; 3 - below crown edge; 4 - 1 m behind base of bole; 5- 0.5 x bole length from base of bole; 6 - 1 x bole length from base of bole. Each graph heading shows the plot number and target tree species.

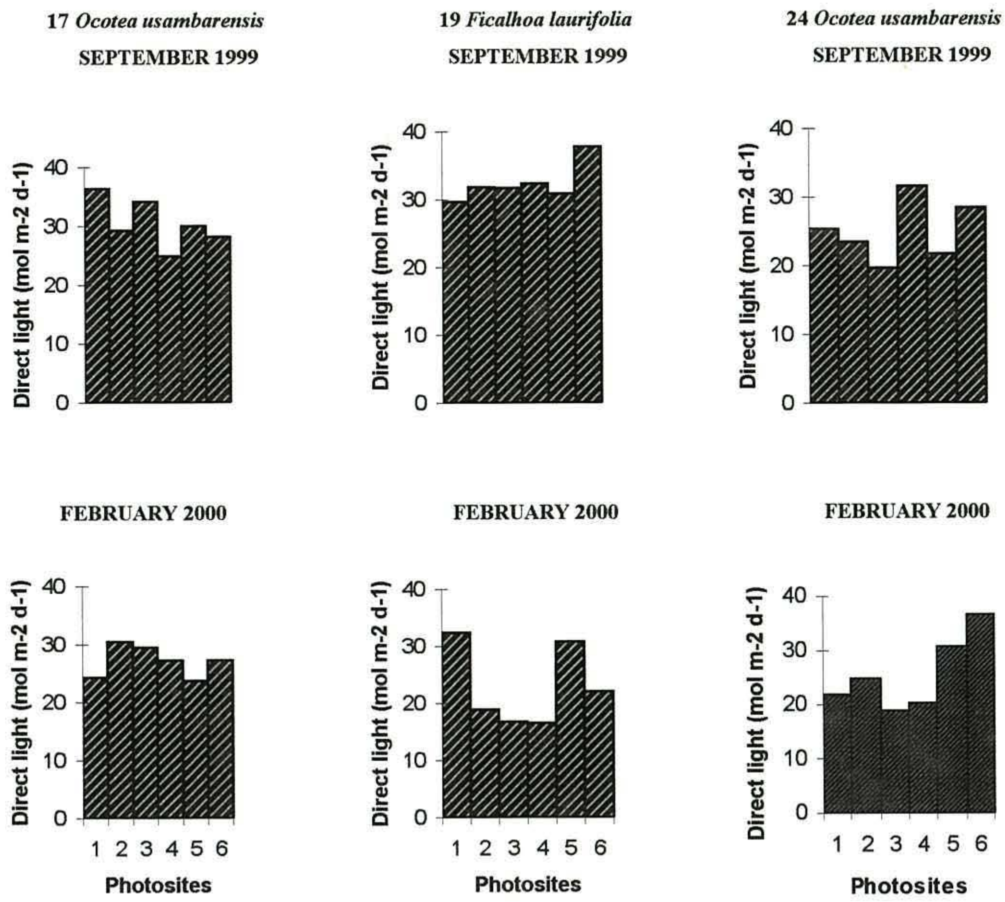


Figure 5.10 Seasonal changes of direct light between assessment periods at Chome for the three plots with two measurements (September 1999 and February 2000). Where photosites are 1 - 20 m behind base of bole; 2 - 10 m behind base of bole; 3 - below crown edge; 4 - 1 m behind base of bole; 5- 0.5 x bole length from base of bole; 6 - 1 x bole length from base of bole. Each graph heading shows the plot number and target tree species.

Table: 5.12 Trees defining felled tree plots and initial pre- and post-felling canopy closure values (%) and corresponding light (mol $m^{-2}d^{-1}$) by photosite position at Chome

Plot (target tree)	Phase and context	Photosite positions					
		Photosite 1: 20 m behind base of bole	Photosite 2 : 10 m behind base of bole	Photosite 3 : Below crown edge	Photosite 4: 1 m behind base of bole	Photosite 5: 0.5 m x bole length from base of bole	Photosite 6: 1 x bole length from base of bole
2 *Podocarpus latifolius*	1: pre-felling	87 (6.3)	85 (3.0)	81 (8.4) [4.8]	74 (17.8)	91 (2.7) [13.7]	89 (3.8) [27.3]
	1: post-felling (immediately after felling)	**85 (11.2)**	**80 (18.4)**	**76 (12.9)**	**63 (19.3)**	**70 (27.0)**	**82 (10.0)**
4 *Ficalhoa laurifolia*	1: pre-felling	65 (17.2)	75 (13.4)	66 (9.4) [9.1]	74 (20.4)	77 (8.2) [16.5]	73 (16.6) [32.9]
	1: post-felling (immediately after felling)	**64 (24.2)**	**72 (17.5)**	**63 (22.3)**	**63 (23.2)**	**70 (16.6)**	**69 (20.7)**
6 *Ocotea usambarensis*	1: pre-felling	83 (7.7)	84 (7.0)	82 (10.0) [12.2]	86 (5.5)	87 (4.6) [15.6]	84 (8.4) [31.1]
	1: post-felling (immediately after felling)	**83 (8.8)**	**82 (11.6)**	**80 (11.0)**	**86 (6.4)**	**75 (13.7)**	**76 (12.1)**
7 *Ocotea usambarensis*	1: pre-felling	82 (9.5)	88 (8.5)	81 (10.5) [8.7]	81 (8.7)	86 (6.2) [13.1]	79 (11.8) [26.2]
	1: post-felling (immediately after felling)	**78 (14.2)**	**85 (12.9)**	**80 (9.5)**	**81 (10.6)**	**79 (12.3)**	**56 (22.2)**
10 *Ocotea usambarensis*	2: pre-felling	32 (39.0)	27 (34.8)	44 (30.1) [6.8]	31 (37.7)	31 (33.0) [12.8]	32 (37.3) [25.6]
	2: post-felling (immediately after felling)	**31 (34.9)**	**31 (29.6)**	**28 (37.8)**	**28 (38.0)**	**30 (37.0)**	**29 (37.5)**
15 *Ficalhoa laurifolia*	2: pre-felling	47 (37.1)	38 (39.5)	47 (30.9) [8.5]	45 (37.4)	52 (33.2) [13.1]	49 (35.8) [26.2]
	2: post-felling (immediately after felling)	**49 (24.5)**	**57 (19.9)**	**47 (22.2)**	**44 (35.7)**	**43 (33.4)**	**51 (24.8)**
16 *Ficalhoa laurifolia*	2: pre-felling	38 (35.5)	35 (37.8)	32 (37.8) [9.5]	27 (37.7)	39 (27.1) [12.2]	26 (36.5) [24.4]
	2: post-felling (immediately after felling)	**49 (38.1)**	**51 (28.8)**	**54 (27.7)**	**56 (34.3)**	**28 (36.0)**	**33 (34.7)**

20 *Ocotea usambarensis*	3: pre-felling	63 (24.0)	56 (35.6)	59 (31.0) [10.2]	32 (33.4)	31 (39.7) [10.9]	23 (39.8) [21.8]
	3: post-felling (immediately after felling)	**60 (25.0)**	**50 (37.1)**	**47 (35.1)**	**49 (35.5)**	**56 (33.7)**	**55 (19.1)**
21 *Ocotea usambarensis*	3: pre-felling	43 (29.7)	40 (29.7)	39 (35.3) [8.8]	30 (37.0)	36 (35.4) [17.1]	51 (29.9) [34.2]
	3: post-felling (immediately after felling)	**45 (20.1)**	**43 (32.0)**	**44 (33.8)**	**36 (31.9)**	**64 (14.9)**	**38 (34.6)**
22 *Ocotea usambarensis*	3: pre-felling	43 (31.4)	30 (36.6)	37 (30.9) [9.6]	47 (33.8)	45 (29.1) [11.0]	44 (36.1) [21.9]
	3: post-felling (immediately after felling)	**33 (35.6)**	**29 (36.6)**	**40 (31.4)**	**38 (32.3)**	**40 (28.3)**	**22 (44.4)**

NB. Numbers in brackets ( ) show light values (mol m^{-2} d^{-1})

Entries in parentheses [ ] represents distances in metres from bole base (Photosites 3, 5 and 6)

Table: 5.13 Effects of tree felling on canopy closure (%) and recovery sequences by tree and by photosite at Chome

Photosite	Plot (target tree)	Pre-fell Mar 99	Post-fell Mar 99	May 99	Sep 99	Feb 00	Plot (target tree)	Pre-fell May 99	Post-fell May 99	Sep 99	Feb 00	Plot (target tree)	Pre-fell Sep 99	Post-fell Sep 99	Feb 00
1	**2** *Podocarpus*	87	85	81	74	50	**10** *Ocotea*	32	31	40	47	**20** *Ocotea*	63	60	63
2		85	80	76	69	50		27	31	64	34		56	50	68
3		81	76	81	64	54		44	28	63	22		59	47	47
4		74	63	86	70	48		31	28	43	36		32	49	32
5		91	70	67	79	46		31	30	48	38		31	56	31
6		89	82	64	76	52		32	29	34	44		23	55	39
1	**4** *Ficalhoa*	65	64	60	78	50	**15** *Ficalhoa*	47	49	39	53	**21** *Ocotea*	43	45	19
2		75	72	64	74	61		38	57	53	59		40	43	29
3		66	63	74	77	46		47	47	52	57		39	44	57
4		74	63	72	70	49		45	44	43	53		30	36	26
5		77	70	82	70	45		52	43	40	37		36	64	25
6		73	69	71	70	46		49	51	52	57		51	38	36
1	**6** *Ocotea*	83	83	72	79	53	**16** *Ficalhoa*	38	49	41	49	**22** *Ocotea*	43	33	29
2		84	82	74	79	50		35	51	47	54		30	29	27
3		82	80	69	72	49		32	54	51	53		37	40	24
4		86	86	72	75	59		27	56	45	38		47	38	25
5		87	75	74	73	44		39	28	45	35		45	40	24
6		84	76	73	70	51		26	33	39	52		44	22	47
1	**7** *Ocotea*	82	78	35	42	48									
2		88	85	34	45	52									
3		81	80	46	45	46									
4		81	81	46	46	49									
5		86	79	82	47	47									
6		79	56	43	44	39									

The recovery process in terms of light reaching the photosites (Table 5.14) broadly follows the trend described for canopy closure percentage.

5.2.2 Kilimanjaro - Machame

5.2.2.1 Seasonal changes

Table 5.15 lists trees defining plots which received the felling treatment and trees defining those which did not. With the exception of one *Macaranga capensis* individual, all target trees defining plots were of *Ocotea usambarensis*. The Table separates three phases (March 1999, May 1999 and September 1999) and shows the dates when the first light readings were taken. Table 5.16 shows the initial light readings of plots which did not receive the felling treatment in the three treatment phases and indicates the corresponding canopy closure values. Most photosites received estimated direct light above 30 mol m^{-2} d^{-1} in all assessment phases (Figure 5.12). The presented light data are relative since no light in the open and cloudiness conditions for calibration were not available. Only in September 1999 to February 2000 season there was statistical evidence of seasonal light variations ($F_{(3,6)} = 1.54$, $\rho = 0.299$ (4 seasons, March 1999, May 1999, September 1999 and February 2000); $F_{(2,10)} = 3.69$, $\rho = 0.063$ (3 seasons, May 1999, September 1999 and February 2000); $F_{(1,7)} = 18.51$, $\rho = 0.004$ (2 seasons, September 1999 and February 2000).

5.2.2.2 Impact of felling

Tree removal from the canopy reduces the canopy closure, increasing the amount of incident light reaching the forest understorey. Table 5.17 shows the changes in the extent of canopy closure at each photosite associated with tree removal. The canopy closure at the photosites tended to decrease with this removal, particularly at photosite positions 4 (one metre from bole base), 5 (half bole length from bole base) and 6 (bole length distance from bole base). Table 5.17 also shows the corresponding estimated direct light values before and after tree removal. Post-felling incident light levels were higher than pre-felling ones for felled plots in Machame (Figure). The mean increase was 35.1% and standard error of the mean of 0.8% of the original values. There was statistically significant difference between these two levels ($t_{0.05}$ = -4.10, N = 20, ρ = 0.0007, df = 18).

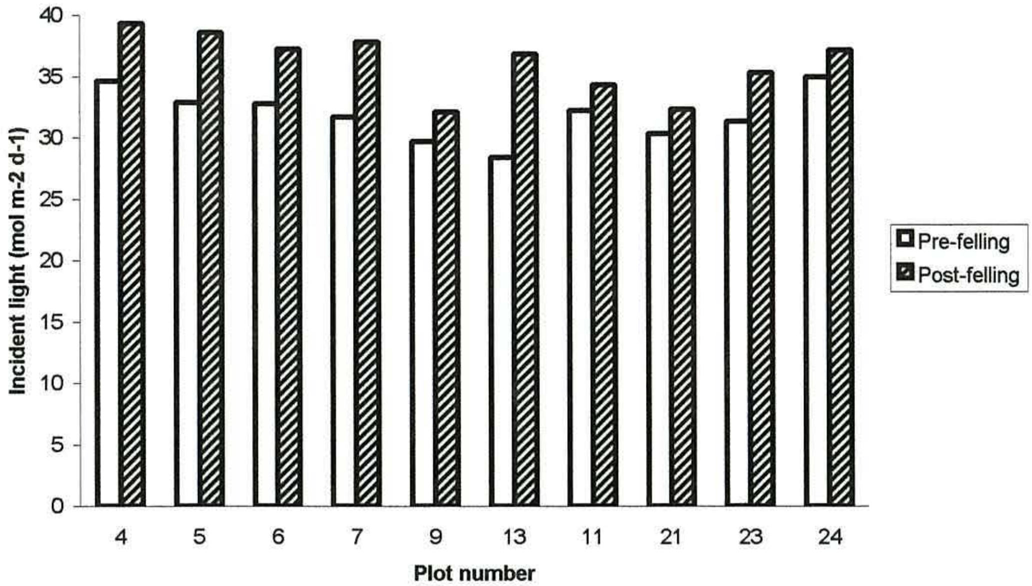


Figure 5.11 Incident light changes following single tree felling at Machame, Tanzania

NB. The plotted data are for photosite 4 (1 m from target tree base). Plots 4-7 were felled in March 1999, plots 9-11 were felled in May 1999 and plots 21-24 were felled in September 1999. Plots 17 and 18 hemispherical photographs were not further analysed as shown in Table 5.17.

5.2.2.3 Progressive recovery

Table 5.18 shows the progressive recovery of canopy closure after initial reduction following single tree removal. Soon after felling and initial canopy closure reduction, the canopy closure percentage continues to decrease due to the drying up of dead branches caused by the felling activity.

Table: 5.14 Effects of tree felling on estimated direct light (mol m^{-2} d^{-1}) and recovery sequences by tree and by photosite at Chome

Photosite	Plot (target tree)	Pre-fell Mar 99	Post-fell Mar 99	May 99	Sep 99	Feb 00	Plot (target tree)	Pre-fell May 99	Post-fell May 99	Sep 99	Feb 00	Plot (target tree)	Pre-fell Sep 99	Post-fell Sep 99	Feb 00
1	**2** *Podocarpus*	6.3	11.2	8.8	11.0	31.3	**10** *Ocotea*	39.0	34.9	33.8	26.6	**20** *Ocotea*	24.0	25.0	19.0
2		3.0	18.4	14.4	21.8	22.2		34.8	29.6	19.2	36.5		35.6	37.1	19.3
3		8.4	12.9	12.2	21.8	30.7		30.1	37.8	18.2	39.3		31.0	35.1	34.6
4		17.8	19.3	6.5	14.7	26.1		37.7	38.0	29.7	34.0		33.4	35.5	35.9
5		2.7	27.0	23.9	16.0	31.1		33.0	37.0	32.6	34.0		39.7	33.7	38.5
6		3.8	10.0	21.7	14.6	28.7		37.3	37.5	29.8	33.4		39.8	19.1	32.8
1	**4** *Ficalhoa*	17.2	24.2	20.0	14.2	25.1	**15** *Ficalhoa*	37.1	24.5	31.8	32.5	**21** *Ocotea*	29.7	20.1	40.4
2		13.4	17.5	20.4	13.9	25.4		39.5	19.9	23.9	22.8		29.7	32.0	37.8
3		9.4	22.3	17.5	10.0	27.4		30.9	22.2	23.0	30.3		35.3	33.8	16.7
4		20.4	23.2	13.9	15.9	32.1		37.4	35.7	34.3	28.8		37.0	31.9	38.3
5		8.2	16.6	9.2	14.5	34.7		33.2	33.4	31.1	29.3		35.4	14.9	35.9
6		16.6	20.7	14.9	15.1	26.5		35.8	24.8	28.5	18.7		29.9	34.6	38.2
1	**6** *Ocotea*	7.7	8.8	11.4	12.8	25.5	**16** *Ficalhoa*	35.5	38.1	30.7	33.0	**22** *Ocotea*	31.4	35.6	38.2
2		7.0	11.6	11.7	12.1	26.5		37.8	28.8	31.1	22.7		36.6	36.6	36.9
3		10.0	11.0	16.4	14.2	28.5		37.8	27.7	26.6	29.9		30.9	31.4	35.5
4		5.5	6.4	14.7	12.4	19.6		37.7	34.3	28.3	38.9		33.8	32.3	37.0
5		4.6	13.7	11.3	13.9	24.7		27.7	36.0	27.4	39.3		29.1	28.3	35.1
6		8.4	12.1	13.9	14.9	32.6		36.5	34.7	33.3	24.6		36.1	44.4	27.1
1	**7** *Ocotea*	9.5	14.2	32.9	30.3	34.5									
2		8.5	12.9	33.2	26.9	23.9									
3		10.5	9.5	26.3	28.2	23.7									
4		8.7	10.6	30.8	28.0	23.0									
5		6.2	12.3	6.5	22.2	28.1									
6		11.8	22.2	29.2	28.5	30.9									

Table 5.15 Trees defining plots and first dates for light readings at Machame

Phase	No felling treatment		Felling treatment		
	Plot (target tree)	**Date of first reading**	**Plot (target tree)**	**Date of pre-felling reading**	**Date of first post-felling reading**
Phase 1	**1** *Ocotea usambarensis*	(1/3/1999)	**4** *Ocotea usambarensis*	(1/3/1999)	(1/3/1999)
	2 *Ocotea usambarensis*	(1/3/1999)	**5** *Ocotea usambarensis*	(1/3/1999)	(1/3/1999)
	3 *Ocotea usambarensis*	(2/3/1999)	**6** *Ocotea usambarensis*	(2/3/1999)	(2/3/1999)
	8* *Ocotea usambarensis*	(2/3/1999)	**7** *Ocotea usambarensis*	(2/3/1999)	(2/3/1999)
Phase 2	**10** *Ocotea usambarensis*	(3/5/1999)	**9** *Ocotea usambarensis*	(3/5/1999)	(3/5/1999)
	12* *Ocotea usambarensis*	(3/5/1999)	**11** *Ocotea usambarensis*	(3/5/1999)	(3/5/1999)
	14 *Ocotea usambarensis*	(4/5/1999)	**13** *Macaranga capensis*	(4/5/1999)	(4/5/1999)
	15 *Ocotea usambarensis*	(4/5/1999)	**17*** *Ocotea usambarensis*	(4/5/1999)	(4/5/1999)
Phase 3	**16** **Ocotea usambarensis*	(2/9/1999)	**18*** *Ocotea usambarensis*	(2/9/1999)	(2/9/1999)
	19 **Ocotea usambarensis*	(2/9/1999)	**21** *Ocotea usambarensis*	(2/9/1999)	(2/9/1999)
	20 *Ocotea usambarensis*	(3/9/1999)	**23** *Ocotea usambarensis*	(3/9/1999)	(3/9/1999)
	22 *Ocotea usambarensis*	(3/9/1999)	**24** *Ocotea usambarensis*	(3/9/1999)	(3/9/1999)

NB. Plots with asterisk (*) were not included in further analysis. The selection procedure is explained in 4.3 for light data.

Table: 5.16 Trees defining non-felling plots and initial light readings (mol $m^{-2}d^{-1}$) and corresponding canopy closure (%) by photosite position at Machame

Phase	Plot (target tree)	Photosite positions					
		Photosite 1: 20 m behind base of bole	Photosite 2: 10 m behind base of bole	Photosite 3: Below crown edge	Photosite 4: 1 m behind base of bole	Photosite 5: 0.5 m x bole length from base of bole	Photosite 6: 1 x bole length from base of bole
Phase 1	**1** *Ocotea usambarensis*	33.1 (41)	35.9 (32)	37.7 (28) [9.5]	37.9 (23)	39.0 (18) [18.4]	38.6 (25) [36.8]
	2 *Ocotea usambarensis*	31.5 (35)	29.6 (38)	30.5 (40) [7.2]	28.1 (46)	32.4 (39) [11.7]	34.7 (36) [23.3]
	3 *Ocotea usambarensis*	34.5 (36)	31.9 (42)	33.2 (32) [5.5]	33.0 (38)	32.6 (40) [9.5]	35.5 (36) [18.9]
Phase 2	**10** *Ocotea usambarensis*	27.4 (48)	27.2 (47)	34.3 (43) [6.3]	34.6 (43)	33.0 (39) [7.7]	31.7 (44) [15.3]
	14 *Ocotea usambarensis*	28.7 (50)	33.0 (44)	20.4 (47) [4.1]	31.2 (41)	32.4 (43) [6.9]	31.5 (46) [13.7]
	15 *Ocotea usambarensis*	37.6 (41)	29.7 (46)	33.0 (42) [3.1]	32.6 (44)	34.8 (46) [6.0]	34.6 (48) [12.0]
Phase 3	**20** *Ocotea usambarensis*	37.5 (41)	36.5 (42)	35.1 (41) [3.4]	33.6 (44)	32.2 (45) [7.9]	27.3 (44) [15.7]
	22 *Ocotea usambarensis*	35.7 (33)	37.4 (36)	36.1 (33) [5.7]	37.5 (34)	30.9 (37) [9.6]	37.4 (33) [19.1]

NB Numbers in brackets ( ) represent canopy closure percentages

Entries in parentheses [ ] represent distances in metres from bole base (Photosites 3, 5 and 6)

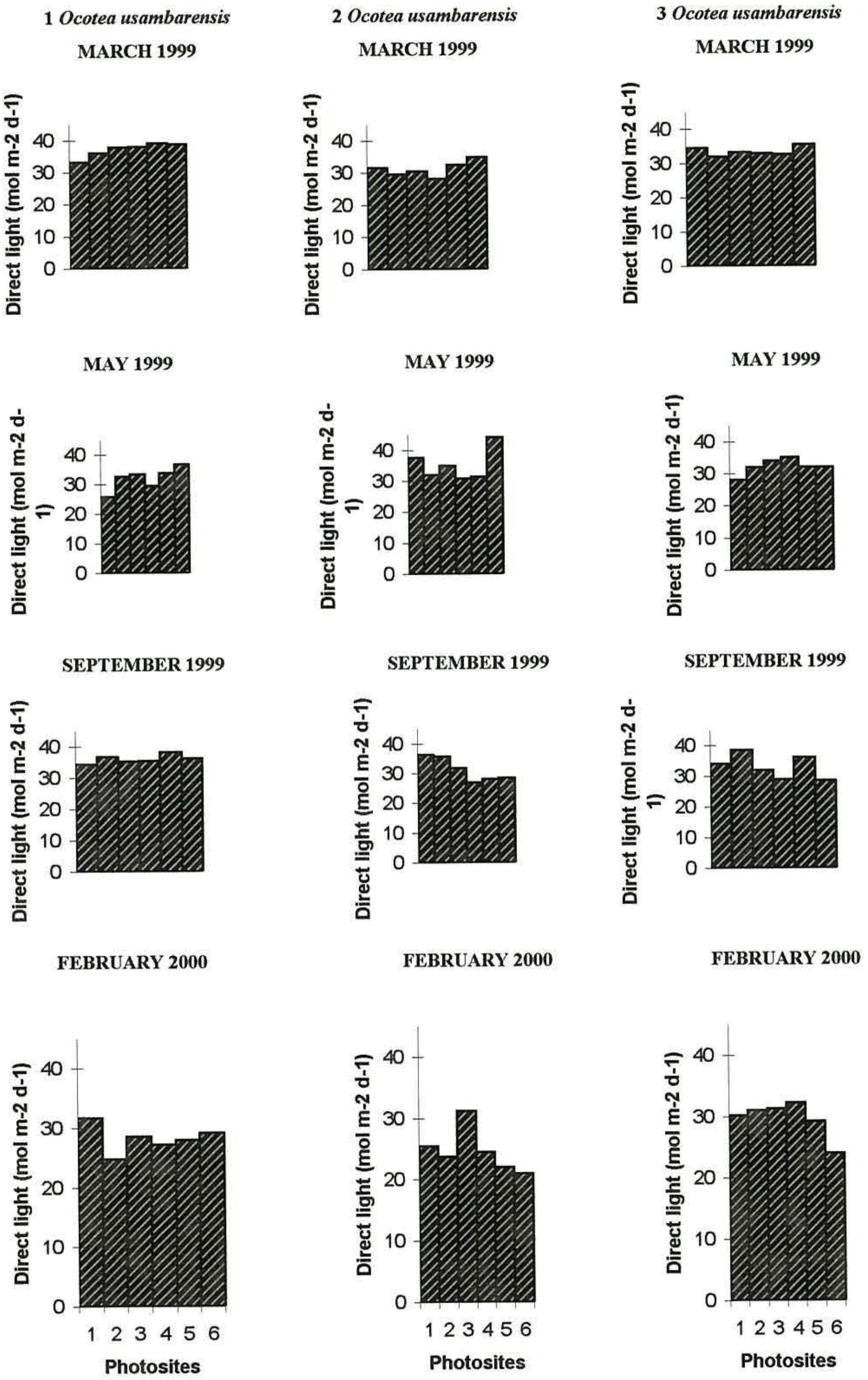


Figure 5.12 Seasonal changes of direct light between assessment periods at Machame for the three plots with four measurements (March 1999 to February 2000). Where photosites are 1 - 20 m behind base of bole; 2 - 10 m behind base of bole; 3 - below crown edge; 4 - 1 m behind base of bole; 5 - 0.5 x bole length from base of bole; 6 - 1 x bole length from base of bole. Each graph heading shows the plot number and target tree species.

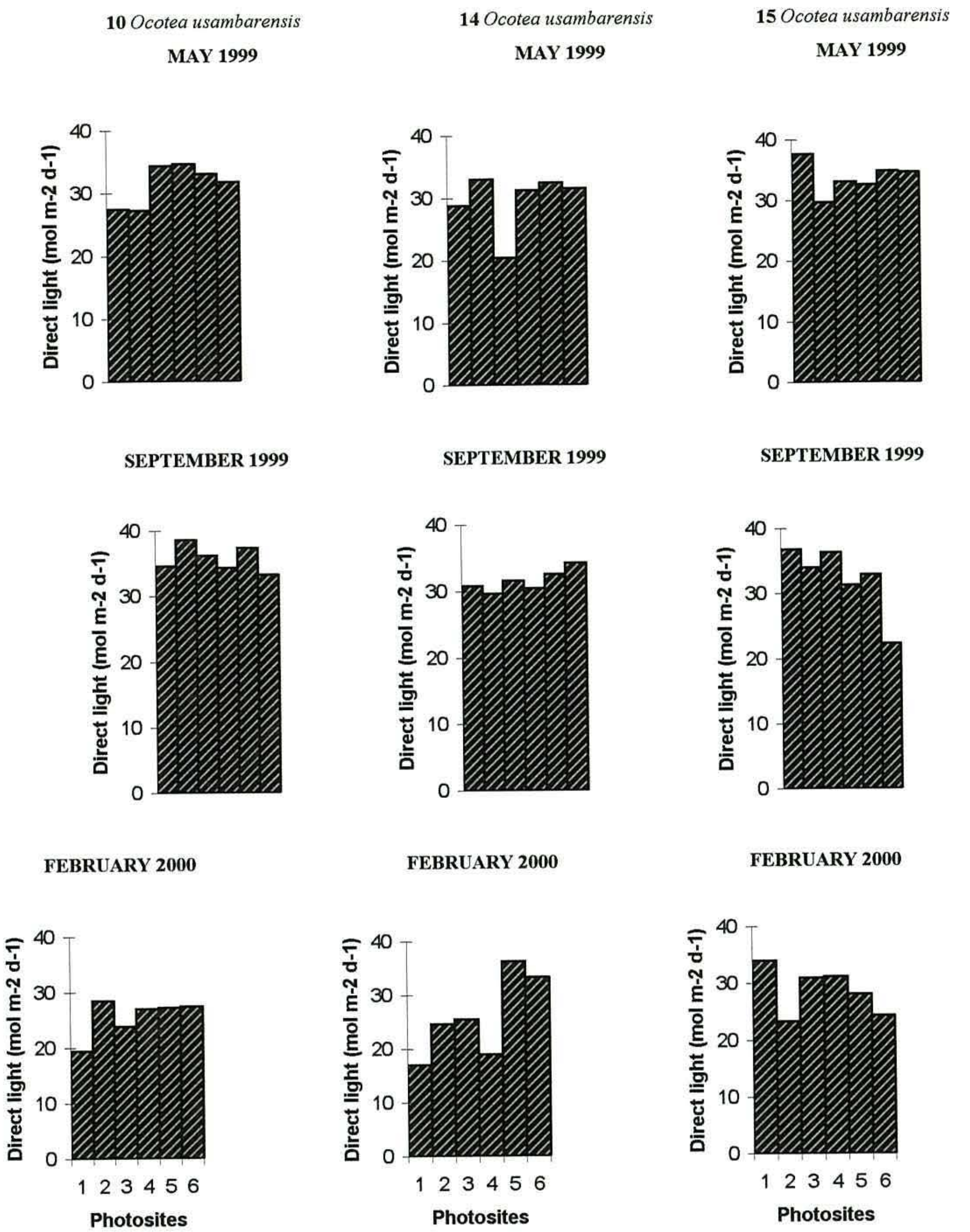


Figure 5.13 Seasonal changes of direct light between assessment periods at Machame for the three plots with three measurements (May 1999 to February 2000). Where photosites are 1 - 20 m behind base of bole; 2 - 10 m behind base of bole; 3 - below crown edge; 4 - 1 m behind base of bole; 5 - 0.5 x bole length from base of bole; 6 - 1 x bole length from base of bole. Each graph heading shows the plot number and target tree species.

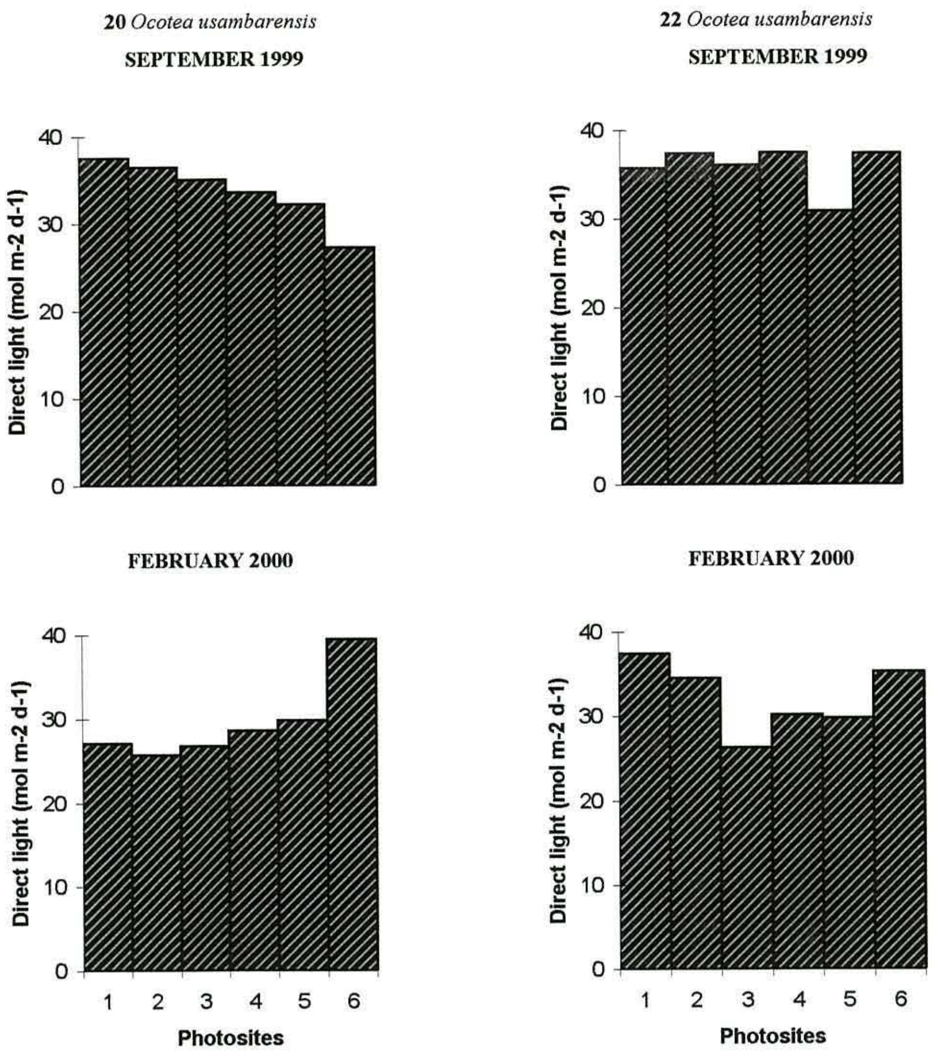


Figure 5.14 Seasonal changes of direct light between assessment periods at Machame for the two plots with two measurements (September 1999 and February 2000). Where photosites are 1 - 20 m behind base of bole; 2 - 10 m behind base of bole; 3 - below crown edge; 4 - 1 m behind base of bole; 5 - 0.5 x bole length from base of bole; 6 - 1 x bole length from base of bole. Each graph heading shows the plot number and target tree species.

Table 5.17 Trees defining felled tree plots and initial pre- and post-felling canopy closure values (%) and corresponding light readings (mol m^{-2} d^{-1}) by photosite position at Machame

Plot (target tree)	Phase and context	Photosite positions					
		Photosite 1: 20 m behind base of bole	Photosite 2 : 10 m behind base of bole	Photosite 3 : Below crown edge	Photosite 4: 1 m behind base of bole	Photosite 5: 0.5 m x bole length from base of bole	Photosite 6: 1 x bole length from base of bole
4 *Ocotea usambarensis*	1: pre-felling	30 (40.9)	35 (38.5)	40 (39.1) [7.5]	26 (34.6)	32 (30.4) [12.4]	29 (29.5) [24.7]
	1: post-felling (immediately after felling)	**23 (41.1)**	**23 (39.8)**	**28 (38.5)**	**16 (39.3)**	**24 (39.0)**	**23 (40.0)**
5 *Ocotea usambarensis*	1: pre-felling	40 (35.8)	22 (39.6)	25 (40.7) [7.1]	30 (32.9)	36 (30.5) [13.9]	40 (30.0) [27.7]
	1: post-felling (immediately after felling)	**28 (36.4)**	**20 (40.6)**	**23 (38.5)**	**39 (38.6)**	**29 (36.8)**	**24 (40.0)**
6 *Ocotea usambarensis*	1: pre-felling	33 (39.8)	24 (41.3)	18 (38.7) [8.7]	30 (32.8)	36 (35.7) [14.2]	38 (33.9) [28.3]
	1: post-felling (immediately after felling)	**32 (39.0)**	**22 (40.4)**	**17 (40.7)**	**26 (37.2)**	**22 (37.1)**	**29 (41.0)**
7 *Ocotea usambarensis*	1: pre-felling	26 (38.0)	27 (35.8)	23 (35.7) [6.8]	25 (31.7)	30 (34.7) [12.8]	42 (30.9) [25.5]
	1: post-felling (immediately after felling)	**27 (38.5)**	**26 (36.3)**	**20 (40.7)**	**28 (37.8)**	**19 (39.8)**	**33 (37.1)**
9 *Ocotea usambarensis*	2: pre-felling	45 (24.4)	44 (29.8)	49 (25.9) [5.8]	40 (29.7)	38 (33.1) [13.4]	43 (33.2) [26.7]
	2: post-felling (immediately after felling)	**41 (30.0)**	**42 (28.3)**	**46 (34.6)**	**37 (32.1)**	**24 (35.8)**	**36 (28.6)**
13 *Macaranga capensis*	2: pre-felling	36 (28.7)	42 (30.9)	50 (32.4) [11.8]	44 (28.4)	35 (37.6) [7.3]	43 (34.1) [14.6]
	2: post-felling (immediately after felling)	**35 (30.7)**	**34 (31.3)**	**41 (32.8)**	**31 (36.8)**	**34 (37.5)**	**36 (35.4)**
11 *Ocotea usambarensis*	2: pre-felling	42 (25.7)	44 (21.8)	42 (31.5) [10.9]	44 (32.2)	49 (34.1) [15.5]	40 (33.2) [31.0]
	2: post-felling (immediately	**41 (29.2)**	**44 (21.8)**	**41 (35.4)**	**39 (34.3)**	**46 (37.6)**	**36 (26.9)**

	after felling)						
21 *Ocotea usambarensis*	3: pre-felling	40 (33.1)	41 (28.9)	44 (23.9) [6.5]	39 (30.3)	36 (33.5) [13.0]	35 (30.8) [26.0]
	3: post-felling (immediately after felling)	**32 (39.2)**	**36 (37.2)**	**36 (29.6)**	**31 (32.3)**	**35 (35.5)**	**31 (35.6)**
23 *Ocotea usambarensis*	3: pre-felling	53 (21.9)	58 (29.4)	49 (30.9) [8.3]	50 (31.3)	52 (24.4) [12.5]	20 (37.8) [24.9]
	3: post-felling (immediately after felling)	**52 (22.3)**	**56 (27.5)**	**56 (32.4)**	**55 (35.3)**	**60 (20.6)**	**57 (21.9)**
24 *Ocotea usambarensis*	3: pre-felling	35 (32.5)	45 (26.2)	43 (29.8) [8.7]	39 (34.9)	47 (28.7) [12.8]	40 (32.7) [25.6]
	3: post-felling (immediately after felling)	**30 (37.8)**	**24 (38.1)**	**30 (35.9)**	**39 (37.1)**	**37 (32.5)**	**34 (37.3)**

NB. Numbers in brackets ( ) represent light readings (mol m^{-2} d^{-1})

Entries in parentheses [ ] represent distances in metres from bole base (Photosites 3, 5 and 6)

Table 5.18 Effects of tree felling on canopy closure (%) and recovery sequences by tree and by photosite at Machame

Photosite	Plot (target tree)	Pre-fell Mar 99	Post-fell Mar 99	May 99	Sep 99	Feb 00	Plot (target tree)	Pre-fell May 99	Post-fell May 99	Sep 99	Feb 00	Plot (target tree)	Pre-fell Sep 99	Post-fell Sep 99	Feb 00
1	4 *Ocotea*	30	23	38	33	42	9 *Ocotea*	45	41	22	43	21 *Ocotea*	40	32	20
2		35	23	41	37	46		44	42	29	44		41	36	37
3		40	28	43	32	28		49	46	32	48		44	36	32
4		26	16	36	34	48		40	37	38	51		39	31	32
5		32	24	38	35	44		38	24	37	41		36	35	31
6		29	23	32	37	50		43	36	29	49		35	31	40
1	5 *Ocotea*	40	28	42	30	54	13 *Macaranga*	36	35	32	31	23 *Ocotea*	53	52	48
2		22	20	38	35	32		42	34	29	30		58	56	57
3		25	23	38	31	31		50	41	24	26		49	56	62
4		30	39	35	41	34		44	31	27	24		50	55	56
5		36	29	37	34	32		35	34	26	30		52	60	59
6		40	24	28	38	49		43	36	35	32		20	57	51
1	6 *Ocotea*	33	32	37	31	42	11 *Ocotea*	42	41	34	36	24 *Ocotea*	35	30	51
2		24	22	34	24	53		44	44	32	33		45	24	42
3		18	17	38	35	20		42	41	38	37		43	30	45
4		30	26	40	38	54		44	39	31	29		39	39	47
5		36	22	42	40	54		49	46	40	38		47	37	50
6		38	29	40	28	46		40	36	37	34		40	34	54
1	7 *Ocotea*	26	27	34	28	31									
2		27	26	38	35	30									
3		23	20	34	36	20									
4		25	28	31	25	46									
5		30	19	25	29	48									
6		42	33	34	48	47									

The light received at the photosites after single tree removal and its subsequent recovery trend (Table 5.19) was similar to that described for canopy closure values.

5.2.3 Kilimanjaro - Rongai

5.2.3.1 Seasonal changes

Table 5.20 lists trees defining plots which received felling and those which did not receive the felling treatment. The target tree species defining plots were *Fagaropsis angolensis* and *Podocarpus falcatus*. Table 5.20 separates the two phases (May 1999 and September 1999) applicable to this site and shows the dates when initial light readings were taken. Table 5.21 shows the initial light readings and corresponding canopy closure values for plots which did not receive the felling treatment. Compared with May 1999, there is more incident light in September 1999.

Figure 5.16 shows a general increase in estimated direct light received by the forest understorey from May 1999 to September 1999. On the other hand, the light levels for September 1999 and February 2000 are almost the same for both seasons (May 1999 to February 2000 and September 1999 to February 2000). The presented light data are relative since light readings in the open and cloudiness conditions data for calibration were not available. Despite these observations, there was no statistical evidence of seasonal light variations ($F_{(2,6)} = 3.25$, $\rho = 0.111$ (3 seasons, May 1999, September 1999 and February 2000); $F_{(1,5)} = 1.53$, $\rho = 0.271$ (2 seasons, September 1999 and February).

5.2.3.2 Impact of felling

Table 5.22 shows the changes in canopy closure values at each photosite position immediately following felling. There is a general decrease in canopy closure at the photosites, most noticeably at photosites 4 (one metre from bole base), 5 (half bole length from bole base) and 6 (bole length distance from bole base). Table 5.22 also shows corresponding estimated direct light values before and after tree removal. In most cases, post-felling incident light levels were higher than those in pre-felling (Figure 5.15). The mean increase was 18.2% and standard error of the mean of 5.7% of the values before felling. There was statistically significant differences between the two ($t_{0.05}$ = -0.10, N = 16, ρ = 0.92, df = 14).

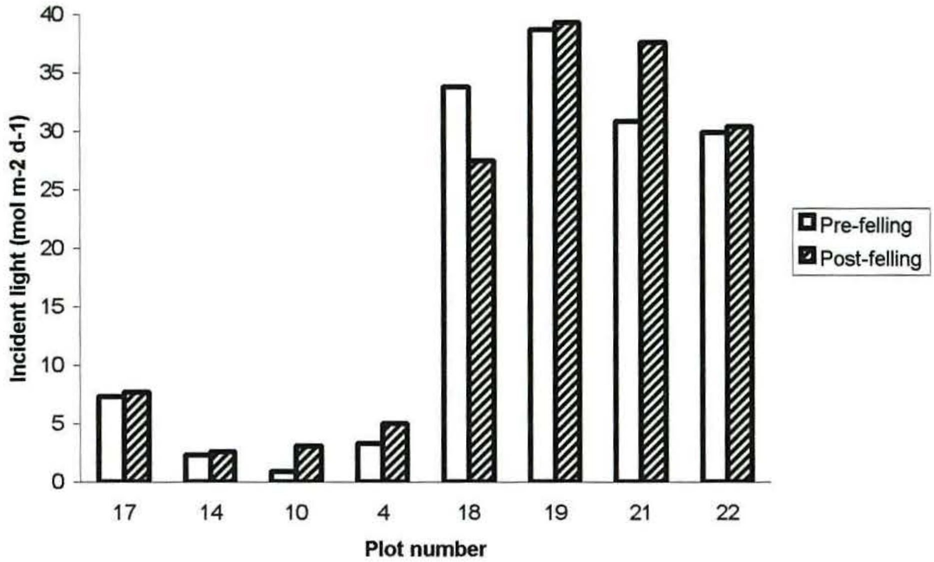


Figure 5.15 Incident light changes following single tree felling at Rongai, Tanzania
NB. The plotted data are for photosite 4 (1 m from target tree base). Plots 4-17 were felled in May 1999 and plots 18-22 were felled in September 1999.

