EVALUATION OF NATURAL REGENERATION POTENTIAL OF A DEGRADED FOREST IN GHANA

BY

YOHANES A.K. HONU. ©

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Lakehead University

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NAME OF STUDENT: Yohanes A.K. Honu

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Regeneration is one of the challenges facing the forestry industry in Ghana. Although artificial regeneration is effective, its application has been limited by the economical power of the country. Cutovers or severely disturbed forest sites are often occupied by an aggressive weed species Chromolaeta odorata, preventing the natural regeneration of tree species. This thesis first investigated the species composition and abundance of seeds and seedlings of trees and other plants under the canopy of Chromolaeta odorata and then examined the response of tree seedlings to the removal of Chromolaet odorata canopy. The findings of this thesis suggest that sites that are dominated by Chromolaeta odorata can be restored back to forests by removing the competing vegetation if there are sufficient tree seedlings. Although there are several important questions that need to be answered before this silvicultural treatment can be adopted by the forest industry, such as how soon the trees can reach the free-to-grow stage, the results of this have significant implications to the future of forest resources in Ghana.

The thesis is well written and easy to read. The research questions were clearly identified and enough background information was given. The fact that the author was able to identify these questions himself indicates his extraordinary qualification as a M.Sc.F. candidate and the potential for as a future scientist. The experiment was well planned and executed. Enough information was given to allow a duplication of the study. The results were properly interpreted and discussed in terms of their ecological and practical implications. It is good that the author pointed out the direction of future research in this area. The weakness of thesis includes the lack of explicit hypotheses to be tested, the lack of replication and short-term of the study. However, the last two points were more limited by the limited time and financial resource available for a M.Sc.F. thesis project than by the ability of the researcher. Nevertheless, the results should be interpreted and used with caution.

Qing-Lai Dang (Ph.D.)
Assistant Professor

November 4, 1999.

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EXTERNAL EXAMINER'S REPORT ON M.SC.F. THESIS

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This is an extremely well written thesis representing a considerable amount of work. The study design is sound, the data appropriately analyzed and the results useful for recommending silvicultural actions on these sites.

I have made minor editorial suggestions- marked on the thesis. The candidate and his committee are commended for producing an excellent thesis.

Dr. Cindy Prescott

October 4, 1999.

ABSTRACT

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Vast areas of forests have been degraded in Ghana. The degraded areas are generally invaded by *Chromolaena odorata*, a strong competing species for trees. Planting is the major primary means that is currently used to restore these areas back to forests. However, natural regeneration or human-assisted natural regeneration may provide an alternative way to regenerate these areas. To evaluate the potential of this alternative, the density and species composition of tree seedlings under the canopy of *Chromolaena odorata* and the seeds of both trees and *Chromolaena odorata* in a degraded area were estimated. The response of tree seedlings to the removal of *Chromolaena odorata* was also examined. One hundred and eight plots were established 20 m apart for assessing the tree seedlings. *Chromolaena odorata* was removed from 50 % of the plots to release tree seedlings and left the other half intact. Seedling height, the number of leaves per seedling, and seedling mortality were assessed in both released and unreleased plots immediately after the release treatment (June 1998) and again three months later (September 1998). Smaller plots (0.25 m^2) next to half of the seedling plots were used to sample the soil seed bank. The soil samples were taken from two different depths and germinated in a germination house. Fifty five species of tree seedlings and seven species of tree seeds were found at the site. There were 11,780 seedlings ha^{-1} and the seedlings were well distributed in the degraded area. The density of tree seeds (46,000 seeds ha^{-1}) was 3.8 times higher than tree seedlings, but the species composition of tree seedlings was 7.8 times higher than the species composition of seeds. The spatial distribution of tree seedlings was more even than that of tree seeds. The tree seed density did not vary significantly with soil depth but the seed density of *Chromolaena odorata* (73.89 million seeds ha^{-1}) decreased with increasing depth from the surface. There were 1,606 times more *Chromolaena odorata* seeds in the soil seed bank than tree seeds. Tree seedlings responded positively to the removal of *Chromolaena odorata*. The height increment and the increase in number of leaves per seedling were three times greater in released seedlings than the unreleased ones three months after the release treatment. Sixty four percent of the species suffered various levels of mortality in the unreleased plots, but all the seedlings of all the species survived in the released plots. The results suggest that there are enough tree seeds and tree seedlings to restore the degraded area back to forest. However, tree seedlings will have to be released from the competition of *Chromolaena odorata*.

Key words: *Chromolaena odorata*, competition, degraded forests, natural regeneration of tropical forests, release treatment, restoration of degraded forests, seed bank of tropical forests, seedling growth, silviculture.

CONTENTS.

TABLES

FIGURES

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DEDICATION

To

My dear wife Mrs. **Patience A. Honu** and my mother **Mad. Àfi Edupe** with love.

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Signature: ______________________

Date: Nov. 4, 1999

A CAUTION TO THE READER

This M.Sc.F. thesis has been through a semi-formal process of review and comments by at least three faculty members.

It is made available for loan by the faculty for the purpose of advancing the practice of professional and scientific forestry.

The reader is reminded that opinions expressed in this document are the opinions and conclusions of the student and do not necessarily reflect the opinions of either the supervisor, advisory commitee members, the Faculty of Forest and the Forest Environment or the University.

1.0. INTRODUCTION

Forests are a valuable resource in Ghana, but there has been a dramatic decline in forested area in the country. Forests covered approximately 66 % (GFD 1991; Avoka 1999) of the total land surface (2.38 x 10^7 ha) in the early 1800s (FAO 1986; Borota 1991). But it is estimated that over 70 % of the areas that were forested in the early 1800s have been since destroyed (IIED 1992; Avoka 1999). Forest products are the third largest export good after cocoa (*Theobroma cacao*) and minerals (MLF 1996; TEDB 1997). The revenue from the forest products constituted 6 % of the country's Gross Domestic Products (GDP) and about 20 % of the export earnings of the country (Gillis *et al.* u.d; Prah 1994; MLF 1996; Repetto 1988). The forest industry employs over 70,000 people and provides about 80 % of the energy needs of the country in the form of fuel wood and charcoal (TEDB 1997). This is equal to 11 million cubic meters of wood or 11 times the volume of wood extracted for timber (TEDB 1997).

The demand for forests and forest products has been increasing in Ghana. The Ghana Forestry Department (GFD 1993) estimates that 200,000 ha of new productive forests are needed in addition to the natural forests to meet the domestic and export demands of the country. Furthermore, the size of the natural forest of the nation has been decreasing at an alarming rate of 22,000 ha per year in recent years (Repetto 1988; Swaine *et al.* 1997). The reasons for the decline include clearing of forest areas for agriculture, fires and unregulated harvesting of timber (Taylor 1962; IIED 1992; UNCED 1992; Hawthorne and Abu-Juam 1995; Avoka 1999). The declined areas have been degraded, that is, these *odorata* Linn (Acheapong), an aggressive weed species. The ecological and economic consequences of this decline have been severe. For instance, the revenue from the export of forest products declined from 20 % of the total export earnings of the country in 1965 (Repetto 1988) to 11% in 1997 (TEDB 1997). Also in dry seasons some rivers experience decreasing flows because of deforestation (Prah 1994) and consequently communities have to travel longer distances to obtain water.