Table 5.19 Effects of tree felling on estimated direct light (mol $m^{-2}d^{-1}$) and recovery sequences by tree and by photosite at Machame

Photosite	Plot (target tree)	Pre-fell Mar 99	Post-fell Mar 99	May 99	Sep 99	Feb 00	Plot (target tree)	Pre-fell May 99	Post-fell May 99	Sep 99	Feb 00	Plot (target tree)	Pre-fell Sep 99	Post-fell Sep 99	Feb 00
1	4 *Ocotea*	40.9	41.1	30.1	36.5	33.9	9 *Ocotea*	24.4	30.0	37.2	26.2	21 *Ocotea*	33.1	39.2	39.8
2		38.5	39.8	36.8	37.4	29.8		29.8	28.3	36.3	27.0		28.9	37.2	33.1
3		39.1	38.5	32.3	36.4	35.5		25.9	34.6	32.8	30.7		23.9	29.6	34.8
4		34.6	39.3	38.1	39.4	27.1		29.7	32.1	34.9	28.5		30.3	32.3	34.6
5		30.4	39.0	34.7	32.3	28.4		33.1	35.8	37.7	27.2		33.5	35.5	18.9
6		29.5	40.0	34.9	33.7	32.5		33.2	28.6	36.5	34.9		30.8	35.6	33.6
1	5 *Ocotea*	35.8	36.4	31.2	37.7	25.0	13 *Macaranga*	28.7	30.7	36.5	35.9	23 *Ocotea*	21.9	22.3	23.8
2		39.6	40.6	31.3	35.8	36.8		30.9	31.3	37.6	34.7		29.4	27.5	30.7
3		40.7	38.5	36.7	28.7	39.2		32.4	32.8	38.1	36.3		30.9	32.4	29.1
4		32.9	38.6	39.2	31.0	36.3		28.4	36.8	34.5	35.2		31.3	35.3	21.5
5		30.5	36.8	37.7	38.2	37.3		37.6	37.5	38.0	37.3		24.4	20.6	22.7
6		30.0	40.0	38.6	31.0	29.5		34.1	35.4	37.2	36.2		37.8	21.9	31.8
1	6 *Ocotea*	39.8	39.0	33.1	35.3	29.9	11 *Ocotea*	25.7	29.2	33.8	34.6	24 *Ocotea*	32.5	37.8	22.5
2		41.3	40.4	34.6	37.1	24.3		21.8	21.8	34.8	31.3		26.2	38.1	25.0
3		38.7	40.7	34.9	35.6	39.3		31.5	35.4	32.0	34.7		29.8	35.9	27.7
4		32.8	37.2	33.7	32.8	27.9		32.2	34.3	34.4	22.9		34.9	37.1	28.6
5		35.7	37.1	36.8	34.6	24.2		34.1	37.6	23.0	30.8		28.7	32.5	21.2
6		33.9	41.0	31.1	37.5	26.1		33.2	26.9	28.8	31.4		32.7	37.3	28.7
1	7 *Ocotea*	38.0	38.5	36.1	36.8	35.9									
2		35.8	36.3	33.8	36.9	34.3									
3		35.7	40.7	31.8	34.6	38.0									
4		31.7	37.8	37.7	35.9	26.7									
5		34.7	39.8	38.7	37.5	27.1									
6		30.9	37.1	35.4	30.0	28.1									

Table: 5.20 Trees defining plots and first dates for light readings at Rongai

Phase	No felling treatment		Felling treatment		
	Plot (target tree)	Date of first reading	Plot (target tree)	Date of pre-felling reading	Date of first post-felling reading
Phase 2	**1*** *Fagaropsis angolensis*	(12/5/1999)	**3** *Fagaropsis angolensis*	(12/5/1999)	(12/5/1999)
	2* *Fagaropsis angolensis*	(12/5/1999)	**4*** *Fagaropsis angolensis*	(12/5/1999)	(12/5/1999)
	5* *Fagaropsis angolensis*	(13/5/1999)	**7** *Fagaropsis angolensis*	(13/5/1999)	(13/5/1999)
	6 *Fagaropsis angolensis*	(13/5/1999)	**8** *Podocarpus falcatus*	(13/5/1999)	(13/5/1999)
	11* *Fagaropsis angolensis*	(14/5/1999)	**9** *Podocarpus falcatus*	(14/5/1999)	(14/5/1999)
	12 *Fagaropsis angolensis*	(14/5/1999)	**10*** *Fagaropsis angolensis*	(14/5/1999)	(14/5/1999)
	13 *Fagaropsis angolensis*	(15/5/1999)	**14*** *Fagaropsis angolensis*	(15/5/1999)	(15/5/1999)
	15 *Fagaropsis angolensis*	(15/5/1999)	**17*** *Fagaropsis angolensis*	(15/5/1999)	(15/5/1999)
Phase 3	**16** *Fagaropsis angolensis*	(13/9/1999)	**18*** *Fagaropsis angolensis*	(13/9/1999)	(13/9/1999)
	20 *Fagaropsis angolensis*	13/9/1999)	**19*** *Fagaropsis angolensis*	(13/9/1999)	(13/9/1999)
	23* *Fagaropsis angolensis*	(14/9/1999)	**21*** *Fagaropsis angolensis*	(14/9/1999)	(14/9/1999)
	24* *Fagaropsis angolensis*	(14/9/1999)	**22*** *Fagaropsis angolensis*	(14/9/1999)	(14/9/1999)

NB. Plots with asterisk (*) were included in further analysis. The selection procedure is explained in 4.3 for light data.

Table: 5.21 Trees defining non-felling plots and initial light readings (mol $m^{-2}d^{-1}$) and corresponding canopy closure values (%) by photosite position at Rongai

Phase	Plot (target tree)	Photosite positions					
		Photosite 1: 20 m behind base of bole	Photosite 2: 10 m behind base of bole	Photosite 3: Below crown edge	Photosite 4: 1 m behind base of bole	Photosite 5: 0.5 m x bole length from base of bole	Photosite 6: 1 x bole length from base of bole
Phase 2	**11** *Fagaropsis angolensis*	24.9 (62)	32.9 (39)	25.4 (69) [4.5]	18.3 (72)	15.9 (63) [5.5]	18.0 (59) [10.9]
	1 *Fagaropsis angolensis*	23.6 (46)	21.0 (65)	20.1 (59) [9.5]	28.1 (65)	18.6 (55) [17.4]	20.2 (60) [34.7]
	2 *Fagaropsis angolensis*	29.7 (49)	28.0 (47)	29.0 (46) [9.1]	29.2 (45)	30.8 (52) [18.6]	23.1 (51) [37.1]
	5 *Fagaropsis angolensis*	33.1 (44)	35.5 (46)	19.9 (53) [10.6]	23.8 (57)	23.1 (59) [19]	27.2 (48) [38.0]
Phase 3	**23** *Fagaropsis angolensis*	25.5 (46)	25.2 (51)	29.1 (51) [7.3]	26.9 (51)	31.7 (53) [12.8]	29.5 (54) [25.5]
	24 *Fagaropsis angolensis*	27.3 (45)	27.6 (51)	26.6 (51) [9.1]	24.8 (53)	24.3 (52) [16.2]	28.9 (48) [32.4]

NB Numbers in brackets ( ) represent canopy closure percentages

Numbers in parentheses [ ] represent distance from target tree bole base in metres (Photosites 3, 5 and 6)

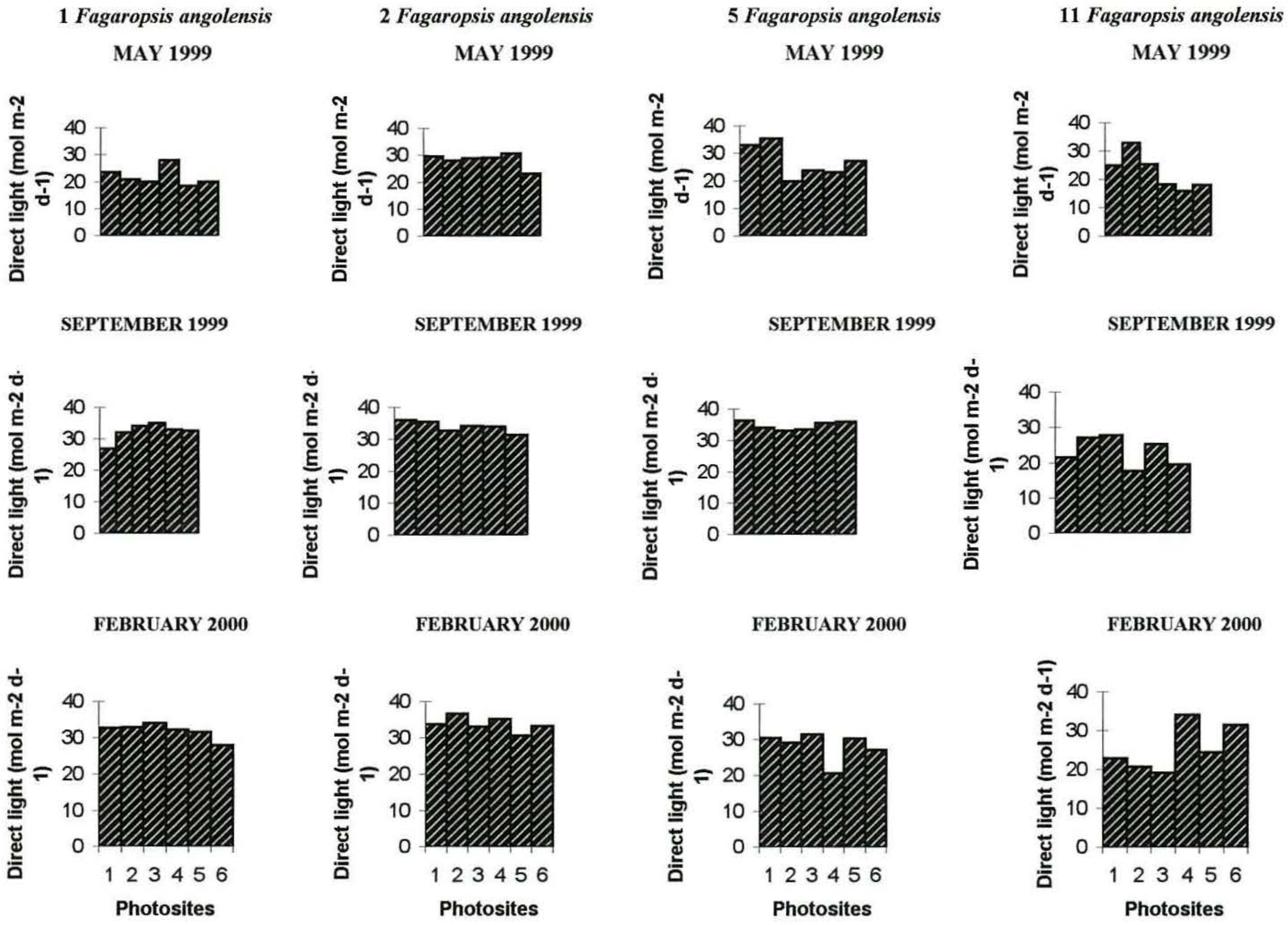


Figure 5.16 Seasonal changes of direct light between assessment periods at Rongai for the four plots with three measurements (May 1999 to February 2000). Where photosites are 1 - 20 m behind base of bole; 2 - 10 m behind base of bole; 3 - below crown edge; 4 - 1 m behind base of bole; 5 - 0.5 x bole length from base of bole; 6 - 1 x bole length from base of bole. Each graph heading shows the plot number and target tree species.

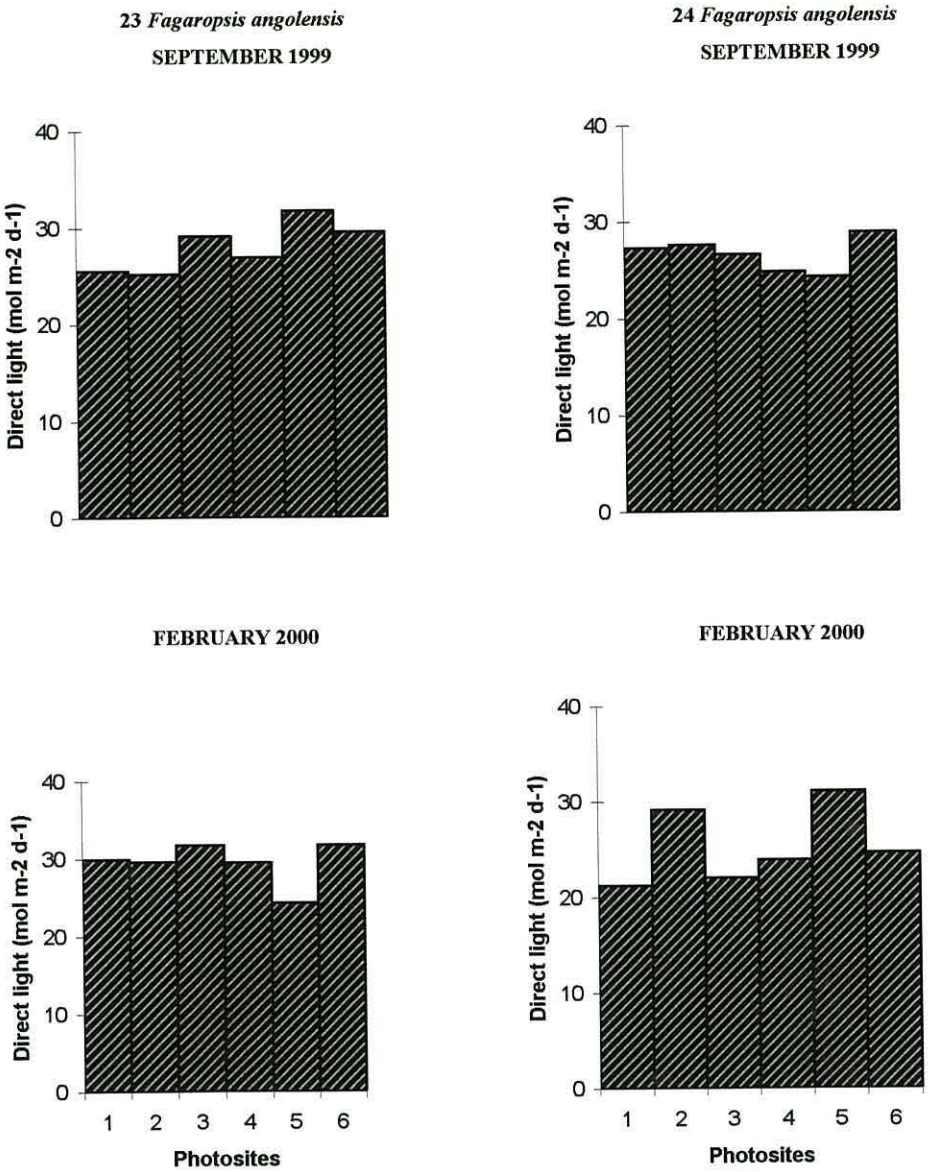


Figure 5.17 Seasonal changes of direct light between assessment periods at Rongai for the two plots with two measurements (September 1999 and February 2000). Where photosites 1 - 20 m behind base of bole; 2 - 10 m behind base of bole; 3 - below crown edge; 4 - 1 m behind base of bole; 5 - 0.5 x bole length from base of bole; 6 - 1 x bole length from base of bole. Each graph heading shows the plot number and target tree species.

Table 5.22 Trees defining felled tree plots and initial pre- and post-felling light readings (mol m^{-2} d^{-1}) and corresponding canopy closure values (%) by photosite position at Rongai

Plot (target tree)	Phase and context	Photosite positions					
		Photosite 1: 20 m behind base of bole	**Photosite 2 : 10 m behind base of bole**	**Photosite 3 : Below crown edge**	**Photosite 4: 1 m behind base of bole**	**Photosite 5: 0.5 m x bole length from base of bole**	**Photosite 6: 1 x bole length from base of bole**
17 *Fagaropsis angolensis*	2: pre-felling	95 (8.3)	91 (2.7)	93 (3.1) [8.3]	94 (7.3)	94 (0.1) [14.6]	80 (2.8) [29.1]
	2: post-felling (immediately after felling)	**95 (9.2)**	**90 (8.3)**	**93 (18.8)**	**91 (7.7)**	**91 (2.9)**	**77 (20.6)**
14 *Fagaropsis angolensis*	2: pre-felling	91 (0.5)	93 (1.6)	81 (1.1) [9.4]	89 (2.3)	91 (8.7) [13.6]	79 (3.8) [27.1]
	2: post-felling (immediately after felling)	**90 (0.8)**	**92 (2.7)**	**89 (1.8)**	**90 (2.6)**	**91 (8.4)**	**94 (3.6)**
10 *Fagaropsis angolensis*	2 : pre-felling	90 (0.9)	95 (6.3)	93 (4.4) [8.2]	87 (0.9)	97 (2.6) [14.7]	91 (3.0) [29.3]
	2: post-felling (immediately after felling)	**82 (1.3)**	**92 (9.5)**	**72 (6.5)**	**83 (3.1)**	**95 (8.8)**	**76 (10.0)**
4 *Fagaropsis angolensis*	2: pre-felling	97 (5.5)	92 (5.5)	96 (12.7) [9.7]	90 (3.3)	87 (1.9) [15.8]	92 (3.5) [31.5]
	2: post-felling (immediately after felling)	**94 (6.7)**	**89 (5.6)**	**93 (4.8)**	**89 (5.0)**	**80 (2.8)**	**85 (3.5)**
18 *Fagaropsis angolensis*	3: pre-felling	48 (24.9)	59 (26.8)	46 (33.4) [8.5]	54 (33.8)	50 (29.2) [18.1]	45 (25.4)) [36.2]
	3: post-felling (immediately after felling)	**40 (30.1)**	**54 (32.6)**	**43 (29.3)**	**50 (27.5)**	**35 (39.3)**	**41 (28.8)**
19 *Fagaropsis angolensis*	3: pre-felling	31 (36.4)	38 (27.9)	32 (26.1) [7.7]	29 (38.7)	27 (37.5) [15.7]	37 (34.4) [31.3]
	3: post-felling (immediately after felling)	**32 (37.2)**	**35 (37.9)**	**33 (26.8)**	**24 (39.3)**	**16 (40.7)**	**23 (38.2)**
21 *Fagaropsis angolensis*	3: pre-felling	58 (26.7)	57 (33.6)	45 (32.8) [8.4]	48 (30.8)	41 (34.6) [17.6]	44 (27.3) [35.2]
	3: post-felling (immediately	**47 (32.1)**	**46 (37.7)**	**39 (36.3)**	**38 (37.6)**	**32 (39.2)**	**35 (30.5)**

	after felling)						
22 *Fagaropsis angolensis*	3: pre-felling	56 (22.2)	57 (20.2)	53 (32.0) [7.9]	46 (29.9)	50 (31.4) [14.0]	51 (24.9) [27.9]
	3: post-felling (immediately after felling)	**55 (25.1)**	**52 (24.7)**	**50 (33.6)**	**48 (30.4)**	**50 (31.2)**	**52 (23.6)**

NB Numbers in brackets ( ) represent direct light (mol m^{-2} d^{-1})

Numbers in parentheses [ ] represent distance from target tree bole base in metres (Photosites 3, 5 and 6)

5.2.3.3 Progressive recovery

Table 5.23 shows progressive recovery in canopy closure percentages of those plots which received felling treatment during the May 1999 and September 1999 treatment phases. The general trend is the reduction in canopy closure following the fellings. During the period immediately after the fellings in September 1999, canopy closure tended to increase. However, in plots where felling took place in May, the positive trend was not reflected in the September values. The recovery process in terms of estimated light received at photosites after felling is indicated in Table 5.24.

Table 5.23 Effects of tree felling on canopy closure (%) and recovery sequences by tree and by photosite at Rongai

Photosite	Plot (target tree)	Pre-fell May 99	Post-fell May 99	Sep 99	Feb 00	Plot (target tree)	Pre-fell Sep 99	Post-fell Sep 99	Feb 00
1	**10** *Fagaropsis*	90	82	92	78	**18** *Fagaropsis*	48	40	52
2		95	92	89	82		59	54	54
3		93	72	81	78		46	43	52
4		87	83	80	80		54	50	56
5		97	95	91	89		50	35	59
6		91	76	77	81		45	41	40
1	**4** *Fagaropsis*	97	94	76	34	**19** *Fagaropsis*	31	32	53
2		92	89	78	33		38	35	50
3		96	93	72	44		32	33	58
4		90	89	82	63		29	24	51
5		87	80	84	52		27	16	48
6		92	85	92	55		37	23	36
1	**17** *Fagaropsis*	95	95	83	39	**21** *Fagaropsis*	58	47	58
2		91	90	93	52		57	46	40
3		93	93	80	55		45	39	42
4		94	91	88	60		48	38	40
5		94	91	100	42		41	32	43
6		80	77	80	40		44	35	50
1	**14** *Fagaropsis*	91	90	91	57	**22** *Fagaropsis*	56	55	60
2		93	92	87	58		57	52	53
3		81	89	91	60		53	50	48
4		89	90	84	62		46	48	55
5		91	91	83	53		50	50	52
6		79	94	88	69		51	52	54

Table 5.24 Effects of tree felling on estimated direct light (mol m^{-2} d^{-1}) and recovery sequences by tree and by photosite at Rongai

Photosite	Plot (target tree)	Pre-fell May 99	Post-fell May 99	Sep 99	Feb 00	Plot (target tree)	Pre-fell Sep 99	Post-fell Sep 99	Feb 00
1	**10** *Fagaropsis*	0.9	1.3	2.9	9.6	**18** *Fagaropsis*	24.9	30.1	32.1
2		6.3	9.5	8.7	7.9		26.8	32.6	23.9
3		4.4	6.5	9.1	9.9		33.4	29.3	24.7
4		0.9	3.1	8.8	9.1		33.8	27.5	32.1
5		2.6	8.8	10.4	28.1		29.2	39.3	22.9
6		3.0	10.0	11.9	6.9		25.4	28.8	35.8
1	**4** *Fagaropsis*	5.5	6.7	7.6	37.3	**19** *Fagaropsis*	36.4	37.2	28.7
2		5.5	5.6	11.7	37.8		27.9	37.9	30.2
3		12.7	4.8	12.9	31.3		26.1	26.8	27.9
4		3.3	5.0	8.9	22.3		38.7	39.3	28.4
5		1.9	2.8	5.0	31.0		37.5	40.7	38.2
6		3.5	3.5	3.2	23.7		34.4	38.2	35.6
1	**17** *Fagaropsis*	8.3	9.2	9.9	39.5	**21** *Fagaropsis*	26.7	32.1	28.4
2		2.7	8.3	2.4	23.8		33.6	37.7	34.3
3		3.1	18.8	4.4	8.2		32.8	36.3	37.3
4		7.3	7.7	4.0	22.3		30.8	37.6	36.2
5		0.1	2.9	5.9	36.3		34.6	39.2	36.0
6		2.8	20.6	22.8	36.6		27.3	30.5	30.1
1	**14** *Fagaropsis*	0.5	0.8	2.6	3.7	**22** *Fagaropsis*	22.2	25.1	25.8
2		1.6	2.7	8.5	3.9		20.2	24.7	32.8
3		1.1	1.8	1.7	1.7		32.0	33.6	36.9
4		2.3	2.6	8.9	5.4		29.9	30.4	24.4
5		8.7	8.4	12.6	9.4		31.4	31.2	33.8
6		3.8	3.6	5.4	8.8		24.9	23.6	26.5

5.3 Assessment and monitoring of the amount of regeneration

Before treatment, the forest understorey in all three sites consist of the marked seedlings, the painted advance regeneration and slashed shrubs. In 32 of the 72 plots no regeneration appeared after treatments were applied. Fifteen of the plots where there was no response were at Rongai, nine at Machame and eight at Chome.

Since litter and tillage did not statistically significantly influenced regeneration of the studied species (Tables 5.27, 5.28, 5.29, 5.33, 5.34 and 5.35), the regeneration response of all species in the three sites were combined and the effect of felling treatment assessed by two-way ANOVA. Regardless of treatment time, number of new recruits in each plot were summed per species and felling treatment. The resultant data set (120 entries) was analysed by two-way ANOVA using MINITAB computer program. Table 5.25 shows that there was no statistically significant regeneration response difference between site/species ($\rho = 0.687$) in this study. For felling treatment, whilst the result was also not significant, there was more evidence of an effect ($\rho = 0.085$). Figure 5.18 and 5.19 show graphically the statistical results presented in Table 5.25 for site/species and felling treament respectively. Figure 5.18 shows that the mean seedlings density for Rongai *Podocarpus falcatus* had the highest variation compared to other site/species. Similarly, control plots had higher mean seedlings/root suckers density compared to the felled plots (Figure 5.19).

Table 5.25 Combined analysis of variance for number of suckers or seedlings

Source	DF	SS	MS	F	ρ
Site/species	4	268	67	0.57	0.687
Felling	1	357	357	3.02	0.085
Interaction	4	289	72	0.61	0.655
Error	110	13000	118		
Total	119	13914			

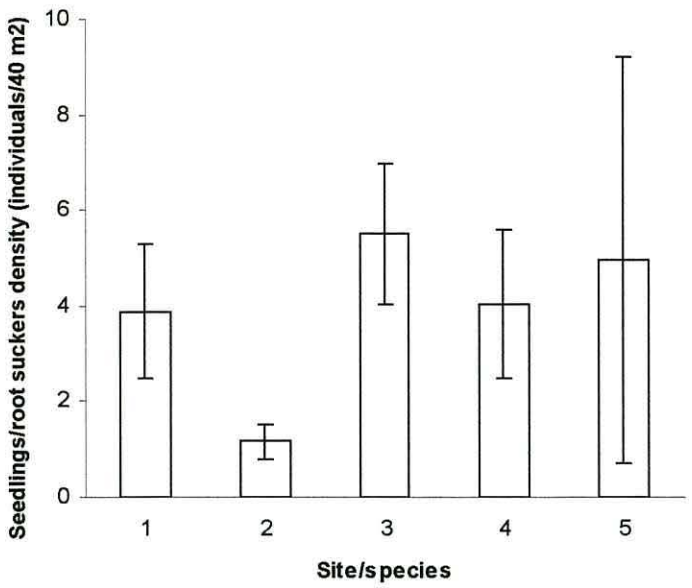


Figure 5.18 Histogram showing seedlings/root suckers density comparison between site/species at Chome, Machame and Rongai. Where 1, is Chome *Ocotea usambarensis*; 2, is Chome *Podocarpus latifolius*; 3, is Machame *Ocotea usambarensis*; 4, is Rongai *Fagaropsis angolensis* and 5, is Rongai *Podocarpus falcatus*.

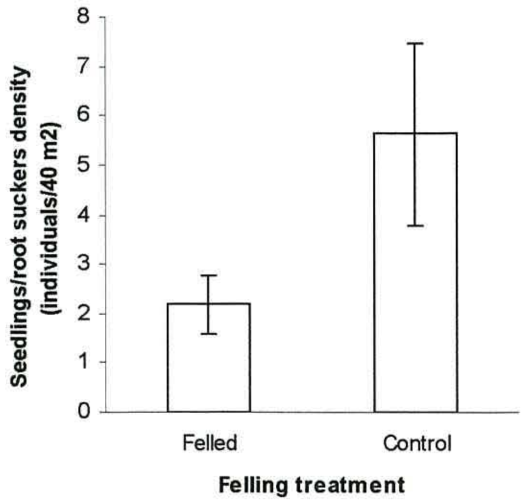


Figure 5.19 Histogram showing comparison of seedlings/root suckers density between felled and control plots at Chome, Machame and Rongai.

5.3.1 Chome

5.3.1.1 Regeneration by treatment

As explained in 4.3 and 4.4.2, the regeneration responses in each replicate strip recorded in the field were pooled to give a single value. The resultant figures were standardized to 10 m^2. Appendices 7 to 9 show that the regeneration response of the target species at Chome varied between plots, treatments and treatment application times. *Ficalhoa laurifolia* had quite a number of mature and pole-sized representatives but neither advance nor new seedlings were seen in the vicinity of these individuals during this study. Appendices 7 to 9 show that *Ocotea usambarensis* and *Podocarpus latifolius* were regenerating in situ. Seedlings of *Podocarpus latifolius* were widespread even in plots centred on *Ocotea usambarensis* or *Ficalhoa laurifolia* individuals (e.g. plots 5, 6, 7 and 8 in Appendix 7). The regeneration (root suckers) of *Ocotea usambarensis* however was almost restricted to plots centred on this species (e.g. plots 1, 3, 5 and 7 in Appendix 7). Advance and new regeneration of *Podocarpus latifolius* out-numbered that of *Ocotea usambarensis* in all assessment periods. Regeneration responses were limited to the period immediately following inclusion in the study and were noted in plots where trees were not felled as well as in those where felling took place.

Only one plot lacked seedlings or suckers of *Podocarpus latifolius* and *Ocotea usambarensis* (Appendix 7). Thus, in general, the regeneration response of these species during March 1999 was good. In the plot which lacked regeneration *Ficalhoa laurifolia* was the target tree. Appendix 8 shows the regeneration responses in plots which were added to the study in May 1999. Out of eight plots, only three gave any response, the lowest of any phase at this location. A regeneration response was detected only during the period immediately following inclusion in the study and only where the target trees were felled. Appendix 9 shows the regeneration responses of plots which were added to the study in September 1999. In two of the eight (1 felled and 1 control) plots no new recruits were recorded.

Figure 5.20 shows that more *Ocotea usambarensis* root sucker regeneration appeared during March 1999 and May 1999 in plots which did not receive felling treatment. There was a statistically significant effect at the March 1999 phase ($t_{0.05} = -3.02$, $\rho = 0.0051$, N = 32, df = 30). The felling treatment which was applied in September 1999, however, did not produce significant differences when compared to the no felling (control) treatment ($t_{0.05} = 0.38$, $\rho = 0.7$, N = 32, df = 30)

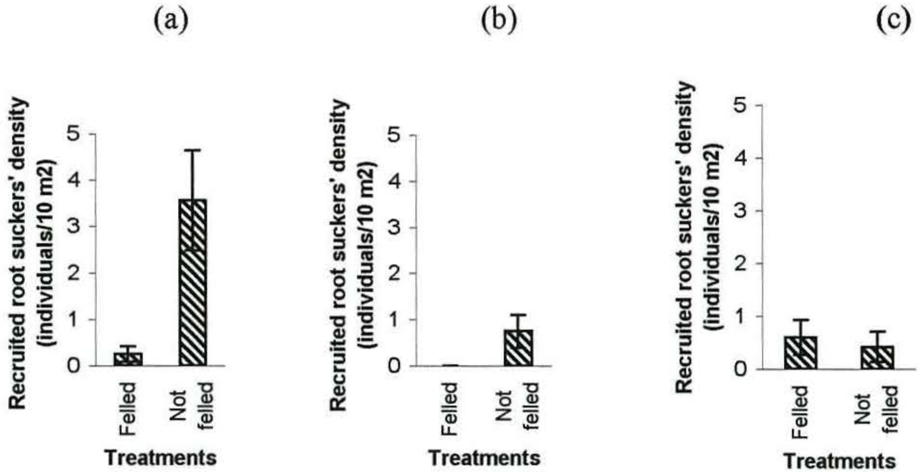


Figure 5.20 Chome *Ocotea usambarensis* recruited root suckers density comparisons between felled and control plots treated in (a) March 1999, (b) May 1999 and (c) September 1999 respectively (number of plots = 4 in each category for each histogram). Values refer to regeneration recorded in the next enumeration (2 - 5 months) after treatment.

Although plots which received no felling (controls) always had recruited seedlings of *Podocarpus latifolius* (Figure 5.21), comparisons of regeneration induction between plots which received felling and those which did not in March 1999 showed no statistically significance between the two ($t_{0.05} = -0.8$, $\rho = 0.43$, N = 32, df = 30). In May 1999 and September 1999 zero regeneration in felled plots were recorded.

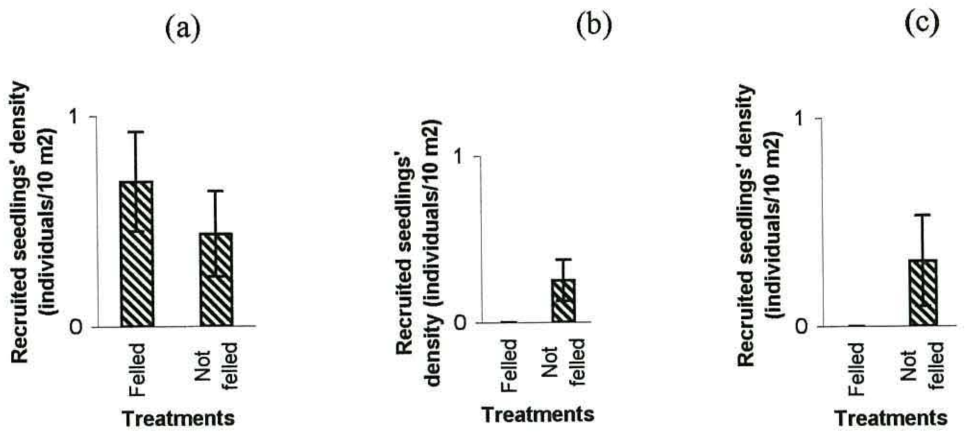


Figure 5.21 Chome *Podocarpus latifolius* recruited seedlings' density comparisons between felled and control plots treated in (a) March 1999, (b) May 1999 and (c) September 1999 respectively (number of plots = 4 in each category for each histogram). Values refer to regeneration recorded in the next enumeration (2 - 5 months) after treatment.

Table 5.26 summarizes the counts of new regeneration and advance regeneration (previously marked with paint). *Ficalhoa laurifolia* lacked regeneration of all size classes. On the other hand, *Ocotea usambarensis* and *Podocarpus latifolius* had regeneration of all sizes. All *Ocotea usambarensis* regeneration in this forest originated as root suckers. There was more regeneration of *Podocarpus latifolius* than of *Ocotea usambarensis*. In both *Ocotea* and *Podocarpus* advance regeneration out-numbered the new regeneration that followed the applied treatments.

Table 5.26 Regeneration summary table for felled and control plots (combined): numbers of regenerating individuals by size, species and cohort - Chome, Tanzania

Regeneration categories	Height class (cm)	Regeneration cohorts					
Felling date		March 1999 (Advance)	March 1999 (new recruits)	May 1999 (Advance)	May 1999 (new recruits)	September 1999 (Advance)	September 1999 (new recruits)
Ficalhoa laurifolia (seedlings)	< 25	0	0	0	0	0	0
Ficalhoa laurifolia (seedlings)	≥ 25 < 50	0	0	0	0	0	0
Ficalhoa laurifolia (seedlings)	≥ 50 < 100	0	0	0	0	0	0
Ficalhoa laurifolia (seedlings)	≥ 100	0	0	0	0	0	0
Ocotea usambarensis (seedlings)	< 25	0	0	0	0	0	0
Ocotea usambarensis (seedlings)	≥ 25 < 50	0	0	0	0	0	0
Ocotea usambarensis (seedlings)	≥ 50 < 100	0	0	0	0	0	0
Ocotea usambarensis (seedlings)	≥ 100	0	0	0	0	0	0
Ocotea usambarensis (suckers)	< 25	1	0	0	45	0	15
Ocotea usambarensis (suckers)	≥ 25 < 50	2	0	2	0	9	0
Ocotea usambarensis (suckers)	≥ 50 < 100	0	0	9	0	24	0
Ocotea usambarensis (suckers)	≥ 100	4	0	13	0	16	0
Podocarpus latifolius (seedlings)	< 25	6	0	12	18	6	5
Podocarpus latifolius (seedlings)	≥ 25 < 50	11	0	17	0	8	0
Podocarpus latifolius (seedlings)	≥ 50 < 100	24	0	54	0	20	0
Podocarpus latifolius (seedlings)	≥ 100	36	0	43	0	24	0

5.3.1.2 Analytical results

After standardizing the data to an area unit of 10 m^2 information was separately analysed for the three cohorts of new regeneration (Tables 5.27 - 5.29). The analytical procedure is included in the SPSS statistical computer package, where it is described as "General linear model - Simple factorial". In the analyses, first the influence of felling on seedlings' density was tested by one-way anova. The influence of litter and tilling on recruited seedlings' density were tested by "General linear model". In all cases, the treatments (felling, litter and tillage) and their interactions did not statistically significantly influenced the appearance of new seedlings (Tables 5.27 - 5.29).

Chome *Ocotea usambarensis* root suckers did not show statistically significant difference of new appearing root suckers between felled plots and non-felled plots (χ^2 = 2.667; df = 1; ρ = 0.102). Analysis of variance for Ocotea usambarensis new recruits also did not show significant differences for felling and litter/tillage treatments in all treatment phases (Tables 5.30 - 5.32).

Table 5.27 Regeneration response of new cohort of *Podocarpus latifolius*, March - May 1999, at Chome after March 1999 treatment

Source of variation	DF	SS	MS	F	P
Replications	3	8.125	2.7083	4.6431	
Felling	1	0.500	0.5000	0.8500	0.92
Error (a)	3	1.750	0.5833		
Litter/tillage	3	2.625	0.8750	1.7300	0.48
Felling x litter/tillage	3	1.750	0.5833	1.1500	0.65
Error (b)	18	9.125	0.5069		
Total	31	23.825			

Table 5.28 Regeneration response of new cohort of *Podocarpus latifolius*, May - September 1999, at Chome after May 1999 treatment

Source of variation	DF	SS	MS	F	P
Replications	3	0.594	0.1980	1.00	
Felling	1	0.781	0.7810	3.95	0.63
Error (a)	3	0.594	0.1979		
Litter/tillage	3	0.594	0.1979	1.16	0.65
Felling x litter/tillage	3	0.594	0.1979	1.16	0.65
Error (b)	18	3.063	0.1700		
Total	31	6.220			

Table 5.29 Regeneration response of new cohort of *Podocarpus latifolius*, September 1999 to February 2000, at Chome after September 1999 treatment

Source of variation	DF	SS	MS	F	P
Replications	3	0.844	0.2813	1.0000	
Felling	1	0.781	0.7810	2.7800	0.74
Error (a)	3	0.844	0.2813		
Litter/tillage	3	2.344	0.7813	2.7800	0.16
Felling x litter/tillage	3	2.344	0.7813	2.7800	0.16
Error (b)	18	5.063	0.2813		
Total	31	12.220			

Table 5.30 Regeneration response of new cohort of *Ocotea usambarensis*, March - May 1999, at Chome after March 1999 treatment

Source of variation	DF	SS	MS	F	P
Replications	3	43.095	14.3650	0.6192	
Felling	1	87.783	87.7825	3.7800	0.65
Error (a)	3	69.593	23.1975		
Litter/tillage	3	27.345	9.1150	1.4000	0.58
Felling x litter/tillage	3	31.803	10.6008	1.6295	0.51
Error (b)	18	117.103	6.5057		
Total	31	376.722			

Table 5.31 Regeneration response of new cohort of *Ocotea usambarensis*, May - September 1999, at Chome after May 1999 treatment

Source of variation	DF	SS	MS	F	P
Replications	3	10.095	3.3650	1.0002	
Felling	1	7.033	7.0325	2.0900	0.80
Error (a)	3	10.093	3.3642		
Litter/tillage	3	3.345	1.1150	0.9500	0.71
Felling x litter/tillage	3	0.283	0.0942	0.0800	0.98
Error (b)	18	21.123	1.1735		
Total	31	51.972			

Table 5.32 Regeneration response of new cohort of *Ocotea usambarensis*, September 1999 - February 2000, at Chome after September 1999 treatment

Source of variation	DF	SS	MS	F	P
Replications	3	1.595	0.5317	0.5158	
Felling	1	1.533	1.5330	1.4900	0.86
Error (a)	3	3.093	1.0308		
Litter/tillage	3	3.595	1.1983	0.5100	0.85
Felling x litter/tillage	3	1.093	0.3642	0.1500	0.95
Error (b)	18	42.595	2.3664		
Total	31	53.504			

5.3.2 Kilimanjaro - Machame

5.3.2.1 Regeneration by treatment

The treatments applied at different times induced (root sucker and seedling) regeneration of *Ocotea usambarensis* to different extent (Appendices 10 to 12). During the whole study only one *Ocotea* seedling was recorded (Appendix 11). This seedling was detected during the May 1999 assessment phase. This seedling was not attached to the root of another *Ocotea* individual as is the case for root suckers. Out of 24 plots in this site, 15, had at least one *Ocotea* sucker as the result of the applied treatments. All plots incorporated into the study in March 1999 responded to the applied treatments by producing new root suckers (Appendix 10). In May 1999 (Appendix 11) new regeneration was recorded in five plots. Six plots out of eight treated in September 1999 (Appendix 12) lacked new regeneration at the February 2000 assessment.

Plots which lacked new regeneration in May 1999 were those where there was no felling (Appendix 11). New regeneration was also detected in two unfelled and four felled plots added to the study in September 1999 (Appendix 12). No new regeneration was recorded at Machame other than in the period immediately following treatment applications.

Figure 5.22 shows that more *Ocotea* root suckers appeared in plots treated in March 1999 than in those treated in May 1999 and September 1999. However the numbers of recruited *Ocotea* root suckers in plots which were felled were not significantly different from those recorded in control plots (March 1999 $t_{0.05} = 0.36$, $\rho = 0.72$, N = 32, df = 30; May 1999 $t_{0.05} = -0.26$, $\rho = 0.8$, N = 32, df = 30; September 1999 $t_{0.05} = 0.36$, $\rho = 0.72$, N = 32, df = 30)

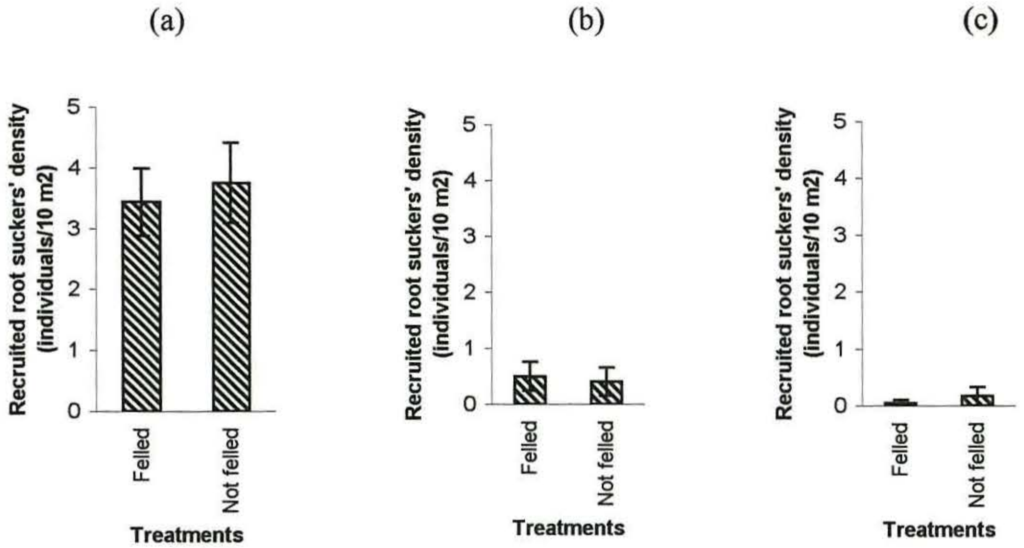


Figure 5.22 Machame *Ocotea usambarensis* root suckers' density comparisons between felled and control plots treated in (a) March 1999, (b) May 1999 and (c) September 1999 respectively (number of plots = 4 in each category for each histogram). Values refer to regeneration recorded in the next enumeration (2 - 5 months) after treatment.

Table 5.33 summarizes advance and new *Ocotea usambarensis* regeneration in sampled area at Machame during this study. Apart from a solitary seedling (May 1999) all regeneration was of root suckers. Most *Ocotea* suckers were in the $\geq$ 25 cm height classes.

Table 5.33 Regeneration summary table for felled and control plots (combined): numbers of regenerating individuals by size, species and cohort - Machame, Tanzania

Regeneration categories	Height class (cm)	Regeneration cohorts					
Felling date		March 1999 (Advance)	March 1999 (new recruits)	May 1999 (Advance)	May 1999 (new recruits)	September 1999 (Advance)	September 1999 (new recruits)
Ocotea usambarensis (seedlings)	< 25	0	0	0	1	0	0
Ocotea usambarensis (seedlings)	≥ 25 < 50	0	0	0	0	0	0
Ocotea usambarensis (seedlings)	≥ 50 < 100	0	0	0	0	0	0
Ocotea usambarensis (seedlings)	≥ 100	0	0	0	0	0	0
Ocotea usambarensis (suckers)	< 25	0	0	1	115	0	14
Ocotea usambarensis (suckers)	≥ 25 < 50	16	0	9	0	14	0
Ocotea usambarensis (suckers)	≥ 50 < 100	81	0	34	0	42	0
Ocotea usambarensis (suckers)	≥ 100	93	0	60	0	75	0

5.3.2.2 Analytical results

The regeneration response of *Ocotea usambarensis* (Appendices 10 - 12) is assumed to be normally distributed since the variances of regeneration response was not statistically significant ($\rho = 0.565$). Machame *Ocotea usambarensis* root suckers in March 1999 did not show significant difference recruited root suckers' density between felled and control plots ($\chi^2 = 0.178$; df = 1; $\rho = 0.673$). With the exception of felling and litter/tillage interaction in May 1999 (Table 5.36), neither felling nor litter/tillage had significant effect on *Ocotea usambarensis* regeneration at Machame (Tables 5.35 - 5.37).

Table 5.34 Contingency table for regeneration response to felling treatment at Machame

Treatment	Ocotea	No Ocotea
Felled	8	4
Unfelled	7	5

Table 5.35 Regeneration response of new cohort of *Ocotea usambarensis*, March - May 1999, at Machame after March 1999 treatment

Source of variation	DF	SS	MS	F	P
Replications	3	1.094	0.3646	0.0240	
Felling	1	0.781	0.7813	0.0500	0.99
Error (a)	3	45.594	15.1979		
Litter/tillage	3	14.844	4.9479	2.2200	0.33
Felling x litter/tillage	3	77.344	25.7813	11.5800	
Error (b)	18	40.063	2.2257		
Total	31	179.720			

Table 5.36 Regeneration response of new cohort of *Ocotea usambarensis*, May - September 1999, at Machame after May 1999 treatment

Source of variation	DF	SS	MS	F	P
Replications	3	2.625	0.8750	0.3231	
Felling	1	0.125	0.1250	0.0500	0.99
Error (a)	3	8.125	2.7080		
Litter/tillage	3	4.125	1.3750	1.3600	0.59
Felling x litter/tillage	3	0.625	0.2083	0.2100	0.94
Error (b)	18	18.250	1.0139		
Total	31	33.875			

Table 5.37 Regeneration response of new cohort of *Ocotea usambarensis*, September 1999 - February 2000, at Machame after September 1999 treatment

Source of variation	DF	SS	MS	F	P
Replications	3	0.344	0.1146	1.0000	
Felling	1	0.281	0.2813	2.4500	0.77
Error (a)	3	0.344	0.1146		
Litter/tillage	3	0.344	0.1146	0.6700	0.80
Felling x litter/tillage	3	0.344	0.1146	0.6700	0.80
Error (b)	18	3.063	0.1701		
Total	31	4.720			

5.3.3 Kilimanjaro - Rongai

5.3.3.1 Regeneration by treatment

The extent of regeneration response for *Fagaropsis angolensis* and *Podocarpus falcatus* varied with treatment and treatment application time (Appendices 13 and 14). The treatments in this site were applied in two phases : in May 1999 (16 plots) and in September 1999 (8 plots). With the exemption of plot 24 (Appendix 14), overall *Fagaropsis angolensis* had more recruits than *Podocarpus falcatus*. The plots where no regeneration was recorded four months after treatment were evenly distributed between those where there was felling and those where there was no felling.

Plots which were not felled produced more *Fagaropsis angolensis* seedlings (Figure 5.23) but, the difference was not statistically significant ($t_{0.05} = 0.59$, $\rho = 0.56$, $N = 64$, $df = 62$). In September 1999 zero regeneration were recorded in both felled and control plots.

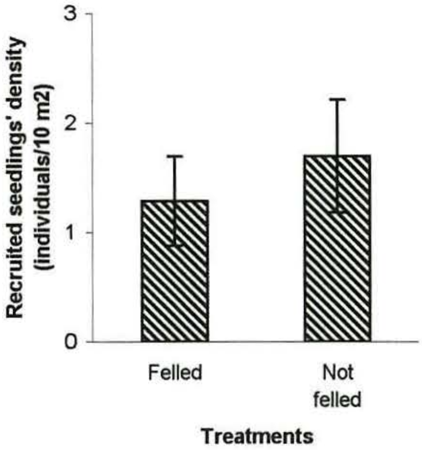


Figure 5.23 Rongai *Fagaropsis angolensis* recruited seedlings' density comparisons between felled and control plots treated in May 1999 (number of plots = 8 in each category). Values refer to regeneration recorded in the next enumeration (4 - 5 months) after treatment.

Plots treated in May 1999 contained similar levels of regeneration of *Podocarpus falcatus* seedlings (Figure 5.24) to control plots and there was no significant difference between them ($t_{0.05}$ = 0.11, ρ = 0.91, N = 64, df = 62). No *Podocarpus falcatus* seedling was recruited in plots which were felled in September 1999.

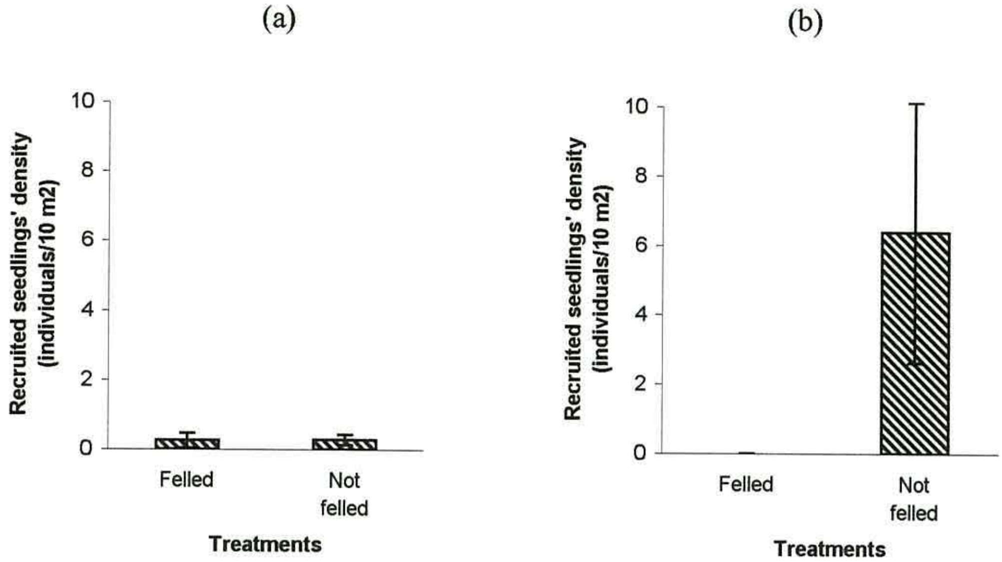


Figure 5.24 Rongai *Podocarpus falcatus* recruited seedlings' density comparisons between felled and control plots treated in (a) May 1999 and (b) September 1999 respectively (number of plots = 4 in each category for each histogram). Values refer to regeneration recorded in the next enumeration (4 - 5 months) after treatment.

Table 5.38 summarizes the advance and new regeneration of *Fagaropsis angolensis* and *Podocarpus falcatus* in the sampled area at Rongai. Advance regeneration, though sparse, includes individuals of all height classes. Plots treated in May 1999 and first assessed in September 1999 (Appendix 13 and last column of Table 5.38) were richer in new recruits of *Fagaropsis angolensis* regeneration.

Table 5.38 Regeneration summary table for felled and control plots (combined): numbers of regenerating individuals by size, species and cohort - Rongai, Tanzania

Regeneration categories	Height class (cm)	Regeneration cohorts			
Felling date		**May 1999 (Advance)**	**May 1999 (new recruits)**	**September 1999 (Advance)**	**September 1999 (new recruits)**
Fagaropsis angolensis	< 25	2	0	14	97
Fagaropsis angolensis	$\geq 25 < 50$	2	0	0	0
Fagaropsis angolensis	$\geq 50 < 100$	1	0	1	0
Fagaropsis angolensis	≥ 100	2	0	2	0
Podocarpus falcatus	< 25	0	0	0	17
Podocarpus falcatus	$\geq 25 < 50$	1	0	1	0
Podocarpus falcatus	$\geq 50 < 100$	6	0	3	0
Podocarpus falcatus	≥ 100	10	0	4	0

5.3.3.2 Analytical results

While the regeneration response of *Fagaropsis angolensis* (Appendix 13) was normally distributed that of *Podocarpus falcatus* (Appendices 13 and 14) was not (ρ = 0.148 and 0.000 respectively). *Podocarpus falcatus* data had to be transformed by logarithm base ten. The transformed data in Appendices 13 and 14 were linked with the applied treatments (felling, litter and tilling). The resultant data were entered in the computer and ANOVA under simple factorial experiment carried out for May and September separately. The results for *Fagaropsis angolensis* are shown in Table 5.39 while that for *Podocarpus falcatus* are shown in Tables 5.40 and 5.41. In *Fagaropsis angolensis,* neither the combined treatments nor individual treatments had statistically significant influence on its regeneration (Tables 5.39). Due to the absence of *Fagaropsis angolensis* regeneration in September 1999, analysis of variance for this time span could not be carried out. On the other hand, *Podocarpus falcatus* regeneration was statistically significantly influenced by the felling treatment during September 1999 (Table 5.41).

Table 5.39 Regeneration response of new cohort of *Fagaropsis angolensis*, May - September 1999, at Rongai after May 1999 treatment

Source of variation	DF	SS	MS	F	P
Replications	7	125.500	17.929	1.0641	0.73
Felling	1	10.563	10.563	0.6269	0.89
Error (a)	7	117.938	16.848		
Litter/tillage	3	2.375	0.792	0.1604	0.95
Felling x litter/tillage	3	4.313	1.438	0.2912	0.90
Error (b)	42	207.313	4.936		
Total	63	468.002			

Table 5.40 Regeneration response of new cohort of *Podocarpus falcatus*, May - September 1999, at Rongai after May 1999 treatment

Source of variation	DF	SS	MS	F	P
Replications	7	10.359	1.4799	0.7031	0.82
Felling	1	0.140	0.1407	0.0668	0.99
Error (a)	7	14.734	2.1049		
Litter/tillage	3	2.547	0.8490	1.1399	0.62
Felling x litter/tillage	3	3.422	1.1406	1.5314	0.49
Error (b)	42	31.281	0.7448		
Total	63	62.483			

Table 5.41 Regeneration response of new cohort of *Podocarpus falcatus*, September 1999 - February 2000, at Rongai after September 1999 treatment

Source of variation	DF	SS	MS	F	P
Replications	3	873.375	291.8750	0.8107	
Felling	1	223.125	223.1250	0.6213	0.94
Error (a)	3	1077.375	359.1250		
Litter/tillage	3	78.625	26.2083	0.4353	0.87
Felling x litter/tillage	3	282.625	94.2083	1.5647	0.53
Error (b)	18	1083.750	60.2083		
Total	31	3618.875			

5.4 Assessment and monitoring of increment

5.4.1 Chome

5.4.1.1 Cohorts of advance regeneration

Survival of the marked *Podocarpus latifolius* seedlings and *Ocotea usambarensis* root suckers was very high (all individuls marked were present in all assessment phase). Appendix 15 lists *Podocarpus latifolius* seedlings and *Ocotea usambarensis* root suckers monitored for height growth in Chome from March 1999. *Ficalhoa laurifolia* had no seedlings which could be marked for height growth. The initial heights of monitored *Podocarpus latifolius* seedlings ranged from 9 to 223 cm high while those of *Ocotea usambarensis* root suckers ranged from 19 to 133 cm high. In general, there were height increments between advance regeneration labelling and the treatment applications (an interval of three months depending on site and phase) before treatments were applied. In some cases these increments were higher than those attained after the treatments were applied. The immediate effect of treatment application was cessation or decrease in height growth (Table 5.42). After this initial slow-down, most seedlings and root suckers picked-up in height growth. Height growth of seedlings and root suckers between and within different treatment combinations differed greatly.

In May 1999, the heights of marked *Podocarpus latifolius* seedlings ranged from 8 to 220 cm while those of *Ocotea usambarensis* root suckers ranged from 44 cm to 172 cm (Appendix 16). Again, no seedlings of *Ficalhoa laurifolia* were detected. Height growth differed greatly between individual seedlings and root suckers. In *Ocotea usambarensis* suckers, height increment was greater than in *Podocarpus latifolius* seedlings.

Appendix 17 lists *Podocarpus latifolius* seedlings and *Ocotea usambarensis* root suckers marked and monitored for height growth at Chome from September 1999. No seedlings of *Ficalhoa laurifolia* were detected during this phase. The initial heights of *Podocarpus latifolius* ranged from 16 to 231 cm while those of *Ocotea usambarensis* ranged from 26 to 184 cm (Appendix 17).

5.4.1.2 Height increment of advance regeneration

The increment of advance regeneration of both *Podocarpus latifolius* and *Ocotea usambarensis* varied between treatments as well as growth phases. In March 1999 *Podocarpus latifolius* advance regeneration cohort, there was statistical significant difference in height increment between treatments and growth phases ($F = 3.45$, $\rho = 0.002$ and $F = 9.12$, $\rho = 0.000$ respectively). On the other hand, in May 1999 *Podocarpus latifolius* advance regeneration cohort, the height increment were statistically significantly different between growth phases only ($F = 20.04$, $\rho = 0.000$). In September 1999 the treatments effect was not significantly different ($F = 0.67$, $\rho = 0.698$). *Ocotea usambarensis* advance regeneration May 1999 cohort had statistically significantly height increment difference between growth phases ($F = 24.21$, $\rho = 0.000$). The rest of the cohorts (March 1999 and September 1999) showed no significance in height increment differences between treatments or growth phases. Table 5.44 shows that *Podocarpus latifolius* advance regeneration in felled plots grew faster than those in un-felled plots. On the other hand, *Ocotea usambarensis* suckers' advance regeneration in un-felled plots grew faster than felled plots in all growth periods (Table 5.45). These Tables (5.44 and 5.45) also show that under similar growth conditions, *Ocotea usambarensis* grows faster than *Podocarpus latifolius*. Regardless of felling treatment, September 1999 - February 2000 had the highest growth rates for both *Podocarpus latifolius* and *Ocotea usambarensis* (Tables 5.44 and 5.45). Tables 5.42 and 5.43 show pre-treatment growth of *Podocarpus latifolius* and *Ocotea usambarensis* advance regeneration growth respectively.

Table 5.42 Summary of *Podocarpus latifolius* pre-treatment advance regeneration increment variations during three (March 1999, May 1999 and September 1999) phases at Chome, Tanzania

Treatment time	Mean increment ± S.E (cm month^{-1})	
	Felled	Not felled
	Pre-treatment height increment (Initially measured in December 1998)	Pre-treatment height increment (Initially measured in December 1998)
March 1999	1.51 ± 0.27 (n = 32)	0.92 ± 0.14 (n = 45)
[range, in cmmonth^{-1}]	[0 - 7.33]	[0 - 3.67]
May 1999	1.07 ± 0.16 (n = 28)	0.93 ± 0.09 (n = 99)
[range, in cmmonth^{-1}]	[0 - 7.33]	[0 - 4.20]
September 1999	0.29 ± 0.06 (n = 33)	0.33 ± 0.07 (n = 26)
[range, in cmmonth^{-1}]	[0 - 1.56]	[0 - 1.22]

Table 5.43 Summary of *Ocotea usambarensis* pre-treatment advance regeneration increment variations during three (March 1999, May 1999 and September 1999) phases at Chome, Tanzania

Treatment time	Mean increment ± S.E (cm month^{-1})	
	Felled	Not felled
	Pre-treatment height increment (Initially measured in December 1998)	Pre-treatment height increment (Initially measured in December 1998)
March 1999	3.92 ± 1.71 (n = 4)	10.3 ± 2.85 (n = 3)
[range, in cmmonth^{-1}]	[0 - 7.67]	[4.67 - 13.67]
May 1999	2.15 ± 0.37 (n = 8)	3.24 ± 0.53 (n = 17)
[range, in cmmonth^{-1}]	[0.4 - 3.20]	[0.4 - 7.8]
September 1999	1.15 ± 0.15 (n = 38)	1.33 ± 0.37 (n = 7)
[range, in cmmonth^{-1}]	[0 - 3.89]	[0.11 - 3.11]

Table 5.44 Summary of *Podocarpus latifolius* advance regeneration increment variations during three (March 1999 - May 1999, May 1999 - September 1999 and September 1999 - February 2000) growth phases at Chome, Tanzania

Treatment time	Mean increment ± S.E (cm month $^{-1}$)					
	Felled			Not felled		
	March '99 - May '99	May '99 - Sep '99	Sep '99 - Feb '99	March '99 - May '99	May '99 - Sep '99	Sep '99 - Feb '99
March 1999	1.22 ± 0.40 (n = 32)	0.22 ± 0.08 (n = 32)	1.23 ± 0.20 (n = 32)	0.48 ± 0.09 (n = 45)	0.18 ± 0.04 (n = 45)	0.56 ± 0.11 (n = 45)
[range, in cmmonth $^{-1}$]	[0 - 9.5]	[0 - 1.5]	[0 - 3.8]	[0 - 2.0]	[0 - 1.25]	[0 - 2.6]
May 1999		0.48 ± 0.19 (n = 28)	0.79 ± 0.19 (n = 28)		0.19 ± 0.07 (n = 99)	0.89 ± 0.11 (n = 99)
[range, in cmmonth $^{-1}$]		[0 - 5.0]	[-0.6 - 3.2]		[0 - 4.0]	[-1.6 - 4.8]
September 1999			1.19 ± 0.33 (n = 33)			0.65 ± 0.13 (n = 26)
[range, in cmmonth $^{-1}$]			[0 - 8.6]			[0 - 2.2]

Table 5.45 Summary of *Ocotea usambarensis* advance regeneration increment variations during three (March 1999 - May 1999, May 1999 - September 1999 and September 1999 - February 2000) growth phases at Chome, Tanzania

Treatment time	Mean increment ± S.E (cm month $^{-1}$)					
	Felled			Not felled		
	March '99 - May '99	May '99 - Sep '99	Sep '99 - Feb '99	March '99 - May '99	May '99 - Sep '99	Sep '99 - Feb '99
March 1999	0.25 ± 0.14 (n = 4)	0.50 ± 0.17 (n =4)	3.90 ± 2.20 (n = 4)	1.67 ± 1.67 (n = 3)	4.33 ± 2.24 (n =3)	5.20 ± 3.22 (n = 3)
[range, in cmmonth $^{-1}$]	[0 - 5.0]	[0 - 7.5]	[2.2 - 5.8]	[0 - 0.5]	[0 - 0.75]	[0.6 - 11.4]
May 1999		0.25 ± 0.09 (n = 8)	3.47 ± 1.43 (n =8)		0.44 ± 0.24 (n = 17)	5.8 ± 1.09 (n = 17)
[range, in cmmonth $^{-1}$]		[0 - 0.75]	[0.4 - 12.4]		[0 - 3.0]	[1.8 - 20.8]
September 1999			7.9 ± 1.06 (n = 38)			3.40 ± 1.46 (n = 7)
[range, in cmmonth $^{-1}$]			[0 - 30.4]			[1.0 - 12.0]

The analysed data are from March 1999 advanced regeneration cohort for both *Podocarpus latifolius* and *Ocotea usambarensis* at Chome. Tables 5.46 - 5.48 shows that there is no evidence that the relationship between *Podocarpus latifolius* advance (seedling) regeneration height increment against light level was significant. Corresponding (sequential) scatter plots are shown in Figure 5.25 (fewer points are shown in the Figure because some points represent multiple observations). However, the relevance of direct light, hence canopy closure, for predicting height increment of advance regeneration of *Podocarpus latifolius* at Chome is very weak (R^2 from 0.1 to 4.6% in Figure 5.25).

Table 5.46 Regression of *Podocarpus latifolius* seedlings' March 1999 advance regeneration increment against light level in felled and non-felled plots (combined) during March 1999 - May 1999 (Phase 1) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	8.621	8.621	3.64	0.060
Residual error	75	177.595	2.368		
Total	76	186.214			

Regression equation : March 1999 - May 1999 height increment (cm/month) = 1.38 - 0.0326 Direct light (mol m^{-2} d^{-1})

Table 5.47 Regression of *Podocarpus latifolius* seedlings' March 1999 advance regeneration increment against light level in felled and non-felled plots (combined) during May 1999 - September 1999 (Phase 2) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	0.0124	0.0124	0.10	0.748
Residual error	75	8.9405	0.1192		
Total	76	8.9529			

Regression equation : May 1999 - September 1999 height increment (cm/month) = 0.217 - 0.00124 Direct light (mol m^{-2} d^{-1})

Table 5.48 Regression of *Podocarpus latifolius* seedlings' March 1999 advance regeneration increment against light level in felled and non-felled plots (combined) during September 1999 - February 2000 (Phase 3) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	0.4383	0.4383	0.48	0.492
Residual error	75	68.9248	0.9190		
Total	76	69.3631			

Regression equation : September 1999 - February 2000 height increment (cm/month) = 0.973 - 0.0074 Direct light (mol $m^{-2}d^{-1}$)$^{-}$

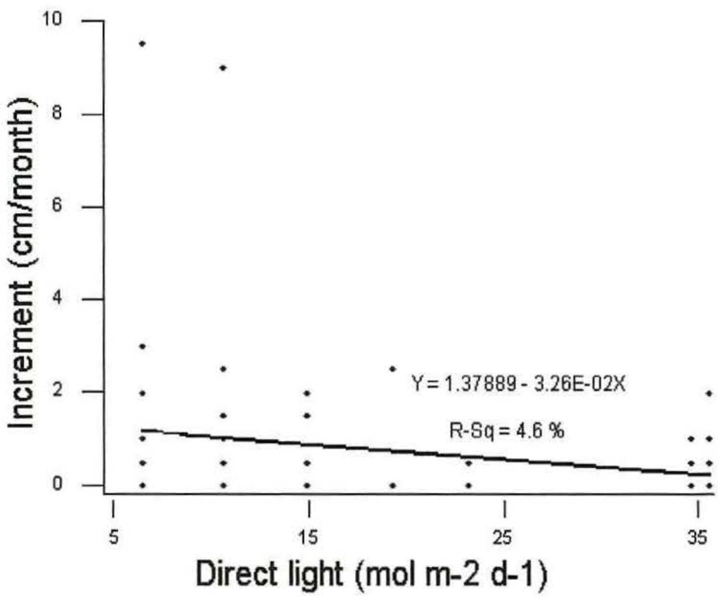


Figure 5.25 (a) Chome : *Podocarpus latifolius* March 1999 advance regeneration cohort height increment x light relationship March - May 1999

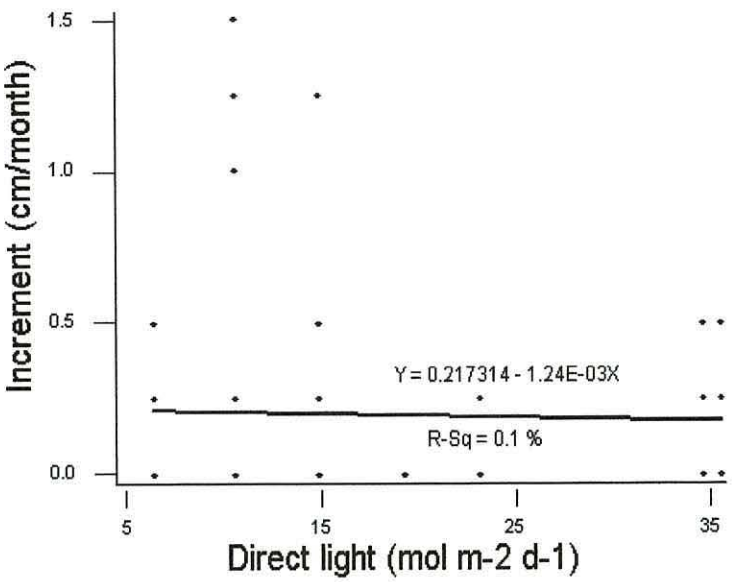


Figure 5.25 (b) Chome : *Podocarpus latifolius* March 1999 advance regeneration cohort height increment x light relationship May - September 1999

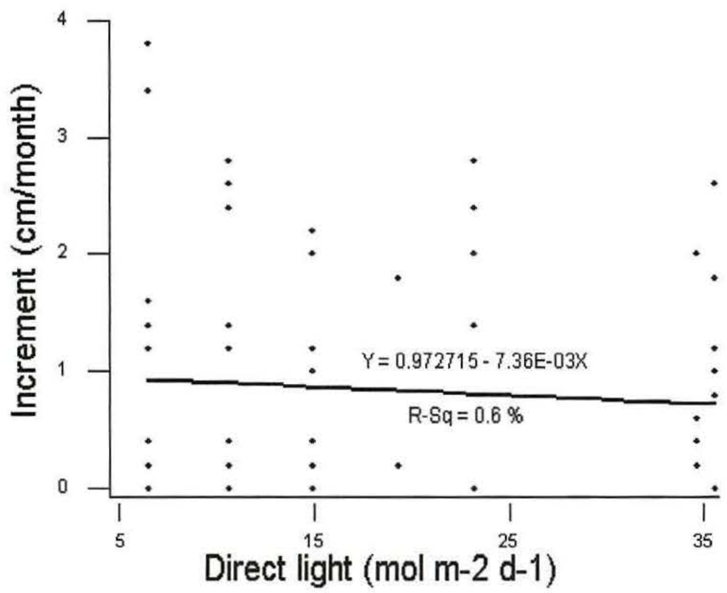


Figure 5.25 (c) Chome : *Podocarpus latifolius* March 1999 advance regeneration cohort height increment x light relationship September 1999 - February 2000

There were no statistically significant relationship of *Ocotea usambarensis* root suckers' advance regeneration height increment against light level in this study (Tables 5.49 - 5.51). The regression lines in each case are graphically presented in Figure 5.26 (fewer points are shown in the Figure because some points represent multiple observations). Unlike *Podocarpus latifolius* (Figure 5.25), height increment of *Ocotea usambarensis* root suckers' advance regeneration can be explained by the magnitude of direct light reaching forest understory (R^2 8.4 to 39.2 in Figure 5.26).

Table 5.49 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration increment against light level in felled and non-felled plots (combined) during March 1999 - May 1999 (Phase 1) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	5.952	5.952	2.07	0.210
Residual error	5	14.405	2.881		
Total	6	20.357			

Regression equation : March 1999 - May 1999 height increment (cm/month) = -1.04 + 0.0921 Direct light light (mol m^{-2} d^{-1})

Table 5.50 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration increment against light level in felled and non-felled plots (combined) during May 1999 - September 1999 (Phase 2) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	4.71	4.71	0.46	0.527
Residual error	5	51.03	10.21		
Total	6	55.73			

Regression equation : May 1999 - September 1999 height increment (cm/month) = 0.45 + 0.082 Direct light light (mol m^{-2} d^{-1})

Table 5.51 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration increment against light level in felled and non-felled plots (combined) during September 1999 - February 2000 (Phase 3) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	25.040	25.040	2.58	0.169
Residual error	5	48.537	9.707		
Total	6	73.577			

Regression equation : September 1999 - February 2000 height increment (cm/month) = 0.56 + 0.189 Direct light light (mol m^{-2} d^{-1})

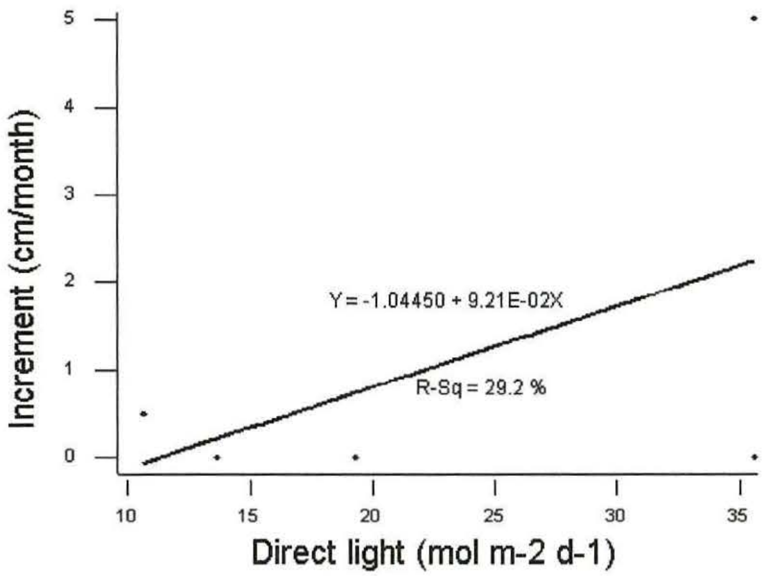


Figure 5.26 (a) Chome : *Ocotea usambarensis* March 1999 advance regeneration cohort height increment x light relationship March - May 1999

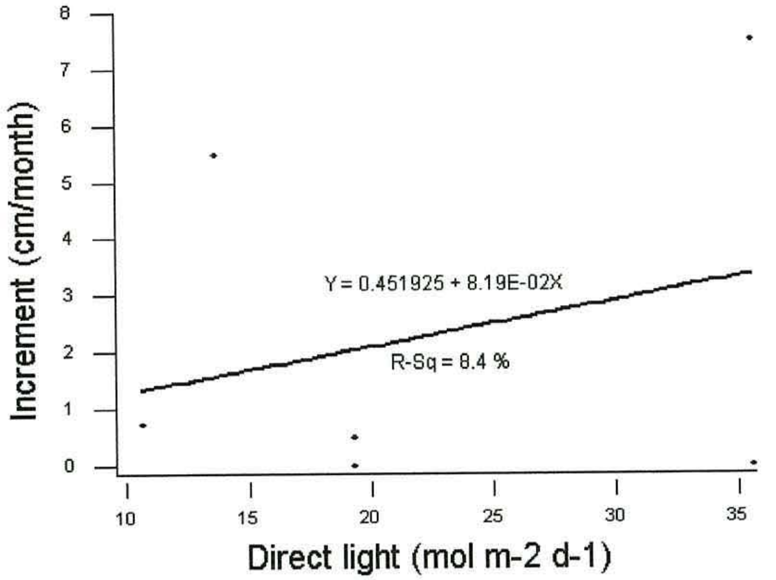


Figure 5.26 (b) Chome : *Podocarpus latifolius* March 1999 advance regeneration cohort height increment x light relationship May - September 1999

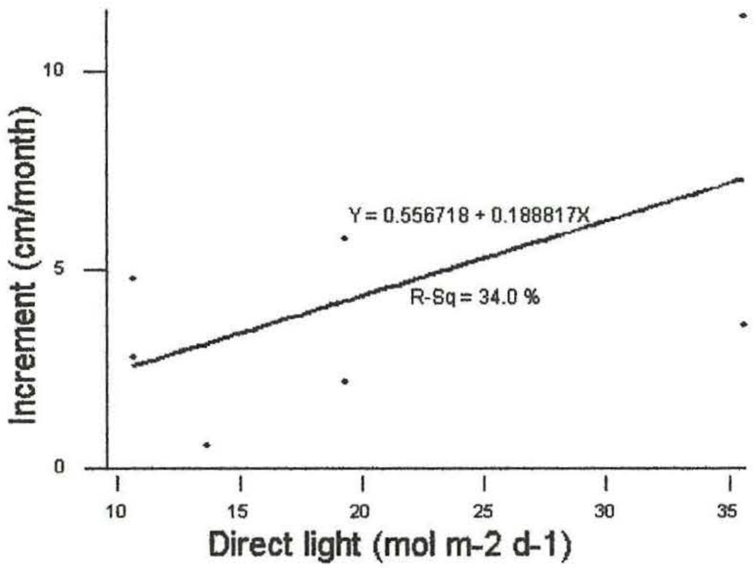


Figure 5.26 (c) Chome : *Podocarpus latifolius* March 1999 advance regeneration cohort height increment x light relationship September 1999 - February 2000

The relationship between *Podocarpus latifolius* seedling advance regeneration increment against initial height at Chome in March 1999 - May 1999 growth phase was significant (Table 5.52). During May 1999 - September 1999 and September 1999 - February 2000 growth phases this relationship was not significant (Tables 5.53 and 5.54 respectively). These relationships are shown graphically in Figure 5.27. In this figure *Podocarpus latifolius* seedling initial height does not seem to be a good predictor of monthly height increment (R^2 = 0.2 to 5.1%)

Table 5.52 Regression of *Podocarpus latifolius* seedlings' March 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during March 1999 - May 1999 (Phase 1) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	9.462	9.462	4.02	0.049
Residual error	75	176.752	2.357		
Total	76	186.214			

Regression equation : March 1999 - May 1999 height increment (cm/month) = 0.116 + 0.0069 Initial height (cm)

Table 5.53 Regression of *Podocarpus latifolius* seedlings' March 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during May 1999 - September 1999 (Phase 2) at Chome, Tanzania.

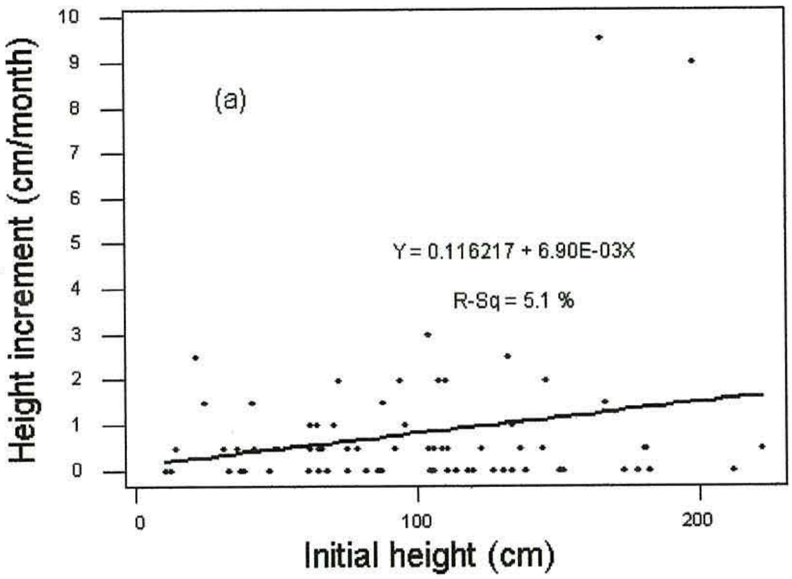
Source of variation	df	SS	MS	F	ρ
Regression	1	0.0549	0.0549	0.46	0.499
Residual error	75	8.8981	0.1186		
Total	76	8.9529			

Regression equation : May 1999 - September 1999 height increment (cm/month) = 0.246 - 0.00526 Initial height (cm)

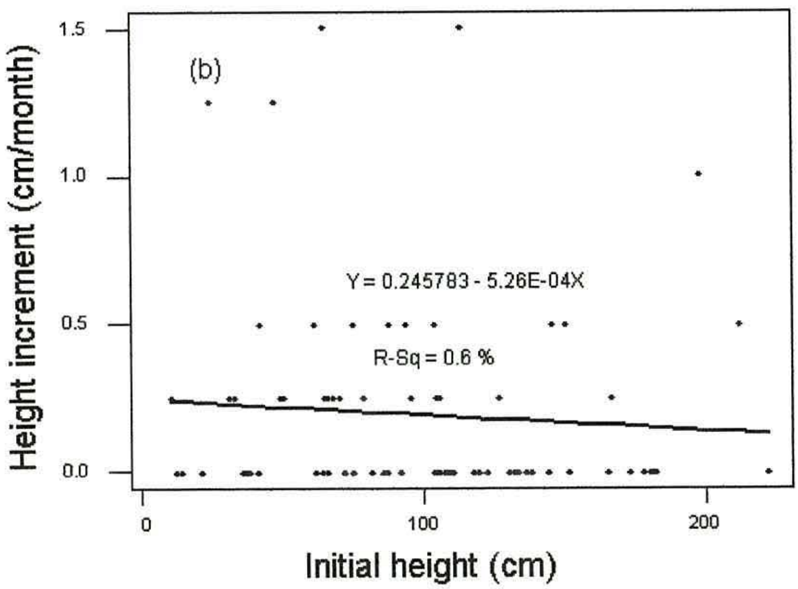
Table 5.54 Regression of *Podocarpus latifolius* seedlings' March 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during September 1999 - February 2000 (Phase 3) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	0.1512	0.1512	0.16	0.687
Residual error	75	69.2119	0.9228		
Total	76	69.3631			

Regression equation : September 1999 - February 2000 height increment (cm/month) = 0.754 - 0.00087 Initial height (cm)



(a)
Y = 0.116217 + 6.90E-03X
R-Sq = 5.1 %
Height increment (cm/month)
Initial height (cm)
0
100
200
10
9
8
7
6
5
4
3
2
1
0



(b)
Y = 0.245783 - 5.26E-04X
R-Sq = 0.6 %
Height increment (cm/month)
Initial height (cm)
0
100
200
1.5
1.0
0.5
0.0

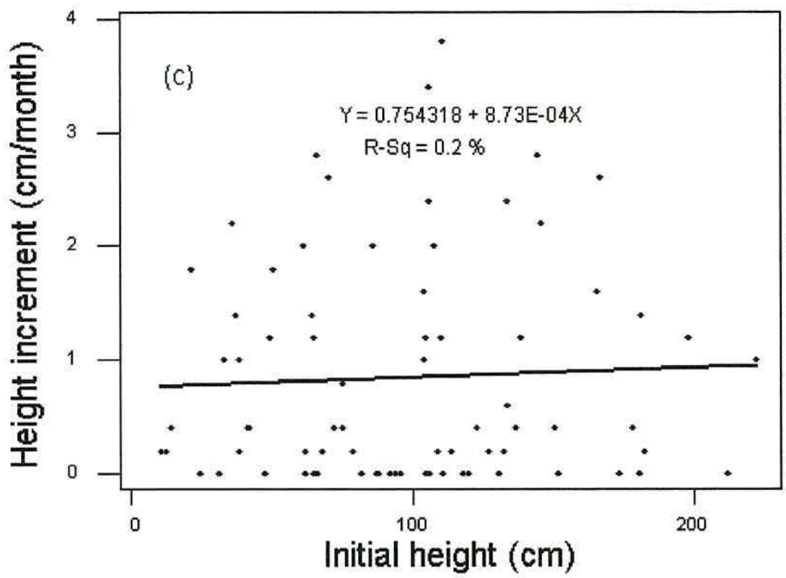


Figure 5.27 Regression plots of *Podocarpus latifolius* March 1999 advance regeneration cohort height increment x initial height relationship in (a) March 1999 - May 1999, (b) May 1999 - September 1999 and (c) September 1999 - February 2000 at Chome, Tanzania.

The relationship between *Ocotea usambarensis* root suckers' advance regeneration height increment against initial sucker height was significant in September 1999 - February 2000 growth phase (Table 5.57). During March 1999 - May 1999 this realationship approached the significance level while in May 1999 - September 1999 it was far from significant (Tables 5.55 and 5.56 respectively). These relationships are shown graphically in Figure 5.28. The relevance of root sucker initial height in predicting height increment in *Ocotea usambarensis* is comparatively better than in the case of *Podocarpus latifolius* (R^2 = 24.5 to 72.8% in Figure 5.28)

Table 5.55 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during March 1999 - May 1999 (Phase 1) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	10.689	10.689	5.53	0.065
Residual error	5	9.668	1.934		
Total	6	20.357			

Regression equation : March 1999 - May 1999 height increment (cm/month) = -2.02 + 0.03 Initial height (cm)

Table 5.56 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during May 1999 - September 1999 (Phase 2) at Chome, Tanzania.

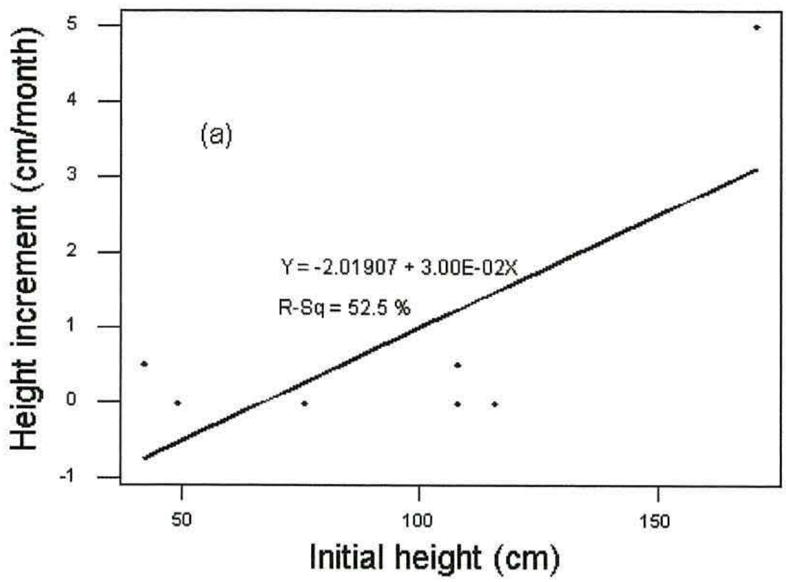
Source of variation	df	SS	MS	F	ρ
Regression	1	13.637	13.637	1.62	0.259
Residual error	5	42.095	8.419		
Total	6	55.732			

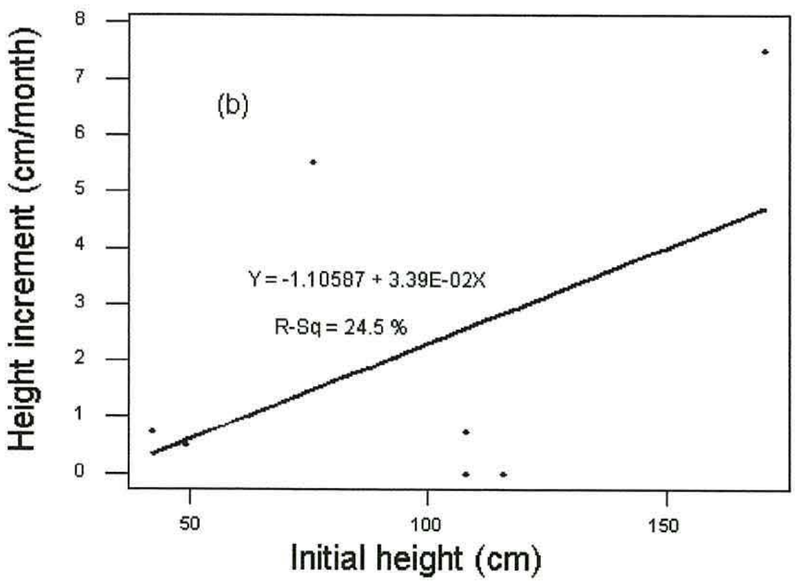
Regression equation : May 1999 - September 1999 height increment (cm/month) = -1.111 + 0.0339 Initial height (cm)

Table 5.57 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during September 1999 - February 2000 (Phase 3) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	53.596	53.596	13.41	0.015*
Residual error	5	19.981	3.996		
Total	6	73.577			

Regression equation : September 1999 - February 2000 height increment (cm/month) = -1.98 + 0.0673 Initial height (cm)


(a)
Y = -2.01907 + 3.00E-02X
R-Sq = 52.5 %
Height increment (cm/month)
Initial height (cm)


(b)
Y = -1.10587 + 3.39E-02X
R-Sq = 24.5 %
Height increment (cm/month)
Initial height (cm)

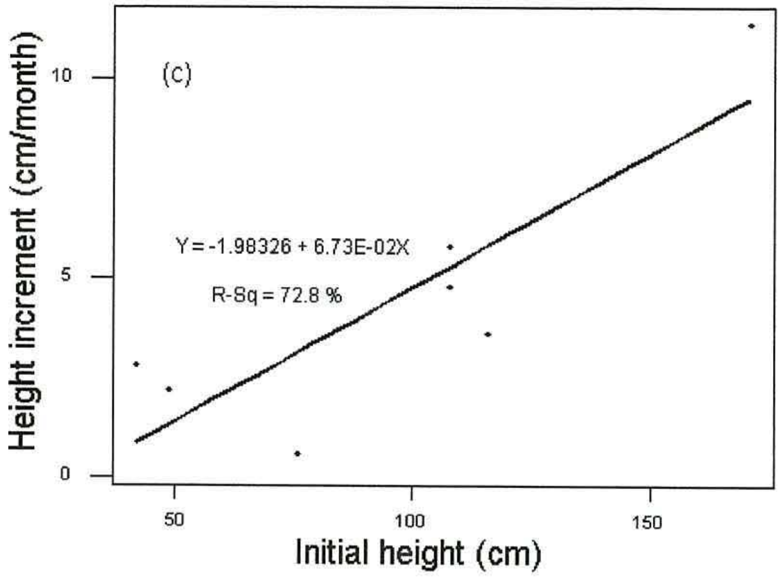


Figure 5.28 Regression plots of *Ocotea usambarensis* March 1999 advance regeneration cohort height increment x initial height relationship in (a) March 1999 - May 1999, (b) May 1999 - September 1999 and (c) September 1999 - February 2000 at Chome, Tanzania.

The relationships of *Ocotea usambarensis* root suckers' advance height increment in different growth phases were compared (Tables 5.58 - 5.60) and only March 1999 - May 1999 height increment against September 1999 - February 2000 was significant. In all cases the relationship was directly proportional with R^2 ranging from 20.1 to 77.4% (Figure 5.29).

Table 5.58 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration March 1999 - May 1999 height increment against May 1999 - September 1999 height increment in felled and non-felled plots (combined) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	11.570	11.570	6.58	0.05
Residual error	5	8.788	1.758		
Total	6	20.357			

Regression equation : March 1999 - May 1999 height increment (cm/month) = -0.119 + 0.459 May 1999 - September 1999 height increment (cm/month)

Table 5.59 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration May 1999 - September 1999 height increment against September 1999 - February 2000 height increment in felled and non-felled plots (combined) at Chome, Tanzania.

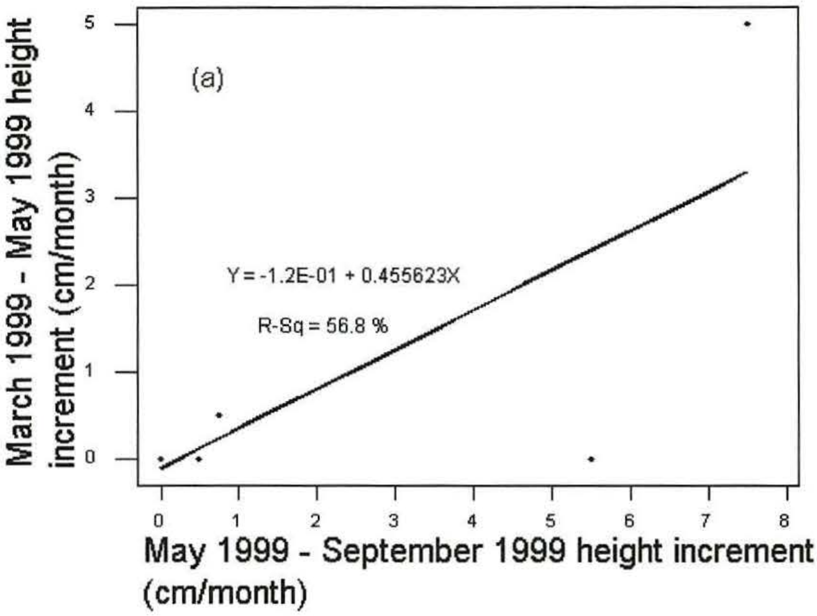
Source of variation	df	SS	MS	F	ρ
Regression	1	11.228	11.228	1.26	0.312
Residual error	5	44.504	8.901		
Total	6	55.732			

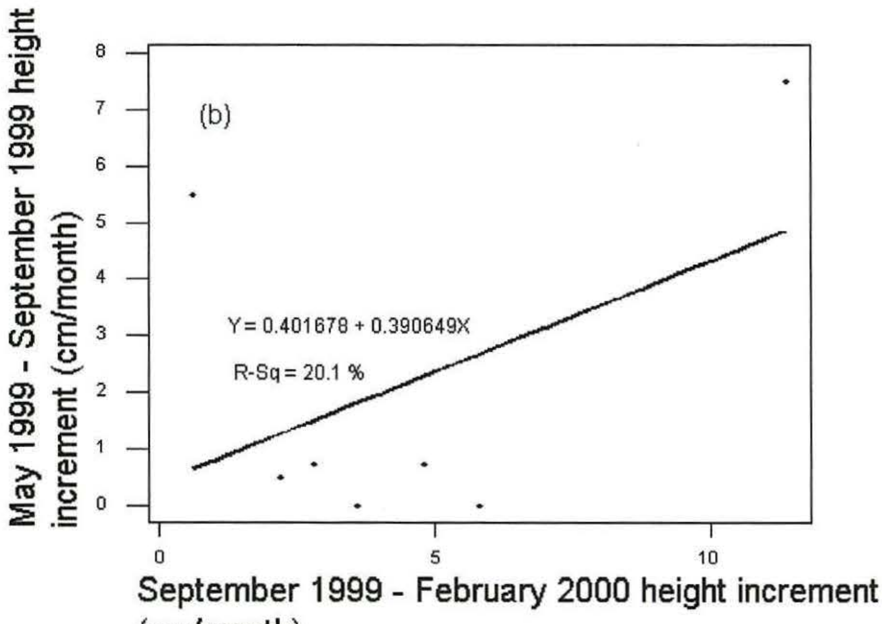
Regression equation : May 1999 - September 1999 height increment (cm/month) = 0.4 + 0.391 September 1999 - February 2000 height increment (cm/month)

Table 5.60 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration March 1999 - May 1999 height increment against September 1999 - February 2000 height increment in felled and non-felled plots (combined) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	15.764	15.764	17.16	0.009*
Residual error	5	4.593	0.919		
Total	6	20.357			

Regression equation : March 1999 - May 1999 height increment (cm/month) = -1.21 + 0.463 September 1999 - February 2000 height increment (cm/month)


(a)
Y = -1.2E-01 + 0.455623X
R-Sq = 56.8 %
March 1999 - May 1999 height increment (cm/month)
May 1999 - September 1999 height increment (cm/month)
0
1
2
3
4
5
6
7
8


(b)
Y = 0.401678 + 0.390649X
R-Sq = 20.1 %
May 1999 - September 1999 height increment (cm/month)
September 1999 - February 2000 height increment (cm/month)
0
5
10

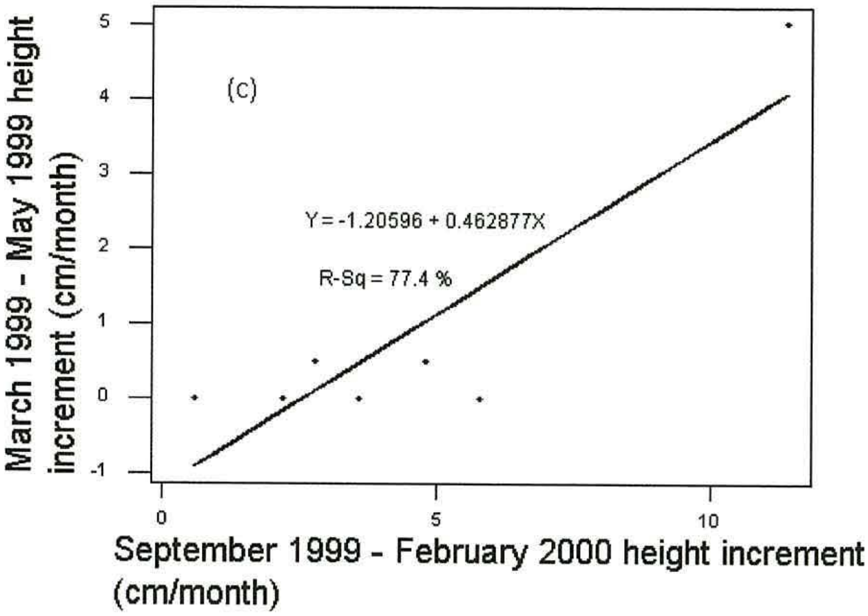


Figure 5.29 Regression plots of *Ocotea usambarensis* March 1999 advance regeneration cohort height increment x height increment relationship in (a) March 1999 - May 1999 against May 1999 - September 1999, (b) May 1999 - September 1999 against September 1999 - February 2000 and (c) March 1999 - May 1999 against September 1999 - February 2000 at Chome, Tanzania.