In 1911 Ghana passed its first law to establish Forest Reserves to prevent the decline of forested areas (Prah 1994). Forest Reserves are forested lands that are managed for the sustainable production of timber and non-timber products and for ecological functions (*e.g.*, in hilly areas and watersheds). This law, however, was not enforced. In 1927 another law called the Forest Ordinance was passed for the establishment of Forest Reserves. The total area of Forest Reserves in the country is currently 2.57 x 10^6 ha (GFD 1991).

The increasing demand for forest products and the large scale degradation of forests have demanded large-scale regeneration programs. Planting has been the primary means of forest regeneration in the country but because of its high cost, it cannot be relied upon to meet the increasing demand. Natural regeneration has been successfully applied in other countries to regenerate forests (Weetman and Vyse 1990) and may provide a viable option for Ghana. Experience in these countries has shown that natural regeneration is much cheaper than planting (Weetman and Vyse 1990).

The natural regeneration of degraded forests in Ghana is generally very poor (Swaine *et al.* 1997) and not well understood. One of the possible explanations for the poor natural regeneration is the aggressive invasion of the degraded areas by *Chromolaena odorata* but there is no information to accept or reject this hypothesis (Hawthorne 1989). Knowledge on the density, species composition and distribution of tree seeds and seedlings under the *Chromolaena odorata* canopy in these degraded forests therefore, may be critical for the prediction of the regeneration potential of *Chromolaena odorata* invaded areas in Ghana. However, there is a paucity of such information (Foster 1995; Swaine *et al.* 1997). Furthermore, given the wide distribution of *Chromolaena odorata*, knowledge on the response of tree seedlings to the removal of *Chromolaena odorata* will represent a significant step towards the understanding of the potential of human-assisted natural regeneration of the degraded forests in Ghana.

This study investigates: 1) the density, species composition and distribution of seeds and seedlings of trees and competing vegetation in a degraded forest, and 2) the effect of the removal of *Chromolaena odorata* on the height increment, increase in number of leaves, and survival of tree seedlings in a degraded forest in Ghana.

2.0. LITERATURE REVIEW

2.1. VEGETATION TYPES IN GHANA

There are five vegetation types in Ghana: Wet Evergreen (WE), Moist Evergreen (ME), Upland Evergreen (UE), Moist Semi-Deciduous (MSD) and Dry Semi-Deciduous (DSD). The MSD occupies the largest area (Hall and Swaine 1981, Figure 2.1). Based on the associations of economic tree species, the WE, ME, MSD, and DSD correspond to the Cynomentra-Lophira-Tarrietia, the Lophira-Triplochiton, the Celtis-Triplochiton and the Antiaris-Chlorophora vegetation types, respectively (Taylor 1960b). The MSD is further divided into the north-west (MSNW) and south-east (MSSE) sub-types and the DSD is also divided into the fire zone (DSFZ) and inner zone (DSIZ) sub-types (Hall and Swaine 1981, Figure 2.1). The remaining areas (1.57×10^7 ha) of the country are covered mainly by Savanna-woodland, Coastal scrub and Grassland, and Maritime (Taylor 1960b).

2.2. PRODUCTS AND ECOLOGICAL FUNCTIONS OF TROPICAL FORESTS

Besides production of timber and non-timber products, tropical forests provide the maintenance of biological diversity, protection of watersheds, regulation of climate, soil conservation, resources for education and research, habitats for wildlife, recreation and tourism, preservation of cultural heritage and scenic beauty (FAO 1985; Poore and Sayer 1991).

The removal of forest cover, especially on slopes, can lead to soil erosion, increased surface run-off, and sedimentation that may increase downstream flooding during the rainy season or decreased stream flow in the dry season (Myers 1980). Soil erosion

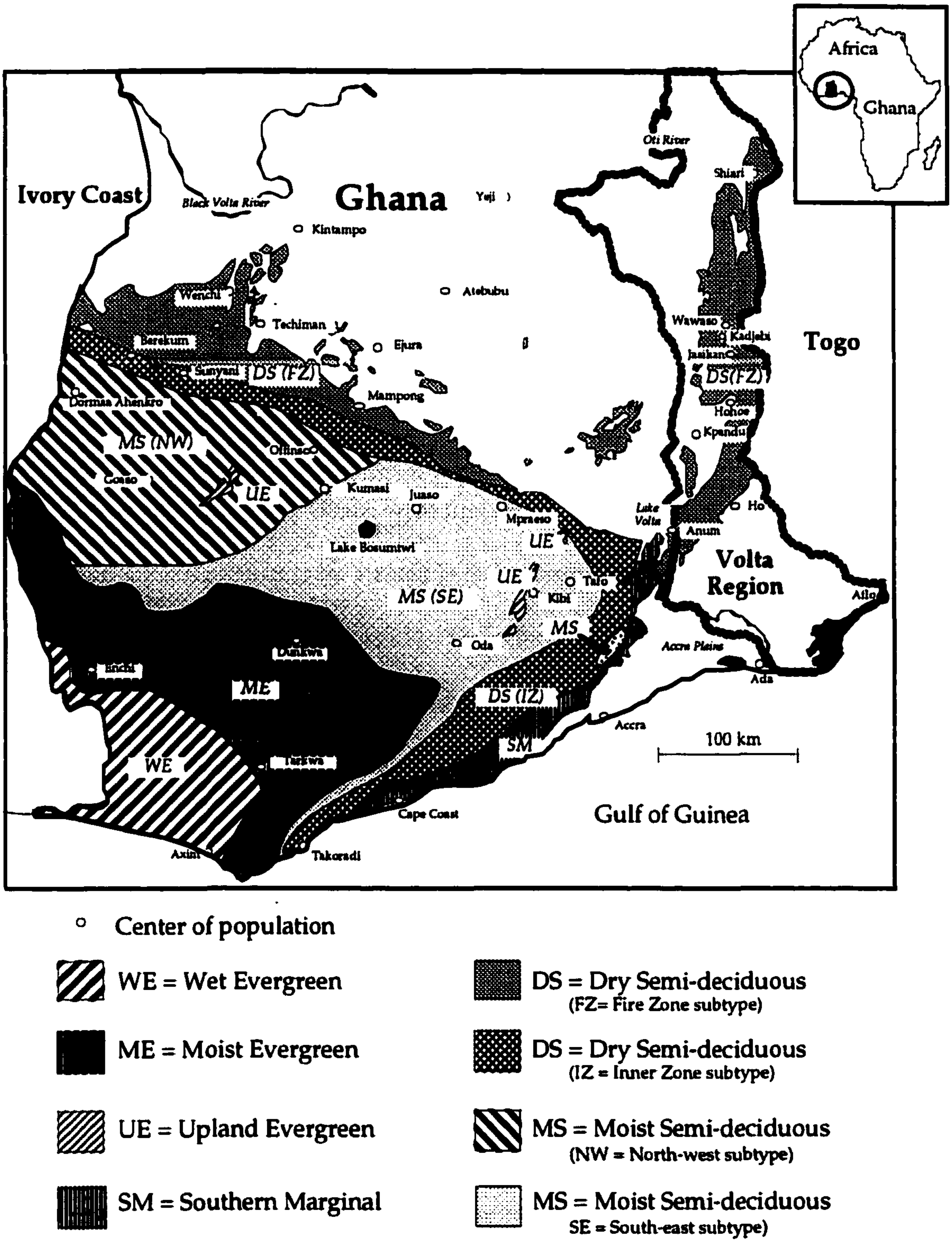

Figure 2.1. Vegetation types of southern Ghana (adapted from Hall and Swaine 1976).

resulting from forest degradation removes the top soil and reduces the potential for natural regeneration (Korem 1985; Zaimeche 1994). Additionally, it is generally believed that recent changes in climatic conditions in Ghana may be caused by deforestation (Prah 1994). Many perennial rivers and streams are also believed to have become seasonal as a result of the climatic change (Prah 1994).