Tables 5.61 to 5.63 show that none of the relationship of height increment of *Podocarpus latifolius* at Chome in different growth phases was significant. With the exception of May 1999 - September 1999 against September 1999 - February 2000, all the relationships were direct proportional (Figure 5.30).

Table 5.61 Regression of *Podocarpus latifolius* seedlings' March 1999 advance regeneration March 1999 - May 1999 height increment against May 1999 - September 1999 height increment in felled and non-felled plots (combined) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	3.184	3.184	1.30	0.257
Residual error	75	183.030	2.440		
Total	76	186.214			

Regression equation : March 1999 - May 1999 height increment (cm/month) = 0.67 + 0.596 May 1999 - September 1999 height increment (cm/month)

Table 5.62 Regression of *Podocarpus latifolius* seedlings' March 1999 advance regeneration May 1999 - September 1999 height increment against September 1999 - February 2000 height increment in felled and non-felled plots (combined) at Chome, Tanzania.

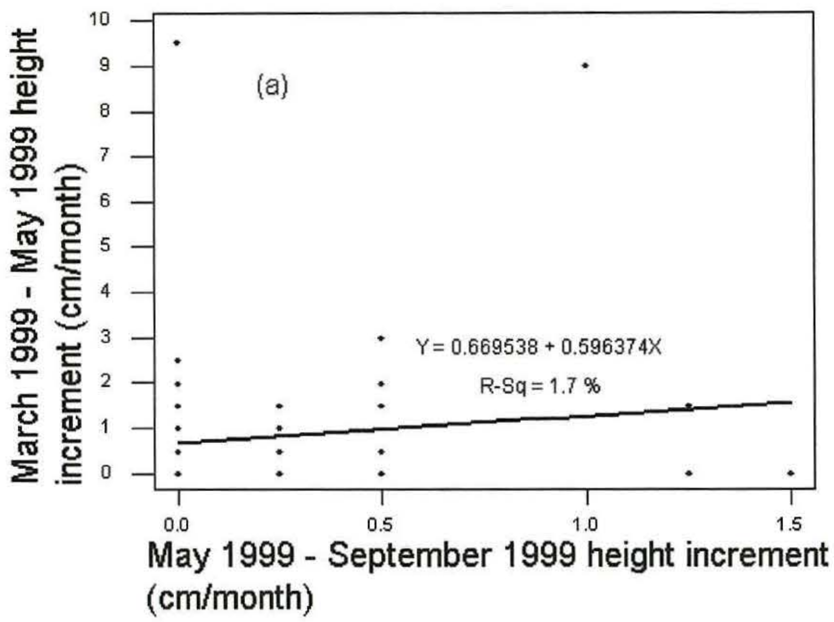
Source of variation	df	SS	MS	F	ρ
Regression	1	0.0257	0.0257	0.22	0.644
Residual error	75	8.9273	0.1190		
Total	76	8.9529			

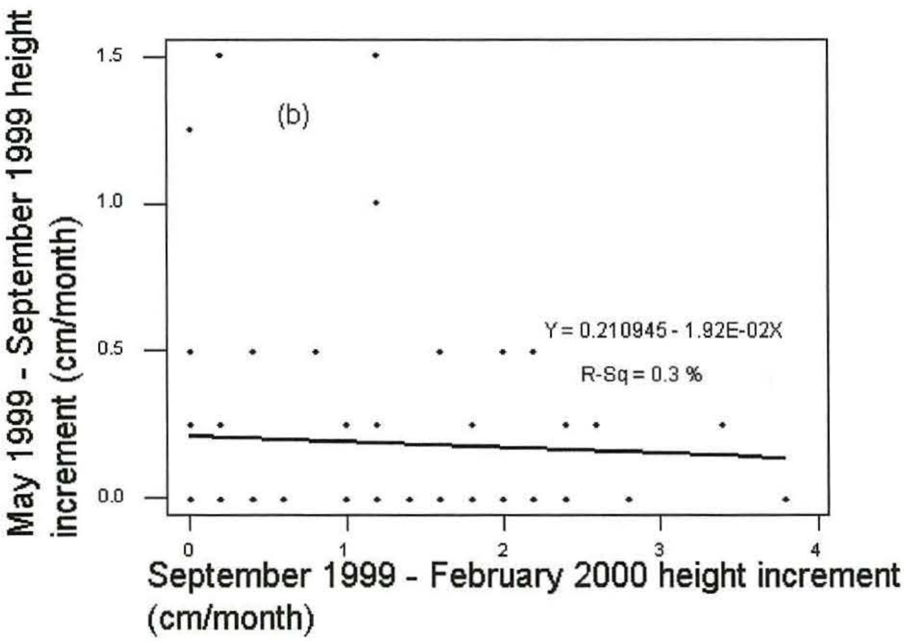
Regression equation : May 1999 - September 1999 height increment (cm/month) = 0.211 - 0.0192 September 1999 - February height increment (cm/month)

Table 5.63 Regression of *Podocarpus latifolius* seedlings' March 1999 advance regeneration March 1999 - May 1999 height increment against September 1999 - February 2000 height increment in felled and non-felled plots (combined) at Chome, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	4.139	4.139	1.70	0.196
Residual error	75	182.076	2.428		
Total	76	186.214			

Regression equation : March 1999 - May 1999 height increment (cm/month) = 0.581 + 0.244 September 1999 - February 2000 height increment (cm/month)


(a)
Y = 0.669538 + 0.596374X
R-Sq = 1.7 %
March 1999 - May 1999 height increment (cm/month)
May 1999 - September 1999 height increment (cm/month)


(b)
Y = 0.210945 - 1.92E-02X
R-Sq = 0.3 %
May 1999 - September 1999 height increment (cm/month)
September 1999 - February 2000 height increment (cm/month)

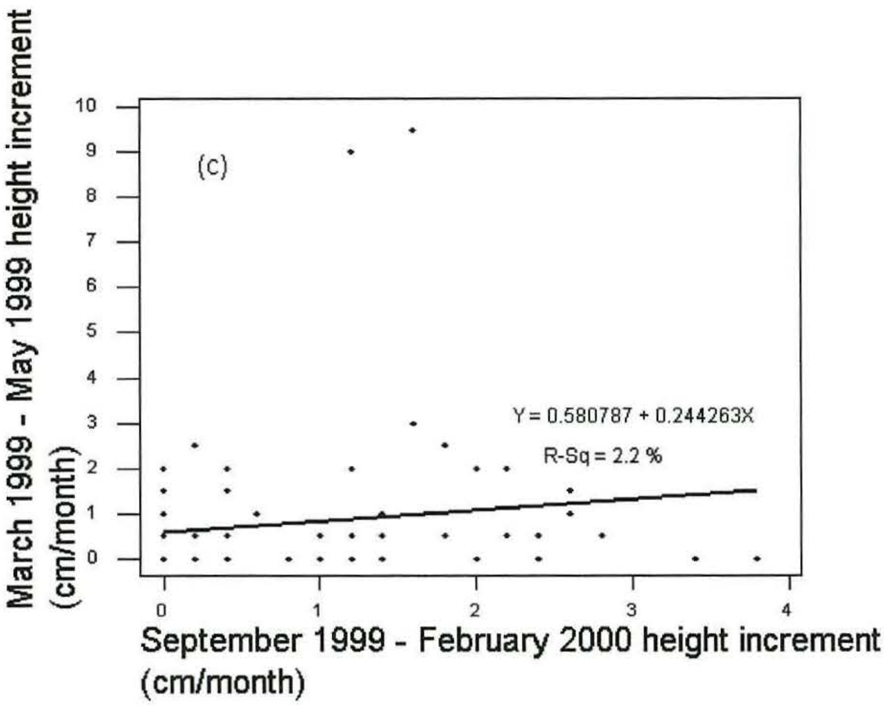


Figure 5.30 Regression plots of *Podocarpus latifolius* March 1999 advance regeneration cohort height increment x height increment relationship in (a) March 1999 - May 1999 against May 1999 - September 1999, (b) May 1999 - September 1999 against September 1999 - February 2000 and (c) March 1999 - May 1999 against September 1999 - February 2000 at Chome, Tanzania.

The superiority of felled plots in terms of higher growth rates (increment) of advanced regeneration of *Podocarpus latifolius* at Chome is shown graphically in Figure 5.31. The growth rate falls from March 1999 - May 1999 towards May 1999 - September 1999 growth season. From May 1999 - September 1999 growth season the growth rate starts to rise again towards September 1999 - February 2000 season. This differences in growth in felled and control plots were found to be not significant ($t = 2.17$, $\rho = 0.162$). On the other hand, although *Ocotea usambarensis* had persistent higher growth rate (increment) in plots which were not felled in all growth seasons (Figure 5.32) individual values were very variable and the differences were not statistically significant ($t = -2.65$, $\rho = 0.118$).

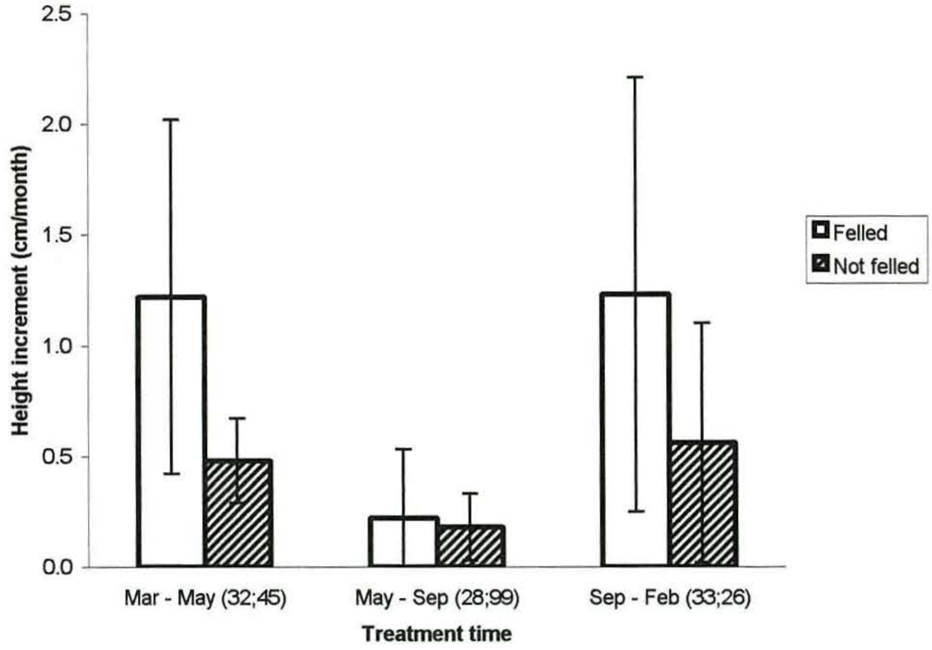


Figure 5.31 *Podocarpus latifolius* advance regeneration seedling increment comparisons in felled and non-felled plots during March 1999 - May 1999, May 1999 - September 1999 and September 1999 - February 2000 at Chome, Tanzania. Numbers of observations used are indicated in parentheses (felled treatments; not felled treatments).

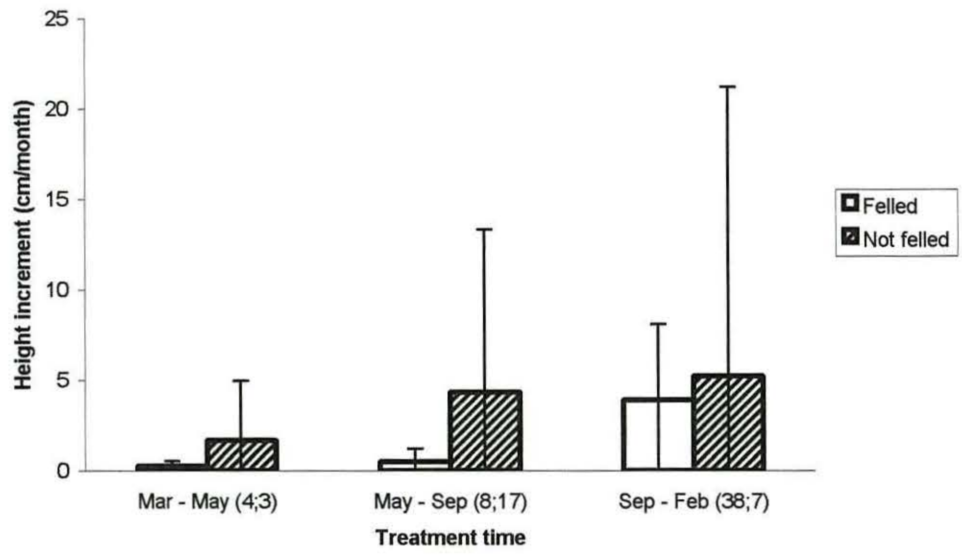


Figure 5.32 *Ocotea usambarensis* advance regeneration root sucker increment comparisons in felled and non-felled plots during March 1999 - May 1999, May 1999 - September 1999 and September 1999 - February 2000 at Chome, Tanzania. Numbers of observations used are indicated in parentheses (felled treatments; not felled treatments).

5.4.2 Kilimanjaro - Machame

5.4.2.1 Cohorts of advance regeneration

Ocotea usambarensis was the only target species monitored for height growth in this site. Survival of marked *Ocotea usambarensis* root suckers was very high (all marked individuals were present in all assessment phases). Appendix 18 lists *Ocotea usambarensis* root suckers monitored for shoot height increments from March 1999. Successive measurements were made in May 1999, September 1999 and February 2000. Initial heights of suckers differed greatly, ranging from 30 cm to 210 cm. Similarly, the successive height increments differed between individuals as well as seasons even for individuals of the same height class.

Appendix 19 lists root suckers of *Ocotea usambarensis* marked in May 1999 and re-measured in September 1999 and February 2000. No *Ocotea usambarensis* seedlings were detected during this activity. The marked root suckers' initial heights ranged from 23 cm to 214 cm. Measured heights sometimes fall between successive measurements following damage caused by humans or animals.

Appendix 20 lists initial heights and height increments of *Ocotea usambarensis* root suckers monitored from September 1999. The initial heights of these ranged from 23 cm to 220 cm.

5.4.2.2 Height increment of advance regeneration

The height increment of *Ocotea usambarensis* advance regeneration cohorts varied between treatments and growth phases. In March 1999 cohort, there was statistically significantly height increment differences between treatments as well as growth phases ($F = 2.04$, $\rho = 0.048$ and $F = 75.03$, $\rho = 0.000$ respectively). On the other hand May 1999 cohort had significant height increment differences between growth phases only ($F = 54.66$, $\rho = 0.000$). In September 1999 cohort there was no significant height growth difference between treatments (F = 0.35, ρ = 0.929). In almost all the growth periods mean increments of *Ocotea usambarensis* advance suckers' regeneration were higher in felled plots (Table 5.65). The highest (3.60 ± 2.56 $cmmonth^{-1}$) height increment was attained during the September 1999 - February 2000 growth period. With the exception of September 1999 phase, height increments were higher before treatment applications (Table 5.64).

Table 5.64 Summary of *Ocotea usambarensis* pre-treatment advance regeneration increment variations during three (March 1999, May 1999 and September 1999) phases at Machame, Tanzania

Treatment time	Mean increment ± S.E (cm $month^{-1}$)	
	Felled	Not felled
	Pre-treatment height increment (Initially measured in November 1998)	Pre-treatment height increment (Initially measured in November 1998)
March 1999	3.18 ± 0.39 (n = 74)	2.06 ± 0.18 (n = 118)
[range, in $cmmonth^{-1}$]	[0 - 24.50]	[0 - 7.75]
May 1999	1.88 ± 0.22 (n = 44)	1.72 ± 0.22 (n = 59)
[range, in $cmmonth^{-1}$]	[0 - 6.83]	[0 - 9.67]
September 1999	1.17 ± 0.12 (n = 86)	1.14 ± 0.17 (n = 41)
[range, in $cmmonth^{-1}$]	[-0.90 - 5.30]	[0 - 4.90]

Table 5.65 Summary of *Ocotea usambarensis* suckers' advance regeneration increment variations during three (March 1999 - May 1999, May 1999 - September 1999 and September 1999 - February 2000) growth phases at Machame, Tanzania

Treatment time	Mean increment ± S.E (cm month^{-1})					
	Felled			Not felled		
	March '99 - May '99	May '99 - Sep '99	Sep '99 - Feb '99	March '99 - May '99	May '99 - Sep '99	Sep '99 - Feb '99
March 1999 [range, in cmmonth^{-1}]	1.68 ± 0.30 (n = 74) [0 - 10.0]	0.39 ± 0.08 (n = 74) [0 - 3.0]	3.40 ± 0.39 (n = 74) [0 - 16.4]	1.34 ± 0.20 (n = 118) [0 - 8.5]	0.29 ± 0.06 (n = 118) [0 - 5.5]	2.61 ± 0.20 (n = 118) [-0.8 - 8.6]
May 1999 [range, in cmmonth^{-1}]		0.76 ± 0.19 (n = 44) [0 - 5.5]	3.60 ± 0.51 (n = 44) [-3.6 - 16.0]		0.30 ± 0.18 (n = 59) [0 - 7.75]	2.89 ± 0.35 (n = 59) [-0.8 - 15.6]
September 1999 [range, in cmmonth^{-1}]			3.34 ± 0.26 (n = 76) [0 - 9.4]			3.35 ± 0.44 (n = 41) [-1.0 - 9.8]

The analysed data are for March 1999 *Ocotea usambarensis* root suckers' advance regeneration. In March 1999 - May 1999 and September 1999 - February 2000 the height increment of *Ocotea usambarensis* was statistically significantly influenced by the amount direct light reaching forest understorey (Tables 5.66 and 5.68 respectively). These Tables show that height increments increased as the amount of direct light reaching forest understorey increased (positive regression lines' gradients). This implies that felled plots had higher height increments of *Ocotea usambarensis* root suckers compared to non-felled plots. There was no statistically significant difference in advance regeneration growth of *Ocotea usambarensis* root suckers between felled and non-felled plots in May 1999 - September 1999 growth season (Table 5.67). The scatter plots of the regression with fitted regression lines for data in Tables 5.66 - 5.68 are shown in Figure 5.33. Direct light only does not explain very well the variation of height increments in *Ocotea usambarensis* root suckers at Machame (R^2 1.6 to 5.1% in Figure 5.33).

Table 5.66 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration increment against light level in felled and non-felled plots (combined) during March 1999 - May 1999 (Phase 1) at Machame, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	24.404	24.404	4.72	0.031
Residual error	190	982.908	5.173		
Total	191	1007.312			

Regression equation : March 1999 - May 1999 height increment (cm/month) = -1.38 + 0.0840 Direct light (mol m^{-2} d^{-1})

Table 5.67 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration increment against light level in felled and non-felled plots (combined) during May 1999 - September 1999 (Phase 2) at Machame, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	1.2551	1.2551	2.99	0.085
Residual error	190	79.6499	0.4192		
Total	191	80.9049			

Regression equation : May 1999 - September 1999 height increment (cm/month) = -0.32 + 0.019 Direct light (mol m^{-2} d^{-1})

Table 5.68 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration increment against light level in felled and non-felled plots (combined) during September 1999 - February 2000 (Phase 3) at Machame, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	72.339	72.339	10.31	0.002
Residual error	190	1333.076	7.016		
Total	191	1405.415			

Regression equation : September 1999 - February 2000 height increment (cm/month) = -1.99 + 0.145 Direct light (mol m^{-2} d^{-1})

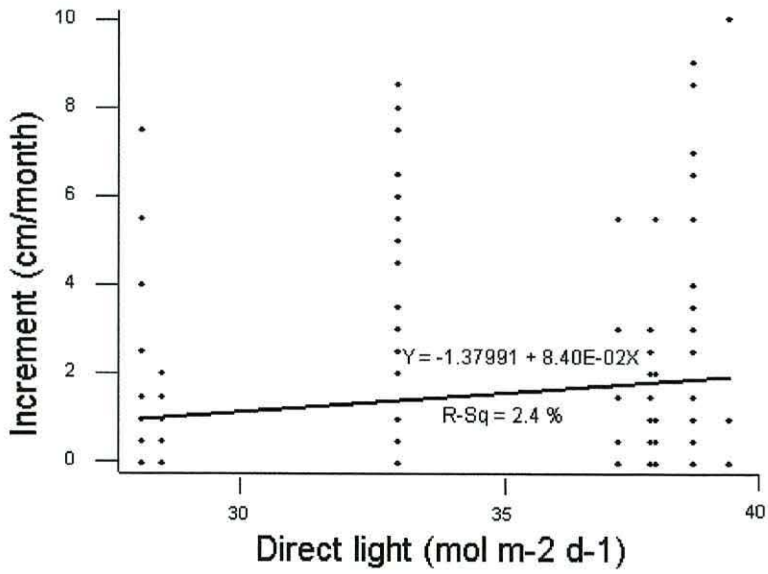


Figure 5.33 (a) Machame : *Ocotea usambarensis* March 1999 advance regeneration cohort height increment x light relationship March - May 1999

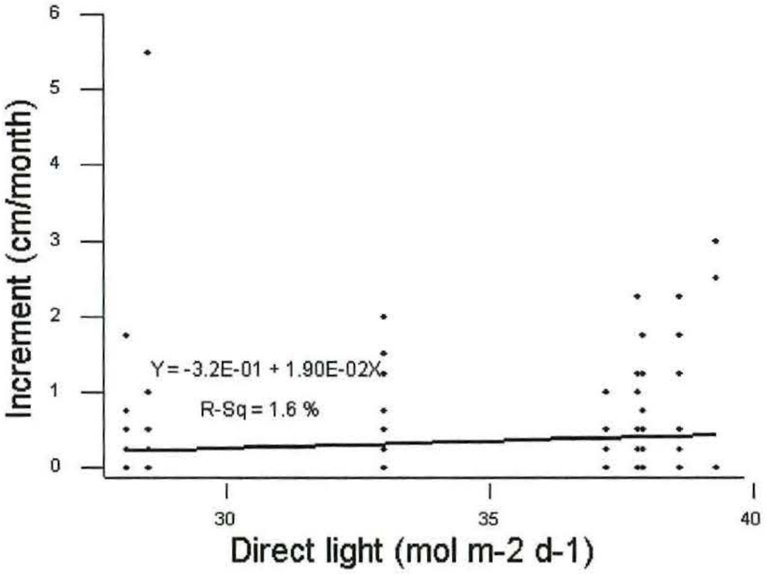


Figure 5.33 (b) Machame : *Ocotea usambarensis* March 1999 advance regeneration cohort height increment x light relationship May - September 1999

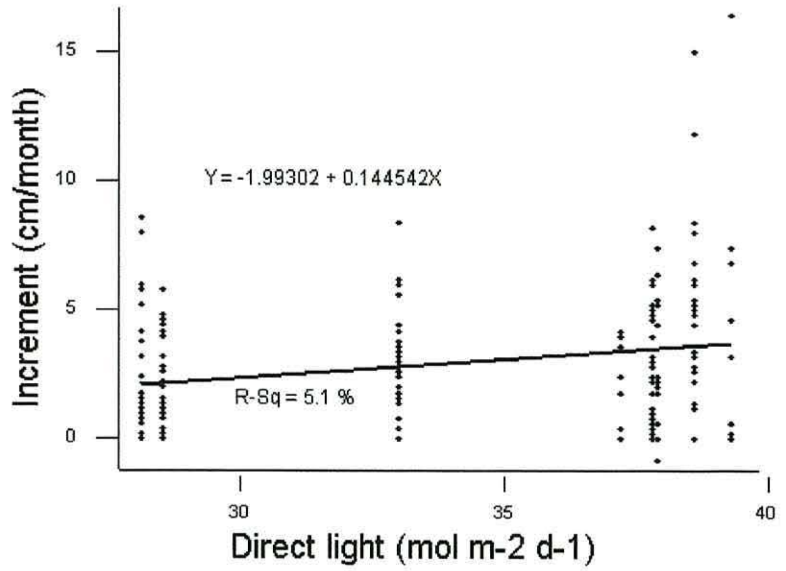


Figure 5.33 (c) Machame : *Ocotea usambarensis* March 1999 advance regeneration cohort height increment x light relationship September 1999 - February 2000

The relationship between *Ocotea usambarensis* root sucker height increment against initial height was significant in March 1999 - May 1999 growth phase (Table 5.69). In the remaining growth phases (May 1999 - September 1999 and September 1999 - February 2000) the relationship was not significant (Tables 5.70 and 5.71 respectively). These relationships are shown graphically in Figure 5.34. In this figure the relationship between height increment against initial height of root sucker in *Ocotea usambarensis* is weak (R^2 = 0.7 to 2.9%).

Table 5.69 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during March 1999 - May 1999 (Phase 1) at Machame, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	23.268	23.268	4.49	0.035*
Residual error	190	984.045	5.179		
Total	191	1007.312			

Regression equation : March 1999 - May 1999 height increment (cm/month) = 2.25 - 0.00655 Initial height (cm)

Table 5.70 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during May 1999 - September 1999 (Phase 2) at Machame, Tanzania.

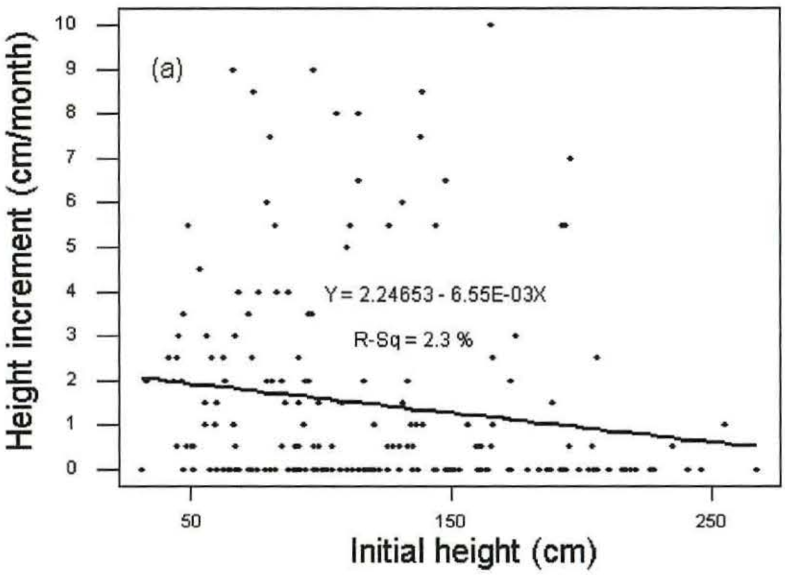
Source of variation	df	SS	MS	F	ρ
Regression	1	0.5387	0.5387	1.27	0.261
Residual error	190	80.3663	0.4230		
Total	191	80.9049			

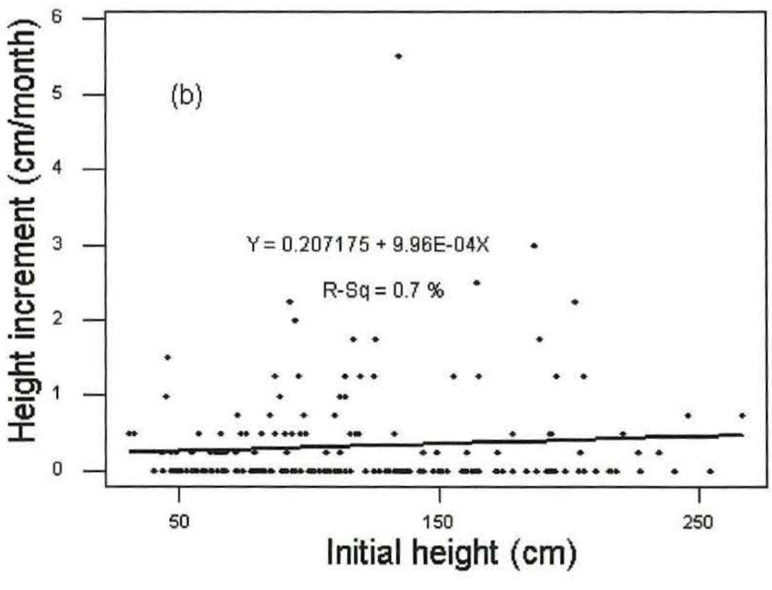
Regression equation : May 1999 - September 1999 height increment (cm/month) = 0.207 + 0.000996 Initial height (cm)

Table 5.71 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during September 1999 - February 2000 (Phase 3) at Machame, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	15.618	15.618	2.14	0.146
Residual error	5	1389.796	7.315		
Total	6	1405.415			

Regression equation : September 1999 - February 2000 height increment (cm/month) = 2.27 + 0.00536 Initial height (cm)


(a)
Y = 2.24653 - 6.55E-03X
R-Sq = 2.3 %
Height increment (cm/month)
Initial height (cm)
0
1
2
3
4
5
6
7
8
9
10
50
150
250


(b)
Y = 0.207175 + 9.96E-04X
R-Sq = 0.7 %
Height increment (cm/month)
Initial height (cm)
0
1
2
3
4
5
6
50
150
250

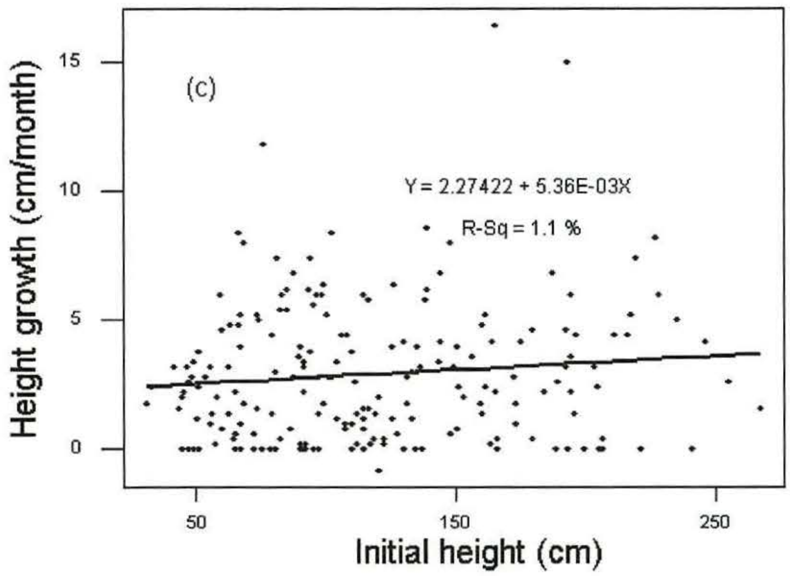


Figure 5.34 Regression plots of *Ocotea usambarensis* March 1999 advance regeneration cohort height increment x initial height relationship in (a) March 1999 - May 1999, (b) May 1999 - September 1999 and (c) September 1999 - February 2000 at Chome, Tanzania.

With the exception of March 1999 - May 1999 against May 1999 - September 1999 height increment relationship for Machame *Ocotea usambarensis* root suckers' advance regeneration (Table 5.72), the rest of the relationships were significant (Tables 5.73 and 5.74). The relevance of the one growth phase predicting another is relatively weak (R^2 = 1.1 - 11.2% in Figure 5.35). Regardless of this weakness, all the relationships were direct proportional.

Table 5.72 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration March 1999 - May 1999 height increment against May 1999 - September 1999 height increment in felled and non-felled plots (combined) at Machame, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	10.631	10.631	2.03	0.156
Residual error	190	996.681	5.246		
Total	191	1007.313			

Regression equation : March 1999 - May 1999 height increment (cm/month) = 1.35 + 0.363 May 1999 - September 1999 height increment (cm/month)

Table 5.73 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration May 1999 - September 1999 height increment against September 1999 - February 2000 height increment in felled and non-felled plots (combined) at Machame, Tanzania.

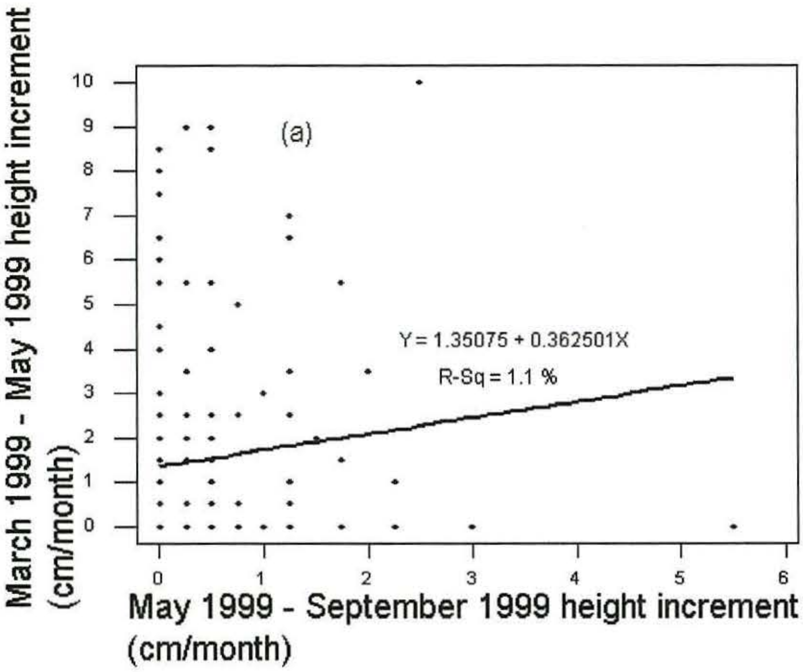
Source of variation	df	SS	MS	F	ρ
Regression	1	2.4546	2.4546	5.94	0.016*
Residual error	190	78.4504	0.4129		
Total	191	80.9049			

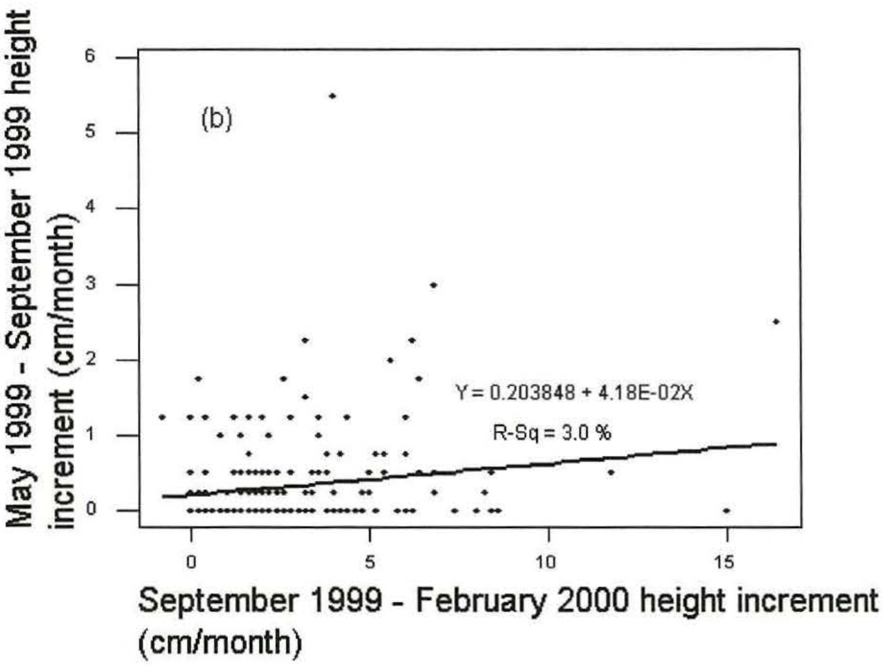
Regression equation : May 1999 - September 1999 height increment (cm/month) = 0.204 + 0.0418 September 1999 - February 2000 height increment (cm/month)

Table 5.74 Regression of *Ocotea usambarensis* root suckers' March 1999 advance regeneration March 1999 - May 1999 height increment against September 1999 - February 2000 height increment in felled and non-felled plots (combined) at Machame, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	113.03	113.03	24.01	0.000*
Residual error	190	894.28	4.71		
Total	191	1007.31			

Regression equation : March 1999 - May 1999 height increment (cm/month) = 0.643 + 0.284 September 1999 - February 2000 height increment (cm/month)


March 1999 - May 1999 height increment (cm/month)
(a)
Y = 1.35075 + 0.362501X
R-Sq = 1.1 %
May 1999 - September 1999 height increment (cm/month)


May 1999 - September 1999 height increment (cm/month)
(b)
Y = 0.203848 + 4.18E-02X
R-Sq = 3.0 %
September 1999 - February 2000 height increment (cm/month)

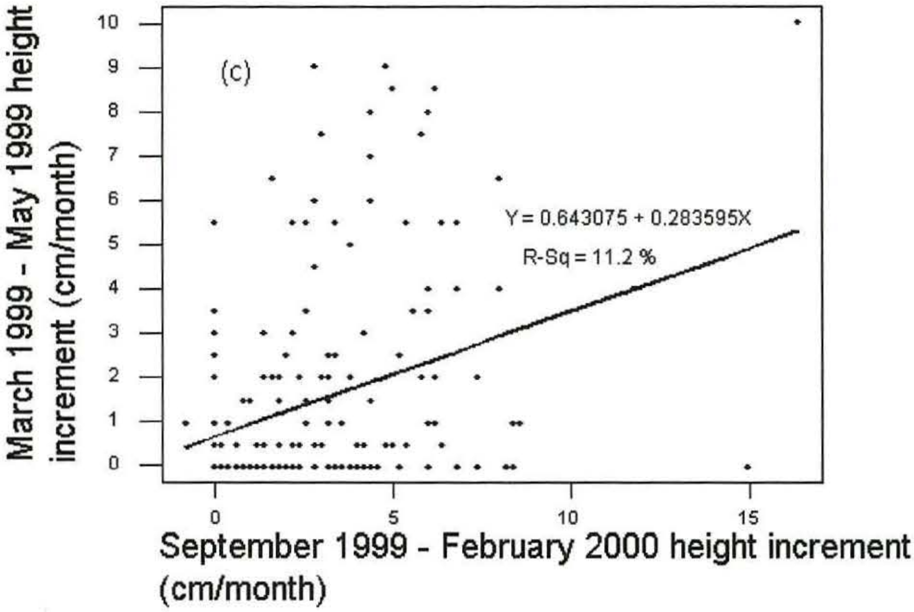


Figure 5.35 Regression plots of *Ocotea usambarensis* March 1999 advance regeneration cohort height increment x height increment relationship in (a) March 1999 - May 1999 against May 1999 - September 1999, (b) May 1999 - September 1999 against September 1999 - February 2000 and (c) March 1999 - May 1999 against September 1999 - February 2000 at Machame, Tanzania.

Regardless of treatment, *Ocotea usambarensis* advance regeneration had its lowest growth rate during the May 1999 - September 1999 growth season and its highest rate during September 1999 - February growth season (Figure 5.36). The growth rates were not significantly different between felled and control plots ($t = 2.01$, $\rho = 0.182$).

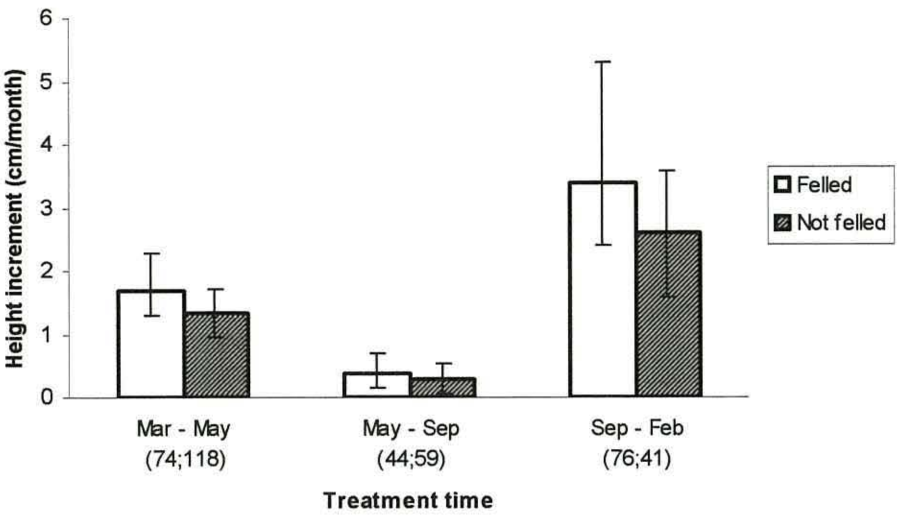


Figure 5.36 *Ocotea usambarensis* advance regeneration root sucker increment comparisons in felled and non-felled plots during March 1999 - May 1999, May 1999 - September 1999 and September 1999 - February 2000 at Machame, Tanzania. Numbers of observations used are indicated in parentheses (felled treatments; not felled treatments).

5.4.3 Kilimanjaro - Rongai

5.4.3.1 Cohorts of advance regeneration

Fagaropsis angolensis and *Podocarpus falcatus* seedlings were marked and monitored for shoot height growth at Rongai. Survival of marked *Fagaropsis angolensis* and *Podocarpus falcatus* was very high (all marked individuals were present in all assessment phases). Appendix 21 lists the initial shoot heights of *Fagaropsis angolensis* and *Podocarpus falcatus* seedlings monitored for shoot height increments from May 1999. The initial heights of these seedlings ranged from 34 cm to 76 cm for *Fagaropsis angolensis* and from 48 cm to 206 cm for *Podocarpus falcatus*.

Appendix 22 lists *Fagaropsis angolensis* and *Podocarpus falcatus* seedlings monitored for height growth from September 1999. The initial shoot heights of seedlings of *Fagaropsis angolensis* ranged from 3 cm to 137 cm while those for *Podocarpus falcatus* ranged from 46 cm to 198 cm.

5.4.3.2 Height increment of advance regeneration

The effect of treatments on height increment of *Fagaropsis angolensis* advance regeneration was statistically significantly different in the September 1999 cohort ($F = 94.78$, $\rho = 0.000$). On the other hand in the May 1999 cohort, neither the effect of treatments nor growth phases on height increment of *Fagaropsis angolensis* advance regeneration were significantly different ($F = 0.64$, $\rho = 0.609$ and $F = 1.56$, $\rho = 0.243$ respectively). Table 5.76 shows *Fagaropsis angolensis* seedlings' advance regeneration had higher (3.50 ± 10.40 cmmonth^{-1}) mean height increments in felled plots than in unfelled plots (0.65 ± 0.48 cmmonth^{-1}). No pre-treatment height increment of *Fagaropsis angolensis* advance regeneration of seedlings was recorded in this study.

Growth phases effect on height increment of *Podocarpus falcatus* advance regeneration was statistically significantly different in the May 1999 cohort ($F = 8.62$, $\rho = 0.007$). Treatment effects were not significantly different in neither May 1999 nor September 1999 cohorts ($F = 1.36$, $\rho = 0.269$ and $F = 1.40$, $\rho = 0.466$ respectively). Table 5.77 shows *Podocarpus falcatus* seedlings' advance regeneration grew faster in felled plots than in the unfelled plots. The highest (2.70 ± 5.52 cmmonth^{-1}) growth rate was in September 1999 - February 2000 growth period. In May 1999 phase pre-treatment height increment of *Podocarpus falcatus* advance regeneration of seedlings was higher than during post-treatment growth phase (Table 5.75).

Table 5.75 Summary of *Podocarpus falcatus* pre-treatment advance regeneration increment variations during two (May 1999 and September 1999) phases at Rongai, Tanzania

Treatment time	Mean increment ± S.E (cm $month^{-1}$)	
	Felled	Not felled
	Pre-treatment height increment (Initially measured in February 1999)	Pre-treatment height increment (initially measured in February 1999)
May 1999	1.88 ± 0.22 (n = 44)	1.72 ± 0.22 (n = 59)
[range, in $cmmonth^{-1}$]	[0 - 6.83]	[0 - 9.67]
September 1999	1.17 ± 0.12 (n = 86)	1.14 ± 0.17 (n = 41)
[range, in $cmmonth^{-1}$]	[-0.90 - 5.30]	[0 - 4.90]

Table 5.76 Summary of *Fagaropsis angolensis* advance regeneration increment variations during two (May 1999 - September 1999 and September 1999 - February 2000) growth phases at Rongai, Tanzania

Treatment time	Mean increment ± S.E (cm $month^{-1}$)			
	Felled		Not felled	
	May '99 - Sep '99	Sep '99 - Feb '99	May '99 - Sep '99	Sep '99 - Feb '99
May 1999 [range, in cm$month^{-1}$]	-	-	0.25 ± 0.11 (n = 6) [0 - 0.75]	0.43 ± 0.12 (n = 6) [0 - 0.8]
September 1999 [range, in cm$month^{-1}$]		3.50 ± 2.07 (n = 4) [0.6 - 4.8]		0.65 ± 0.10 (n = 13) [0 - 5.4]

- , The variable could not be calculated since there was only one individual in felled plots

Table 5.77 Summary of *Podocarpus falcatus* advance regeneration increment variations during two (May 1999 - September 1999 and September 1999 - February 2000) growth phases at Rongai, Tanzania

Treatment time	Mean increment ± S.E (cm $month^{-1}$)			
	Felled		Not felled	
	May '99 - Sep '99	Sep '99 - Feb '99	May '99 - Sep '99	Sep '99 - Feb '99
May 1999 [range, in cm$month^{-1}$]	0.31 ± 0.16 (n = 9) [0 - 1.25]	1.7 ± 0.41 (n = 9) [0.2 - 4.0]	0.25 ± 0.22 (n = 8) [0 - 1.75]	2.3 ± 0.74 (n = 8) [0 - 4.6]
September 1999 [range, in cm$month^{-1}$]		2.70 ± 1.10 (n = 4) [0 - 9.4]		1.95 ± 1.18 (n = 4) [0.2 - 1.6]

The analysed height increment data are for May 1999 - September 1999 growth season for both *Fagaropsis angolensis* and *Podocarpus falcatus.* In neither *Fagaropsis angolensis* nor *Podocarpus falcatus* the relationship between seedlings' advance regeneration height increment against light level statistically significant (Tables 5.78 - 5.81). The scatter plots for the regression lines in tables 5.78 to 5.81 are shown in Figure 5.37. The *Podocarpus falcatus* seedlings' growth rate was, however, higher during the September 1999 - February 2000 growth season than in the May 1999 - September 1999 season, regardless of light level (Figure 5.37).

Table 5.78 Regression of *Fagaropsis angolensis* seedlings' May 1999 advance regeneration increment against light level in felled and non-felled plots (combined) during May 1999 - September 1999 (Phase 2) at Rongai, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	0.05655	0.05655	0.76	0.423
Residual error	5	0.37202	0.07440		
Total	6	0.42857			

Regression equation: May 1999 - September 1999 height increment (cm/month) = 0.449 - 0.0101 Direct light (mol m^{-2} d^{-1})

Table 5.79 Regression of *Fagaropsis angolensis* seedlings' May 1999 advance regeneration increment against light level in felled and non-felled plots (combined) during September 1999 - February 2000 (Phase 3) at Rongai, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	0.0079	0.0079	0.07	0.798
Residual error	5	0.5407	0.1081		
Total	6	0.5486			

Regression equation: September 1999 - February 2000 height increment (cm/month) = 0.547 - 0.0038 Direct light (mol m^{-2} d^{-1})

Table 5.80 Regression of *Podocarpus falcatus* seedlings' May 1999 advance regeneration increment with light level in felled and non-felled plots (combined) during May 1999 - September 1999 (Phase 2) at Rongai, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	0.0117	0.0117	0.04	0.845
Residual error	15	4.4735	0.2982		
Total	16	4.4853			

Regression equation : May 1999 - September 1999 height increment (cm/month) = 0.252 + 0.0027 Direct light (mol m^{-2} d^{-1})

Table 5.81 Regression of *Podocarpus falcatus* seedlings' May 1999 advance regeneration increment with light level in felled and non-felled plots (combined) during September 1999 - February 2000 (Phase 3) at Rongai, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	4.257	4.257	1.51	0.239
Residual error	15	42.388	2.826		
Total	16	46.645			

Regression equation : September 1999 - February 2000 height increment (cm/month) = 0.999 + 0.0513 Direct light (mol m^{-2} d^{-1})

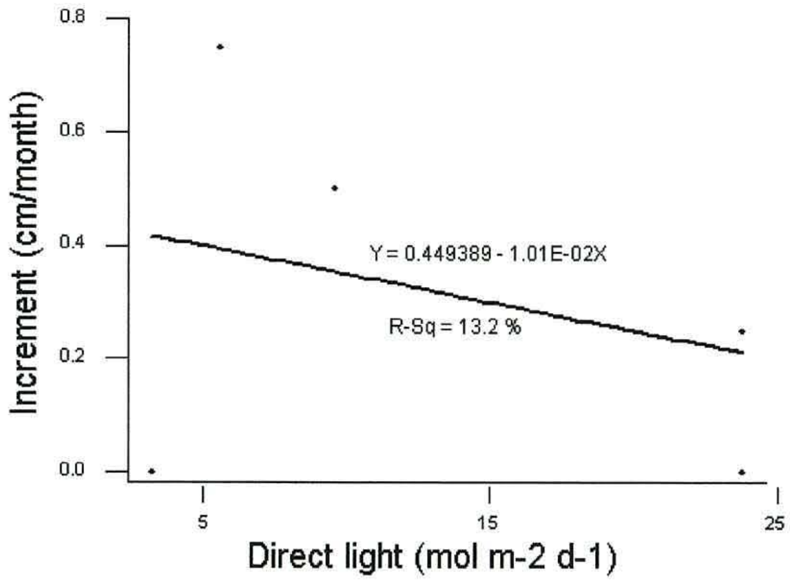


Figure 5.37 (a) Rongai : *Fagaropsis angolensis* May 1999 advance regeneration cohort height increment x light relationship May - September 1999

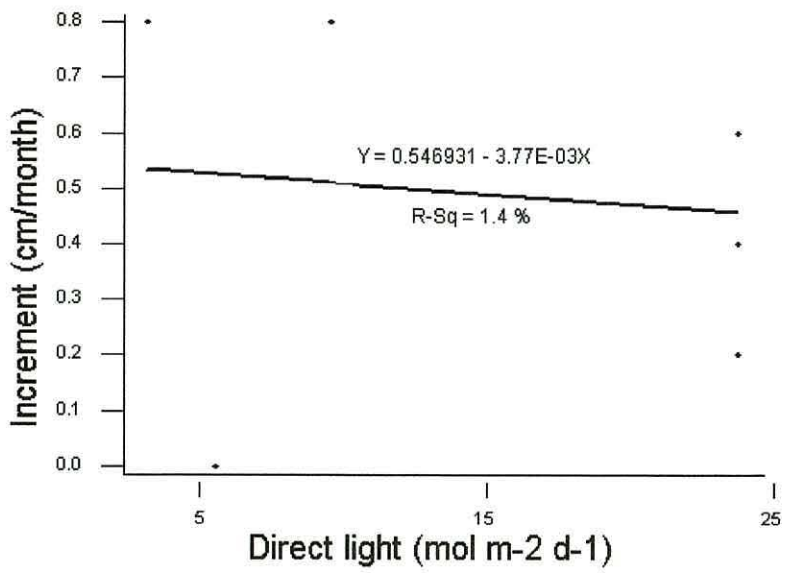


Figure 5.37 (b) Rongai : *Fagaropsis angolensis* May 1999 advance regeneration cohort height increment x light relationship September 1999 - February 2000

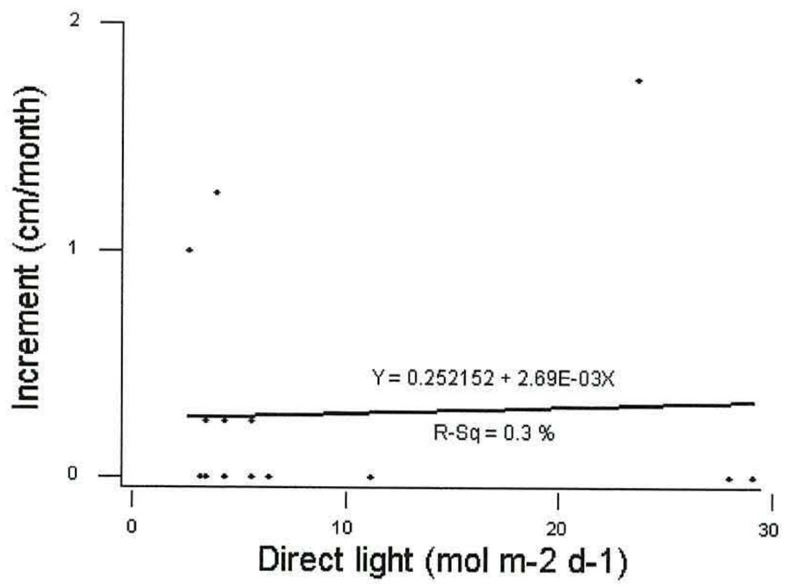


Figure 5.37 (c) Rongai : *Podocarpus falcatus* May 1999 advance regeneration cohort height increment x light relationship May - September 1999

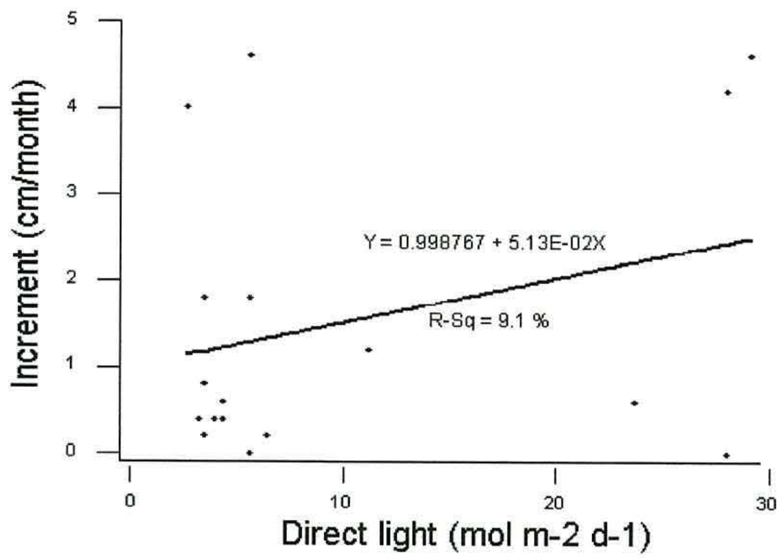


Figure 5.37 (d) Rongai : *Podocarpus falcatus* May 1999 advance regeneration cohort height increment x light relationship September 1999 - February 2000

The relationship between advance regeneration seedling height increment against initial height was not significant in neither *Fagaropsis angolensis* nor *Podocarpus falcatus* (Tables 5.82 - 5.85). These relationships are shown graphically in Figures 5.38 and 5.39 for *Fagaropsis angolensis* and *Podocarpus falcatus* respectively. The relevance of initial height in predicting height increment for *Fagaropsis angolensis* did not exist in May 1999 - September 1999 growth phase (R^2 = 0.0 % in Figure 5.38) while in *Podocarpus falcatus* was weak (R^2 = 0.2 - 2.5% in Figure 5.39).

Table 5.82 Regression of *Fagaropsis angolensis* seedlings' May 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during May 1999 - September (Phase 2) at Rongai, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	0.00003	0.00003	0.00	0.987
Residual error	5	0.42855	0.08571		
Total	6	0.42857			

Regression equation : May 1999 - September 1999 height increment (cm/month) = 0.288 - 0.00005 Initial height (cm)

Table 5.83 Regression of *Fagaropsis angolensis* seedlings' May 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during September 1999 - February 2000 (Phase 3) at Rongai, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	0.17788	0.17788	2.40	0.182
Residual error	5	0.37069	0.07414		
Total	6	0.54857			

Regression equation : September 1999 - February 2000 height increment (cm/month) = 0.281 + 0.00377 Initial height (cm)

Table 5.84 Regression of *Podocarpus falcatus* seedlings' May 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during May 1999 - September 1999 (Phase 2) at Rongai, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	0.0081	0.0081	0.03	0.872
Residual error	15	4.4772	0.2985		
Total	16	4.4853			

Regression equation : May 1999 - September 1999 height increment (cm/month) = 0.225 + 0.00039 Initial height (cm)

Table 5.85 Regression of *Podocarpus falcatus* seedlings' May 1999 advance regeneration increment against initial height in felled and non-felled plots (combined) during September 1999 - February 2000 (Phase 3) at Rongai, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	1.166	1.166	0.38	0.544
Residual error	15	45.478	3.032		
Total	16	46.645			

Regression equation : September 1999 - February 2000 height increment (cm/month) = 0.87 + 0.00475 Initial height (cm)

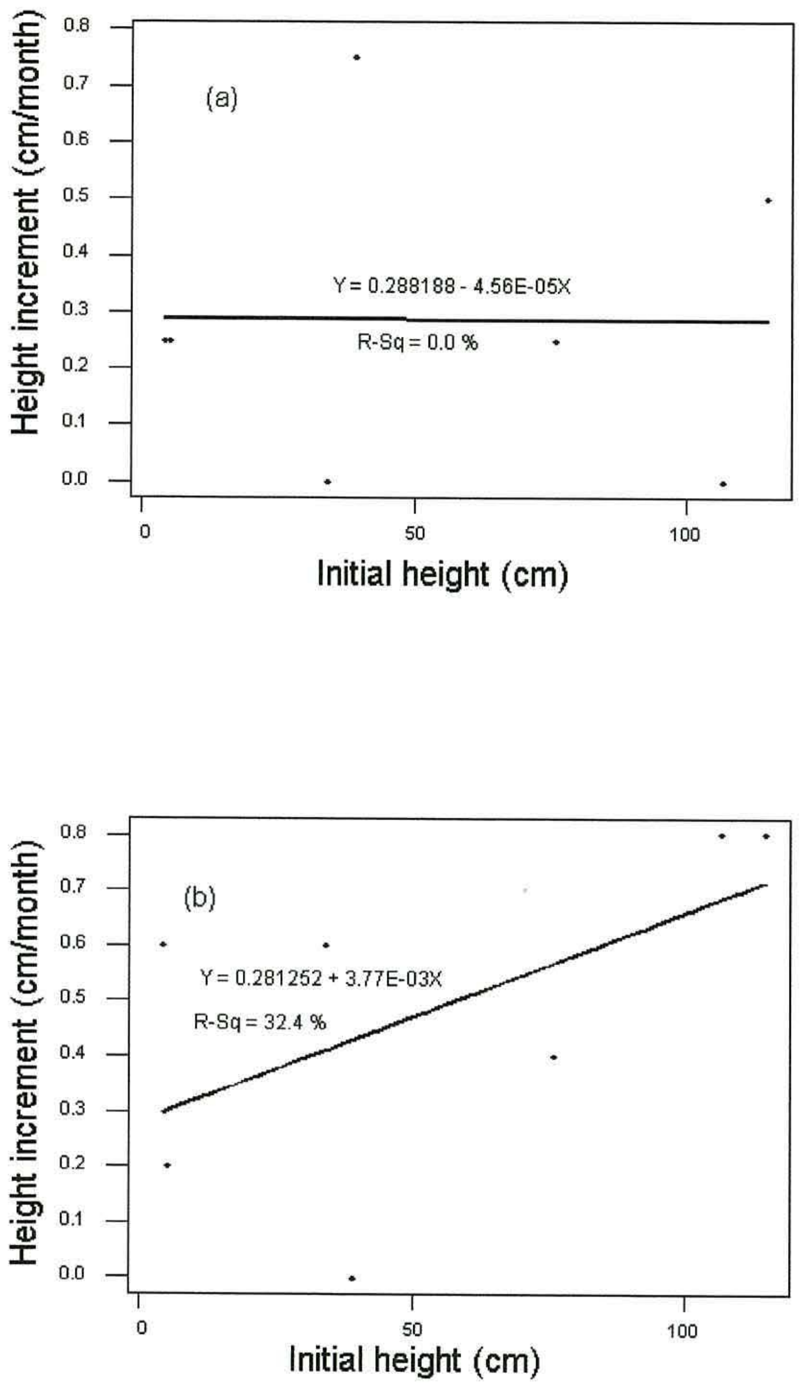


Figure 5.38 Regression plots of *Fagaropsis angolensis* March 1999 advance regeneration cohort height increment x initial height relationship in (a) May 1999 - September 1999 and (b) September 1999 - February 2000 at Rongai, Tanzania.

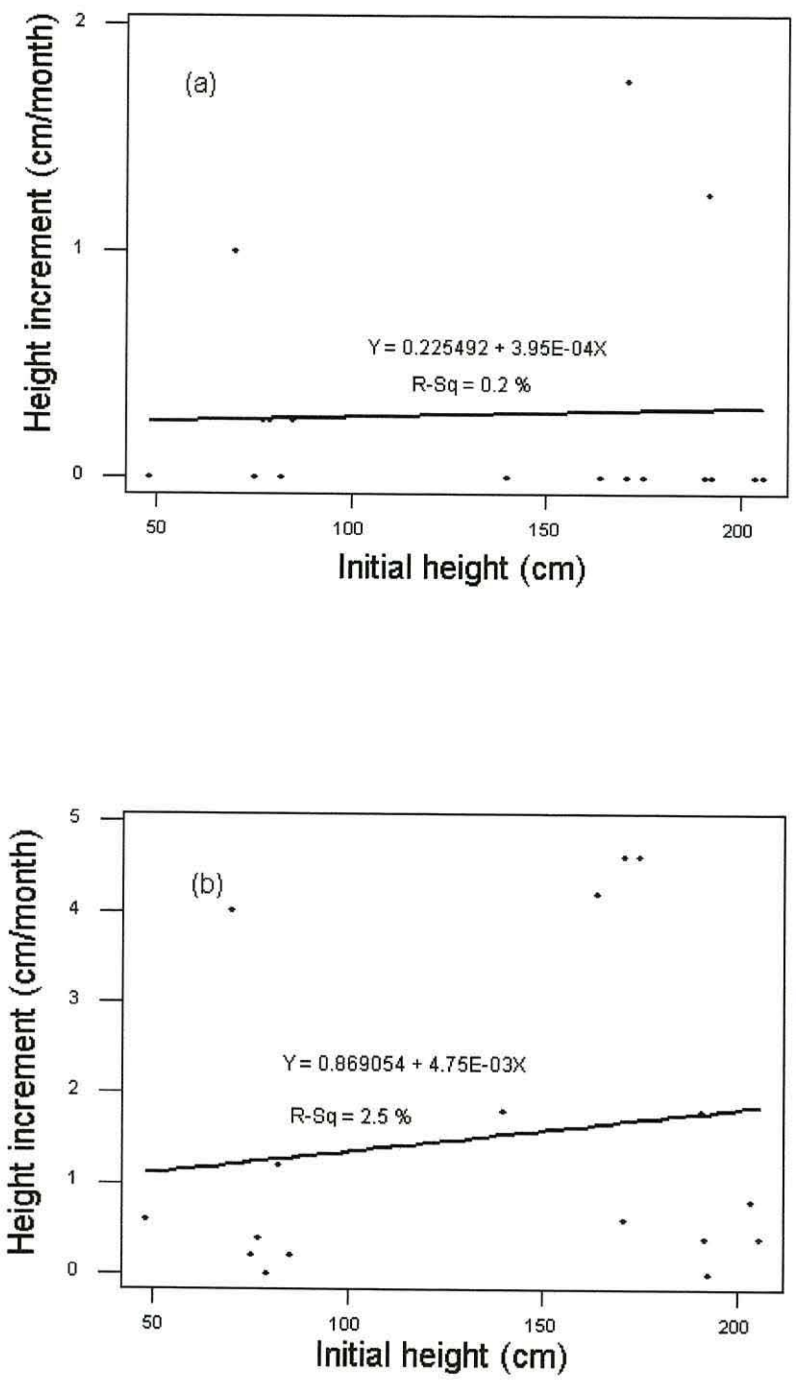


Figure 5.39 Regression plots of *Podocarpus falcatus* May 1999 advance regeneration cohort height increment x initial height relationship in (a) May 1999 - September 1999 and (b) September 1999 - February 2000 at Rongai, Tanzania.

In neither *Fagaropsis angolensis* nor *Podocarpus falcatus* the relationship between height increment of seedling advance regeneration between different growth phases significant (Tables 5.86 and 5.87). Regardless of this, height increment in September 1999 - February 2000 was a better predictor of May 1999 - September 1999 height increment and vice versa in *Fagaropsis angolensis* (R^2 = 31.3% in Figure 5.40) than in *Podocarpus falcatus* (R^2 = 1.1 in Figure 5.40). In both cases the relationship was inverse proportional.

Table 5.86 Regression of *Fagaropsis angolensis* seedlings' May 1999 advance regeneration May 1999 - September 1999 height increment against September 1999 - February 2000 height increment in felled and non-felled plots (combined) at Rongai, Tanzania.

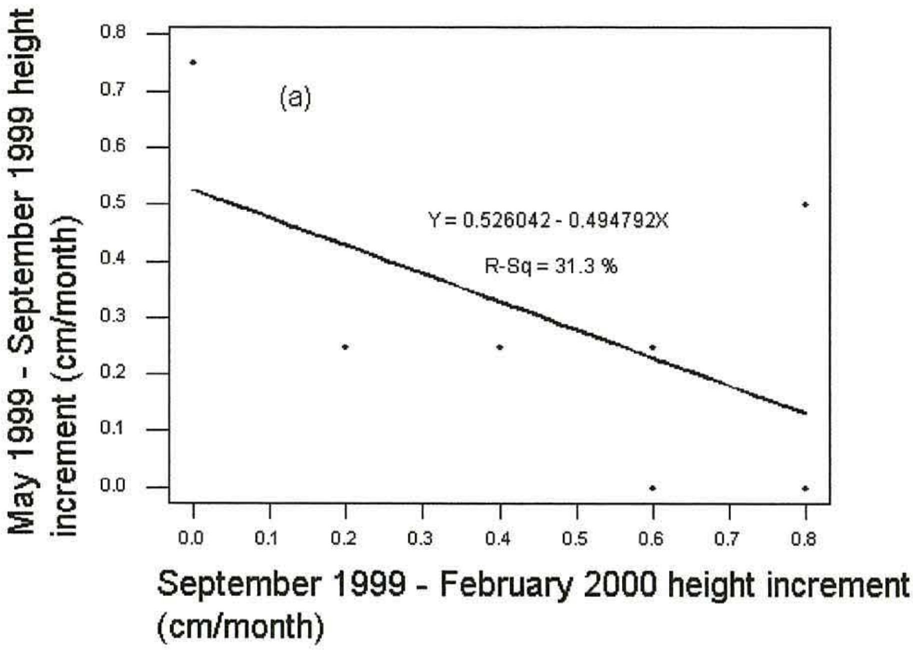
Source of variation	df	SS	MS	F	ρ
Regression	1	0.1343	0.1343	2.28	0.191
Residual error	5	0.29427	0.05885		
Total	6	0.42857			

Regression equation : May 1999 - September 1999 height increment (cm/month) = 0.526 + 0.495 September 1999 - February 2000 height increment (cm/month)

Table 5.87 Regression of *Podocarpus falcatus* seedlings' May 1999 advance regeneration May 1999 - September 1999 height increment against September 1999 - February 2000 height increment in felled and non-felled plots (combined) at Rongai, Tanzania.

Source of variation	df	SS	MS	F	ρ
Regression	1	0.0488	0.0488	0.17	0.690
Residual error	15	4.4365	0.2958		
Total	16	4.4853			

Regression equation : May 1999 - September 1999 height increment (cm/month) = 0.329 - 0.0323 height increment (cm/month)



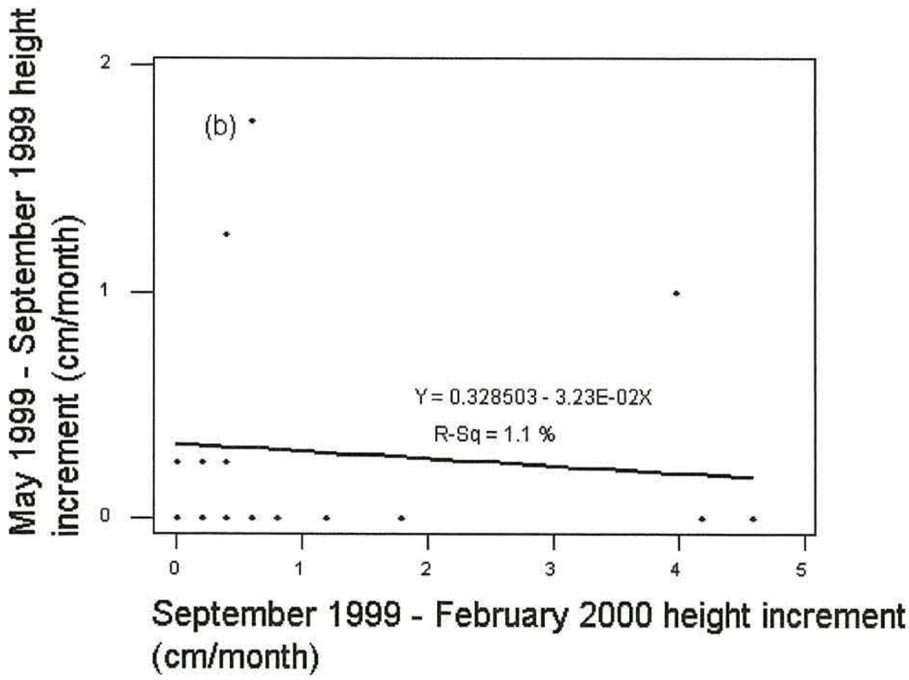


Figure 5.40 Regression plots of *Fagaropsis angolensis and Podocarpus falcatus* May 1999 advance regeneration cohort height increment x height increment relationship in (a) May 1999 - September 1999 against September 1999 - February 2000 for *Fagaropsis angolensis* (b) May 1999 - September 1999 against September 1999 - February 2000 for *Podocarpus falcatus* at Rongai, Tanzania.

Figure 5.41 shows that there is very small difference in height increment of *Podocarpus falcatus* seedling advance regeneration between felled and control plots. These differences were found to be non-significant (t = 1.55, $\rho = 0.366$).

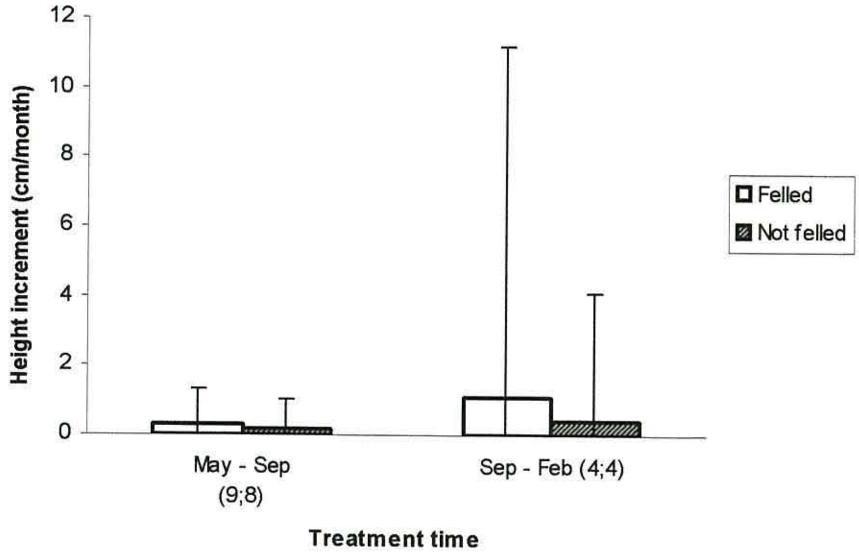


Figure 5.41 *Podocarpus falcatus* advance regeneration seedling increment comparisons in felled and non-felled plots during May 1999 - September 1999 and September 1999 - February 2000 at Rongai, Tanzania. Numbers of observations used are indicated in parentheses (felled treatments; not felled treatments).

CHAPTER SIX : DISCUSSION

This chapter discusses the canopy closure changes and resulting incident light variations due to single tree felling at Chome, Machame and Rongai forests. These changes influenced regeneration recruitment and growth of advanced regeneration of economically important Tanzanian timber trees. The influence of litter/tillage on seedling density is also discussed. The variation in growth of advanced regeneration of studied tree species with initial seedling height and growth phases is reported. Finally, the suitability of the research methods used and the difficulties encountered are discussed.

Felling had only a modest impact on canopy closure; most recorded changes were ± 5% and, as expected larger changes tended to be negative. In Chome, in May, however, the response was more positive. This was mainly due to active growth during this phase since pre- and post-felling records were taken on the same day (within the rainy season Figure 3.3). Pre- and post-felling readings show a general fall in canopy closure. This fall ranged from 0 to 47 percent. The fall is most noticeable, as expected at photosites 5 and 6 (half distance from bole base and one distance from bole base). Similar observations are reported by Clark (1990) and Mack *et al.* (1999). The change become positive in subsequent assessments. Presumably, this would be brought by lateral growth of neighbouring trees considering this was the rainy season at this site. Response in the period following the initial post-felling period was weak or negative (i.e. canopy closure changed little or was reduced) at both sites (Chome, Machame) for which May - September information was collected. More strongly defined responses were recorded for September - February for Chome (positive) and Rongai (negative). Change in the September - February period was small and positive at Machame. September - February extends into the rainy season at Rongai. A general increase in canopy closure is more marked in the September - February period at Machame. Elsewhere no well-defined seasonal period of increasing canopy closure was apparent. Generally, Rongai data include relatively few positive (increase > 10%) responses in terms of canopy closure suggesting that Rongai is a more sensitive ecosystem with less recovery ability after felling. This would be consistent with location on a drier part of the experimental site compared to Machame and Chome and where there are rain shadow effects. No convincing evidence that closure processes vary with photosite position was obtained although at Chome reduced closure seemed were frequent at photosites 4 and 5 (mid-gap). Less variable closure values were recorded towards the gap limits.

The canopy closure changes following single tree felling was accompanied by an increase of estimated direct light reaching the forest understorey (Denslow, 1987; Dirzo *et al.*, 1992; Coates and Burton, 1997; Clearwater, 1997). The results concur with those of (Raich, 1989) who found that mean daily PPFD (Photosynthetic Photon Flux Density) was highly correlated with canopy coverage in both short-term and long-term experiments. The extent of this varied depending on the photosite position, size of felled canopy tree and site. This was an important finding since without canopy opening, many understorey plants rely on sunflecks for their light requirements (Vickery, 1984). Light availability has been reported to be the primary limiting factor of seedling growth (Sasaki and Mori, 1981; Oberbauer *et al.*, 1989; Boot, 1990; Kitajima, 1996; Whitmore and Brown, 1996). If so, then, the increased light reaching the forest floor would be expected to enhance growth of advanced regeneration of light demanding species. Although light flux data in the clearing could not be measured (Barton *et al.*, 1989) and correction for cloudiness (Ter Steege, 1993) could not be made, relative data obtained were sufficient to monitor changes in light conditions below the canopy. Only at Machame was the extent of estimated direct light increase following single tree felling statistically significantly different from control plots. This validates for Machame the hypothesis that the light environment in the forest understorey is changed by single tree felling and suggests that further work (with more observations) at Chome and Rongai would also support the hypotheis. It has been reported that slashing with single tree felling reduces competition for light, water and nutrients (Welander and Ottosson, 2000). Apart from tree species seedlings and saplings, all sampled plots in this study were cleared of undergrowth.

The three sites represented two forest types - camphor (*Ocotea*) forest at Chome and Machame (Afromontane rain forest) and more mixed forest at Rongai (Dry transitional montane forest). This study has been able to assess the regeneration status of the currently exploited timber species in these forests. In general, the regeneration potential of a species includes assessment of the frequency of seed years, the length of seed viability, seedling survival, the general abundance of seedling regeneration on the forest floor, the rate of development and competitive potential of the regeneration, its shade tolerance at the seedling stage, and its height response to canopy opening and increasing light (Wyatt-Smith, 1987). The last five criteria were ascertained during this study. One of the hypotheses was to ascertain whether single tree felling does affect the seedling density of the principle timber tree species present at the site. Although in general felling had no statistically significant influence on seedling density of studied tree species, the closeness of the obtained value to the standard value shows that felling had moderate influence on regeneration of these species. Similar results were obtained by (Sharew *et al.* 1997) who found that there was no evidence that regeneration was correlated with light intensity. The felling effect was different and specific to a particular species. Out of five studied tree species, with felling and soil tilling treatments four species (*Ocotea usambarensis*, *Fagaropsis angolensis*, *Podocarpus falcatus* and *P. latifolius*) showed the potential of regenerating successfully in situ (Appendices 7-14). Although collectively the studied species showed single tree felling had no statistically significance on their regeneration, different results are obtained when the species are treated separately. Thus the importance of considering species separately in an ecosystem emerges (Mostacedo and Fredericksen, 1999). This is because canopy opening (tree felling) may induce regeneration in some species and in others might not (Sharew *et al.*, 1997 and Johnson *et al.*, 1997). The study of Cameron and Ives (1997) showed that canopy openness was weakly correlated with number of regenerating seedlings per plot. On the other hand (Chazdon *et al.*, 1996) found that photosynthetic utilization of light is a major component of the regeneration responses of forest species within the larger context of forest dynamics and succession. The negative results for litter treatment concur with the results by Benitez-Malvido and Kossmann-Ferraz, (1999) who found that differences in litter quantity differentially affect tree species with similar biology (i.e. large seeds, shade tolerance) in life stages other than germination and early establishment. The variability in species responses to litter might be an important factor in determining species richness, abundance and distribution of tropical rain forest tree species at the seedling level. But *Ocotea usambarensis* seedlings have been reported to grow well in an area with a less thick humus and litter layer (Backeus, 1982).

At Chome, many *Ocotea usambarensis* root suckers were recruited in plots which were not felled. In March 1999 statistically significant more root suckers appeared in plots which were not felled than in felled plots. These results agree with those of Abraham (1958) that *Ocotea usambarensis* in its seedling and small-sapling stages are especially susceptible to direct light. It conforms to a non-pioneer plant species which can germinate under-canopy to form a sucker bank before canopy opening (equivalent to the seedling bank of Mabberley, 1992). This explains the presence of fewer *Ocotea* root suckers as advance regeneration under the more broken canopy at Chome compared to the less disturbed forest at Machame (Appendices 15-20). Illegal *Ocotea* exploitation by pitsawing is still rampant at Chome compared to Machame. In almost every plot at Chome there was a pitsawyer's pit nearby. Regeneration of *Ocotea* by root suckers in Machame portrays a different picture. In this forest there was no statistically significant difference in *Ocotea* root suckers appearing after treatment between felled and control plots.

More *Podocarpus latifolius* seedlings were recruited in plots which were not felled. Plots treated in March 1999 showed no statistically significant difference in regeneration in felled and control plots. These results concur with those of Geldenhuys (1996) who reported that this species can regenerate and become established even under the canopy of another species. On the other hand, *Podocarpus falcatus* showed no statistically significant difference in regeneration between felled and control plots. Generally, as in the case of *Podocarpus latifolius*, more seedlings were recruited in control plots especially in plots treated in September 1999 where no seedling was recruited in felled plots. Although there was no statistically significance of *Fagaropsis angolensis* regeneration between felled and control plots, more seedlings were recruited in control plots. The limited recruitment of both species (*Podocarpus latifolius* and *P. falcatus*) may be brought about by the presence of the stony sclerotesta which delays germination up to a year (Geldenhuys, 1993). In other cases, *Podocarpus* regeneration has been reported to be spread in time for up to four years (Healey, 1990; Teketay and Granström, 1997).

One of the important points to consider when the canopy is opened is the timing of opening (Denslow, 1987; Keapoletswe, 1993). Time also has bearing on good seed timing which are required for species which regenerate from seeds (Bobinac *et al*., 2000). In addition, treatment time has a bearing on seedling survival and growth, regardless of species (Manokaran and Swaine, 1994). A noticeable pattern was that a pulse of new regeneration appeared in the period immediately after the March and May treatments were imposed, at all sites (Appendices 7, 8, 10, 11 and 13). However, the picture is incomplete as it was not possible to apply treatments at Rongai in March. The absence or weakness of a response to September treatment (Appendices 9, 12 and 14), although statistical tests showed lack of seasonal contrast at Chome and Rongai, suggests a seasonal influence is interacting with treatment. The stronger March treatment effect at Chome (compared with May at Chome - Appendices 7 and 8 respectively) supports a seasonal effect. The stronger May response at Rongai (compared with the May responses at Chome and Machame - Appendices 13, 8 and 11 respectively) could be similarly explained considering the different pattern of climatic seasonality at Rongai. However, interpretation is complicated because the forest at Rongai is of a different type and the target species there are different.

Of the target species it seems that *Ficalhoa* regenerates irregularly - perhaps under conditions that did not arise during the study period. Whether the abundance of *Podocarpus latifolius* and *P. falcatus* regeneration was in response to a general treatment impact (unlikely) or reflects a normal annual situation is unclear. *Fagaropsis* regeneration at Rongai is similarly interpreted. *Ocotea* is well-known, relatively, silviculturally and the proliferation of suckers in the plots conforms to existing knowledge of this species (Holmes, 1995b).

A worst-case scenario for the future of tropical forests is based on beliefs that tropical forests are unusually fragile, that continued population growth will raise demands for forest products beyond what they can produce, that increased dependence on technology will result in faster and more catastrophic destruction of resources, and that human greed, misguided public policies, and market failure will also cause destruction of tropical forests no matter what else is done to protect them (Lugo, 1995). Today, ecologists emphasize tropical forest resiliency and its capacity to regenerate after natural disturbances (Leslie, 1994). Humans must step up management activities to include the whole landscape over a long-term scale and use ecologically sensitive technologies to rehabilitate damaged ecosystems (Lugo, 1995). One of the challenges of forest management today is how to promote the regeneration of species with high economic value, in order to maintain their populations, and preserve their genetic variability (D'Oliveira, 2000). There is clear evidence that management, when properly done, can stimulate natural regeneration of desirable species. Thus, the real challenge is to identify the appropriate management intervention which will promote regeneration of desirable species. Knowledge of the patterns and processes with which species regenerate in small and large gaps can be seen as a prerequisite for the design of forest management systems based on the natural dynamics of tropical rain forests (Boot, 1990). When removal is limited to increment, and sufficient time is allowed for natural recovery, a natural management in that pure sence may be possible (FAO, 1989). A series of other factors (phenology, seed viability, predation, dispersion and availability of seeds) also influence the success of the natural regeneration of the desirable species (D'Oliveira, 2000). All these could not be identified in current study.

Advance growth could be monitored for *Ocotea* suckers at Chome (a few) and Machame (many). A limited number of *Podocarpus latifolius* individuals were available for monitoring at Chome and a few *Podocarpus falcatus* and *Fagaropsis* at Rongai. *Ocotea* advance growth grew relatively well in the September - February period at Chome and Machame compared with the other periods in both Chome and Machame indicating a seasonal growth cycle. *Ocotea* suckers vary widely in growth, even within a site, over the same period presumably because of micro-environmental factors that directly influence the individual shoots concerned. In the main growing season at Chome (March to May) the most vigorous shoots extended considerably while growth was negligible in many others. March to May was also the period of most active *Ocotea* growth at Machame. It is noteworthy that this seasonality contracts with the timing when new regeneration appeared at these sites. This shows that single tree felling affects the growth of advance regeneration of the principle timber tree species present at the site. This concurs with the observations of (Clearwater, 1997) who found that dipterocarp seedling height and leaf totals increased rapidly with small increases in light availability after logging, but above 5 mol m^{-2} day^{-1} PPFD there was little further increase in seedling size. Also (Mack *et al.*, 1999) found that seedlings transplanted to gaps grew faster and had more leaves, larger total leaf surface area, longer secondary roots, and greater root mass than shaded seedlings. Although growth of seedlings is improved by higher light levels caused for example by logging, great care should be taken with logging intensity, which may increase seed mortality (Ter Steege *et al.*, 1994). The results have also shown that *Ocotea usambarensis* in its seedling and sapling stages is a non-pioneer shade tolerant. As such its advance regeneration can well withstand delayed release. Species that are tolerant of shade are usually found to be slower growing in high PPFD than less shade tolerant species (Clearwater, 1997). It has been reported that *Ocotea usambarensis* beyond sapling stage is a light demander. This concurs with the observations of Kimaryo, (1971) that the best average height growth in *Ocotea usambarensis* beyond the sapling stage is attained where felling has taken place. Advance regeneration of Chome *Podocarpus latifolius*, Rongai *Fagaropsis angolensis* and Rongai *Podocarpus falcatus* respectively grew faster in felled plots. These species can very well classified as non-pioneer light demanders. As such growth of their advance regeneration is enhanced by canopy opening which increases the amount of light reaching the forest floor. This implies that early release is beneficial to these species. Light demanding and large upper storey species are reported to grow faster than shade-tolerant and lower storey species (Felfili, 1995). These results concur with the observations of Healey (1990) for *Podocarpus urbanii* and Geldenhuys (1993) for *Podocarpus falcatus* that *Podocarpus* responds well to canopy opening. The results also agree with the general literature that advance regeneration grows better in gaps than under closed canopy (Turner, 1990; Flores, 1992; Ter Steege, 1993; Osunkoya *et al.*, 1994; Tappeiner *et al.*, 1997; Franklin *et al.*, 1997; Clearwater, 1997; Fraver *et al.*, 1998 and Clearwater *et al.*, 1999). Whether shade tolerant or light demander in seedling and sapling stages, the results show the importance of ensuring the presence of advance regeneration on the forest understorey before a felling decision is made. This can be done through pre-felling seedling inventory of target species as done for dipterocarp forests in Asia (Clearwater, 1997). Post-felling seedling inventory would also prove to be useful in order to assess how many seedlings escaped the logging disturbance. This is because survival of advance regeneration and seedling establishment are sparse under the fallen crowns of new treefalls (Denslow, 1987).

A different picture is portrayed with the Chome *Ocotea usambarensis* population where advance regeneration grew faster in control. Possibly the lower growth rate was caused by illegal pitsawing, which is rampant, opening the forest even further. *Ocotea usambarensis* has been reported to be susceptible to direct light in its seedling and small-sapling stages although in its large-sapling, pole and tree stages is essentially a light demander (Abraham, 1958). These observations concur with those of Saenz and Guariguata (2001) for *Ocotea austinii* that its saplings grew faster to overstorey removal than seedlings. The situation is worsened by carelessness during felling and processing, when a lot of advance regeneration and residual trees are destroyed (Howard, 1991). The lower growth rate in combination with natural mortality eventually reduces the amount of advance regeneration in the forest understorey.

While no clear treatment effects emerged for *Ocotea,* or the other target species, there is some indication that at Machame suckers monitored in the tilled treatments did not respond with as much growth as other suckers (Appendices 18, 19 and 20). Possibly, direct damage in the tilled strips interrupted growth and if monitoring had continued longer active extension might have resumed after a lag. However, the March - May period, when this apparent effect was noted, was one of minimal activity in the sucker population as a whole. It was not noted during the May - September or September - February periods but this could have been because it was obscured by overall high variability in response from sucker to sucker. There was no suggestion that particular *Ocotea* individuals demonstrated sustained growth among the large number monitored at Machame. Periods of vigorous extension were followed by periods of relative quiescence in this study.

Podocarpus latifolius advance growth at Chome differed from that of *Ocotea* suckers. Smaller *Podocarpus* individuals increased more in height, although this was in the March - May period, generally one of low growth. Like *Ocotea* suckers at the same site, increment was higher in the May - September and September - February periods. Seasonality in increment was clearly shown, despite the few individuals monitored, for *Fagaropsis* at Rongai : all individuals growing faster from September - February than in the preceding May - September period. Thus at all three sites the data collected suggest advance growth grows more in September - February period. This period extends into the rainy season at Rongai (Appendix 4) and into the relatively dry period at Chome and Machame (Figure 3.3 and Appendix 5 respectively).

The growth of advanced regeneration in response to canopy opening has been reported to depend on initial seedling height at the time of opening (Manokaran and Swaine, 1994). The response tends to reinforce any pre-existing dominance hierarchy (Brown *et al.*, 1999). It has also been reported that maximum height growth rates increase with increasing plant size, but average growth rates are not; this disparity suggests the importance of release from understorey suppression for long-term recruitment success (De Steven, 1994). The results of this study have shown that the relationship between height increment against initial height vary between species. As such the relationships should be considered on species basis. This makes a possibility of predicting future growth of species having strong relationship between initial height of advance regeneration against height increment (Chome *Ocotea usambarensis*, *Podocarpus latifolius* and Machame *Ocotea usambarensis*) interesting to the forest managers.

The predictive nature of growth of advance regeneration in one growth phase to the other should not be under-estimated. This may help in predicting the growth and hence future stocking of the forest. In one study seedlings were found to show a clear positive growth response in the second growing season after release (Sundkvist, 1993). In this study, this power has been shown to be effective in *Ocotea usambarensis* at both Chome and Machame. In the other species (*Podocarpus latifolius*, *Podocarpus falcatus* and *Fagaropsis angolensis*) the relationship was weak. This growth variations between growth phases is mainly due to differences in climatic conditions. Climate is one of the parameters which determine distribution and performance of plants in a particular place (Lind and Morrison, 1974). Climates may differ not necessarily between seasons but within a season in the same forest e.g. in a forest gap (Raich, 1989). This is because forest gaps are not discreet areas; they are environmental continua in both space and time.

The study was very demanding logistically because of the geographical locations of the sites and the need to visit them physically every time assessment was due. The sites experience different seasonality and, in certain instances it was impossible to make some scheduled visits due to unsuitable weather (e.g. Rongai in March 1999). The amount of advance regeneration sampled for monitoring was considerable. An average of ten seedlings or root suckers were monitored per strip - a total of some 5760 seedlings and root suckers for the whole study. These were marked and measured individually every time the sites were visited.

Hemispherical photography is versatile and easy to use (Becker *et al.*, 1989). Its non-destructive nature is an added advantage for conservation forestry. Measures obtained from hemispherical photographs analysis are considered better correlated with gap microclimate than gap area measured physically on the ground (Whitmore *et al.*, 1993).