2.3. BRIEF HISTORY OF FOREST RESERVES

2.3.1. Process of Forest Reservation

Areas of intact forests in Ghana were first cleared by farmers. Coffee was the first export agricultural product to be planted in the deforested areas followed by oil palm in the early 1800s (Hall and Swaine 1981). The deforested land also provided the most suitable environment for the cultivation of cocoa which was introduced into the country in the late 1800s (Prah 1994). Because of the high commercial value of cocoa and the relatively quick financial returns compared to timber, farmers rapidly removed forests to establish cocoa farms. Ghana was the world's leading producer of cocoa from 1911 to 1978 (Hall and Swaine 1981).

Because of the rapid loss of forests a British forestry officer (Thompson, H. N.) was commissioned in 1908 to study and report on the status of Ghanaian forests. He found agriculture was the main factor responsible for the rapid deforestation and recommended: 1) the establishment of Forest Reserves, 2) the establishment of the Forestry Department, and 3) the formulation of legislation to conserve the forests (Hall and Swaine 1981; Prah 1994).

The Forestry Department was established in 1909 and has been legally responsible for the conservation and management of the Forest Reserves to ensure a sustainable supply of timber and non-timber products and to protect the forest environment (Prah 1994). The first forest reservation law was passed in 1911 but that law was greatly opposed by the local communities who thought it was a means to take away their lands (Prah 1994). The local people were encouraged to reserve part of their forests voluntarily but were reluctant to do so (FAO 1986; Prah 1994). By 1923 only 26,000 ha of forests had been reserved (FAO 1986; Prah 1994). In 1927 a Forest Ordinance was passed that allowed the government to order reservations where the local people continued to resist (FAO 1986; Hawthorne and Abu-Juam 1995). A total of 291 Forest Reserves covering 2.57×10^6 ha was established since 1911 (GFD 1991).

Following the Forest Ordinance, a series of legislation were introduced to protect forests and to regulate harvesting and the trade of timber and non timber forest products. For example, the Concessions Act of 1992 (Act 124) which significantly modified the Forest Ordinance, declared that all timber resources and all the timber production lands be vested in the state in trust for the communities (Prah 1994).

At present, the proportion of each forest type (Figure 2.1) reserved is 29 % of WE, 31 % of ME, 100 % of UE, 20 % of MSD, and 17 % of DSD (IUCN 1988). The Forest Reserves have been classified into timber production, protection (*e.g.*, hilly areas), research and national parks for wildlife conservation (Prah 1994). The boundaries of the Forest Reserves are clearly demarcated (FAO 1986); cocoa farms (66,421 ha) existing within the boundaries (GFD 1991) were allowed to remain (Hall and Swaine 1981;

Hawthorne and Abu-Juam 1995). The cocoa farms within the reserves are known as "admitted" farms. Some of the Forest Reserves even had permanent villages within them during the time of forest reservation (Hawthorne and Abu-Juam 1995). The average size of admitted farms in Kabo River Forest Reserve is 349.70 ha (GFD u.d.). Unauthorized farms are known as "illegal" farms.

2.3.2. **Ownership of Forest Reserves**

The designation of an area as a Forest Reserve does not affect the ownership of the land and the forest. Most Forest Reserves are owned by local communities with the rest belonging to the state. However, all Forest Reserves are managed by the Forestry Department on behalf of the government for the benefit of the communities (FAO 1986; Prah 1994). Management regulations, allow communities access to the reserves for domestic use (*e.g.*, for firewood) only; the consent of the Forestry Department is required for any commercial use of the forest (ITTO/IIED 1993).

2.3.3. **Degradation of Forest Reserves**

2.3.3.1. **Illegal Farms**

Large forest areas in Ghana have been destroyed by the establishment of illegal farms as a result of lack of enforcement of regulations (IIED 1992). Areas such as Volta Region, Juaboso District and Ochi Headwaters have been invaded heavily by illegal farms that clear forests and prevent regeneration (Hawthorne and Abu-Juam 1995). These farms also serve as a source of fire within the Forest Reserve boundary (Hawthorne and Abu-Juam 1995). For example, the average size of illegal farms in Kabo River

Forest Reserve is about 1,381.30 ha (GFD u.d.; Foster 1995). In the Volta Region the Forest Reserves were originally created to protect the watersheds and soils on the steep hills above Lake Volta. However, the natural forest in the reserves is now almost completely destroyed (Hawthorne and Abu-Juam 1995). These badly degraded forests have no chance of regenerating themselves unless assisted by community forestry initiatives (Hawthorne and Abu-Juam 1995).

2.3.3.2. **Unregulated Harvesting of Timber**

Unregulated and poor harvesting practices are recognized as important causes of forest degradation (FAO 1996, Avoka 1999). The timber from Ghana possesses good mechanical properties and is widely sought by Europe (Borota 1991). Initially the timber was harvested from forests outside reserves but as those areas gradually diminished the bulk of the timber supplies from the Forest Reserves increased from 51 % in 1971 (Brookman-Amissah 1981) to 80 % in 1997 (TEDB 1997). Many reserves which had previously served only protective functions (*e.g.*, Volta Region) became timber producers (Hawthorne and Abu-Juam 1995). If timber production is to be sustained nothing should be done that will irreversibly reduce the potential of the forest to produce future crops of marketable timber (Poore and Sayer 1991). But forest harvesting has not been properly managed in Ghana and is one of the factors responsible for the poor quality of many Forest Reserves (Hawthorne and Abu-Juam 1995). It is estimated that at the 1991 rate of timber harvesting, most of Ghana's economic species will reach extinction about the year 2010 (Hawthorne and Abu-Juam 1993; ITTO/IIED 1993).

Sometimes it is government policy for achieving economic goals that drives the destruction of tropical forests and other reservoirs of biological diversity (WCED 1987; Repetto 1988). For instance, to arrest and reverse the deterioration of economic performance the government of Ghana initiated an Economic Recovery Program in 1983 that increased timber harvesting from 560, 000 m^3 per year (US $ 13 million) in 1983 to 890,000 m^3 per year (US $ 56 million) in 1986 (UNCED 1992).

2.3.3.3. **Forest Fire**

Bush fire is an annual problem in Ghana. About 4 million cubic meters of high quality timber was destroyed by fire in the early 1980s (Hawthorne and Abu-Juam 1993). The causes of the fires are summarized by FORUM (1996) as follows: (a) farmers prepare their fields by burning slash and the fires can easily get out of control; (b) palm wine tappers fell palm trees and use torches on them to obtain palm wine; sparks may start fires as the tappers move between trees; (c) hunters set the bush on fire to trap animals; also fires may result from a type of soft sponge-like material used in local guns; (d) charcoal burners do not put their fires out when leaving the site; (e) distillers normally do not properly clear off debris in and around the distilling sites of local gin (akpeteshie) from palm wine. This debris can catch flying sparks of fire easily; and (f) honey harvesters use fires on hives but may fail to douse the fires afterwards. Forest degradation as a result of removal of forests for farming, unregulated timber harvesting and fires destroy not only Forest Reserves but also non-reserve forests (Hawthorne and Abu-Juam 1993; Prah 1994).