Generally speaking then, as a research tool, fisheye (hemispherical) photographic analysis provides an accurate, reproducible method of characterizing understorey light conditions, levels of competition, and canopy architecture (Chan *et al.*, 1986). But this requires availability of light readings in the open and cloudiness conditions in order to estimate absolute incident light values (Pearcy, 1989; Clearwater, 1997). The hemispherical photography technique can also monitor well changes in light conditions and canopy closure.

However, in the collection of light data some problems arise. Images have to be taken before 8.00 h or after 16.00 h, local time, when the sun is not overhead. This limits the number of plots which can be processed in a day. The processing rate in this study was four plots (two control and two felled) in a day. More time was required in plots where the felling treatment was applied since hemispherical photographs had to be taken before and after treatment. Time elapses between these two situations while the feller decides the felling direction and clears the stump area. Therefore, after pre-felling hemispherical photographs were taken in a plot, the photographer moved to a control plot to take photographs while the tree feller continued with the felling operation. The photographer had to return to the previous plot soon after felling activity to take the post-felling images. When two plots receiving attention on the same day were distant from each other, the time to move between them was long. Hence planning was important to ensure that the set of plots to be processed was located as close together as possible. The technique produces more reliable data in areas where there is robust meteorological information to use in the hemispherical image analysis.

There was some disruption from vandalism in the form of theft of marking pegs, manilla strings and occasional the cutting of individuals marked for height monitoring. This sometimes made re-identification of plot boundaries difficult. In a study restricted to a single site, a guard could be engaged to protect plots in the researcher's absence.

CHAPTER SEVEN : CONCLUSION AND RECOMMENDATIONS

At the scale of this study none of the ground-level treatments applied had significant influence on seedling density of *Ocotea usambarensis*, *Podocarpus latifolius*, *Fagaropsis angolensis* and *Podocarpus falcatus* at Chome, Machame and Rongai. Regeneration responses recorded were in some instances brought by single tree felling while in others were apparently a consequence of the general disturbance of plot establishment. There is a response to felling in the form of the subsequent appearance of regeneration and timing felling appropriately should maximize this. As far as stimulating the appearance of new regeneration is concerned, the response to felling is early. This indicates that the effect of felling operation in stimulating new regeneration can be gauged within a few months i.e. depends on species presence in soil seed bank / immediate seed rain.

For *Podocarpus latifolius* seedlings at Chome and *Fagaropsis angolensis* seedlings at Rongai there was negative felling effects in this study. There were no indications of felling effect on *Ocotea usambarensis* suckers at Machame. It would be premature to assume responses at different sites or from different species were the same. For *Podocarpus latifolius* seedlings at Chome and for *Fagaropsis angolensis* seedlings at Rongai the clearest increment effect was that of the seasonal cycle. There was also evidence of a seasonal cycle of increment in *Ocotea usambarensis* suckers at Chome and Machame. All of the studied species can be classified as non-pioneer species since they had advance regeneration in closed forests. As *Ocotea usambarensis* in both Chome and Machame forests could withstand shade in their seedling and sapling stages, it can be classified as non-pioneer shade-tolerant (NPST) at these stages. After these stages, its growth is enhanced by canopy opening. On the other hand, both *Podocarpus* species (*Podocarpus latifolius* and *P. falcatus*) and *Fagaropsis angolensis* are non-pioneer light demanders (NPLD) in their seedling and sapling stages. Thus in order to enhance growth of studied species early release of *Podocarpus latifolius*, *P. falcatus* and *Fagaropsis angolensis* is advantageous while delayed release in *Ocotea usambarensis* beyond seedling and sapling should work well.

Simple and effective management treatments for Afromontane forest remain elusive and no useful pointers emerged from this study. Felling had only a modest impact on canopy closure and this may be part of the explanation, any litter and tilling effects were at levels too low to detect in the absence of more light penetration. Single-tree gaps are too small to generate sufficiently uniform forest floor conditions to justify management use as a forest regeneration technique. Larger gaps and or greater frequency of disturbance might be a more useful management tool. Possibly forest of the Rongai type, White's (1983) "undifferentiated Afromontane forest", renews canopy less rapidly than Afromontane rain forest.

Monitoring of regeneration responses to changes in growing conditions due to forest management / exploitation activity should take close account of conditions at the level of the regenerating individual shoot. This would overcome the problem of relating responses to more general environmental measures from groups of individuals differing in stature and phases of growth activity. Investigation of tillage and litter removal / retention as possible means of encouraging the regeneration of desirable economic trees should be extended but larger individual units should receive treatments. As securing regeneration of *Fagaropsis*, *Ocotea* and *Podocarpus* appears straight forward, attention should now be concentrated on the survival and vigorous growth of seedlings into larger individuals. With additional data on fecundity (seed production) and growth on higher size classes of studied species, the collected growth data of seedlings and saplings may be useful for prediction of the stability and future population size and structure of the species populations within studied forests by transition matrix models (Enright and Ogden, 1979).

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APPENDICES

Appendix 1. Height measurements for advance growth of regeneration of *Ocotea usambarensis* and *Podocarpus latifolius*, first recorded in March 1999, sorted by forest, plot, strip/treatment and measurement data

Forest	Plot (target tree)	Strip/treatment	Regenerating species	December 1998 (cm)	March 1999 (cm)	May 1999 (cm)	September 1999 (cm)	February 2000 (cm)
1	1 *Ocotea usambarensis*	3/ flT	*O. usambarensis*	190	217	217	217	243
			O. usambarensis	154	173	177	177	186
			O. usambarensis	210	211	211	211	233
		4 /fLt	*O. usambarensis*	151	151	151	151	163
			O. usambarensis	119	126	137	144	176
			O. usambarensis	112	120	122	127	123
			O. usambarensis	77	85	86	89	116
			O. usambarensis	139	148	148	148	151
			O. usambarensis	77	99	100	102	134
			O. usambarensis	78	94	94	94	131
			O. usambarensis	73	91	91	93	104
		5/ flt	*O. usambarensis*	37	65	65	66	77
		6/ fLT	*O. usambarensis*	65	81	85	85	122
			O. usambarensis	84	91	92	94	94
		7/ flT	*O. usambarensis*	105	120	120	125	135
	2 *Ocotea usambarensis*	1/ flt	*O. usambarensis*	57	60	63	63	67
			O. usambarensis	108	138	153	153	182
			O. usambarensis	214	241	241	241	241
		2/ fLT	*O. usambarensis*	66	67	67	67	93
			O. usambarensis	55	55	57	57	73
			O. usambarensis	51	51	51	51	70
			O. usambarensis	25	50	51	51	57
			O. usambarensis	86	117	117	124	125
		3/ flT	*O. usambarensis*	180	195	196	196	203
			O. usambarensis	53	59	61	61	91
		5/ flt	*O. usambarensis*	243	246	246	249	270
			O. usambarensis	166	173	173	174	179
			O. usambarensis	43	49	60	60	60

		O. usambarensis	256	267	267	270	278
		O. usambarensis	217	221	221	223	223
	6/fLT	*O. usambarensis*	127	127	128	128	131
		O. usambarensis	138	161	162	163	175
		O. usambarensis	126	139	141	141	184
	7/ flT	*O. usambarensis*	70	73	78	81	107
		O. usambarensis	85	90	91	91	92
		O. usambarensis	71	86	89	89	93
	8/ fLt	*O. usambarensis*	154	159	160	160	169
		O. usambarensis	66	73	73	73	81
		O. usambarensis	63	68	76	76	116
3 *Ocotea usambarensis*	1/ flt	*O. usambarensis*	80	107	107	107	111
		O. usambarensis	41	44	49	50	60
		O. usambarensis	56	58	63	65	75
		O. usambarensis	160	160	160	160	167
		O. usambarensis	72	87	87	92	106
		O. usambarensis	98	106	122	122	144
		O. usambarensis	106	111	122	122	135
		O. usambarensis	132	139	156	156	187
	2/ fLT	*O. usambarensis*	91	95	102	110	138
		O. usambarensis	47	53	62	62	76
		O. usambarensis	95	98	98	101	131
		O. usambarensis	99	110	120	123	142
		O. usambarensis	75	75	75	75	75
	3/ flT	*O. usambarensis*	79	97	98	98	105
		O. usambarensis	53	62	62	63	70
		O. usambarensis	186	194	194	194	224
		O. usambarensis	113	114	127	132	140
	4/ fLt	*O. usambarensis*	66	67	73	73	73
		O. usambarensis	31	33	37	39	51
		O. usambarensis	30	31	31	33	42
	5/ flt	*O. usambarensis*	79	79	83	84	91
		O. usambarensis	74	79	91	91	113

		O. usambarensis	45	47	54	55	68
		O. usambarensis	40	41	46	46	62
		O. usambarensis	129	131	143	143	157
		O. usambarensis	131	133	137	137	152
		O. usambarensis	96	104	104	104	121
		O. usambarensis	106	114	130	130	160
		O. usambarensis	73	80	95	95	110
	6/ fLT	O. usambarensis	128	143	143	143	160
		O. usambarensis	93	96	103	108	138
		O. usambarensis	115	118	118	120	122
		O. usambarensis	141	149	149	150	166
		O. usambarensis	51	51	51	51	51
		O. usambarensis	39	43	47	48	56
		O. usambarensis	163	164	164	164	185
	7/ flT	O. usambarensis	125	134	136	136	136
		O. usambarensis	80	94	98	100	119
		O. usambarensis	95	95	99	99	99
		O. usambarensis	152	156	158	163	181
	8/ fLt	O. usambarensis	49	49	60	61	78
		O. usambarensis	122	130	131	131	152
		O. usambarensis	94	102	102	102	144
		O. usambarensis	44	46	50	56	72
4 *Ocotea usambarensis*	1/ Flt	O. usambarensis	61	65	65	65	68
		O. usambarensis	167	179	179	179	202
		O. usambarensis	135	165	185	195	277
	2/ FLT	O. usambarensis	121	219	219	219	256
	3/ FIT	O. usambarensis	168	187	187	199	233
		O. usambarensis	123	163	163	163	164
	4/ FLt	O. usambarensis	133	136	138	138	154
		O. usambarensis	87	90	90	90	90
5 *Ocotea usambarensis*	1/ Flt	O. usambarensis	185	216	216	216	238
		O. usambarensis	189	189	192	199	212

		O. usambarensis	114	148	161	161	201
		O. usambarensis	84	91	96	98	115
		O. usambarensis	97	97	115	117	131
		O. usambarensis	66	74	91	93	118
		O. usambarensis	158	165	166	166	177
	2/ FLT	*O. usambarensis*	52	56	62	62	69
		O. usambarensis	65	72	79	80	80
		O. usambarensis	114	125	126	131	137
		O. usambarensis	58	76	84	86	145
	3/ FIT	*O. usambarensis*	155	172	172	172	186
	4/ FLt	*O. usambarensis*	180	196	210	215	237
		O. usambarensis	179	193	193	193	268
		O. usambarensis	183	194	205	205	216
		O. usambarensis	79	83	91	91	121
		O. usambarensis	60	82	93	95	122
	5/ Flt	*O. usambarensis*	120	144	155	156	190
		O. usambarensis	74	87	95	97	131
		O. usambarensis	57	66	84	85	109
		O. usambarensis	83	93	95	104	135
	6/ FLT	*O. usambarensis*	61	66	68	70	112
		O. usambarensis	51	62	67	67	83
	7/ FIT	*O. usambarensis*	94	100	100	100	126
6 *Ocotea usambarensis*	1/ Flt	*O. usambarensis*	64	68	68	69	78
	2/ FLT	*O. usambarensis*	175	204	205	205	217
		O. usambarensis	97	99	102	104	113
	6/ FLT	*O. usambarensis*	172	179	179	181	183
		O. usambarensis	57	67	68	69	89
		O. usambarensis	79	89	89	93	111
	7/ FIT	*O. usambarensis*	44	44	45	45	45
		O. usambarensis	169	175	181	181	202
		O. usambarensis	186	194	194	196	214
		O. usambarensis	189	193	204	206	206

7 *Ocotea usambarensis*	1/ Flt	*O. usambarensis*	132	161	161	161	187
		O. usambarensis	63	63	67	67	91
		O. usambarensis	63	64	64	65	67
		O. usambarensis	103	125	125	125	145
	2/ FLT	*O. usambarensis*	106	131	134	134	143
		O. usambarensis	61	65	65	65	65
	3/ FIT	*O. usambarensis*	63	80	80	80	80
		O. usambarensis	107	112	112	113	114
		O. usambarensis	90	92	92	93	93
		O. usambarensis	178	192	192	192	215
		O. usambarensis	94	110	110	110	115
		O. usambarensis	70	78	78	78	78
	4/ FLt	*O. usambarensis*	149	166	171	171	171
		O. usambarensis	66	85	89	89	120
		O. usambarensis	86	107	107	108	113
		O. usambarensis	65	72	72	72	75
		O. usambarensis	40	45	51	55	66
		O. usambarensis	127	133	134	136	142
	5/ Flt	*O. usambarensis*	99	114	114	118	122
		O. usambarensis	53	67	67	67	72
		O. usambarensis	210	228	228	228	258
		O. usambarensis	112	112	112	112	113
		O. usambarensis	123	135	136	136	151
	6/ FLT	*O. usambarensis*	78	90	90	90	110
		O. usambarensis	193	203	203	212	228
		O. usambarensis	109	114	114	114	114
	7/ FIT	*O. usambarensis*	43	48	49	49	63
		O. usambarensis	206	206	211	216	216
		O. usambarensis	204	227	227	228	269
		O. usambarensis	219	235	236	237	262
	8/ FLt	*O. usambarensis*	162	166	168	173	175
		O. usambarensis	39	51	52	52	64
8 *Ocotea usambarensis*	1/ flt	*O. usambarensis*	188	199	199	199	199

	O. usambarensis	231	255	257	257	270
	O. usambarensis	188	188	188	188	188
	O. usambarensis	134	137	137	137	137
	O. usambarensis	88	104	105	105	111
	O. usambarensis	187	206	206	206	208
	O. usambarensis	93	102	102	102	116
2/ fLT	*O. usambarensis*	120	135	135	157	177
	O. usambarensis	113	122	122	122	123
	O. usambarensis	57	60	60	60	83
	O. usambarensis	153	160	161	161	185
	O. usambarensis	103	110	110	110	110
	O. usambarensis	170	184	184	184	195
3/ flT	*O. usambarensis*	126	130	130	130	130
	O. usambarensis	96	97	97	97	97
	O. usambarensis	113	122	122	122	124
	O. usambarensis	96	108	111	111	133
	O. usambarensis	47	47	47	47	47
4/ fLt	*O. usambarensis*	195	205	205	206	206
	O. usambarensis	117	119	119	121	128
	O. usambarensis	56	57	57	57	58
	O. usambarensis	99	112	112	116	123
5/ flt	*O. usambarensis*	148	150	150	150	170
	O. usambarensis	106	114	114	114	120
	O. usambarensis	89	91	94	94	110
6/ fLT	*O. usambarensis*	150	150	150	150	154
	O. usambarensis	88	92	92	92	93
7/ flT	*O. usambarensis*	123	144	144	144	165
	O. usambarensis	38	55	58	59	64
	O. usambarensis	101	101	101	101	115
	O. usambarensis	93	116	120	120	149
8/ fLt	*O. usambarensis*	147	153	153	153	163
	O. usambarensis	182	192	192	192	208
	O. usambarensis	79	82	82	82	84
	O. usambarensis	115	116	116	118	126

	9 *Ocotea usambarensis*	2/ FLT	*O. usambarensis*	67	67	67	67	74
2	1 *Ocotea usambarensis*	3/ flT	*Podocarpus latifolius*	46	50	51	52	61
			Podocarpus latifolius	92	94	98	100	100
		4/ fLt	*Podocarpus latifolius*	28	33	33	34	39
			Podocarpus latifolius	105	105	105	106	112
			Podocarpus latifolius	69	75	75	77	81
		5/ flt	*Podocarpus latifolius*	65	70	72	73	86
			Podocarpus latifolius	56	62	64	64	64
			Podocarpus latifolius	36	38	38	38	43
		6/ fLT	*Podocarpus latifolius*	171	174	174	174	174
			Ocotea usambarensis	133	171	181	211	268
			Ocotea usambarensis	102	116	116	116	134
	2 *Podocarpus latifolius*	1/ Flt	*Ocotea usambarensis*	108	108	108	108	137
			Ocotea usambarensis	32	49	49	51	62
		5/ Flt	*Podocarpus latifolius*	38	38	38	38	39
		8/ FLt	*Podocarpus latifolius*	21	21	26	26	35
	3 *Ocotea usambarensis*	3/ flT	*Podocarpus latifolius*	30	31	32	33	33
			Podocarpus latifolius	22	24	27	32	32
		4/ fLt	*Podocarpus latifolius*	72	72	76	76	78
			Podocarpus latifolius	135	146	150	152	163
		6/ fLT	*Podocarpus latifolius*	206	213	213	215	215
		7/ flT	*Podocarpus latifolius*	103	108	112	112	122
	4 *Ficalhoa laurifolia*	6/ FLT	*Podocarpus latifolius*	143	145	146	146	160
		7/ FIT	*Podocarpus latifolius*	106	106	107	108	120
			Podocarpus latifolius	64	66	67	68	68
			Podocarpus latifolius	82	86	86	86	96
		8/ FLt	*Podocarpus latifolius*	179	182	183	183	190
	5 *Ocotea usambarensis*	1/ flt	*Podocarpus latifolius*	103	105	105	105	105

	2/ fLT	*Podocarpus latifolius*	39	42	43	45	47
		Podocarpus latifolius	47	49	50	51	57
		Podocarpus latifolius	131	131	131	131	131
		Podocarpus latifolius	118	118	118	118	118
		Podocarpus latifolius	111	111	112	112	112
		Podocarpus latifolius	64	68	68	69	70
	3/ flT	*Podocarpus latifolius*	137	137	138	138	140
		Podocarpus latifolius	175	179	179	179	181
	4/ fLt	*Podocarpus latifolius*	138	146	146	147	154
		Podocarpus latifolius	223	223	224	224	229
	5/ flt	*Podocarpus latifolius*	64	65	66	67	67
		Podocarpus latifolius	120	120	120	120	120
	6/ fLT	*Podocarpus latifolius*	76	78	78	78	80
		Podocarpus latifolius	67	74	75	75	75
	7/ flT	*Podocarpus latifolius*	35	36	37	37	48
		Podocarpus latifolius	87.5	88	91	93	93
		Podocarpus latifolius	79	79	80	81	82
		Podocarpus latifolius	91	92	93	93	93
		Podocarpus latifolius	125	127	127	128	129
		Ocotea usambarensis	35	76	76	98	101
	8/ fLt	*Podocarpus latifolius*	100.5	104	105	105	110
		Podocarpus latifolius	81	82	82	82	82
		Podocarpus latifolius	100	106	106	106	106
6 *Ocotea usambarensis*	2/ FLT	*Podocarpus latifolius*	59	64	66	66	73
		Podocarpus latifolius	154	166	185	185	193
		Podocarpus latifolius	104	104	110	112	120
		Podocarpus latifolius	87	109	110	110	111
		Podocarpus latifolius	111	111	111	111	130
	4/ FLt	*Podocarpus latifolius*	120	123	124	124	126
		Podocarpus latifolius	61	62	63	63	64
		Podocarpus latifolius	107	110	114	114	120
	6/ FLT	*Podocarpus latifolius*	99	106	106	107	124
	7/ FIT	*Podocarpus latifolius*	64	69	74	75	80

		Podocarpus latifolius	134	139	139	139	145
	8/ FLt	*Podocarpus latifolius*	179	181	182	182	182
		Podocarpus latifolius	147	152	152	152	152
7 *Ocotea usambarensis*	1/ Flt	*Podocarpus latifolius*	102	114	114	120	121
		Podocarpus latifolius	39	41	44	44	46
		Podocarpus latifolius	92	96	98	99	99
	3/ FlT	*Podocarpus latifolius*	167	167	170	171	184
		Podocarpus latifolius	129	134	134	134	146
	4/ FLt	*Podocarpus latifolius*	192	199	217	221	227
		Podocarpus latifolius	83	87	87	87	87
	5/ Flt	*Podocarpus latifolius*	29	37	37	37	44
		Podocarpus latifolius	60	65	65	71	77
		Podocarpus latifolius	41	47	47	52	52
	6/ FLT	*Podocarpus latifolius*	125	133	138	138	139
	7/ FlT	*Podocarpus latifolius*	63	66	67	67	81
		Ocotea usambarensis	101	108	109	112	136
	8/ FLt	*Ocotea usambarensis*	19	42	43	46	60
8 *Ficalhoa laurifolia*	5/ flt	*Podocarpus latifolius*	128	134	136	136	139
		Podocarpus latifolius	59	61	61	63	73
		Podocarpus latifolius	12	12	12	12	13
		Podocarpus latifolius	11	12	12	12	13
		Podocarpus latifolius	9	10	10	11	12
		Podocarpus latifolius	13	14	15	15	17
		Podocarpus latifolius	173	183	183	183	184
		Podocarpus latifolius	145	151	151	153	155
	8/ fLt	*Podocarpus latifolius*	68	75	76	76	78

NB Forests: 1, Machame; 2, Chome

Treatment codes: F, felled; f, not felled; L, litter retained; l, litter removed; T, tilled; t, not tilled.

Regenerating species: *O. usambarensis*, *Ocotea usambarensis*

Appendix 2 : Height measurements for advance growth of regeneration of *Ocotea usambarensis*, *Podocarpus latifolius*, *Podocarpus falcatus* and *Fagaropsis angolensis* first recorded in May 1999, sorted by forest, plot, strip/treatment and measurement data

Forest	Plot (target tree)	Strip number/ treatment	Regenerating species	January 1999 (cm)	May 1999 (cm)	September 1999 (cm)	February 2000 (cm)
1	9 *Ocotea usambarensis*	6/ FLT	O	105	121	122	144
				115	134	137	151
				103	127	133	136
				162	165	169	171
				115	126	130	130
		8/ FLt		77	93	93	137
	10 *Ocotea usambarensis*	2/ fLT		96	100	100	108
				132	146	147	163
		3/ flT		78	96	98	109
				69	72	77	82
				75	76	77	79
				108	109	109	109
		4/ fLt		89	101	101	115
				65	75	76	86
		5/ flt		107	119	124	135
				111	119	122	136
				76	78	88	97
				129	138	138	154
		6/ fLT		112	113	113	128
				128	186	186	207
				134	147	149	165
		7/ flT		73	81	81	83
		8/ fLt		23	56	57	63
				151	166	166	175
	11 *Ocotea usambarensis*	3/ FIT		33	47	48	69
				76	95	98	100
				179	181	188	188
		4/ FLt		38	38	38	56
		5/ Flt		69	110	115	153

		64	72	72	96
		68	74	76	117
		76	103	103	126
	6/ FLT	48	63	64	66
		190	190	190	190
	7/ FlT	129	139	139	201
		158	158	158	169
	8/ FLt	59	73	76	92
		79	84	85	98
12 *Ocotea usambarensis*	4/ fLt	135	145	148	163
		169	189	189	208
	6/ fLT	74	82	83	89
		113	123	124	135
		67	79	79	87
		145	156	158	166
	7/ flT	158	159	161	158
	8/ fLt	135	141	153	156
13 *Macaranga capensis*	1/ Flt	163	184	184	202
		120	133	134	155
		160	183	183	217
		75	77	78	85
		44	52	54	59
		161	164	186	216
	2/ FLT	163	179	201	183
		200	210	210	224
		75	78	79	91
		101	108	108	122
		107	112	112	120
	3/ FlT	103	111	115	133
		53	54	54	66
		99	104	104	114
	4/ FLt	158	177	178	198

		106	118	125	144
		44	58	58	146
	6/ FLT	86	97	105	135
		50	56	66	71
		50	56	66	74
		177	180	182	203
	7/ FIT	69	83	83	163
		96	117	117	133
		163	183	184	216
	8/ FLt	47	55	55	76
14 *Ocotea usambarensis*	1/ flt	71	74	81	94
		165	165	166	163
		69	69	70	81
	2/ fLT	78	80	80	96
	3/ flT	50	56	56	60
	4/ fLt	123	139	163	186
		101	131	136	163
	6/ fLT	188	201	201	221
		30	32	33	36
	8/ fLt	37	47	47	55
15 *Ocotea usambarensis*	1/ flt	177	190	221	273
		214	234	242	275
		111	111	111	111
		168	168	168	190
		69	72	72	86
	2/ fLT	35	40	49	45
	3/ flT	106	113	114	114
	4/ fLt	120	120	120	198
		124	133	139	154
	5/ flt	190	197	201	221
		210	222	225	247

	16 *Ocotea usambarensis*	1/ flt		184	189	189	217
		2/ fLT		117	133	133	154
		4/ fLt		101	121	122	149
				75	92	100	118
		5/ flt		154	154	157	184
				153	167	167	167
		7/ flT		97	118	118	127
				168	180	183	212
				161	164	164	186
		8/ fLt		148	179	181	194
				164	170	182	189
				137	142	152	177
2	9 *Ocotea usambarensis*	2/ fLT		119	121	123	143
				48	65	65	77
		3/ flT		142	154	154	167
				130	135	135	146
				149	161	161	170
				172	180	180	189
				61	94	94	119
				68	94	94	110
			Pl	90	105	105	125
				24	33	34	37
				101	108	108	111
		4/ fLt		149	161	161	162
			O	91	95	95	116
			Pl	21	25	26	28
				76	84	84	86
		5/ flt	O	171	210	210	249
				46	70	70	109
			Pl	147	154	154	154
			O	44	67	67	80
			Pl	85	93	93	104
				48	55	55	59

			28	34	34	35
			131	140	140	143
			112	118	118	120
			80	84	92	97
	6/ fLT		87	87	97	105
			119	137	146	159
			62	72	72	79
		O	40	58	58	82
		Pl	93	101	117	109
	7/ flT		27	30	30	37
			103	113	113	137
	8/ fLt	O	90	95	95	127
			139	146	158	262
			151	178	178	208
10 *Ocotea usambarensis*	1/ Flt	Pl	82	83	88	86
			70	82	82	92
	2/ FLT		84	92	92	99
			85	91	91	92
	4/ FLt		20	22	24	25
	5/ Flt		76	80	80	88
			201	201	201	208
	6/ FLT		69	77	78	82
	7/ FlT		91	92	97	97
	8/ FLt		204	214	214	216
			200	202	202	202
			25	26	26	26
11 *Podocarpus latifolius*	1/ flt		97	98	98	98
			84	86	86	91
			89	90	90	104
			15	17	17	18
			116	116	116	126
			63	64	64	67

		170	171	172	172
		32	36	37	43
		107	107	110	112
		23	24	26	28
		61	66	66	67
	2/ fLT	34	39	39	39
		12	14	14	16
		26	29	29	35
		46	46	47	53
		144	150	155	152
		160	160	160	160
	3/ flT	104	104	105	113
		46	46	46	46
		60	66	66	68
		101	103	103	103
		15	18	18	19
		133	135	135	144
	4/ fLt	26	31	31	35
	5/ flt	86	86	86	87
		130	135	137	138
		176	179	182	183
		8	9	9	13
	6/ fLT	81	84	84	84
		16	21	21	39
	7/ flT	37	42	42	43
		112	116	116	123
	8/ fLt	60	64	64	70
		56	56	56	58
		53	53	55	60
		62	65	66	65
12 *Ocotea usambarensis*	2/ fLT	72	73	73	79
		77	81	81	81
	3/ flT	39	42	42	49

	4/ fLt		48	50	57	68
	6/ fLT		172	175	175	172
			122	122	123	137
			79	82	84	86
	7/ flT		85	96	98	98
	8/ fLt		32	33	34	38
			71	71	71	76
			110	113	113	117
13 *Ocotea usambarensis*	1/ flt		19	21	21	27
			100	103	110	116
	2/ fLT		90	90	92	97
			59	61	61	65
	3/ flT	O	64	79	84	102
		Pl	73	87	93	95
	4/ fLt		52	58	58	58
	5/ flt		185	187	191	199
			32	34	34	37
			107	114	116	127
		O	117	133	144	165
		Pl	87	93	93	101
			29	34	35	37
			103	105	105	116
	6/ fLT		84	86	86	88
			66	66	66	70
	7/ flT		170	173	174	174
			65	74	74	76
	8/ fLt		137	142	144	153
			124	145	145	145
			95	98	98	104
			196	211	215	225
			89	104	107	116
			214	233	235	235
			56	56	56	56

			112	112	120	120
			86	90	90	98
			33	39	40	41
			69	74	75	77
			69	74	74	74
			99	102	102	106
			83	84	87	90
			87	97	97	102
			148	148	149	161
15 *Ficalhoa laurifolia*	4/ FLt		59	64	72	84
	5/ Flt		208	213	215	212
			220	226	226	242
	6/ FLT		76	80	80	82
	6/ FLT		114	120	120	121
16 *Ficalhoa laurifolia*	1/ Flt		109	113	114	125
			45	50	52	57
	3/ FIT		78	85	86	90
	5/ Flt		51	51	54	57
	6/ FLT		22	28	28	32
18 *Ocotea usambarensis*	2/ FLT		59	70	73	87
			193	195	198	197
	3/ FIT		14	19	19	20
	4/ FLt		174	194	214	213
			147	149	149	149
	6/ FLT		51	56	56	61
	7/ FIT	O	70	86	86	103
	8/ FLt	Pl	184	187	190	190
		O	137	148	148	156
			163	176	179	191
			156	158	159	165
			165	169	170	172

				46	56	57	119
				79	93	95	125
				77	93	93	95
3	1 *Fagaropsis angolensis*	1/ flt	Pf	193	193	193	193
				164	164	164	185
	2 *Fagaropsis angolensis*	8/ fLt		174	175	175	198
	3 *Fagaropsis angolensis*	3/ FIT		69	77	78	80
		4/ FLt		48	48	48	51
	5 *Fagaropsis angolensis*	4/ fLt		171	171	178	181
			F		5	6	7
					4	5	8
		5/ flt			76	77	79
					34	34	37
	7 *Fagaropsis angolensis*	5/ Flt	Pf	190	192	197	199
	8 *Podocarpus falcatus*	2/ FLT		73	75	75	76
	9 *Podocarpus falcatus*	4/ FLt		81	82	82	88
	11 *Fagaropsis angolensis*	6/ fLT	F		107	107	111
		7/ flT	Pf	206	206	206	208
	14 *Fagaropsis angolensis*	7/ FIT		65	70	74	94
	16 *Fagaropsis angolensis*	1/ flt	F		39	42	41
			Pf	140	140	140	149
		7/ flT		171	171	171	194
				79	79	80	80

17 *Fagaropsis angolensis*	2/ FLT		204	204	204	208
	5/ Flt	F		115	117	121
	8/ FLt	Pf	189	191	191	200
			85	85	86	87

NB Forests: 1, Machame; 2, Chome; 3, Rongai

Treatment codes: F, felled; f, not felled; L, litter retained; l, litter removed; T, tilled; t, not tilled.

Regenerating species: O, *Ocotea usambarensis*; Pl, *Podocarpus latifolius*; Pf, *Podocarpus falcatus*; F, *Fagaropsis angolensis*

Appendix 3 : Height measurements for advance growth of regeneration of *Ocotea usambarensis*, *Podocarpus latifolius*, *Podocarpus falcatus* and *Fagaropsis angolensis* first recorded in September 1999, sorted by forest, plot, strip/treatment and measurement data

Forest	Plot (target tree)	Strip/ treatment	Regenerating species	February 1999 (cm)	September 1999 (cm)	February 2000 (cm)
1	17 *Ocotea usambarensis*	1/ Flt	O	119	141	169
				73	83	100
		2/ FLT		78	92	101
				140	144	148
				110	119	126
				119	119	135
				59	62	62
	18 *Ocotea usambarensis*	1/ Flt		96	102	125
				140	165	188
				127	127	153
				42	52	55
		2/ FLT		122	125	141
				123	141	185
		3/ FlT		129	167	200
				123	160	197
		5/ Flt		143	163	163
				26	38	55
		6/ FLT		107	127	154
				106	117	135
		7/ FlT		68	79	93
				119	144	158
				132	132	150
				43	54	63
				99	100	115
		8/ FLt		47	47	53
				103	104	115
				84	86	101
				152	153	170
	19 *Ocotea usambarensis*	1/ flp		184	190	214

	2/ fLT	81	81	114
		179	193	188
		102	111	140
	3/ flT	77	87	102
		71	78	87
		77	126	145
		174	206	230
	4/ fLt	150	151	154
		73	74	122
		143	158	183
	5/ flt	141	145	148
		190	207	231
		144	155	179
	6/ fLT	52	57	67
		119	120	127
		101	119	167
		146	153	153
	7/ flT	123	135	148
	8/ fLt	100	100	110
20 *Ocotea usambarensis*	1/ flt	110	112	120
		120	153	156
	2/ fLT	63	75	83
	3/ flT	86	87	136
	4/ fLt	30	39	49
		130	134	166
	5/ flt	98	106	114
	6/ fLT	89	96	96
		27	37	48
	8/ fLt	97	121	134
		47	50	89
21 *Ocotea usambarensis*	1/ Flt	86	104	123
		62	85	85

		128	134	139
	2/ FLT	121	122	124
		91	101	116
	3/ FIT	64	68	74
		41	61	91
		107	110	137
		87	94	98
		139	146	148
		160	166	171
	6/ FLT	125	132	141
		135	161	207
		92	92	92
		45	60	91
	7/ FIT	151	158	158
		153	173	209
		182	199	241
		168	184	196
		165	196	225
	8/ FLt	139	144	161
		54	63	78
		178	194	223
		189	193	227
		184	220	253
		120	124	140
22 *Ocotea usambarensis*	1/ flt	127	145	157
		64	69	74
	2/ fLT	117	117	117
	3/ flT	80	94	115
	4/ fLt	75	115	127
		163	177	201
		97	106	111
	5/ flt	69	86	88
	6/ fLT	157	163	189

	7/ flT	116	130	166
23 *Ocotea usambarensis*	2/ FLT	78	86	133
		83	103	107
		99	114	123
		40	44	63
	4/ FLt	162	167	186
		49	55	67
	6/ FLT	78	80	82
		117	121	121
		40	44	48
	7/ FIT	102	122	141
		169	186	187
	8/ FLt	83	136	161
		149	152	165
		174	194	216
		112	139	160
		91	94	96
24 *Ocotea usambarensis*	1/ Flt	59	83	111
		105	115	123
		77	105	129
		149	174	195
		71	106	116
		122	113	122
		129	143	147
	2/ FLT	73	79	91
		125	125	165
		40	54	71
	3/ FIT	82	85	91
	4/ FLt	183	190	212
		32	66	91
		144	147	186
	6/ FLT	169	170	192

				146	153	173
		7/ FIT		172	172	198
				188	200	220
				180	180	206
		8/ FLt		55	59	71
2	17 *Ocotea usambarensis*	3/ flT	O	91	96	107
				136	148	208
		4/ fLt	Pl	139	144	144
				23	24	29
				16	16	17
				69	73	75
				191	191	191
			O	56	84	97
		5/ flt		53	70	79
		6/ fLT	Pl	87	88	92
				191	192	192
				75	76	80
		8/ fLt		22	22	25
				69	70	74
				35	38	42
				83	89	92
				17	26	32
				25	30	35
				78	79	82
	19 *Ficalhoa laurifolia*	3/ flT		156	159	159
				42	49	59
		4/ fLt		139	139	149
		5/ flt		231	234	236
		7/ flT		124	135	146
	20 *Ocotea usambarensis*	4/ FLt	O	30	39	43
				35	47	49

	5/ Flt		75	82	160
			89	89	153
			54	61	213
			60	74	120
			43	53	65
	6/ FLT		46	81	107
			184	193	246
			162	165	217
			59	75	75
	7/ FIT		112	125	125
			111	122	129
			69	72	107
			49	66	96
	8/ FLt	Pl	118	127	127
			31	34	38
			22	25	26
		O	98	103	127
			107	110	152
21 *Ocotea usambarensis*	1/ Flt		130	134	134
			155	182	230
			129	133	161
	2/ FLT		54	67	101
			82	92	128
			76	86	208
			94	105	124
			151	151	159
			178	200	242
	4/ FLt		92	94	109
			45	57	119
			114	128	178
	5/ Flt	Pl	118	118	118
			49	52	58
	7/ FIT	O	123	123	211

			99	99	126
22 *Ocotea usambarensis*	5/ Flt	Pl	173	173	184
	6/ FLT		117	121	121
			158	164	166
	7/ FIT		204	205	219
			102	107	108
			52	56	58
	8/ FLt		185	189	189
		O	66	66	100
		Pl	129	129	129
23 *Ocotea usambarensis*	4/ FLt		55	55	56
	5/ Flt		88	92	101
			173	174	174
			45	49	52
	6/ FLT		115	121	164
			67	73	73
			23	29	39
			82	82	82
	7/ FIT		53	53	54
		O	107	120	131
		Pl	79	79	86
			70	70	70
			54	58	64
			92	106	107
		O	199	210	233
		Pl	56	56	61
		O	69	71	102
			59	63	81
		Pl	73	76	77
			55	59	60
			39	39	46
			163	170	179

				48	49	55
		8/ FLt		144	144	145
				205	205	217
				132	132	136
			O	71	103	135
				43	50	51
				41	61	86
	24 *Ocotea usambarensis*	3/ flT		50	60	66
				26	37	52
		5/ flt	Pl	139	139	139
		8/ fLt		231	232	232
				59	59	61
			O	58	59	64
3	1 *Fagaropsis angolensis*	1/ flt	F		3.5	6
					4	6
					3	5
		2/ fLT			3	6
					4	7
					3.5	7
		7/ flT			5	8
	2 *Fagaropsis angolensis*	2/ fLT	Pf	192	198	225
	6 *Fagaropsis angolensis*	5/ flt	F		4	7
		4/ fLt			4	12
					5.5	8
					5	9
		2/ fLT			7	12
		6/ fLT			13	14
	9 *Podocarpus falcatus*	8/ FLt	Pf	42	46	51

15 *Fagaropsis angolensis*	3/ flT		145	146	146
	7/ flT		97	106	112
	8/ fLt		170	179	185
18 *Fagaropsis angolensis*	3/ FlT		92	96	99
		F		82	98
19 *Fagaropsis angolensis*	5/ Flt	Pf	78	88	112
		F		137	137
	6/ FLT			112	159
	8/ FLt			13	20
23 *Fagaropsis angolensis*	7/ flT	Pf	154	156	178

NB Forests: 1, Machame; 2, Chome; 3, Rongai

Treatment codes: F, felled; f, not felled; L, litter retained; l, litter removed; T, tilled; t, not tilled.

Regenerating species: O, *Ocotea usambarensis*; Pl, *Podocarpus latifolius*; Pf, *Podocarpus falcatus*; F, *Fagaropsis angolensis*

Appendix 4 : Month by month rainfall totals for Rongai, January 1981 - January 2000

Year	January (mm)	February (mm)	March (mm)	April (mm)	May (mm)	June (mm)	July (mm)	August (mm)	September (mm)	October (mm)	November (mm)	December (mm)
1981	21	43	165	94	2	0	0	0	0	7	0	169
1982	102	62	20	30	81	0	3	0	0	0	35	236
1983	130	101	67	69	214	0	0	0	0	0	47	194
1984	125	75	0	56	130	26	0	0	0	0	107	222
1985	41	39	42	117	86	37	27	0	0	0	0	211
1986	319	192	78	255	192	18	0	0	0	6	2	218
1987	133	105	49	35	159	85	0	0	0	0	60	69
1988	85	54	128	214	217	60	0	0	0	0	43	211
1989	82	109	0	121	86	0	0	0	0	0	7	126
1990	205	15	45	104	263	30	14	0	0	0	26	153
1991	197	307	60	20	0	0	0	0	0	0	33	117
1992	297	24	106	179	30	0	0	0	0	0	41	237
1993	119	102	76	77	59	0	0	0	0	114	191	58
1994	29	129	53	13	0	0	0	0	0	112	82	50
1997	0	0	59	245	90	0	0	0	0	43	392	409
1998	607	68	69	290	171	0	0	0	0	0	134	55
1999	44	20	239	112	0	0	0	0	0	0	223	176
2000	7											

Appendix 5 : Daily rainfall figures for Machame, November 1998 - December 1999

Date	November (mm)	December (mm)	January (mm)	February (mm)	March (mm)	April (mm)	May (mm)	June (mm)	July (mm)	August (mm)	September (mm)	October (mm)	November (mm)	December (mm)
1	0	2	0	0	0	46	29	29	37	12	0	0	0	0
2	0	4	25	0	0	43	45	26	33	10	1	0	0	0
3	0	0	0	0	7	42	41	13	18	5	1	0	0	2
4	4	4	0	0	4	45	39	12	16	0	0	0	0	0
5	0	0	0	0	4	6	0	16	11	0	0	0	0	0
6	0	0	0	0	0	5	0	0	10	15	0	0	0	0
7	0	5	0	0	1	8	42	21	6	11	1	0	2	0
8	1	0	3	0	0	6	27	12	11	4	0	0	0	3
9	0	0	0	0	4	8	24	24	20	0	0	0	5	0
10	0	0	0	0	10	8	22	23	31	6	0	0	7	0
11	0	0	0	0	6	7	36	26	2	19	0	11	8	0
12	0	0	0	0	5	8	38	12	0	19	0	0	9	0
13	0	3	0	0	5	6	37	0	12	10	0	6	4	2
14	0	4	8	0	0	7	34	0	11	0	0	0	0	0
15	0	0	7	0	8	8	33	0	20	0	0	0	1	0
16	0	0	11	0	10	7	57	0	0	5	1	0	0	0
17	0	4	0	6	5	12	43	7	16	3	3	0	0	0
18	9	0	4	0	0	19	20	6	18	2	1	0	0	8
19	0	5	0	0	0	21	19	0	22	0	0	0	10	0
20	1	8	0	0	0	20	29	0	12	0	0	0	4	0
21	0	11	4	0	0	17	0	0	7	0	0	0	2	0
22	0	0	0	0	3	21	0	2	21	6	0	0	4	2
23	0	0	0	0	0	18	0	0	12	7	0	0	6	0
24	0	0	0	20	0	16	11	0	0	2	0	0	9	5
25	7	0	0	2	13	17	14	0	23	0	0	0	10	2
26	22	0	0	4	20	20	13	2	13	0	0	0	11	0
27	2	0	0	9	3	13	15	7	21	0	0	0	21	2
28	0	0	0	0	13	21	18	30	19	7	0	0	37	0
29	0	0	0		13	16	23	22	22	7	0	0	40	3
30	0	0	0		13	20	12	20	12	3	2	16	46	4
31		0	0		15	0	13			3				
TOTAL	46	50	62	41	162	511	734	310	456	156	10	33	236	33

Appendix 6 : Canopy closure and light radiation by site, felling status, season and photosite position

Site	Plot/ Target tree	Felling status	Season	Photosite position					
				1	2	3	4	5	6
Machame	1 *Ocotea usambarensis*	No-fell	Mar 1999	29.2 (41)	*	*	*	*	*
		Rec	May 1999	23.1 (41)	*	*	*	*	*
		Rec	Sep 1999	36.9 (22)	*	*	*	*	*
		Rec	Feb 2000	28.1 (48)	*	*	*	*	*
	2 *Ocotea usambarensis*	No-fell	Mar 1999	*	*	*	*	*	34.7 (28)
		Rec	May 1999	*	*	*	*	*	31.9 (38)
		Rec	Feb 2000	*	*	*	*	*	24.3 (53)
	3 *Ocotea usambarensis*	Rec	May 1999	*	*	*	*	35.5 (23)	*
		Rec	Sep 1999	*	*	*	*	25.2 (34)	*
		Rec	Feb 2000	*	*	*	*	25.2 (41)	*
	5 *Ocotea usambarensis*	Pre-F		*	*	*	*	*	*
		Post-F	Mar 1999	*	38.2 (21)	*	*	*	*
		Rec	May 1999	*	32.1 (36)	*	*	*	*
		Rec	Sep 1999	*	36.8 (27)	*	*	*	*
		Rec	Feb 2000	*	32.2 (34)	*	*	*	*
	6 *Ocotea usambarensis*	Pre-F		*	*	*	*	*	*
		Post-F	Mar 1999	37.1 (22)	*	*	*	*	*
		Rec	May 1999	32.5 (33)	*	*	*	*	*
		Rec	Sep 1999	33.6 (31)	*	*	*	*	*
		Rec	Feb 1999	34.0 (35)	*	*	*	*	*
	9 *Ocotea usambarensis*	Pre-F	May 1999	24.4 (45)	29.8 (44)	*	29.7 (40)	*	33.2 (43)
		Post-F	May 1999	30.0 (41)	28.3 (42)	*	32.1 (37)	35.8 (24)	28.6 (36)

		Rec	Sep 1999	37.2 (22)	36.3 (29)	*	34.9 (28)	37.7 (37)	36.5 (29)
		Rec	Feb 2000	26.2 (43)	27.0 (44)	*	28.5 (51)	27.2 (51)	*
	21 *Ocotea usambarensis*	Pre-F	Sep 1999	33.1 (40)	28.9 (41)	23.9 (44)	30.3 (39)	35.5 (36)	30.8 (35)
		Post-F	Sep 1999	39.2 (32)	37.2 (36)	29.6 (36)	32.3 (31)	33.5 (35)	35.6 (31)
		Rec	Feb 2000	39.9 (20)	33.1 (37)	34.8 (32)	34.6 (31)	18.9 (69)	33.6 (40)
Chome	2 *Podocarpus latifolius*	Pre-F	Mar 1999	6.3 (87)	3.0 (85)	8.4 (81)	17.8 (74)	2.7 (91)	3.8 (89)
		Post-F	Mar 1999	11.2 (85)	18.4 (80)	12.9 (76)	19.3 (63)	27.0 (70)	10.0 (82)
		Rec	May 1999	8.8 (81)	*	12.2 (81)	6.5 (86)	23.9 (67)	21.7 (64)
		Rec	Sep 1999	11.0 (74)	21.8 (69)	21.8 (64)	14.5 (70)	16.0 (79)	*
		Rec	Feb 2000	31.3 (50)	22.2 (50)	30.7 (54)	26.1 (48)	31.1 (46)	28.7 (52)
	3 *Ocotea usambarensis*	No-fell	Mar 1999	*	*	*	14.9 (73)	*	*
		Rec	May 1999	*	*	*	25.4 (56)	*	*
		Rec	Sept 1999	*	*	*	23.4 (49)	*	*
		Rec	Feb 2000	*	*	*	28.9 (52)	*	*
	4 *Ficalhoa laurifolia*	Pre-F	Mar 1999	17.2 (64.6)	13.4 (75)	*	20.4 (74)	8.2 (77)	16.6 (73)
		Post-F	Mar 1999	24.2 (64)	17.5 (72)	22.3 (63)	23.2 (63)	16.6 (70)	20.7 (69)
		Rec	May 1999	20.0 (60)	20.4 (64)	17.5 (74)	13.9 (72)	9.2 (82)	14.9 (71)
		Rec	Sep 1999	14.2 (78)	13.9 (74)	10.0 (77)	15.9 (70)	14.5 (70)	15.1 (70)
		Rec	Feb 2000	25.1 (50)	25.4 (61)	27.4 (46)	32.1 (49)	34.7 (45)	26.5 (46)
	5 *Ocotea usambarensis*	No-fell	Mar 1999	16.9 (74)	*	*	*	*	*
		Rec	May 1999	23.1 (57)	*	*	*	*	*
		Rec	Sept 1999	37.9 (26)	*	*	*	*	*
		Rec	Feb 2000	33.6 (27)	*	*	*	*	*
	6 *Ocotea usambarensis*	Pre-F	Mar 1999	7.7 (83)	7.0 (84)	10.0 (82)	5.5 (86)	4.6 (87)	8.4 (84)
		Post-F	Mar 1999	8.8 (83)	11.6 (82)	11.0 (80)	6.4 (86)	13.7 (75)	12.1 (76)

		Rec	May 1999	11.4 (72)	11.7 (74)	16.4 (69)	14.7 (72)	11.3 (74)	13.9 (73)
		Rec	Sept 1999	12.8 (79)	12.1 (79)	14.2 (72)	12.4 (75)	13.9 (73)	14.9 (70)
		Rec	Feb 2000	25.5 (53)	26.5 (50)	28.5 (49)	19.6 (59)	24.7 (44)	32.6 (51)
	7 *Ocotea usambarensis*	Pre-F	Mar 1999	14.2 (78)	8.5 (88)	10.5 (81)	8.7 (81)	*	22.2 (56)
		Post-F	Mar 1999	9.5 (82)	12.9 (85)	9.5 (80)	10.6 (81)	12.3 (79)	11.8 (79)
		Rec	May 1999	32.9 (35)	33.2 (34)	26.3 (46)	30.8 (46)	6.5 (82)	29.2 (43)
		Rec	Sept 1999	30.3 (42)	26.9 (45)	28.2 (45)	28.0 (46)	22.2 (47)	28.5 (44)
		Rec	Feb 2000	34.5 (48)	23.9 (52)	23.7 (46)	23.0 (49)	28.1 (47)	*
Rongai	1 *Fagaropsis angolensis*	No-Fell	May 1999	*	*	*	9.1 (83)	*	4.7 (90)
		Rec	Sep 1999	*	*	*	11.7 (88)	*	14.1 (84)
		Rec	Feb 2000	*	*	*	29.7 (53)	*	24.3 (49)
	2 *Fagaropsis angolensis*	No-Fell	May 1999	*	*	11.3 (83)	6.2 (84)	*	*
		Rec	Sep 1999	*	*	13.3 (83)	8.6 (85)	*	*
		Rec	Feb 2000	*	*	34.3 (48)	33.4 (42)	*	*
	4 *Fagaropsis angolensis*	Pre-F	May 1999	*	5.5 (93)	*	3.3 (89)	*	*
		Post-F	May 1999	*	5.6 (92)	*	5.0 (90)	*	*
		Rec	Sep 1999	*	11.7 (78)	*	8.9 (82)	*	*
		Rec	Feb 2000	*	37.8 (33.4)	*	22.3 (63)	*	*
	5 *Fagaropsis angolensis*	No-Fell	May 1999	*	*	*	*	8.3 (88)	*
		Rec	Sep 1999	*	*	*	*	8.5 (87)	*
		Rec	Feb 2000	*	*	*	*	36.2 (50)	*
	10 *Fagaropsis angolensis*	Pre-F	May 1999	*	6.3 (91)	*	0.9 (94)	*	*
		Post-F	May 1999	1.3 (95)	9.5 (90)	*	3.1 (91)	*	*
		Rec	Sep 1999	2.9 (92)	8.7 (80)	*	8.8 (80)	*	*
		Rec	Feb 2000	9.6 (78)	7.9 (82)	*	9.1 (80)	*	*

11 *Fagaropsis angolensis*	No-Fell	May 1999	4.6 (88)	*	*	7.9 (77)	*	*
	Rec	Sep 1999	7.2 (80)	*	*	5.5 (82)	*	*
	Rec	Feb 2000	34.5 (62)	*	*	33.2 (49)	*	*
14 *Fagaropsis angolensis*	Pre-F	May 1999	*	1.6 (92)	*	2.3 (90)	8.7 (87)	*
	Post-F	May 1999	*	2.7 (89)	*	2.6 (89)	8.4 (80)	*
	Rec	Sep 1999	*	8.5 (87)	*	8.9 (84)	12.6 (83)	*
	Rec	Feb 2000	*	3.9 (88)	*	5.4 (86)	9.4 (81)	*
17 *Fagaropsis angolensis*	Pre-F	May 1999	8.3 (90)	*	3.1 (93)	7.3 (87)	*	*
	Post-F	May 1999	9.2 (82)	*	18.8 (72)	7.7 (83)	*	*
	Rec	Sep 1999	9.9 (83)	*	4.4 (80)	4.0 (88)	*	*
	Rec	Feb 2000	39.5 (39)	*	8.2 (86)	22.3 (60)	*	*

NB * Photographs were not analysed

Felling status: Pre-F (Pre-felling); Post-F (Immediate Post-felling); No-Fell (Target tree was not felled); Rec (Recovery which refers to the later assessments)

Photosite position: 1 (20 m behind tree), 2 (10 m behind tree), 3 (under target tree crown edge), 4 (1 m behind base of bole), 5 (0.5 x bole length forward from tree), 6 (1.0 x bole length forward from tree)

Numbers in brackets ( ) represent canopy closure percentages

Appendix 7 : Regeneration counts standardized to 10 m^2 at Chome treated in March 1999 and first assessed in May 1999

Plot	Tree defining plot: identity; dbh (cm); crown diameter (m)	Treatment phase	Felled	Regenerating species	Regenerating individuals first recorded in May 1999				Regenerating individuals first recorded in September 1999				Regenerating individuals first recorded in February 2000			
					Litter		No litter		Litter		No litter		Litter		No litter	
					No till	Till	No till	Till	No till	Till	No till	Till	No till	Till	No till	Till
1	*Ocotea usambarensis*; 87.0; 18.95	March 1999	No	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0	0	0	0	0
				Ocotea usambarensis	2	2	2	1	0	0	0	0	0	0	0	0
				Podocarpus latifolius	0	0	0	0	0	0	0	0	0	0	0	0
3	*Ocotea usambarensis*; 62.0, 17.25	March 1999	No	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0	0	0	0	0
				Ocotea usambarensis	5	3	1	16	0	0	0	0	0	0	0	0
				Podocarpus latifolius	0	0	0	0	0	0	0	0	0	0	0	0
5	*Ocotea usambarensis*; 50.5; 13.80	March 1999	No	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0	0	0	0	0
				Ocotea usambarensis	9	3	3	9	0	0	0	0	0	0	0	0
				Podocarpus latifolius	0	1	1	0	0	0	0	0	0	0	0	0
8	*Ficalhoa laurifolia*; 49.5; 15.4	March 1999	No	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0	0	0	0	0
				Ocotea usambarensis	0	0	1	0	0	0	0	0	0	0	0	0
				Podocarpus latifolius	3	0	1	1	0	0	0	0	0	0	0	0
2	*Podocarpus latifolius*; 56.5; 9.45	March 1999	Yes	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0	0	0	0	0
				Ocotea usambarensis	0	0	0	0	0	0	0	0	0	0	0	0
				Podocarpus latifolius	2	2	0	0	0	0	0	0	0	0	0	0
4	*Ficalhoa laurifolia*; 98.5; 18.2	March 1999	Yes	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0	0	0	0	0
				Ocotea usambarensis	0	0	0	0	0	0	0	0	0	0	0	0

				Podocarpus latifolius	0	0	0	0	0	0	0	0	0	0	0	0
6	*Ocotea usambarensis*; 85.0; 24.25	March 1999	Yes	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0	0	0	0	0
				Ocotea usambarensis	0	0	0	0	0	0	0	0	0	0	0	0
				Podocarpus latifolius	0	1	0	0	0	0	0	0	0	0	0	0
7	*Ocotea usambarensis*; 60.0;17.40	March 1999	Yes	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0	0	0	0	0
				Ocotea usambarensis	2	2	0	0	0	0	0	0	0	0	0	0
				Podocarpus latifolius	2	2	2	0	0	0	0	0	0	0	0	0

NB. Numbers represent new suckers counts

Appendix 8 : Regeneration counts standardized to 10 m^2 at Chome treated in May 1999 and first assessed in September 1999

Plot	Tree defining plot: identity; dbh (cm); crown diameter (m)	Treatment phase	Felled	Regenerating species	Regenerating individuals first recorded in September 1999				Regenerating individuals first recorded in February 2000			
					Litter		No litter		Litter		No litter	
					No till	Till	No till	Till	No till	Till	No till	Till
9	*Ocotea usambarensis*; 95.0; 20.50	May 1999	No	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0
				Ocotea usambarensis	3	6	2	0	0	0	0	0
				Podocarpus latifolius	0	1	0	2	0	0	0	0
11	*Podocarpus latifolius*; 32.0; 7.2	May 1999	No	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0
				Ocotea usambarensis	0	0	0	0	0	0	0	0
				Podocarpus latifolius	0	0	0	0	0	0	0	0
12	*Ocotea usambarensis*; 51.0, 15.10	May 1999	No	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0
				Ocotea usambarensis	0	0	0	0	0	0	0	0
				Podocarpus latifolius	1	0	0	0	0	0	0	0
13	*Ocotea usambarensis*; 36.0; 15.35	May 1999	No	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0
				Ocotea usambarensis	0	1	3	0	0	0	0	0
				Podocarpus latifolius	0	0	0	1	0	0	0	0
14	*Podocarpus latifolius*; 52.0; 12.3	May 1999	No	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0
				Ocotea usambarensis	0	0	0	0	0	0	0	0
				Podocarpus latifolius	0	0	0	0	0	0	0	0
10	*Ocotea usambarensis*; 60.3; 13.6	May 1999	Yes	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0
				Ocotea								

				usambarensis	0	0	0	0	0	0	0	0
				Podocarpus latifolius	0	0	0	0	0	0	0	0
15	*Ficalhoa laurifolia*; 53.0; 16.92	May 1999	Yes	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0
				Ocotea usambarensis	0	0	0	0	0	0	0	0
				Podocarpus latifolius	0	0	0	0	0	0	0	0
16	*Ficalhoa laurifolia*; 54.5; 19.02	May 1999	Yes	*Ficalhoa laurifolia*	0	0	0	0	0	0	0	0
				Ocotea usambarensis	0	0	0	0	0	0	0	0
				Podocarpus latifolius	0	0	0	0	0	0	0	0

NB. Numbers represent new suckers counts

Appendix 9 : Regeneration counts standardized to 10 m^2 at Chome treated in September 1999 and first assessed in February 2000

Plot	Tree defining plot: identity; dbh (cm); crown diameter (m)	Treatment phase	Felled	Regenerating species	Regenerating individuals first recorded in February 2000: Litter, No till	Litter, Till	No litter, No till	No litter, Till
17	*Ocotea usambarensis*; 58.0; 18.40	September 1999	No	*Ficalhoa laurifolia*	0	0	0	0
				Ocotea usambarensis	0	0	0	3
				Podocarpus latifolius	0	0	0	0
19	*Ficalhoa laurifolia*; 36.5; 9.85	September 1999	No	*Ficalhoa laurifolia*	0	0	0	0
				Ocotea usambarensis	0	0	0	0
				Podocarpus latifolius	0	0	0	0
24	*Ocotea usambarensis*; 81.5; 16.7	September 1999	No	*Ficalhoa laurifolia*	0	0	0	0
				Ocotea usambarensis	0	0	2	0
				Podocarpus latifolius	3	0	0	0
18	*Ocotea usambarensis*; 57.0, 16.80	September 1999	Yes	*Ficalhoa laurifolia*	0	0	0	0
				Ocotea usambarensis	0	0	0	0
				Podocarpus latifolius	2	0	0	0
20	*Ocotea usambarensis*; 90.5; 20.30	September 1999	Yes	*Ficalhoa laurifolia*	0	0	0	0
				Ocotea usambarensis	0	0	0	4
				Podocarpus latifolius	0	0	0	0
21	*Ocotea usambarensis*; 78.0; 17.45	September 1999	Yes	*Ficalhoa laurifolia*	0	0	0	0
				Ocotea usambarensis	4	0	0	0
				Podocarpus latifolius	0	0	0	0
22	*Ocotea usambarensis*; 87.0; 19.05	September 1999	Yes	*Ficalhoa laurifolia*	0	0	0	0
				Ocotea usambarensis	0	0	0	0
				Podocarpus latifolius	0	0	0	0
23	*Ocotea usambarensis*; 88.5; 21.75	September 1999	Yes	*Ficalhoa laurifolia*	0	0	0	0
				Ocotea usambarensis	0	0	4	0
				Podocarpus latifolius	0	0	0	0

NB. Numbers represent new suckers counts

Appendix 10 : Regeneration counts standardized to 10 m^2 at Machame treated in March 1999 and first assessed in May 1999

Plot	Tree defining plot: identity; dbh (cm); crown diameter (m)	Treatment phase	Felled	Regenerating species	Regenerating individuals first recorded in May 1999				Regenerating individuals first recorded in September 1999				Regenerating individuals first recorded in February 2000			
					Litter		No litter		Litter		No litter		Litter		No litter	
					No till	Till	No till	Till	No till	Till	No till	Till	No till	Till	No till	Till
1	*Ocotea usambarensis*; 87.0; 18.95	March 1999	No	*Ocotea usambarensis*	2	6	5	7	0	0	0	0	0	0	0	0
2	*Ocotea usambarensis*; 48.0; 14.40	March 1999	No	*Ocotea usambarensis*	0	0	2	6	0	0	0	0	0	0	0	0
3	*Ocotea usambarensis*; 45.0; 10.90	March 1999	No	*Ocotea usambarensis*	0	5	3	6	0	0	0	0	0	0	0	0
8	*Ocotea usambarensis*; 53.5; 13.40	March 1999	No	*Ocotea usambarensis*	2	2	7	7	0	0	0	0	0	0	0	0
4	*Ocotea usambarensis*; 58.5; 14.85	March 1999	Yes	*Ocotea usambarensis*	4	1	0	2	0	0	0	0	0	0	0	0
5	*Ocotea usambarensis*; 57.0; 14.10	March 1999	Yes	*Ocotea usambarensis*	7	5	5	3	0	0	0	0	0	0	0	0
6	*Ocotea usambarensis*; 67.5; 17.30	March 1999	Yes	*Ocotea usambarensis*	7	5	1	4	0	0	0	0	0	0	0	0
7	*Ocotea usambarensis*; 46.5; 13.50	March 1999	Yes	*Ocotea usambarensis*	5	0	3	3	0	0	0	0	0	0	0	0

NB. Numbers represent new suckers counts

Appendix 11 : Regeneration counts standardized to 10 m^2 at Machame treated in May 1999 and first assessed in September 1999

Plot	Tree defining plot: identity; dbh (cm); crown diameter (m)	Treatment phase	Felled	Regenerating species	Regenerating individuals first recorded in September 1999				Regenerating individuals first recorded in February 2000			
					Litter		No litter		Litter		No litter	
					No till	Till	No till	Till	No till	Till	No till	Till
10	*Ocotea usambarensis*; 45.0; 12.45	May 1999	No	*Ocotea usambarensis*	1	5	1	0	0	0	0	0
14	*Ocotea usambarensis*; 31.0; 8.10	May 1999	No	*Ocotea usambarensis*	1	0	0	0	0	0	0	0
12	*Ocotea usambarensis*; 52.5; 9.50	May 1999	No	*Ocotea usambarensis*	0	0	0	0	0	0	0	0
15	*Ocotea usambarensis*; 31.0; 6.10	May 1999	No	*Ocotea usambarensis*	0	0	0	0	0	0	0	0
16	*Ocotea usambarensis*; 48.5; 11.6	May 1999	No	*Ocotea usambarensis*	0	0	0	0	0	0	0	0
9	*Ocotea usambarensis*; 64.5; 11.60	May 1999	Yes	*Ocotea usambarensis*	1	0	0	0	0	0	0	0
11	*Ocotea usambarensis*; 79.5; 21.80	May 1999	Yes	*Ocotea usambarensis*	0	3	0	1	0	0	0	0
13	*Macaranga capensis*; 78.5; 23.50	May 1999	Yes	*Ocotea usambarensis*	1 1*	0	0	0	0	0	0	0

NB. Numbers represent new suckers or seedlings counts

*** *Ocotea usambarensis* seedling**

Appendix 12 : Regeneration counts standardized to 10 m^2 at Machame treated in September 1999 and first assessed in February 2000

Plot	Tree defining plot: identity; dbh (cm); crown diameter (m)	Treatment phase	Felled	Regenerating species	Regenerating individuals first recorded in February 2000			
					Litter		No litter	
					No till	Till	No till	Till
19	*Ocotea usambarensis*; 43.5; 8.35	September 1999	No	*Ocotea usambarensis*	2	0	0	0
20	*Ocotea usambarensis*; 39.0; 6.70	September 1999	No	*Ocotea usambarensis*	0	0	0	0
22	*Ocotea usambarensis*; 54.5; 11.3	September 1999	No	*Ocotea usambarensis*	0	0	0	0
17	*Ocotea usambarensis*; 75.5; 22.75	September 1999	Yes	*Ocotea usambarensis*	0	1	0	0
18	*Ocotea usambarensis*; 58.0; 11.50	September 1999	Yes	*Ocotea usambarensis*	0	0	0	0
21	*Ocotea usambarensis*; 67.0; 12.85	September 1999	Yes	*Ocotea usambarensis*	0	0	0	0
23	*Ocotea usambarensis*; 71.0; 16.45	September 1999	Yes	*Ocotea usambarensis*	0	0	0	0
24	*Ocotea usambarensis*; 63.5; 17.4	September 1999	Yes	*Ocotea usambarensis*	0	0	0	0

NB. Numbers represent new suckers counts

Appendix 13 : Regeneration counts standardized to 10 m^2 at Rongai treated in May 1999 and first assessed in September 1999

Plot	Tree defining plot: identity; dbh (cm); crown diameter (m)	Treatment phase	Felled	Regenerating species	Regenerating individuals first recorded in September 1999				Regenerating individuals first recorded in February 2000			
					Litter		No litter		Litter		No litter	
					No till	Till	No till	Till	No till	Till	No till	Till
1	*Fagaropsis angolensis*; 87.0; 18.95	May 1999	No	*Fagaropsis angolensis*	3	6	2	11	0	0	0	0
				Podocarpus falcatus	1	0	0	0	0	0	0	0
2	*Fagaropsis angolensis*; 72.0; 18.1	May 1999	No	*Fagaropsis angolensis*	0	0	0	0	0	0	0	0
				Podocarpus falcatus	0	0	0	0	0	0	0	0
5	*Fagaropsis angolensis*; 105.4; 21.10	May 1999	No	*Fagaropsis angolensis*	3	0	11	0	0	0	0	0
				Podocarpus falcatus	0	0	0	0	0	0	0	0
6	*Fagaropsis angolensis*; 59.5; 18.70	May 1999	No	*Fagaropsis angolensis*	7	6	5	5	0	0	0	0
				Podocarpus falcatus	3	0	2	4	0	0	0	0
11	*Fagaropsis angolensis*; 33.0; 8.90	May 1999	No	*Fagaropsis angolensis*	0	0	0	0	0	0	0	0
				Podocarpus falcatus	0	0	0	0	0	0	0	0
12	*Fagaropsis angolensis*; 42.0; 15.00	May 1999	No	*Fagaropsis angolensis*	0	0	0	0	0	0	0	0
				Podocarpus falcatus	0	0	0	0	0	0	0	0
13	*Fagaropsis angolensis*; 61.5; 13.60	May 1999	No	*Fagaropsis angolensis*	2	0	0	0	0	0	0	0
				Podocarpus falcatus	0	0	0	0	0	0	0	0
15	*Fagaropsis angolensis*; 70.0; 18.40	May 1999	No	*Fagaropsis angolensis*	0	0	0	0	0	0	0	0
				Podocarpus								

				falcatus	0	0	0	0	0	0	0	0
16	*Fagaropsis angolensis*; 52.5; 14.70	May 1999	No	*Fagaropsis angolensis*	0	0	0	0	0	0	0	0
				Podocarpus falcatus	0	0	0	0	0	0	0	0
3	*Fagaropsis angolensis*; 88.8; 18.40	May 1999	Yes	*Fagaropsis angolensis*	0	5	6	6	0	0	0	0
				Podocarpus falcatus	0	0	1	0	0	0	0	0
4	*Fagaropsis angolensis*; 87.0; 19.40	May 1999	Yes	*Fagaropsis angolensis*	3	7	3	2	0	0	0	0
				Podocarpus falcatus	0	0	0	0	0	0	0	0
7	*Fagaropsis angolensis*; 112.5; 26.2	May 1999	Yes	*Fagaropsis angolensis*	0	0	0	0	0	0	0	0
				Podocarpus falcatus	0	0	0	0	0	0	0	0
8	*Fagaropsis angolensis*; 83.3; 19.00	May 1999	Yes	*Fagaropsis angolensis*	0	0	0	0	0	0	0	0
				Podocarpus falcatus	0	0	0	0	0	0	0	0
9	*Podocarpus falcatus*; 58.5; 14.50	May 1999	Yes	*Fagaropsis angolensis*	1	0	0	2	0	0	0	0
				Podocarpus falcatus	0	0	6	0	0	0	0	0
10	*Fagaropsis angolensis*; 55.5; 16.3	May 1999	Yes	*Fagaropsis angolensis*	0	0	0	0	0	0	0	0
				Podocarpus falcatus	0	0	0	0	0	0	0	0
14	*Fagaropsis angolensis*; 82.0; 18.80	May 1999	Yes	*Fagaropsis angolensis*	1	0	0	0	0	0	0	0
				Podocarpus falcatus	0	0	0	0	0	0	0	0

NB. Numbers represent new seedlings counts

Appendix 14 : Regeneration counts standardized to 10 m^2 at Rongai treated in September 1999 and first assessed in February 2000

Plot	Tree defining plot: identity; dbh (cm); crown diameter (m)	Treatment phase	Felled	Regenerating species	Regenerating individuals first recorded in February 2000			
					Litter		No litter	
					No till	Till	No till	Till
20	*Fagaropsis angolensis*; 34.5; 9.85	September 1999	No	*Fagaropsis angolensis*	0	0	0	0
				Podocarpus falcatus	0	0	0	0
23	*Fagaropsis angolensis*; 49.5; 14.45	September 1999	No	*Fagaropsis angolensis*	0	0	0	0
				Podocarpus falcatus	0	0	0	0
24	*Fagaropsis angolensis*; 63.0; 18.20	September 1999	No	*Fagaropsis angolensis*	0	0	0	0
				Podocarpus falcatus	0	34	51	17
17	*Fagaropsis angolensis*; 62.5; 16.50	September 1999	Yes	*Fagaropsis angolensis*	0	0	0	0
				Podocarpus falcatus	0	0	0	0
18	*Fagaropsis angolensis*; 70.5; 16.90	September 1999	Yes	*Fagaropsis angolensis*	0	0	0	0
				Podocarpus falcatus	0	0	0	0
19	*Fagaropsis angolensis*; 70.0; 15.25	September 1999	Yes	*Fagaropsis angolensis*	0	0	0	0
				Podocarpus falcatus	0	0	0	0
21	*Fagaropsis angolensis*; 70.0; 16.75	September 1999	Yes	*Fagaropsis angolensis*	0	0	0	0
				Podocarpus falcatus	0	0	0	0
22	*Fagaropsis angolensis*; 54.25; 15.70	September 1999	Yes	*Fagaropsis angolensis*	0	0	0	0
				Podocarpus falcatus	0	0	0	0

NB. Numbers represent new seedlings counts

Appendix 15 : Heights recorded for the advance cohort of regeneration in the March 1999 treatment plots at Chome, Tanzania

Plot (Target tree)	Treatment	Regenerating species	Heights (cm)				
			A	B	C	D	E
1 *Ocotea*	f, l, t	*Podocarpus latifolius*	28.0	33.0	33.0	34.0	39.0
		Podocarpus latifolius	105.0	105.0	105.0	106.0	112.0
		Podocarpus latifolius	69.0	75.0	75.0	77.0	81.0
	f, l, T	*Podocarpus latifolius*	171.0	174.0	174.0	174.0	174.0
		Ocotea usambarensis	133.0	171.0	181.0	211.0	268.0
		Ocotea usambarensis	102.0	116.0	116.0	116.0	134.0
	f, L, t	*Podocarpus latifolius*	65.0	70.0	72.0	73.0	86.0
		Podocarpus latifolius	56.0	62.0	64.0	64.0	64.0
		Podocarpus latifolius	36.0	38.0	38.0	38.0	43.0
	f, L, T	*Podocarpus latifolius*	46.0	50.0	51.0	52.0	61.0
		Podocarpus latifolius	92.0	94.0	98.0	100.0	100.0
3 *Ocotea*	f, L, t	*Podocarpus latifolius*	30.0	31.0	32.0	33.0	33.0
		Podocarpus latifolius	22.0	24.0	27.0	32.0	32.0
		Podocarpus latifolius	72.0	72.0	76.0	76.0	78.0
		Podocarpus latifolius	135.0	146.0	150.0	152.0	163.0
		Podocarpus latifolius	206.0	213.0	213.0	215.0	215.0
		Podocarpus latifolius	103.0	108.0	112.0	112.0	122.0
5 *Ocotea*	f, l, t	*Podocarpus latifolius*	137.0	137.0	138.0	138.0	140.0
		Podocarpus latifolius	223.0	223.0	224.0	224.0	229.0
		Podocarpus latifolius	100.5	104.0	105.0	105.0	110.0
		Podocarpus latifolius	81.0	82.0	82.0	82.0	82.0
		Podocarpus latifolius	100.0	106.0	106.0	106.0	106.0
	f, l, T	*Podocarpus latifolius*	39.0	42.0	43.0	45.0	47.0
		Podocarpus latifolius	47.0	49.0	50.0	51.0	57.0
		Podocarpus latifolius	131.0	131.0	131.0	131.0	131.0
		Podocarpus latifolius	118.0	118.0	118.0	118.0	118.0
		Podocarpus latifolius	111.0	111.0	112.0	112.0	112.0
		Podocarpus latifolius	64.0	68.0	68.0	69.0	70.0
	f, L, t	*Podocarpus latifolius*	103.0	105.0	105.0	105.0	105.0
		Podocarpus latifolius	64.0	65.0	66.0	67.0	67.0
		Podocarpus latifolius	120.0	120.0	120.0	120.0	120.0
	f, L, T	*Podocarpus latifolius*	137.0	137.0	138.0	138.0	140.0
		Podocarpus latifolius	175.0	179.0	179.0	179.0	181.0
		Podocarpus latifolius	35.0	36.0	37.0	37.0	48.0
		Podocarpus latifolius	87.5	88.0	91.0	93.0	93.0
		Podocarpus latifolius	79.0	79.0	80.0	81.0	82.0
		Podocarpus latifolius	91.0	92.0	93.0	93.0	93.0
		Podocarpus latifolius	125.0	127.0	127.0	128.0	129.0
		Ocotea usambarensis	35.0	76.0	76.0	98.0	101.0

8 *Ficalhoa*	f, L, t	***Podocarpus latifolius***	128.0	134.0	136.0	136.0	139.0
		Podocarpus latifolius	59.0	61.0	61.0	63.0	73.0
		Podocarpus latifolius	12.0	12.0	12.0	12.0	13.0
		Podocarpus latifolius	11.0	12.0	12.0	12.0	13.0
		Podocarpus latifolius	9.0	10.0	10.0	11.0	12.0
		Podocarpus latifolius	13.0	14.0	15.0	15.0	17.0
		Podocarpus latifolius	173.0	183.0	183.0	183.0	184.0
		Podocarpus latifolius	145.0	151.0	151.0	153.0	155.0
		Podocarpus latifolius	68.0	75.0	76.0	76.0	78.0
2 *Podocarpus*	F, L, t	***Ocotea usambarensis***	108.0	108.0	108.0	108.0	137.0
		Ocotea usambarensis	32.0	49.0	49.0	51.0	62.0
		Podocarpus latifolius	38.0	38.0	38.0	38.0	39.0
		Podocarpus latifolius	21.0	21.0	26.0	26.0	35.0
4 *Ficalhoa*	F, L, T	***Podocarpus latifolius***	106.0	106.0	107.0	108.0	120.0
		Podocarpus latifolius	64.0	66.0	67.0	68.0	68.0
		Podocarpus latifolius	82.0	86.0	86.0	86.0	96.0
	F, l, t	***Podocarpus latifolius***	179.0	182.0	183.0	183.0	190.0
	F, l, T	***Podocarpus latifolius***	143.0	145.0	146.0	146.0	160.0
6 *Ocotea*	F, L, T	***Podocarpus latifolius***	59.0	64.0	66.0	66.0	73.0
		Podocarpus latifolius	134.0	139.0	139.0	139.0	145.0
	F, l, t	***Podocarpus latifolius***	120.0	123.0	124.0	124.0	126.0
		Podocarpus latifolius	61.0	62.0	63.0	63.0	64.0
		Podocarpus latifolius	107.0	110.0	114.0	114.0	120.0
		Podocarpus latifolius	179.0	181.0	182.0	182.0	182.0
		Podocarpus latifolius	147.0	152.0	152.0	152.0	152.0
	F, l, T	***Podocarpus latifolius***	59.0	64.0	66.0	66.0	73.0
		Podocarpus latifolius	154.0	166.0	185.0	185.0	193.0
		Podocarpus latifolius	104.0	104.0	110.0	112.0	120.0
		Podocarpus latifolius	87.0	109.0	110.0	110.0	111.0
		Podocarpus latifolius	111.0	111.0	111.0	111.0	130.0
		Podocarpus latifolius	99.0	106.0	106.0	107.0	124.0
7 *Ocotea*	F, L, t	***Podocarpus latifolius***	102.0	114.0	114.0	120.0	121.0
		Podocarpus latifolius	39.0	41.0	44.0	44.0	46.0
		Podocarpus latifolius	92.0	96.0	98.0	99.0	99.0
		Podocarpus latifolius	167.0	167.0	170.0	171.0	184.0
		Podocarpus latifolius	129.0	134.0	134.0	134.0	146.0
		Podocarpus latifolius	192.0	199.0	217.0	221.0	227.0
		Podocarpus latifolius	83.0	87.0	87.0	87.0	87.0
		Podocarpus latifolius	29.0	37.0	37.0	37.0	44.0
		Podocarpus latifolius	60.0	65.0	65.0	71.0	77.0
		Podocarpus latifolius	41.0	47.0	47.0	52.0	52.0

	Podocarpus latifolius	125.0	133.0	138.0	138.0	139.0
	Podocarpus latifolius	63.0	66.0	67.0	67.0	81.0
	Ocotea usambarensis	101.0	108.0	109.0	112.0	136.0
	Ocotea usambarensis	19.0	42.0	43.0	46.0	60.0

NB. Treatment codes: F, felled; f, not felled; L, litter retained; l, litter removed; T, tilled; t, not tilled. Where a treatment combination is not entered for a plot (Target tree), it indicates there was no advance regeneration of *Ficalhoa laurifolia, Ocotea usambarensis* or *Podocarpus latifolius*

Height headings : A, pre-treatment height (January 1999); B, height at treatment (March 1999); C, height in May 1999; D, height in September 1999; E, height in February 2000

Appendix 16 : Heights recorded for the advance cohort of regeneration in the May 1999 treatment plots at Chome, Tanzania

Plot (Target tree)	Treatment	Regenerating species	Heights (cm)			
			A	B	C	D
9 *Ocotea*	f, L, T	*Ocotea usambarensis*	119.0	121.0	123.0	143.0
		Ocotea usambarensis	48.0	65.0	65.0	77.0
		Podocarpus latifolius	87.0	87.0	97.0	105.0
		Podocarpus latifolius	119.0	137.0	146.0	159.0
		Podocarpus latifolius	62.0	72.0	72.0	79.0
		Podocarpus latifolius	40.0	58.0	58.0	82.0
		Podocarpus latifolius	93.0	101.0	117.0	109.0
	f, l, T	*Ocotea usambarensis*	142.0	154.0	154.0	167.0
		Ocotea usambarensis	130.0	135.0	135.0	146.0
		Ocotea usambarensis	149.0	161.0	161.0	170.0
		Ocotea usambarensis	172.0	180.0	180.0	189.0
		Ocotea usambarensis	61.0	94.0	94.0	119.0
		Ocotea usambarensis	68.0	94.0	94.0	110.0
		Podocarpus latifolius	90.0	105.0	105.0	125.0
		Podocarpus latifolius	24.0	33.0	34.0	37.0
		Podocarpus latifolius	101.0	108.0	108.0	111.0
		Podocarpus latifolius	27.0	30.0	30.0	37.0
		Podocarpus latifolius	103.0	113.0	113.0	137.0
	f, L, t	*Podocarpus latifolius*	149.0	161.0	161.0	162.0
		Podocarpus latifolius	21.0	25.0	26.0	28.0
		Podocarpus latifolius	76.0	84.0	84.0	86.0
		Ocotea usambarensis	91.0	95.0	95.0	116.0
		Ocotea usambarensis	90.0	95.0	95.0	127.0
		Ocotea usambarensis	139.0	146.0	158.0	262.0
		Ocotea usambarensis	151.0	178.0	178.0	208.0
	f, l, t	*Ocotea usambarensis*	171.0	210.0	210.0	249.0
		Ocotea usambarensis	46.0	70.0	70.0	109.0
		Ocotea usambarensis	44.0	67.0	67.0	80.0
		Podocarpus latifolius	147.0	154.0	154.0	154.0
		Podocarpus latifolius	85.0	93.0	93.0	104.0
		Podocarpus latifolius	48.0	55.0	55.0	59.0
		Podocarpus latifolius	28.0	34.0	34.0	35.0
		Podocarpus latifolius	131.0	140.0	140.0	143.0
		Podocarpus latifolius	112.0	118.0	118.0	120.0
		Podocarpus latifolius	80.0	84.0	92.0	97.0
10 *Ocotea*	F, l, t	*Podocarpus latifolius*	82.0	83.0	88.0	86.0
		Podocarpus latifolius	70.0	82.0	82.0	92.0
		Podocarpus latifolius	76.0	80.0	80.0	88.0
		Podocarpus latifolius	201.0	201.0	201.0	208.0

	F, L, T	*Podocarpus latifolius*	84.0	92.0	92.0	99.0
		Podocarpus latifolius	85.0	91.0	91.0	92.0
		Podocarpus latifolius	69.0	77.0	78.0	82.0
	F, L, t	*Podocarpus latifolius*	20.0	22.0	24.0	25.0
		Podocarpus latifolius	204.0	214.0	214.0	216.0
		Podocarpus latifolius	200.0	202.0	202.0	202.0
		Podocarpus latifolius	25.0	26.0	26.0	26.0
11 *Podocarpus*	f, l, t	*Podocarpus latifolius*	97.0	98.0	98.0	98.0
		Podocarpus latifolius	84.0	86.0	86.0	91.0
		Podocarpus latifolius	89.0	90.0	90.0	104.0
		Podocarpus latifolius	15.0	17.0	17.0	18.0
		Podocarpus latifolius	116.0	116.0	116.0	126.0
		Podocarpus latifolius	63.0	64.0	64.0	67.0
		Podocarpus latifolius	170.0	171.0	172.0	172.0
		Podocarpus latifolius	32.0	36.0	37.0	43.0
		Podocarpus latifolius	107.0	107.0	110.0	112.0
		Podocarpus latifolius	23.0	24.0	26.0	28.0
		Podocarpus latifolius	61.0	66.0	66.0	67.0
		Podocarpus latifolius	86.0	86.0	86.0	87.0
		Podocarpus latifolius	130.0	135.0	137.0	138.0
		Podocarpus latifolius	176.0	179.0	182.0	183.0
		Podocarpus latifolius	8.0	9.0	9.0	13.0
	f, L, T	*Podocarpus latifolius*	34.0	39.0	39.0	39.0
		Podocarpus latifolius	12.0	14.0	14.0	16.0
		Podocarpus latifolius	26.0	29.0	29.0	35.0
		Podocarpus latifolius	46.0	46.0	47.0	53.0
		Podocarpus latifolius	144.0	150.0	155.0	152.0
		Podocarpus latifolius	160.0	160.0	160.0	160.0
		Podocarpus latifolius	81.0	84.0	84.0	84.0
		Podocarpus latifolius	16.0	21.0	21.0	39.0
	f, l, T	*Podocarpus latifolius*	104.0	104.0	105.0	113.0
		Podocarpus latifolius	46.0	46.0	46.0	46.0
		Podocarpus latifolius	60.0	66.0	66.0	68.0
		Podocarpus latifolius	101.0	103.0	103.0	103.0
		Podocarpus latifolius	15.0	18.0	18.0	19.0
		Podocarpus latifolius	133.0	135.0	137.0	138.0
		Podocarpus latifolius	37.0	42.0	42.0	43.0
		Podocarpus latifolius	112.0	116.0	116.0	123.0
	f, L, t	*Podocarpus latifolius*	26.0	31.0	31.0	35.0
		Podocarpus latifolius	60.0	64.0	64.0	70.0
		Podocarpus latifolius	56.0	56.0	56.0	58.0
		Podocarpus latifolius	53.0	53.0	55.0	60.0
		Podocarpus latifolius	62.0	65.0	66.0	65.0
12 *Ocotea*	f, L, T	*Podocarpus latifolius*	72.0	73.0	73.0	79.0

		Podocarpus latifolius	77.0	81.0	81.0	81.0
		Podocarpus latifolius	172.0	175.0	175.0	172.0
		Podocarpus latifolius	122.0	122.0	123.0	137.0
		Podocarpus latifolius	79.0	82.0	84.0	86.0
	f, l, T	*Podocarpus latifolius*	39.0	42.0	42.0	49.0
		Podocarpus latifolius	85.0	96.0	98.0	98.0
	f, L, t	*Podocarpus latifolius*	48.0	50.0	57.0	68.0
		Podocarpus latifolius	32.0	33.0	34.0	38.0
		Podocarpus latifolius	71.0	71.0	71.0	76.0
		Podocarpus latifolius	110.0	113.0	113.0	117.0
13 *Ocotea*	f, l, t	*Podocarpus latifolius*	19.0	21.0	21.0	27.0
		Podocarpus latifolius	100.0	103.0	110.0	116.0
		Podocarpus latifolius	185.0	187.0	191.0	199.0
		Podocarpus latifolius	32.0	34.0	34.0	37.0
		Podocarpus latifolius	107.0	114.0	116.0	127.0
		Podocarpus latifolius	87.0	93.0	93.0	101.0
		Podocarpus latifolius	29.0	34.0	35.0	37.0
		Podocarpus latifolius	103.0	105.0	105.0	116.0
		Ocotea usambarensis	117.0	133.0	144.0	165.0
	f, L, T	*Podocarpus latifolius*	90.0	90.0	92.0	97.0
		Podocarpus latifolius	59.0	61.0	61.0	65.0
		Podocarpus latifolius	84.0	86.0	86.0	88.0
		Podocarpus latifolius	66.0	66.0	66.0	70.0
	f, l, T	*Ocotea usambarensis*	64.0	79.0	84.0	102.0
		Podocarpus latifolius	73.0	87.0	93.0	95.0
		Podocarpus latifolius	170.0	173.0	174.0	174.0
		Podocarpus latifolius	65.0	74.0	74.0	76.0
	f, L, t	*Podocarpus latifolius*	52.0	58.0	58.0	58.0
		Podocarpus latifolius	137.0	142.0	144.0	153.0
		Podocarpus latifolius	124.0	145.0	145.0	145.0
		Podocarpus latifolius	95.0	98.0	98.0	104.0
		Podocarpus latifolius	196.0	211.0	215.0	225.0
		Podocarpus latifolius	89.0	104.0	107.0	116.0
		Podocarpus latifolius	214.0	233.0	235.0	235.0
		Podocarpus latifolius	56.0	56.0	56.0	56.0
		Podocarpus latifolius	112.0	112.0	120.0	120.0
		Podocarpus latifolius	86.0	90.0	90.0	98.0
		Podocarpus latifolius	33.0	39.0	40.0	41.0
		Podocarpus latifolius	69.0	74.0	75.0	77.0
		Podocarpus latifolius	69.0	74.0	74.0	74.0
		Podocarpus latifolius	99.0	102.0	102.0	106.0
		Podocarpus latifolius	83.0	84.0	87.0	90.0
		Podocarpus latifolius	87.0	97.0	97.0	102.0
		Podocarpus latifolius	148.0	148.0	149.0	161.0

15 *Ficalhoa*	**F, L, t**	***Podocarpus latifolius***	59.0	64.0	72.0	84.0
	F, l, t	***Podocarpus latifolius***	208.0	213.0	215.0	212.0
		Podocarpus latifolius	220.0	226.0	226.0	242.0
	F, L, T	***Podocarpus latifolius***	76.0	80.0	80.0	82.0
		Podocarpus latifolius	114.0	120.0	120.0	121.0
16 *Ficalhoa*	**F, l, t**	***Podocarpus latifolius***	109.0	113.0	114.0	125.0
		Podocarpus latifolius	45.0	50.0	52.0	57.0
		Podocarpus latifolius	51.0	51.0	54.0	57.0
	F, l, T	***Podocarpus latifolius***	78.0	85.0	86.0	90.0
	F, L, T	***Podocarpus latifolius***	22.0	28.0	28.0	32.0
18 *Ocotea*	**F, L, T**	***Podocarpus latifolius***	59.0	70.0	73.0	87.0
		Podocarpus latifolius	193.0	195.0	198.0	197.0
		Podocarpus latifolius	51.0	56.0	56.0	61.0
	F, l, T	***Podocarpus latifolius***	14.0	19.0	19.0	20.0
		Ocotea usambarensis	70.0	86.0	86.0	103.0
	F, L, t	***Podocarpus latifolius***	174.0	194.0	214.0	213.0
		Podocarpus latifolius	147.0	149.0	149.0	149.0
		Podocarpus latifolius	184.0	187.0	190.0	190.0
		Ocotea usambarensis	137.0	148.0	148.0	156.0
		Ocotea usambarensis	163.0	176.0	179.0	191.0
		Ocotea usambarensis	156.0	158.0	159.0	165.0
		Ocotea usambarensis	165.0	169.0	170.0	172.0
		Ocotea usambarensis	46.0	56.0	57.0	119.0
		Ocotea usambarensis	79.0	93.0	95.0	125.0
		Ocotea usambarensis	77.0	93.0	93.0	95.0

NB. Treatment codes: F, felled; f, not felled; L, litter retained; l, litter removed; T, tilled; t, not tilled.