2.3.4. Non-Reserve Forests

The social and cultural values placed on forests (*e.g.*, sacred groves) continue to preserve portions of the non-reserve forests (Prah 1994). These portions are better preserved than other parts (Prah 1994). The amount of forests estimated to be left in the non-reserve forests varies from 0.10 x 10^6 to 3.74 x 10^6 ha (Nsenkyire 1992; Whitemore and Sayer 1992). Timber extraction from non-reserve forests constitutes about 20 % of total timber production in Ghana (TEDB 1997). Unregulated timber harvesting, farming and fires have also been detrimental to the economic and ecological quality of the non-reserve forests (Hawthorne and Abu-Juam 1993; Prah 1994). About 80 % of the non-reserve forests have been destroyed by these activities (Hawthorne and Abu-Juam 1995).

2.4. REGENERATION

Regeneration depends on the production of seeds but information on the flowering and fruiting of Ghanaian tree species is very limited (Swaine *et al.* 1997). Ghanaian trees generally bear fruits between October and November but the prediction of seed production is not well understood (Swaine *et al.* 1997). Natural regeneration processes in tropical and temperate forests are similar in some ways, but in the former they are more complex and more diverse because of their greater variety in tree species (Whitmore 1982) and are poorly understood (Richards 1996).

Natural regeneration of tropical trees varies from species to species (Whitemore 1989) and depends on five regeneration sources: (a) seeds produced locally, (b) seeds dispersed from outside the stand, (c) seed bank, (d) seedling reservoir, and (e) sprouting (Richards

1996; Harper 1977). The soil seed bank is the principal source of regeneration for most species (Swaine *et al.* 1997).

Various silvicultural regeneration systems have been tested in Ghana such as Tropical Shelterwood System (TSS), Modified Selection System (MSS), Enrichment Planting (EP), and Taungya (Prah 1994). The general principle of the TSS is to regenerate the forest by natural means under mother trees (Taylor 1962). The TSS allows the development of a young generation under a gradually disappearing overstorey through cuttings and thinning. The application of the TSS system in two Forest Reserves in the MSD forest resulted in less than 10 % natural regeneration of economic species, so the system was abandoned (Prah 1994). The MSS system involves the mapping of all economic species of 0.82 diameter at breast height (dbh) or bigger. After the mapping, all immature uneconomic trees are poisoned and removed (FAO 1985). This system favors the growth of only economic species. The system was tested in MSD forests but is no longer used because some species such as *Pericopsis elata* that was formerly not economic became one of the highly priced timber species (FAO 1985; Hawthorne and Abu-Juam 1995). The EP involves weeding, canopy opening and planting of seedlings and can be used if successful natural regeneration will not occur (Taylor 1962). Seedlings in a part trial in the MSD forests were choked by weeds and the 2,500 ha test area was abandoned (Prah 1994). The taungya system involves leasing degraded forest lands to farmers by the Forestry Department. The farmers clear, burn, plant and tend both the food crops (*e.g.*, maize) and the tree seedlings (*e.g.*, teak). Farmers continue to plant their crops and tend the plants until canopy closure of the trees. Thereafter, the farmer is moved to a new site for a new taungya. The Forestry Department benefits by getting the degraded area restored back to forest at less cost and the farmer also benefits from the food crops. The taungya system was practiced in the ME, MSD, and DSD forests; teak being the most successful for this system (Prah 1994).

Light requirement of tropical trees varies widely (Richards 1996). Light demanding trees (shade intolerant, pioneer or secondary species) can develop to maturity only in canopy gaps (Swaine and Hall 1988; Hawthorne 1989). The non-pioneer light demanding species tolerate shade in the juvenile stage but may die off later if the canopy is not broken (Hawthorne 1989). Shade tolerant trees (non-pioneer or primary species) and their seedlings may survive and reach maturity under unbroken canopies (Hawthorne 1989; Richards 1996). When forest openings are created they are often invaded by upper canopy (less shade-tolerant) species (Richards 1996). Seeds and seedlings of tree species which do not exist in the upper canopy may also invade gaps (Swaine and Hall 1988).

The distribution of size classes in tropical forests is typical of natural uneven-aged forests regenerated from seeds (Swaine *et al.* 1987). Most of these forests have an inverse J-shaped size class distribution (Harwthorne 1995; Poorter *et al.* 1996). However, species that cannot grow in forest shade tend to diverge from the inverse J-shape size class distribution (Swaine and Hall 1988).

The majority of tree species in Ghana have sufficient natural regeneration capability (Hawthorne 1995) and the mother trees of most species in the understorey can be found in the same area (Swaine and Hall 1988). For example, Lawson *et al.* (1970) and Swaine and Hall (1988) found that 78 % of the seedling species under a forest canopy have corresponding mature trees in the canopy. However, seedlings of light demanding species are virtually absent in the understorey (Poorter *et al.* 1996) so that it seems that these species are disappearing from the community (Richards 1996).

2.4.1. **Seed production and dispersal**

Tree species differ in the quantity and frequency of seed production (Lamprecht 1989; Richards 1996). Some species produce seeds regularly while others produce seed irregularly (Lamprecht 1989). Sometimes empty seeds are formed (Augspurger 1984a; Albrecht 1993). A large proportion of seeds reaching the ground are destroyed by seed predators such as insects and small mammals (Janzen 1970). Seeds may also become infected by fungi (Janzen 1970). Many of the seed predators, particularly insects, are host specific, attacking only a single species or group of species (Janzen 1970). Chances of seed survival are increased if seeds are buried in the soil by burrowing rodents, worms, other animals or by non-biological physical forces to form the seed bank (Richards 1996). Tree species may also enhance survival by producing abundant seeds at long and irregular intervals or by producing toxic secondary compounds in seeds or leaves (Janzen 1970).

The seed dispersal distance of tropical trees ranges from 10 to 1000 m (Ridley 1930; Webber 1934; Fox 1973). Tropical tree species disperse their seeds by means such as wind, birds, insects, and other animals. Wind dispersal of seeds is the most common in overstorey tree species (Richards 1996). Wind dispersal can be advantageous to a particular species because it may move offspring away from an infected parent tree or from soils infected by pathogens (Augspurger 1984a). In this way, the wind dispersal may reduce the mortality of subsequent seedlings during the establishment stage (Augspurger 1984a; Albrecht 1993). Janzen (1970) believed that the wind dispersal of seeds was the explanation for the widely scattered distribution of many species characteristic of most tropical trees.

2.4.2. **Seed dormancy and germination**

Water, oxygen and temperature are the most important factors governing tree seed germination in the tropics (Perera 1986; Swaine *et al.* 1997). Seeds of most tropical trees will germinate immediately after dispersal if they land on moist soils (Swaine *et al.* 1997). Room (1973) found that seed germination, establishment and growth of seedlings was more successful in full sunlight than in shade. However there is no information on the timing of seed germination in the field in Ghana.

Seed dormancy for tropical tree species is often caused by the lack of suitable conditions for germination (Perera 1986; Swaine *et al.* 1997). Photoblasticity has also been observed in many tropical tree species (Hall and Swaine 1980; Swaine *et al.* 1997).

2.4.3. **Seed bank estimation**

The time and method of sampling can influence the estimate of the seed bank content because seed production and germination vary with seasons (Perera 1986). The timing is particularly important for studying the seed bank of forests in Ghana because most tree species can disperse their seeds from November to May (Taylor 1960a and 1962; Swaine *et al.* 1997).

A plot size of 0.008 m^2 to 0.12 m^2 is suggested to be suitable for studying seed banks (Roberts 1981). Enright (1978) has shown that seed bank content decreases with increasing depth from the ground surface and a sampling depth of 4 - 5 cm is common (Hall and Swaine 1980; Roberts 1981; Perera 1986).

There are two common methods that are presently used for studying soil seed banks: 1) separation of seeds in the soil sample by sieving and flotation (Barbour & Lange 1967; Roberts 1981), and 2) germination samples in the sun (Hall & Swaine 1980; Perera 1986; Swaine *et al.* 1997). The sieve method may include non-viable seeds thereby overestimating the potential of seeds to occupy the site (Perera 1986). The germination method may under-estimate the viable seed content and the regeneration potential since some viable seeds may not germinate during the test period (Perera 1986). The regeneration of forest openings often takes a long period of time and seed germination can occur any time during the regeneration period. Therefore, to assess the natural regeneration of the opening, it is important to assess both the seed bank and seedling stock.

2.4.4. Seedling reservoir and mortality

The abundance of tree seedlings depends on microsite conditions, disturbances (Perera 1986), and the availability of viable seeds (Richards 1996). The rate of growth and pattern of tree seedlings depends on the micro environmental conditions which includes light, temperarure and moisture (Kwasiga *et al.* 1986).

To have a more complete picture of the regeneration potential of an area it is important to investigate seedling mortality in addition to seed bank and seedling reservoir. Not every seedling survives and grows to a mature tree. The rate and spatial distribution of seedling mortality depends on the tree species (Augspurger 1984a). Mortality can be caused by many factors including inability to compete with weeds (Ashton 1990), and attacks by pathogens (Richards 1996). Seedling fungal pathogens are generally favored by low light intensity, high humidity, and low temperature under the canopy of competing vegetation (Weber 1973; Garwood 1983). Mortality of seedlings is lower in gaps than in shade regardless of the seedling density (Augspurger 1984a; Augspurger and Kelly 1984). The seedlings of fast growing and less shade-tolerant species are more prone to pathogens than slow growing and shade-tolerant species (Augspurger 1984b). The pathogens tend to be soil borne but secondary infection may also arise from previously infected seedlings or as a result of saprophytes (Walker 1969). Seedlings vary in their vulnerability to specific pathogens (Burdon and Chilvers 1976) but their vulnerability decreases as they undergo cell wall thickening and lignification (Walker 1969).

Mortality is high for seedlings of shade-intolerant species when they grow under the canopy of competing species (Richards 1996). Seedling mortality is particularly high in the early stages, so the species composition of forests is often determined during the juvenile stage (Swaine and Hall 1988). There is an equilibrium between the mortality and recruitment of species (Swaine *et al.* 1987); species that have a low density of regeneration also have a low mortality (*e.g.*, *Celtis mildbraedii*, Swaine and Hall 1988).

2.5. SILVICS OF THE MOST ECONOMIC SPECIES IN THE STUDY AREA

2.5.1. *Antiaris toxicaria* (Lesecheault) (Kyenkyen)

Antiaris toxicaria is found throughout the forest zone of Ghana (Figure 2.1; Taylor 1960a). This species is a deciduous (November to February) high light demanding tree species (shade-intolerant).

Antiaris toxicaria flowers from November to January after which new leaves appear (Taylor 1960a). *Antiaris toxicaria* has fleshy fruit (Swaine and Hall 1983) and although seeds may be dispersed from December to April by birds and animals, large quantities fall under the mother tree (Taylor 1960a; Hawthorne 1990).

Antiaris toxicaria produces abundant regeneration wherever it occurs (Swaine and Hall 1988) but seedlings are not able to compete with weeds and most seedlings die in the first year (Taylor 1960a). Seedlings of *Antiaris toxicaria* can tolerate moderate shade (Taylor 1960a; Akanbi 1980). The seedlings are prone to aphid attacks which may cause die-back of the shoot (Taylor 1960a).

2.5.2. *Ceiba pentandra* (L) Gaertn (Onyina)

Ceiba pentandra is found throughout the forest zone of Ghana (Figure 2.1; Hawthorne 1990). *Ceiba pentandra* is upper canopy deciduous (October to March) tree species (Taylor 1960a; Carson and Abbiw 1990), high light demanding tree species (Riddoch *et al.* 1991; Molofsky and Augspurger 1992). It is the biggest tree in Ghana both in height (more than 60 m) and dbh (more than 1.7 m) (Taylor 1960a; Hawthorne 1990). *Ceiba pentandra* does not grow well in swampy areas (Taylor 1960a).

Ceiba pentandra generally flowers from October to January and seeds are dispersed (February to April) by wind. Seed viability is high (Taylor 1960a) and *Ceiba pentandra* regenerates abundantly in open areas (Riddoch *et al.* 1991). Initial height growth of the seedlings is positively correlated to seed size (Sudhakara *et al.*1995).

2.5.3. ***Milicia excelsa* (Wew) C. C. Berg (Odum)**

Milicia excelsa occurs in all forest types in Ghana and throughout tropical Africa (Figure 2.1; FAO 1956). It is a high light demanding, fast growing, and upper canopy deciduous (December to January) tree species up to a height of about 50 m (Taylor 1960a; Taylor 1962; Hawthorne 1990). *Milicia excelsa* can be found at sea level to altitudes of 1350 m. It requires a minimum annual rainfall of 1,000 mm (Taylor 1962), prefers a well drained soil and is intolerant to impeded drainage (Taylor 1960a).

Milicia excelsa generally flowers in December a few weeks after partly or completely shedding its leaves (Taylor 1962; Albrecht 1993). Leaf shedding and flushing of new leaves are not closely correlated with the seasons (Taylor 1962). It has fleshy fruits (Swine and Hall 1983) whose seeds are dispersed between March and May (Taylor 1960a) by birds, bats and other animals; many of the seeds also fall under the mother tree (Taylor 1960a; Hawthorne 1990). The seeds have a short life span and low viability (Taylor 1960a).

Natural regeneration of *Milicia excelsa* occurs in canopy gaps (Taylor 1960a; Riddoch *et al.* 1991) where the weed growth is not extensive and seedlings develop rapidly (Taylor 1960a). Seedlings of *Milicia excelsa* prefer light shade (Taylor 1960a).

A mass of root suckers may arise around the base of the stump, especially after fires (Taylor 1960a).

The only important pest to *M. excelsa* is the gall-fly *Phytolyma lata* Scott (Taylor 1962) that causes dieback of foliage down to the woody tissue but the species becomes resistant to the attack when it is above 3.6 m in height (Taylor 1960a).

2.5.4. ***Nesorgodonia papaverifera* (A. Chev.) R. capuron (Danta)**

Nesorgodonia papaverifera is found in the ME, MSD, and DSD forest types of Ghana (Figure 2.1; Taylor 1960a). *Nesorgodonia papaverifera* is generally evergreen, upper canopy and a light demanding tree species (Taylor 1960a; Cujoe 1967). It can grow up to 36 m in height and a dbh of 1.60 m (Cujoe 1967). *Nesorgodonia papaverifera* does not grow well in swampy areas (Taylor 1960a).