Where a treatment combination is not entered for a plot (Target tree), it indicates there was no advance regeneration of *Ficalhoa laurifolia, Ocotea usambarensis* or *Podocarpus latifolius*

Height headings : A, pre-treatment height (January 1999); B, height at treatment (May 1999); C, height in September 1999; D, height in February 2000

Appendix 17 : Heights recorded for the advance cohort of regeneration in the September 1999 treatment plots at Chome, Tanzania

Plot (Target tree)	Treatment	Regenerating species	Heights (cm)		
			A	B	C
17 *Ocotea*	**f, l, T**	***Ocotea usambarensis***	91.0	96.0	107.0
		Ocotea usambarensis	136.0	148.0	208.0
	f, L, t	***Podocarpus latifolius***	139.0	144.0	144.0
		Podocarpus latifolius	23.0	24.0	29.0
		Podocarpus latifolius	16.0	16.0	18.0
		Podocarpus latifolius	69.0	73.0	75.0
		Podocarpus latifolius	191.0	191.0	191.0
		Podocarpus latifolius	22.0	22.0	25.0
		Podocarpus latifolius	69.0	70.0	74.0
		Podocarpus latifolius	35.0	38.0	42.0
		Podocarpus latifolius	83.0	89.0	92.0
		Podocarpus latifolius	17.0	26.0	32.0
		Podocarpus latifolius	25.0	30.0	35.0
		Podocarpus latifolius	78.0	79.0	82.0
		Ocotea usambarensis	56.0	84.0	97.0
	f, l, t	***Ocotea usambarensis***	53.0	70.0	79.0
	f, L, T	***Podocarpus latifolius***	87.0	88.0	92.0
		Podocarpus latifolius	191.0	192.0	192.0
		Podocarpus latifolius	75.0	76.0	80.0
19 *Ficalhoa*	**f, l, T**	***Podocarpus latifolius***	156.0	159.0	159.0
		Podocarpus latifolius	42.0	49.0	59.0
		Podocarpus latifolius	124.0	135.0	146.0
	f, L, t	***Podocarpus latifolius***	139.0	139.0	149.0
	f, l, t	***Podocarpus latifolius***	231.0	234.0	236.0
20 *Ocotea*	**F, L, t**	***Ocotea usambarensis***	30.0	39.0	43.0
		Ocotea usambarensis	35.0	47.0	49.0
		Ocotea usambarensis	98.0	103.0	127.0
		Ocotea usambarensis	107.0	110.0	152.0
		Podocarpus latifolius	118.0	127.0	127.0
		Podocarpus latifolius	31.0	34.0	38.0
		Podocarpus latifolius	22.0	25.0	26.0
	F, l, t	***Ocotea usambarensis***	75.0	82.0	160.0
		Ocotea usambarensis	89.0	89.0	153.0
		Ocotea usambarensis	54.0	61.0	213.0
		Ocotea usambarensis	60.0	74.0	120.0
		Ocotea usambarensis	43.0	53.0	65.0
		Ocotea usambarensis	46.0	81.0	107.0
		Ocotea usambarensis	184.0	193.0	246.0

		Ocotea usambarensis	162.0	165.0	217.0
		Ocotea usambarensis	59.0	75.0	75.0
	F, l, T	*Ocotea usambarensis*	112.0	125.0	125.0
		Ocotea usambarensis	111.0	122.0	129.0
		Ocotea usambarensis	69.0	72.0	107.0
		Ocotea usambarensis	49.0	66.0	96.0
21 *Ocotea*	F, l, t	*Ocotea usambarensis*	130.0	134.0	134.0
		Ocotea usambarensis	155.0	182.0	230.0
		Ocotea usambarensis	129.0	133.0	161.0
		Podocarpus latifolius	118.0	118.0	118.0
		Podocarpus latifolius	49.0	52.0	58.0
	F, L, T	*Ocotea usambarensis*	54.0	67.0	101.0
		Ocotea usambarensis	82.0	92.0	128.0
		Ocotea usambarensis	76.0	86.0	208.0
		Ocotea usambarensis	94.0	105.0	124.0
		Ocotea usambarensis	151.0	151.0	159.0
		Ocotea usambarensis	178.0	200.0	242.0
	F, L, t	*Ocotea usambarensis*	92.0	94.0	109.0
		Ocotea usambarensis	45.0	57.0	119.0
		Ocotea usambarensis	114.0	128.0	178.0
	F, l, T	*Ocotea usambarensis*	123.0	123.0	211.0
		Ocotea usambarensis	99.0	99.0	126.0
22 *Ocotea*	F, l, t	*Podocarpus latifolius*	173.0	173.0	184.0
	F, L, T	*Podocarpus latifolius*	117.0	121.0	121.0
		Podocarpus latifolius	158.0	164.0	166.0
	F, l, T	*Podocarpus latifolius*	204.0	205.0	219.0
		Podocarpus latifolius	102.0	107.0	108.0
		Podocarpus latifolius	52.0	56.0	58.0
	F, L, t	*Podocarpus latifolius*	185.0	189.0	189.0
		Podocarpus latifolius	66.0	66.0	100.0
		Podocarpus latifolius	129.0	129.0	129.0
23 *Ocotea*	F, L, t	*Podocarpus latifolius*	55.0	55.0	56.0
		Podocarpus latifolius	144.0	144.0	145.0
		Podocarpus latifolius	205.0	205.0	217.0
		Podocarpus latifolius	132.0	132.0	136.0
		Ocotea usambarensis	71.0	103.0	135.0
		Ocotea usambarensis	43.0	50.0	51.0
		Ocotea usambarensis	41.0	61.0	86.0
	F, l, t	*Podocarpus latifolius*	88.0	92.0	101.0
		Podocarpus latifolius	173.0	174.0	174.0
		Podocarpus latifolius	45.0	49.0	52.0
	F, L, T	*Podocarpus latifolius*	115.0	121.0	164.0
		Podocarpus latifolius	67.0	73.0	73.0

		Podocarpus latifolius	23.0	29.0	39.0
		Podocarpus latifolius	82.0	82.0	82.0
	F, l, T	*Podocarpus latifolius*	53.0	53.0	54.0
		Podocarpus latifolius	79.0	79.0	86.0
		Podocarpus latifolius	70.0	70.0	70.0
		Podocarpus latifolius	54.0	58.0	64.0
		Podocarpus latifolius	92.0	106.0	107.0
		Podocarpus latifolius	56.0	56.0	61.0
		Podocarpus latifolius	73.0	76.0	77.0
		Podocarpus latifolius	55.0	59.0	60.0
		Podocarpus latifolius	39.0	39.0	46.0
		Podocarpus latifolius	163.0	170.0	179.0
		Podocarpus latifolius	48.0	49.0	55.0
		Ocotea usambarensis	107.0	120.0	131.0
		Ocotea usambarensis	199.0	210.0	233.0
		Ocotea usambarensis	69.0	71.0	102.0
		Ocotea usambarensis	59.0	63.0	81.0
24 *Ocotea*	f, l, T	*Ocotea usambarensis*	50.0	60.0	66.0
		Ocotea usambarensis	26.0	37.0	52.0
	f, l, t	*Podocarpus latifolius*	139.0	139.0	139.0
	f, L, t	*Podocarpus latifolius*	231.0	232.0	232.0
		Podocarpus latifolius	59.0	59.0	61.0
		Ocotea usambarensis	58.0	59.0	64.0

NB. Treatment codes: F, felled; f, not felled; L, litter retained; l, litter removed; T, tilled; t, not tilled. Where a treatment combination is not entered for a plot (Target tree), it indicates there was no advance regeneration of *Ficalhoa laurifolia, Ocotea usambarensis* or *Podocarpus latifolius*

Height headings : A, pre-treatment height (January 1999); B, height at treatment (September 1999); C, in February 2000

Appendix 18 : Heights recorded for the advance cohort of regeneration in the March 1999 treatment plots at Machame, Tanzania

Plot (Target tree)	Treatment	Regenerating species	Heights (cm)				
			A	B	C	D	E
1 *Ocotea*	f, l, t	*Ocotea usambarensis*	151.0	151.0	151.0	151.0	163.0
		Ocotea usambarensis	119.0	126.0	137.0	144.0	176.0
		Ocotea usambarensis	112.0	120.0	122.0	127.0	123.0
		Ocotea usambarensis	77.0	85.0	86.0	89.0	116.0
		Ocotea usambarensis	139.0	148.0	148.0	148.0	151.0
		Ocotea usambarensis	77.0	99.0	100.0	102.0	134.0
		Ocotea usambarensis	78.0	94.0	94.0	94.0	131.0
		Ocotea usambarensis	73.0	91.0	91.0	93.0	104.0
	f, l, T	*Ocotea usambarensis*	65.0	81.0	85.0	85.0	122.0
		Ocotea usambarensis	84.0	91.0	92.0	94.0	94.0
	f, L, t	*Ocotea usambarensis*	37.0	65.0	65.0	66.0	77.0
	f, L, T	*Ocotea usambarensis*	190.0	217.0	217.0	217.0	243.0
		Ocotea usambarensis	154.0	173.0	177.0	177.0	186.0
		Ocotea usambarensis	210.0	211.0	211.0	211.0	233.0
		Ocotea usambarensis	112.0	120.0	120.0	125.0	135.0
2 *Ocotea*	f, L, t	*Ocotea usambarensis*	57.0	60.0	63.0	63.0	67.0
		Ocotea usambarensis	108.0	138.0	153.0	153.0	182.0
		Ocotea usambarensis	214.0	241.0	241.0	241.0	241.0
		Ocotea usambarensis	66.0	67.0	67.0	67.0	93.0
		Ocotea usambarensis	55.0	55.0	57.0	57.0	73.0
		Ocotea usambarensis	51.0	51.0	51.0	51.0	70.0
		Ocotea usambarensis	25.0	50.0	51.0	51.0	57.0
		Ocotea usambarensis	86.0	117.0	117.0	124.0	125.0
		Ocotea usambarensis	180.0	195.0	196.0	196.0	203.0
		Ocotea usambarensis	53.0	59.0	61.0	61.0	91.0
		Ocotea usambarensis	243.0	246.0	246.0	249.0	270.0
		Ocotea usambarensis	166.0	173.0	173.0	174.0	179.0
		Ocotea usambarensis	43.0	49.0	60.0	60.0	60.0
		Ocotea usambarensis	256.0	267.0	267.0	270.0	278.0
		Ocotea usambarensis	217.0	221.0	221.0	223.0	223.0
		Ocotea usambarensis	127.0	127.0	128.0	128.0	131.0
		Ocotea usambarensis	138.0	161.0	162.0	163.0	175.0
		Ocotea usambarensis	126.0	139.0	141.0	141.0	184.0
		Ocotea usambarensis	70.0	73.0	78.0	81.0	107.0
		Ocotea usambarensis	85.0	90.0	91.0	91.0	92.0
		Ocotea usambarensis	71.0	86.0	89.0	89.0	93.0
		Ocotea usambarensis	154.0	159.0	160.0	160.0	169.0
		Ocotea usambarensis	66.0	73.0	73.0	73.0	81.0
		Ocotea usambarensis	63.0	68.0	76.0	76.0	116.0
3 *Ocotea*	f, l, t	*Ocotea usambarensis*	66.0	67.0	73.0	73.0	73.0

		Ocotea usambarensis	31.0	33.0	37.0	39.0	51.0
		Ocotea usambarensis	30.0	31.0	31.0	33.0	42.0
		Ocotea usambarensis	49.0	49.0	60.0	61.0	78.0
		Ocotea usambarensis	122.0	130.0	131.0	131.0	152.0
		Ocotea usambarensis	94.0	102.0	102.0	102.0	144.0
		Ocotea usambarensis	44.0	46.0	50.0	56.0	72.0
	f, l, T	*Ocotea usambarensis*	91.0	95.0	102.0	110.0	138.0
		Ocotea usambarensis	47.0	53.0	62.0	62.0	76.0
		Ocotea usambarensis	95.0	98.0	98.0	101.0	131.0
		Ocotea usambarensis	99.0	110.0	120.0	123.0	142.0
		Ocotea usambarensis	75.0	75.0	75.0	75.0	75.0
		Ocotea usambarensis	128.0	143.0	143.0	143.0	160.0
		Ocotea usambarensis	93.0	96.0	103.0	108.0	138.0
		Ocotea usambarensis	115.0	118.0	118.0	120.0	122.0
		Ocotea usambarensis	141.0	149.0	149.0	150.0	166.0
		Ocotea usambarensis	51.0	51.0	51.0	51.0	51.0
		Ocotea usambarensis	39.0	43.0	47.0	48.0	56.0
		Ocotea usambarensis	163.0	164.0	164.0	164.0	185.0
	f, L, t	*Ocotea usambarensis*	80.0	107.0	107.0	107.0	111.0
		Ocotea usambarensis	41.0	44.0	49.0	50.0	60.0
		Ocotea usambarensis	56.0	58.0	63.0	65.0	75.0
		Ocotea usambarensis	160.0	160.0	160.0	160.0	167.0
		Ocotea usambarensis	72.0	87.0	87.0	92.0	106.0
		Ocotea usambarensis	98.0	106.0	122.0	122.0	144.0
		Ocotea usambarensis	106.0	111.0	122.0	122.0	135.0
		Ocotea usambarensis	132.0	139.0	156.0	156.0	187.0
		Ocotea usambarensis	79.0	79.0	83.0	84.0	91.0
		Ocotea usambarensis	74.0	79.0	91.0	91.0	113.0
		Ocotea usambarensis	45.0	47.0	54.0	55.0	68.0
		Ocotea usambarensis	40.0	41.0	46.0	46.0	62.0
		Ocotea usambarensis	129.0	131.0	143.0	143.0	157.0
		Ocotea usambarensis	131.0	133.0	137.0	137.0	152.0
		Ocotea usambarensis	96.0	104.0	104.0	104.0	121.0
		Ocotea usambarensis	106.0	114.0	130.0	130.0	160.0
		Ocotea usambarensis	73.0	80.0	95.0	95.0	110.0
	f, L, T	*Ocotea usambarensis*	79.0	97.0	98.0	98.0	105.0
		Ocotea usambarensis	53.0	62.0	62.0	63.0	70.0
		Ocotea usambarensis	186.0	194.0	194.0	194.0	224.0
		Ocotea usambarensis	113.0	114.0	127.0	132.0	140.0
		Ocotea usambarensis	125.0	134.0	136.0	136.0	136.0
		Ocotea usambarensis	80.0	94.0	98.0	100.0	119.0
		Ocotea usambarensis	95.0	95.0	99.0	99.0	99.0
		Ocotea usambarensis	152.0	156.0	158.0	163.0	181.0
8 *Ocotea*	**f, l, t**	*Ocotea usambarensis*	195.0	205.0	205.0	206.0	206.0
		Ocotea usambarensis	117.0	119.0	119.0	121.0	128.0

		Ocotea usambarensis	56.0	57.0	57.0	57.0	58.0
		Ocotea usambarensis	99.0	112.0	112.0	116.0	123.0
		Ocotea usambarensis	147.0	153.0	153.0	153.0	163.0
		Ocotea usambarensis	182.0	192.0	192.0	192.0	208.0
		Ocotea usambarensis	79.0	82.0	82.0	82.0	84.0
		Ocotea usambarensis	115.0	116.0	116.0	118.0	126.0
	f, l, T	*Ocotea usambarensis*	120.0	135.0	135.0	157.0	177.0
		Ocotea usambarensis	113.0	122.0	122.0	122.0	123.0
		Ocotea usambarensis	57.0	60.0	60.0	60.0	83.0
		Ocotea usambarensis	153.0	160.0	161.0	161.0	185.0
		Ocotea usambarensis	103.0	110.0	110.0	110.0	110.0
		Ocotea usambarensis	170.0	184.0	184.0	184.0	195.0
		Ocotea usambarensis	150.0	150.0	150.0	150.0	154.0
		Ocotea usambarensis	88.0	92.0	92.0	92.0	93.0
	f, L, t	*Ocotea usambarensis*	188.0	199.0	199.0	199.0	199.0
		Ocotea usambarensis	231.0	255.0	257.0	257.0	270.0
		Ocotea usambarensis	188.0	188.0	188.0	188.0	188.0
		Ocotea usambarensis	134.0	137.0	137.0	137.0	137.0
		Ocotea usambarensis	88.0	104.0	105.0	105.0	111.0
		Ocotea usambarensis	187.0	206.0	206.0	206.0	208.0
		Ocotea usambarensis	93.0	102.0	102.0	102.0	116.0
		Ocotea usambarensis	148.0	150.0	150.0	150.0	170.0
		Ocotea usambarensis	106.0	114.0	114.0	114.0	120.0
		Ocotea usambarensis	89.0	91.0	94.0	94.0	110.0
	f, L, T	*Ocotea usambarensis*	126.0	130.0	130.0	130.0	130.0
		Ocotea usambarensis	96.0	97.0	97.0	97.0	97.0
		Ocotea usambarensis	113.0	122.0	122.0	122.0	124.0
		Ocotea usambarensis	96.0	108.0	111.0	111.0	133.0
		Ocotea usambarensis	47.0	47.0	47.0	47.0	47.0
		Ocotea usambarensis	123.0	144.0	144.0	144.0	165.0
		Ocotea usambarensis	38.0	55.0	58.0	59.0	64.0
		Ocotea usambarensis	101.0	101.0	101.0	101.0	115.0
		Ocotea usambarensis	93.0	116.0	120.0	120.0	149.0
4 *Ocotea*	F, L, t	*Ocotea usambarensis*	61.0	65.0	65.0	65.0	68.0
		Ocotea usambarensis	167.0	179.0	179.0	179.0	202.0
		Ocotea usambarensis	135.0	165.0	185.0	195.0	277.0
		Ocotea usambarensis	121.0	219.0	219.0	219.0	256.0
		Ocotea usambarensis	168.0	187.0	187.0	199.0	233.0
		Ocotea usambarensis	123.0	163.0	163.0	163.0	164.0
		Ocotea usambarensis	133.0	136.0	138.0	138.0	154.0
		Ocotea usambarensis	87.0	90.0	90.0	90.0	90.0
5 *Ocotea*	F, l, t	*Ocotea usambarensis*	180.0	196.0	210.0	215.0	237.0
		Ocotea usambarensis	179.0	193.0	193.0	193.0	268.0
		Ocotea usambarensis	183.0	194.0	205.0	205.0	216.0

		Ocotea usambarensis	79.0	83.0	91.0	91.0	121.0
		Ocotea usambarensis	60.0	82.0	93.0	95.0	122.0
	F, l, T	*Ocotea usambarensis*	52.0	56.0	62.0	62.0	69.0
		Ocotea usambarensis	65.0	72.0	79.0	80.0	80.0
		Ocotea usambarensis	114.0	125.0	126.0	131.0	137.0
		Ocotea usambarensis	58.0	76.0	84.0	86.0	145.0
		Ocotea usambarensis	61.0	66.0	68.0	70.0	112.0
		Ocotea usambarensis	51.0	62.0	67.0	67.0	83.0
	F, L, t	*Ocotea usambarensis*	185.0	216.0	216.0	216.0	238.0
		Ocotea usambarensis	189.0	189.0	192.0	199.0	212.0
		Ocotea usambarensis	114.0	148.0	161.0	161.0	201.0
		Ocotea usambarensis	84.0	91.0	96.0	98.0	115.0
		Ocotea usambarensis	97.0	97.0	115.0	117.0	131.0
		Ocotea usambarensis	66.0	74.0	91.0	93.0	118.0
		Ocotea usambarensis	158.0	165.0	166.0	166.0	177.0
		Ocotea usambarensis	120.0	144.0	155.0	156.0	190.0
		Ocotea usambarensis	74.0	87.0	95.0	97.0	131.0
		Ocotea usambarensis	57.0	66.0	84.0	85.0	109.0
		Ocotea usambarensis	83.0	93.0	95.0	104.0	135.0
	F, L, T	*Ocotea usambarensis*	155.0	172.0	172.0	172.0	186.0
		Ocotea usambarensis	94.0	100.0	100.0	100.0	126.0
6 *Ocotea*	F, L, t	*Ocotea usambarensis*	64.0	68.0	68.0	69.0	78.0
		Ocotea usambarensis	175.0	204.0	205.0	205.0	217.0
		Ocotea usambarensis	97.0	99.0	102.0	104.0	113.0
		Ocotea usambarensis	172.0	179.0	179.0	181.0	183.0
		Ocotea usambarensis	57.0	67.0	68.0	69.0	89.0
		Ocotea usambarensis	79.0	89.0	89.0	93.0	111.0
		Ocotea usambarensis	44.0	44.0	45.0	45.0	45.0
		Ocotea usambarensis	169.0	175.0	181.0	181.0	202.0
		Ocotea usambarensis	186.0	194.0	194.0	196.0	214.0
		Ocotea usambarensis	189.0	193.0	204.0	206.0	206.0
7 *Ocotea*	F, l, t	*Ocotea usambarensis*	149.0	166.0	171.0	171.0	171.0
		Ocotea usambarensis	66.0	85.0	89.0	89.0	120.0
		Ocotea usambarensis	86.0	107.0	107.0	108.0	113.0
		Ocotea usambarensis	65.0	72.0	72.0	72.0	75.0
		Ocotea usambarensis	40.0	45.0	51.0	55.0	66.0
		Ocotea usambarensis	127.0	133.0	134.0	136.0	142.0
		Ocotea usambarensis	162.0	166.0	168.0	173.0	175.0
		Ocotea usambarensis	39.0	51.0	52.0	52.0	64.0
	F, l, T	*Ocotea usambarensis*	106.0	131.0	134.0	134.0	143.0
		Ocotea usambarensis	61.0	65.0	65.0	65.0	65.0
		Ocotea usambarensis	78.0	90.0	90.0	90.0	110.0
		Ocotea usambarensis	193.0	203.0	203.0	212.0	228.0
		Ocotea usambarensis	109.0	114.0	114.0	114.0	114.0

F, L, t	*Ocotea usambarensis*	132.0	161.0	161.0	161.0	187.0
	Ocotea usambarensis	63.0	63.0	67.0	67.0	91.0
	Ocotea usambarensis	63.0	64.0	64.0	65.0	67.0
	Ocotea usambarensis	103.0	125.0	125.0	125.0	145.0
	Ocotea usambarensis	99.0	114.0	114.0	118.0	122.0
	Ocotea usambarensis	53.0	67.0	67.0	67.0	72.0
	Ocotea usambarensis	210.0	228.0	228.0	228.0	258.0
	Ocotea usambarensis	112.0	112.0	112.0	112.0	113.0
	Ocotea usambarensis	123.0	135.0	136.0	136.0	151.0
F, L, T	*Ocotea usambarensis*	63.0	80.0	80.0	80.0	80.0
	Ocotea usambarensis	107.0	112.0	112.0	113.0	114.0
	Ocotea usambarensis	90.0	92.0	92.0	93.0	93.0
	Ocotea usambarensis	178.0	192.0	192.0	192.0	215.0
	Ocotea usambarensis	94.0	110.0	110.0	110.0	115.0
	Ocotea usambarensis	70.0	78.0	78.0	78.0	78.0
	Ocotea usambarensis	43.0	48.0	49.0	49.0	63.0
	Ocotea usambarensis	206.0	206.0	211.0	216.0	216.0
	Ocotea usambarensis	204.0	227.0	227.0	228.0	269.0
	Ocotea usambarensis	219.0	235.0	236.0	237.0	262.0

NB. Treatment codes: F, felled; f, not felled; L, litter retained; l, litter removed; T, tilled; t, not tilled. Where a treatment combination is not entered for a plot (Target tree), it indicates there was no advance regeneration of *Ocotea usambarensis*

Height headings : A, pre-treatment height (December 1999); B, height at treatment (March 1999); C, height in May 1999; D, height in September 1999; E, height in February 2000

Appendix 19 : Heights recorded for the advance cohort of regeneration in May 1999 treatment plots at Machame, Tanzania

Plot (Target tree)	Treatment	Regenerating species	Heights (cm)			
			A	B	C	D
9 *Ocotea*	F, L, T	*Ocotea usambarensis*	105.0	121.0	122.0	144.0
		Ocotea usambarensis	115.0	134.0	137.0	151.0
		Ocotea usambarensis	103.0	127.0	133.0	136.0
		Ocotea usambarensis	162.0	165.0	169.0	171.0
		Ocotea usambarensis	115.0	126.0	130.0	130.0
	F, L, t	*Ocotea usambarensis*	77.0	93.0	93.0	137.0
10 *Ocotea*	f, L, T	*Ocotea usambarensis*	96.0	100.0	100.0	108.0
		Ocotea usambarensis	132.0	146.0	147.0	163.0
		Ocotea usambarensis	112.0	113.0	113.0	128.0
		Ocotea usambarensis	128.0	186.0	186.0	207.0
		Ocotea usambarensis	134.0	147.0	149.0	165.0
	f, l, T	*Ocotea usambarensis*	78.0	96.0	98.0	109.0
		Ocotea usambarensis	69.0	72.0	77.0	82.0
		Ocotea usambarensis	75.0	76.0	77.0	79.0
		Ocotea usambarensis	108.0	109.0	109.0	109.0
		Ocotea usambarensis	73.0	81.0	81.0	83.0
	f, L, t	*Ocotea usambarensis*	89.0	101.0	101.0	115.0
		Ocotea usambarensis	65.0	75.0	76.0	86.0
		Ocotea usambarensis	23.0	56.0	57.0	63.0
		Ocotea usambarensis	151.0	166.0	166.0	175.0
	f, l, t	*Ocotea usambarensis*	107.0	119.0	124.0	135.0
		Ocotea usambarensis	111.0	119.0	122.0	136.0
		Ocotea usambarensis	76.0	78.0	88.0	97.0
		Ocotea usambarensis	129.0	138.0	138.0	154.0
11 *Ocotea*	F, l, T	*Ocotea usambarensis*	33.0	47.0	48.0	69.0
		Ocotea usambarensis	76.0	95.0	98.0	100.0
		Ocotea usambarensis	179.0	181.0	188.0	188.0
		Ocotea usambarensis	129.0	139.0	139.0	201.0
		Ocotea usambarensis	158.0	158.0	158.0	169.0
	F, L, t	*Ocotea usambarensis*	38.0	38.0	38.0	56.0
		Ocotea usambarensis	59.0	73.0	76.0	92.0
		Ocotea usambarensis	79.0	84.0	85.0	98.0
	F, l, t	*Ocotea usambarensis*	69.0	110.0	115.0	153.0
		Ocotea usambarensis	64.0	72.0	72.0	96.0
		Ocotea usambarensis	68.0	74.0	76.0	117.0
		Ocotea usambarensis	76.0	103.0	103.0	126.0
	F, L, T	*Ocotea usambarensis*	48.0	63.0	64.0	66.0
		Ocotea usambarensis	190.0	190.0	190.0	190.0

12 *Ocotea*	**f, L, t**	***Ocotea usambarensis***	135.0	145.0	148.0	163.0
		Ocotea usambarensis	169.0	189.0	189.0	208.0
		Ocotea usambarensis	135.0	141.0	153.0	156.0
	f, L, T	***Ocotea usambarensis***	74.0	82.0	83.0	89.0
		Ocotea usambarensis	113.0	123.0	124.0	135.0
		Ocotea usambarensis	67.0	79.0	79.0	87.0
		Ocotea usambarensis	145.0	156.0	158.0	166.0
	f, l, T	***Ocotea usambarensis***	158.0	159.0	161.0	158.0
13 *Macaranga*	**F, l, t**	***Ocotea usambarensis***	163.0	184.0	184.0	202.0
		Ocotea usambarensis	120.0	133.0	134.0	155.0
		Ocotea usambarensis	160.0	183.0	183.0	217.0
		Ocotea usambarensis	75.0	77.0	78.0	85.0
		Ocotea usambarensis	44.0	52.0	54.0	59.0
		Ocotea usambarensis	161.0	164.0	186.0	216.0
	F, L, T	***Ocotea usambarensis***	163.0	179.0	201.0	183.0
		Ocotea usambarensis	200.0	210.0	210.0	224.0
		Ocotea usambarensis	75.0	78.0	79.0	91.0
		Ocotea usambarensis	101.0	108.0	108.0	122.0
		Ocotea usambarensis	107.0	112.0	112.0	120.0
		Ocotea usambarensis	86.0	97.0	105.0	135.0
		Ocotea usambarensis	50.0	56.0	66.0	71.0
		Ocotea usambarensis	50.0	56.0	66.0	74.0
		Ocotea usambarensis	177.0	180.0	182.0	203.0
	F, l, T	***Ocotea usambarensis***	103.0	111.0	115.0	133.0
		Ocotea usambarensis	53.0	54.0	54.0	66.0
		Ocotea usambarensis	99.0	104.0	104.0	114.0
		Ocotea usambarensis	69.0	83.0	83.0	163.0
		Ocotea usambarensis	96.0	117.0	117.0	133.0
		Ocotea usambarensis	163.0	183.0	184.0	216.0
	F, L, t	***Ocotea usambarensis***	158.0	177.0	178.0	198.0
		Ocotea usambarensis	106.0	118.0	125.0	144.0
		Ocotea usambarensis	47.0	55.0	55.0	76.0
14 *Ocotea*	**f, l, t**	***Ocotea usambarensis***	71.0	74.0	81.0	94.0
		Ocotea usambarensis	165.0	165.0	166.0	163.0
		Ocotea usambarensis	69.0	69.0	70.0	81.0
	f, L, T	***Ocotea usambarensis***	78.0	80.0	80.0	96.0
		Ocotea usambarensis	188.0	201.0	201.0	221.0
		Ocotea usambarensis	30.0	32.0	33.0	36.0
	f, l, T	***Ocotea usambarensis***	50.0	56.0	56.0	60.0
	f, L, t	***Ocotea usambarensis***	123.0	139.0	163.0	186.0
		Ocotea usambarensis	101.0	131.0	136.0	163.0
		Ocotea usambarensis	37.0	47.0	47.0	55.0
15 *Ocotea*	**f, l, t**	***Ocotea usambarensis***	177.0	190.0	221.0	273.0

		Ocotea usambarensis	214.0	234.0	242.0	275.0
		Ocotea usambarensis	111.0	111.0	111.0	111.0
		Ocotea usambarensis	168.0	168.0	168.0	190.0
		Ocotea usambarensis	69.0	72.0	72.0	86.0
		Ocotea usambarensis	190.0	197.0	201.0	221.0
		Ocotea usambarensis	210.0	222.0	225.0	247.0
	f, L, T	*Ocotea usambarensis*	35.0	40.0	49.0	45.0
	f, l, T	*Ocotea usambarensis*	106.0	113.0	114.0	114.0
	f, L, t	*Ocotea usambarensis*	120.0	120.0	120.0	198.0
		Ocotea usambarensis	124.0	133.0	139.0	154.0
16 *Ocotea*	f, l, t	*Ocotea usambarensis*	184.0	189.0	189.0	217.0
		Ocotea usambarensis	154.0	154.0	157.0	184.0
		Ocotea usambarensis	153.0	167.0	167.0	167.0
	f, L, T	*Ocotea usambarensis*	117.0	133.0	133.0	154.0
	f, L, t	*Ocotea usambarensis*	101.0	121.0	122.0	149.0
		Ocotea usambarensis	75.0	92.0	100.0	118.0
		Ocotea usambarensis	148.0	179.0	181.0	194.0
		Ocotea usambarensis	164.0	170.0	182.0	189.0
		Ocotea usambarensis	137.0	142.0	152.0	177.0
	f, l, T	*Ocotea usambarensis*	97.0	118.0	118.0	127.0
		Ocotea usambarensis	168.0	180.0	183.0	212.0
		Ocotea usambarensis	161.0	164.0	164.0	186.0

NB. Treatment codes: F, felled; f, not felled; L, litter retained; l, litter removed; T, tilled; t, not tilled. Where a treatment combination is not entered for a plot (Target tree), it indicates there was no advance regeneration of *Ocotea usambarensis*

Height headings : A, pre-treatment height (December 1999); B, height at treatment (May 1999); C, height in September 1999; D, height in February 2000

Appendix 20 : Heights recorded for the advance cohort of regeneration in the September 1999 treatment plots at Machame, Tanzania

Plot (Target tree)	Treatment	Regenerating species	Heights (cm)		
			A	B	C
17 *Ocotea*	F, l, t	*Ocotea usambarensis*	119.0	141.0	169.0
		Ocotea usambarensis	73.0	83.0	100.0
	F, L, T	*Ocotea usambarensis*	78.0	92.0	101.0
		Ocotea usambarensis	140.0	144.0	148.0
		Ocotea usambarensis	110.0	119.0	126.0
		Ocotea usambarensis	119.0	119.0	135.0
		Ocotea usambarensis	59.0	62.0	62.0
18 *Ocotea*	F, l, t	*Ocotea usambarensis*	96.0	102.0	125.0
		Ocotea usambarensis	140.0	165.0	188.0
		Ocotea usambarensis	127.0	127.0	153.0
		Ocotea usambarensis	42.0	52.0	55.0
		Ocotea usambarensis	143.0	163.0	163.0
		Ocotea usambarensis	26.0	38.0	55.0
	F, l, T	*Ocotea usambarensis*	129.0	167.0	200.0
		Ocotea usambarensis	123.0	160.0	197.0
		Ocotea usambarensis	68.0	79.0	93.0
		Ocotea usambarensis	119.0	144.0	158.0
		Ocotea usambarensis	132.0	132.0	150.0
		Ocotea usambarensis	43.0	54.0	63.0
		Ocotea usambarensis	99.0	100.0	115.0
	F, L, t	*Ocotea usambarensis*	47.0	47.0	53.0
		Ocotea usambarensis	103.0	104.0	115.0
		Ocotea usambarensis	84.0	86.0	101.0
		Ocotea usambarensis	152.0	153.0	170.0
19 *Ocotea*	f, l, t	*Ocotea usambarensis*	184.0	190.0	214.0
		Ocotea usambarensis	141.0	145.0	148.0
		Ocotea usambarensis	190.0	207.0	231.0
		Ocotea usambarensis	144.0	155.0	179.0
	f, L, T	*Ocotea usambarensis*	81.0	81.0	114.0
		Ocotea usambarensis	179.0	193.0	188.0
		Ocotea usambarensis	102.0	111.0	140.0
		Ocotea usambarensis	52.0	57.0	67.0
		Ocotea usambarensis	119.0	120.0	127.0
		Ocotea usambarensis	101.0	119.0	167.0
		Ocotea usambarensis	146.0	153.0	153.0
	f, l, T	*Ocotea usambarensis*	77.0	87.0	102.0
		Ocotea usambarensis	71.0	78.0	87.0
		Ocotea usambarensis	77.0	126.0	145.0
		Ocotea usambarensis	174.0	206.0	230.0
		Ocotea usambarensis	123.0	135.0	148.0

	f, L, t	***Ocotea usambarensis***	150.0	151.0	154.0
		Ocotea usambarensis	73.0	74.0	122.0
		Ocotea usambarensis	143.0	158.0	183.0
		Ocotea usambarensis	100.0	100.0	110.0
20 *Ocotea*	**f, l, t**	***Ocotea usambarensis***	110.0	112.0	120.0
		Ocotea usambarensis	120.0	153.0	156.0
		Ocotea usambarensis	98.0	106.0	114.0
	f, L, T	***Ocotea usambarensis***	63.0	75.0	83.0
		Ocotea usambarensis	89.0	96.0	96.0
		Ocotea usambarensis	27.0	37.0	48.0
	f, l, T	***Ocotea usambarensis***	86.0	87.0	136.0
	f, L, t	***Ocotea usambarensis***	30.0	39.0	49.0
		Ocotea usambarensis	130.0	134.0	166.0
		Ocotea usambarensis	97.0	121.0	134.0
		Ocotea usambarensis	47.0	50.0	89.0
21 *Ocotea*	**F, l, t**	***Ocotea usambarensis***	86.0	104.0	123.0
		Ocotea usambarensis	62.0	85.0	85.0
		Ocotea usambarensis	128.0	134.0	139.0
	F, L, T	***Ocotea usambarensis***	121.0	122.0	124.0
		Ocotea usambarensis	91.0	101.0	116.0
		Ocotea usambarensis	125.0	132.0	141.0
		Ocotea usambarensis	135.0	161.0	207.0
		Ocotea usambarensis	92.0	92.0	92.0
		Ocotea usambarensis	45.0	60.0	91.0
	F, l, T	***Ocotea usambarensis***	64.0	68.0	74.0
		Ocotea usambarensis	41.0	61.0	91.0
		Ocotea usambarensis	107.0	110.0	137.0
		Ocotea usambarensis	87.0	94.0	98.0
		Ocotea usambarensis	139.0	146.0	148.0
		Ocotea usambarensis	160.0	166.0	171.0
		Ocotea usambarensis	151.0	158.0	158.0
		Ocotea usambarensis	153.0	173.0	209.0
		Ocotea usambarensis	182.0	199.0	241.0
		Ocotea usambarensis	168.0	184.0	196.0
		Ocotea usambarensis	165.0	196.0	225.0
	F, L, t	***Ocotea usambarensis***	139.0	144.0	161.0
		Ocotea usambarensis	54.0	63.0	78.0
		Ocotea usambarensis	178.0	194.0	223.0
		Ocotea usambarensis	189.0	193.0	227.0
		Ocotea usambarensis	184.0	220.0	253.0
		Ocotea usambarensis	120.0	124.0	140.0
22 *Ocotea*	**f, l, t**	***Ocotea usambarensis***	127.0	145.0	157.0
		Ocotea usambarensis	64.0	69.0	74.0

		Ocotea usambarensis	117.0	117.0	117.0
		Ocotea usambarensis	80.0	94.0	115.0
		Ocotea usambarensis	75.0	115.0	127.0
		Ocotea usambarensis	163.0	177.0	201.0
		Ocotea usambarensis	97.0	106.0	111.0
		Ocotea usambarensis	69.0	86.0	88.0
	f, L, T	*Ocotea usambarensis*	157.0	163.0	189.0
	f, l, T	*Ocotea usambarensis*	116.0	130.0	166.0
23 *Ocotea*	F, L, T	*Ocotea usambarensis*	78.0	86.0	133.0
		Ocotea usambarensis	83.0	103.0	107.0
		Ocotea usambarensis	99.0	114.0	123.0
		Ocotea usambarensis	40.0	44.0	63.0
		Ocotea usambarensis	78.0	80.0	82.0
		Ocotea usambarensis	117.0	121.0	121.0
		Ocotea usambarensis	40.0	44.0	48.0
	F, L, t	*Ocotea usambarensis*	162.0	167.0	186.0
		Ocotea usambarensis	49.0	55.0	67.0
		Ocotea usambarensis	83.0	136.0	161.0
		Ocotea usambarensis	149.0	152.0	165.0
		Ocotea usambarensis	174.0	194.0	216.0
		Ocotea usambarensis	112.0	139.0	160.0
		Ocotea usambarensis	91.0	94.0	96.0
	F, l, T	*Ocotea usambarensis*	102.0	122.0	141.0
		Ocotea usambarensis	169.0	186.0	187.0
24 *Ocotea*	F, l, t	*Ocotea usambarensis*	59.0	83.0	111.0
		Ocotea usambarensis	105.0	115.0	123.0
		Ocotea usambarensis	77.0	105.0	129.0
		Ocotea usambarensis	149.0	174.0	195.0
		Ocotea usambarensis	71.0	106.0	116.0
		Ocotea usambarensis	122.0	113.0	122.0
		Ocotea usambarensis	129.0	143.0	147.0
	F, L, T	*Ocotea usambarensis*	73.0	79.0	91.0
		Ocotea usambarensis	125.0	125.0	165.0
		Ocotea usambarensis	40.0	54.0	71.0
		Ocotea usambarensis	169.0	170.0	192.0
		Ocotea usambarensis	146.0	153.0	173.0
	F, l, T	*Ocotea usambarensis*	82.0	85.0	91.0
		Ocotea usambarensis	172.0	172.0	198.0
		Ocotea usambarensis	188.0	200.0	220.0
		Ocotea usambarensis	180.0	180.0	206.0
	F, L, t	*Ocotea usambarensis*	183.0	190.0	212.0
		Ocotea usambarensis	32.0	66.0	91.0
		Ocotea usambarensis	144.0	147.0	186.0
		Ocotea usambarensis	55.0	59.0	71.0

NB. Treatment codes: F, felled; f, not felled; L, litter retained; l, litter removed; T, tilled; t, not tilled. Where a treatment combination is not entered for a plot (Target tree), it indicates there was no advance regeneration of *Ocotea usambarensis*

Height headings : A, pre-treatment height (December 1999); B, height at treatment (September 1999); C, height in February 2000

Appendix 21 : Heights recorded for the advance cohort of regeneration in the May 1999 treatment plots at Rongai, Tanzania

Plot (Target tree)	Treatment	Regenerating species	Heights (cm)			
			A	B	C	D
1 *Fagaropsis*	f, L, t	*Podocarpus falcatus*	193.0	193.0	193.0	193.0
		Podocarpus falcatus	164.0	164.0	164.0	185.0
2 *Fagaropsis*	f, L, t	*Podocarpus falcatus*	174.0	175.0	175.0	198.0
5 *Fagaropsis*	f, l, t	*Podocarpus falcatus*	171.0	171.0	178.0	181.0
		Fagaropsis angolensis		5.0	6.0	7.0
		Fagaropsis angolensis		4.0	5.0	8.0
	f, L, t	*Fagaropsis angolensis*		76.0	77.0	79.0
		Fagaropsis angolensis		34.0	34.0	37.0
11 *Fagaropsis*	f, l, t	*Podocarpus falcatus*	206.0	206.0	206.0	208.0
	f, l, T	*Fagaropsis angolensis*		107.0	107.0	111.0
16 *Fagaropsis*	f, L, t	*Podocarpus falcatus*	140.0	140.0	140.0	149.0
		Podocarpus falcatus	171.0	171.0	171.0	194.0
		Podocarpus falcatus	79.0	79.0	80.0	80.0
		Fagaropsis angolensis		39.0	42.0	42.0
3 *Fagaropsis*	F, L, t	*Podocarpus falcatus*	69.0	77.0	78.0	80.0
		Podocarpus falcatus	48.0	48.0	48.0	51.0
7 *Fagaropsis*	F, L, t	*Podocarpus falcatus*	190.0	192.0	197.0	199.0
8 *Podocarpus*	F, L, t	*Podocarpus falcatus*	73.0	75.0	75.0	76.0
9 *Podocarpus*	F, l, T	*Podocarpus falcatus*	81.0	82.0	82.0	88.0
14 *Fagaropsis*	F, L, T	*Podocarpus falcatus*	65.0	70.0	74.0	94.0
17 *Fagaropsis*	F, l, t	*Podocarpus falcatus*	189.0	191.0	191.0	200.0
		Podocarpus falcatus	85.0	85.0	86.0	87.0
	F, l, T	*Podocarpus falcatus*	204.0	204.0	204.0	208.0
	F, L, t	*Fagaropsis angolensis*		115.0	117.0	121.0

NB. Treatment codes: F, felled; f, not felled; L, litter retained; l, litter removed; T, tilled; t, not tilled. Where a treatment combination is not entered for a plot (Target tree), it indicates there was no advance regeneration of *Fagaropsis angolensis* or *Podocarpus falcatus*

Height headings : A, pre-treatment height (December 1999); B, height at treatment (May 1999); C, height in September 1999; D, height in February 2000

Appendix 22 : Heights recorded for the Advance Cohort of regeneration in the September 1999 treatment plots at Rongai, Tanzania

Plot (Target tree)	Treatment	Regenerating species	Heights (cm)		
			A	B	C
1 *Fagaropsis*	f, l, t	*Fagaropsis angolensis*		3.5	6.0
		Fagaropsis angolensis		4.0	6.0
		Fagaropsis angolensis		3.0	5.0
	f, L, t	*Fagaropsis angolensis*		3.0	6.0
		Fagaropsis angolensis		4.0	7.0
		Fagaropsis angolensis		3.5	7.0
	f, l, T	*Fagaropsis angolensis*		5.0	8.0
2 *Fagaropsis*	f, L, T	*Podocarpus falcatus*	192.0	198.0	225.0
6 *Fagaropsis*	f, l, t	*Fagaropsis angolensis*		4.0	7.0
		Fagaropsis angolensis		5.0	9.0
		Fagaropsis angolensis		7.0	12.0
	f, L, t	*Fagaropsis angolensis*		4.0	12.0
	f, L, T	*Fagaropsis angolensis*		5.5	8.0
		Fagaropsis angolensis		13.0	14.0
9 *Podocarpus*	F, L, t	*Podocarpus falcatus*	42.0	46.0	51.0
15 *Fagaropsis*	f, l, T	*Podocarpus falcatus*	145.0	146.0	146.0
		Podocarpus falcatus	97.0	106.0	112.0
	f, L, t	*Podocarpus falcatus*	170.0	179.0	185.0
18 *Fagaropsis*	F, l, T	*Podocarpus falcatus*	92.0	96.0	99.0
		Fagaropsis angolensis		82.0	98.0
19 *Fagaropsis*	F, l, t	*Podocarpus falcatus*	78.0	88.0	112.0
		Fagaropsis angolensis		137.0	137.0
	F, L, T	*Fagaropsis angolensis*		112.0	159.0
	F, L, t	*Fagaropsis angolensis*		13.0	20.0
23 *Fagaropsis*	F, l, T	*Podocarpus falcatus*	154.0	156.0	178.0

NB. Treatment codes: F, felled; f, not felled; L, litter retained; l, litter removed; T, tilled; t, not tilled. Where a treatment combination is not entered for a plot (Target tree), it indicates there was no advance regeneration of *Fagaropsis angolensis* or *Podocarpus falcatus*

Height headings : A, pre-treatment height (February 1999); B, height at treatment (September 1999); C, height in February 2000

Appendix 23 : *Ocotea usambarensis, Podocarpus latifolius, Ficalhoa laurifolia, Fagaropsis angolensis* and other woody plants basal area ((m^2/ha) of the forest in and around each plot at Chome, Machame and Rongai, Tanzania.

Forest	*Ocotea usambarensis* (m^2/ha)	*Podocarpus latifolius* (m^2/ha)	*Podocarpus falcatus* (m^2/ha)	*Ficalhoa laurifolia* (m^2/ha)	*Fagaropsis angolensis* (m^2/ha)	Other woody plants (m^2/ha)	Total basal area (m^2/ha)
Chome	5	0	0	0	0	19	24
	3	1	0	2	0	12	18
	4	1	0	6	0	26	37
	2	0	0	5	0	23	30
	2	2	0	1	0	26	31
	5	0	0	0	0	12	17
	3	2	0	1	0	30	36
	2	1	0	4	0	24	31
	8	0	0	0	0	22	30
	3	1	0	0	0	26	30
	0	2	0	1	0	29	32
	2	0	0	0	0	34	36
	6	1	0	1	0	27	35
	0	1	0	3	0	29	33
	2	0	0	9	0	11	36
	0	0	0	7	0	29	36
	2	0	0	19	0	16	37
	5	0	0	1	0	48	54
	0	0	0	12	0	36	48
	3	0	0	7	0	22	32
	7	1	0	8	0	13	29
	8	1	0	0	0	29	38
	16	0	0	0	0	19	35
	6	3	0	4	0	22	35
Machame	6	0	0	0	0	7	13
	11	0	0	0	0	17	28
	10	0	0	0	0	23	33
	10	0	0	0	0	12	22
	5	0	0	0	0	19	24
	17	0	0	0	0	2	19
	20	0	0	0	0	4	24
	20	0	0	0	0	2	22
	21	0	0	0	0	7	28
	10	0	0	0	0	9	19
	13	0	0	0	0	6	19
	10	0	0	0	0	14	24
	3	0	0	0	0	24	27
	10	0	0	0	0	18	28
	8	0	0	0	0	19	27
	3	0	0	0	0	24	27
	5	0	0	0	0	11	16
	5	0	0	0	0	11	16
	3	0	0	0	0	16	19
	7	0	0	0	0	23	30
	9	0	0	0	0	12	21
	11	0	0	0	0	6	17
	13	0	0	0	0	11	24
	10	0	0	0	0	16	26
Rongai	0	0	0	0	0	32	32
	0	0	0	0	1	44	45

	0	0	0	0	1	37	38
	0	0	0	0	2	28	30
	0	0	0	0	2	33	35
	0	0	7	0	1	22	30
	0	0	5	0	1	19	25
	0	0	7	0	0	30	37
	0	0	6	0	0	23	29
	0	0	0	0	2	21	23
	0	0	0	0	5	14	19
	0	0	0	0	2	13	15
	0	0	0	0	2	19	21
	0	0	0	0	1	15	16
	0	0	2	0	2	23	27
	0	0	0	0	1	31	32
	0	0	1	0	1	31	33
	0	0	1	0	1	25	27
	0	0	0	0	2	20	22
	0	0	0	0	2	26	28
	0	0	3	0	3	29	35
	0	0	6	0	2	26	34
	0	0	10	0	4	37	51
	0	0	10	0	2	23	35