Nesorgodonia papaverifera generally has long flowering (January to July) and fruiting (March to November) periods (Cujoe 1967). Fruiting is abundant but most of the capsules fall unopened and rot under the mother trees (Taylor 1960a). The seed (1.6 cm wide) is wind dispersed and has a short life span (Taylor 1960a).

Nesorgodonia papaverifera produces little regeneration compared to the amount of seeds produced (Taylor 1960a). Seedlings prefer light shade and are prone to aphid attacks (Taylor 1960a).

2.5.5. ***Piptadeniastrum africanum* (Dahoma)**

Piptadeniastrum africanum occurs in all forest types in Ghana (Figure 2.1; Taylor 1960a). It is an upper canopy deciduous tree species (Hawthorne 1990).

Piptadeniastrum africanum is a non-pioneer light demanding tree species (Poorter *et al.* 1996), therefore, seedlings prefer moderate shade. However, growth may cease for several years if the shade is too heavy (Taylor 1960a). *Piptadeniastrum africanum* can grow up to 60 m in height (Taylor 1960a; Poorter *et al.* 1996). It prefers moist and free-draining soils (Taylor 1960a).

Piptadeniastrum africanum seeds are dispersed from December to February by wind (Taylor 1960a; Swaine and Hall 1983; Hawthorne 1990). It regenerates poorly (Swaine and Hall 1983) and seedlings are rare in the understorey (Poorter *et al.* 1996).

2.5.6. ***Steculia rhinopetala* K. Schum (Wawabima)**

Steculia rhinopetala is found throughout the MSD and DSD forests in Ghana (Figure 2.1) and is a deciduous (August to September) shade-intolerant species (Taylor 1960a; Cujoe 1967). It can grow up to 60 m in height and 1.43 m dbh (Cujoe 1967).

Steculia rhinopetala flowers from August to October (Cujoe 1967). The seeds (1.5 cm long, 0.76 wide) are dispersed from November to January (Taylor 1960a). The seedlings tolerate light shade (Taylor 1960a; Cujoe 1967; Riddoch *et al.* 1991). This species is a host for the cocoa swollen-shoot virus (Legg and Lockwood 1981).

2.5.7. ***Triplochiton scleroxyloxn* K. Schum (Wawa)**

Triplochiton scleroxylon is an indigenous West African hardwood species (Jones 1974) and grows naturally in clusters in all forest types in Ghana (Figure 2.1; Taylor 1960a; Cujoe 1967). *Triplochiton scleroxylon* is a fast growing, shade-intolerant, upper canopy and deciduous (December to March) tree species (Cujoe 1967; Jones 1974). It can grow up to 60 m in height (Cujoe 1967), but cannot grow well in wet areas (Jones and Howland 1974). *Triplochiton scleroxylon* serves as a forest type indicator in Ghana (Cujoe 1967). It has annual growth rings but the rings are only visible after iodine staining (Lowe 1968).

Triplochiton scleroxylon forms flowers between November and March after leaf fall (Gyimah 1986). It loses its leaves every year but does not flower every year. It can produce a very large number of flower buds but many of them fall before they open (Jones 1975). Many of the fruits also fall before they mature (Jones 1975). *Triplochiton scleroxylon* produces fruits irregularly (Jones 1995). The flowering of *Triplochiton scleroxylon* is favored by below average rainfalls in July and August (Taylor 1960a; Jones 1974). Seed year occurs every 2 or 3 years (FAO 1956). *Triplochiton scleroxylon* starts flowering at the age of 15 years (Leakey *et al.* 1981). Seeds are dispersed by wind by March before the appearance of new leaves (Cujoe 1967; Jones 1974; Gyimah 1986; Richards 1996). Mature seeds can be found in unripe fruits but those seeds may not contain an embryo (Jones 1975). The quality and quantity of collectable seeds (length = 0.5 cm) are generally poor (Jones 1974; Richards 1996). It is possible that all the seeds on a tree are destroyed by weevil, *Apion ghanaense* Voss (Jones and Kudler 1970; Jones 1975).

Fresh healthy seeds of *Triplochiton scleroxylon* germinate quickly under favorable environmental conditions but lose viability rapidly during storage (Cujoe 1967; Jones and Howland 1974). Regeneration in good seed years tends to be abundant in open areas

(FAO 1956; Cujoe 1967) but germination is always low because a large percentage of the seeds are immature (Jones 1975).

3.0. MATERIALS AND METHODS

3.1. Study site

The study was conducted in the Kabo River Forest Reserve (DSD forest) in the Volta Region (8^{o}50'N to 6^{o} 9'S, 0^{o}20'W to 1^{o}6'E, Figures 2.1 and 3.1) of Ghana. The site is adjacent to natural forest stands on the North Eastern (NE) and South Western (SW) sides (Figures 3.2 and 3.3). The South Eastern (SE) and North Western (NW) sides are bounded with farms (Figure 3.3). The presence of trees higher than 2 m was minimum (Figure 3.2). The study area is characterized by the alternation of wet (major and minor rainfalls) and dry (hamattan) seasons with a total annual rainfall of 1250 to 1500 mm (Hall and Swaine 1976; MSRR 1998). The site (4 ha) is flat and generally well drained. The soil in the site is Orthic-Ferric Acrisols (Adu, 1992) formerly known as Forest Ochrosol (Hall and Swaine, 1981) and is friable reddish brown and fine granular silty loam. A Munsel chart (Anon., 1973) was used to quantify soil color characteristics. There have been no disturbances to the site since a wildfire occurred in 1983 (J. Kyekye, Personal Communication).

The study site was 95 % covered by *Chromolaena odorata*, a weed species. The flux density of photosynthetically active radiation under the *Chromolaena odorata* canopy was only 7 % of the ambient level as measured by Li-Cor Li-250 light meter at 12:00 noon.

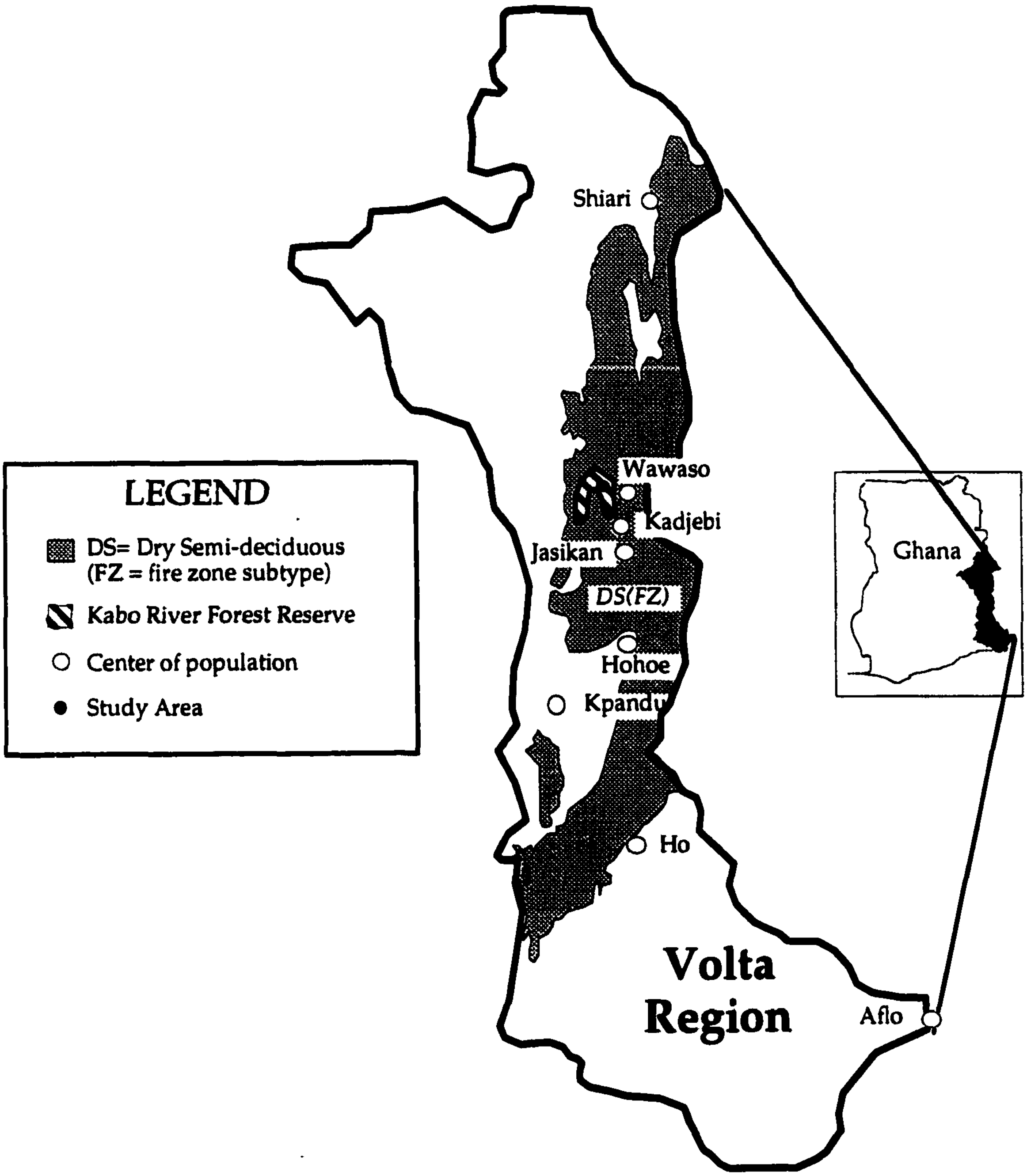

Figure 3.1. The study area in a Dry Semi-Deciduous forest.

Figure 3.2: A photograph of the South Western side of the study site in a Dry Semi-Deciduous forest.

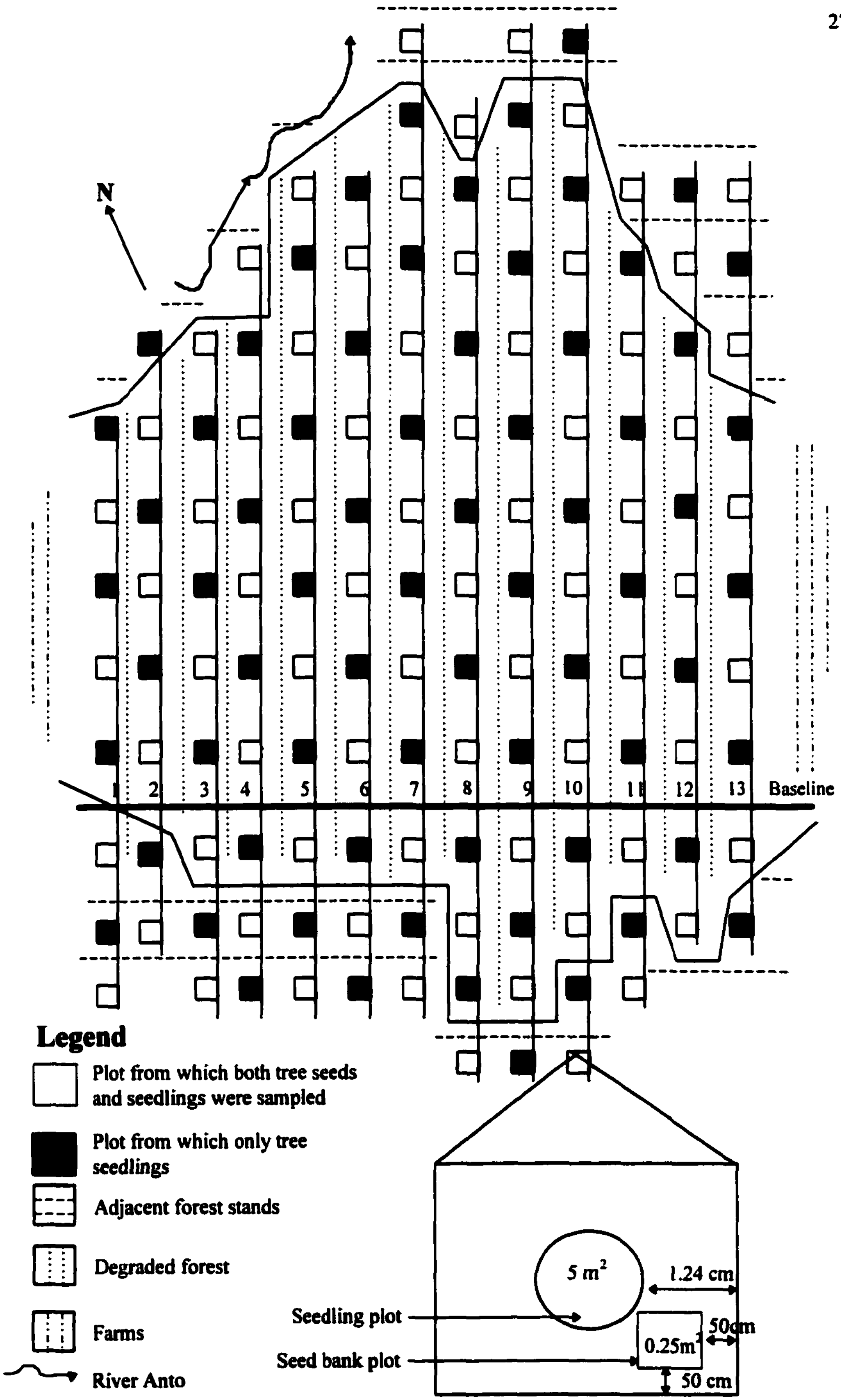

Figure 3.3: Layout of sampling plots.

3.2. SURVEY PROCEDURES

3.2.1. Assessment of seedling stocks

The site was surveyed for seedling (all plants ≤ 2 m high) density, species composition and their distribution, using systematic random sampling with a random starting point (Cochran 1997). A base line was established at the SW side of the study area along the boundary to the adjacent forest stand (Figure 3.3). A total of 13 transects were established at 20 m intervals along the baseline (Figure 3.3). The first transect was established at 1 m from the starting point of the baseline by using a random number generator. A total of 108 and 34 square plots of 5 x 5 m were established in the degraded area and the adjacent forest stands, respectively. The plots were 20 m apart along the transects. The first plot was established 13 m away from the starting point of the first transect using a random number generator. There were fewer plots in the adjacent forest on the northern side because of the proximity of the River Anto (Figure 3.3). Circular sampling plots of 5 m^2 were established at the center of each square plot (Figure 3.3). Tree seedlings within the circular plots were identified based on Hawthorne (1990) and tallied in June 1998. The reason that sampling plots (5 m^2) were much smaller than the square plots (25 m^2) is to avoid edge effect.

3.2.2. Assessment of viable seed stocks

Smaller plots (50 x 50 cm) were established next to 50 % (every other) of the circular seedling plots in the degraded area and 19 plots in the adjacent forest stands (Figure 3.3). The first seed bank plot was selected using a random number generator. A wooden frame, hand trowel and a shovel were used to take soil samples at two horizontal layers, *i.e.*, 0 - 2 cm (upper layer) and 2 - 4 cm (bottom layer). The samples were collected on June 2 and 3, 1998 and were placed in black plastic bags to prevent light from reaching them. The bags were put into larger sacks to facilitate transportation to a temporary germination house in Jasikan (Figure 3.1).

The germination house (18 m x 18 m, 1.2 m high) was constructed using wood and was completely covered with fine-mesh net to prevent contamination from natural seed dispersal. The flux density of photosynthetically active radiation in the germination house was 32 % of the ambient light level measured by Li-Cor Li-250 light meter at 12 noon. Wooden boxes (50 cm x 100 cm, 6.5 cm high) with perforated bottoms were used as germination trays. The small perforations at the bottom of the boxes allowed free drainage to prevent waterlogging and seed rotting. Washed river sand was spread at the bottom of the trays (4 cm deep) as the bedding for the soil samples. The germination tray and sand were set up 25 days before the onset of the experiment to allow any seeds present in the sand to germinate and to be removed. Sixteen of the germination trays contained only washed river sand and served as controls. These controls were randomly located in the germination house. The washed river sand was found to contain no tree seeds.

The soil samples were spread evenly on the washed river sand in the germination trays on June 3, 1998. The soil was carefully pressed with a smooth wood board to mimic the field condition. The thickness of the sample soil in each wooden box was about 1 cm.

The samples were watered every morning (between 6 am and 8 am) with 1.5 to 3.0 liters of water per tray depending on the soil moisture condition. Germinants were identified and counted 25, 50, 75, and 100 days after the start of the germination test (*i.e.*, June 28, July 23, August 17, and September 11, respectively). The germinants were carefully removed after each identification and counting. The germinants were used as an index of viable seeds and will be referred to as such hereafter. Although no information is available on the timing of seed germination in the field, germination is believed to coincide with the start of the rain season. But sampling could not start earlier in this study because of water shortages in the area until June 2, 1998.

3.2.3. Assessment of response of tree seedlings to the removal of *Chromolaena odorata* Linn (Acheapong)

Chromolaena odorata and all other non-tree plants were removed removed manually using cutlass from the plots from which both tree seeds and seedlings were sampled (Figure 3.2) between May 29 and June 1, 1998 to release tree seedlings. The tree seedlings were exposed to full sunlight after the release treatment. These plots and the seedlings in them will be referred to as released plots and released seedlings, respectively. Other plots were left intact and those plots and the seedlings in them will be referred to as unreleased plots and unreleased seedlings, respectively.

The height and the number of leaves per seedling were measured on all tree seedlings (trees $\leq$ 2 m tall) in the circular plot in early June, 1998. A 2.5 m measuring pole was used to measure seedling heights to the nearest centimeter (Philip 1983). All fresh fallen leaves under tree seedlings were removed from the plots and all the mature leaves that were likely to fall during the study period were marked with indelible ink for the convenience of easy identification of fallen leaves. The tree seedlings were identified according to Hawthorne (1990) and classified into three classes according to the Ghanaian System of Tree Classification (Ghartey 1989). Class 1 contained tree species that have been exported from Ghana in the past 15 years. Class 2 contained tree species that can attain 70 cm diameter at breast height (dbh) and/or occur at a frequency of at least 1 tree per 100 ha but have not been exported. All other trees were classified as Class 3 tree species. This classification system was adopted because information regarding the response of the three commercial classes of trees is critical for the Forest Managers in Ghana. The identified tree seedlings were labeled with plastic tags for easy identification. A second removal of weeds was done on July 22, 1998. The height and the number of leaves per seedling in all sampling plots were measured again in early September of the same year.

Height increment and changes in number of leaves were calculated from the difference between the measurements in June and in September. Seedling mortality was calculated as the difference in the number of seedlings in each species in June and in September. Dead seedlings were visually inspected for symptoms of pathogen infection.

3.2.4. Seed producing trees

Trees of 20 cm dbh or above are defined as seed producing trees in this study. Seed producing trees were identified and counted in a 30 m wide strip along the edge and into the adjacent forests.

3.3. STATISTICAL ANALYSES

Tree seedling density and species composition were graphically examined for the normality of distribution using probability plots and for homogeneity of variances using scatter plots (Norusis 1993). Linear regression analysis was used to describe the relationship between the density and species composition of seedlings to the distance from adjacent natural forests because the scatter plots showed linear relationships. The regression analysis was done separately for each of the 13 transects (Figure 3.3).

The spatial distribution of three strong wind dispersed tree species (*Ceiba pentandra*, *Piptadeniastrum africanum* and *Triplochiton sclerozylon*) were examined separately from other species to verify if the linear regression analysis for all species together had masked the wind dispersed species (Taylor 1960a; Jones 1974; Swaine and Hall 1983; Hawthorne 1990; Richards 1996).

The viable seeds of trees and *Chromolaena odorata* were graphically examined for the normality of distribution using probability plots and for homogeneity of variances using Levene Test (Norusis 1993). This data set was subjected to $\log_{10}$ transformation before the one-way analysis of variance (ANOVA) because it did not follow a normal distribution. The *Chromolaena odorata* seeds were analyzed separately from the tree seeds in order to see the variability of the tree seed density and *Chromolaena odorata* seed density with increasing depth from the ground surface.

The height increment and number of leaves per seedling were graphically examined for the normality of distribution using probability plots and for homogeneity of variances using Levene Test (Norusis 1993). Since the data did not follow a normal distribution, $\log_{10}$ transformations were performed. Analysis of Covariance (Steel and Torrie 1980) was used to test the difference between released and unreleased plots (first all species combined, then by individual species) using the June measurement as the covariant. A total of 55 species was recorded in the study, 18 of which were present only once either in the released and/or unreleased plots. These 18 species were eliminated from the analysis because no statistics could be calculated for them. An additional five species were present only in released plots and four other species were present only in unreleased plots. These nine species were also eliminated from the analysis. Therefore, 28 tree species were used in the analysis.

4.0. RESULTS

4.1. Seedling stocks

The species composition ranged from 0 to 9 species per plot (5 m^2). A total of 55 tree species were present in the degraded area (Table 4.1). The most common tree species was *Blighia unijugata* (30 % frequency, Table 4.1). Fourteen of the 55 species were only present in 1 % of the plots and 64 % of the seedling species had no corresponding seed producing trees in the adjacent forests (Table 4.1).

The seedling density for all the species together was 11,780 seedlings ha^{-1} (Table 4.1). Three percent of the sample plots contained no seedlings (Figure 4.1). The seedling density of individual plots ranged from 0 to 21 seedlings per plot (5 m^2, Figure 4.1).

The seedling density for all tree species together was generally correlated to the distance from the adjacent forest along the direction of the prevailing wind, decreasing from SW to NE (Figure 4.1, Table 4.2). The number of species per plot followed a similar trend as the tree seedling density, decreasing from SW to NE (Figure 4.2, Table 4.2). The strength of the relationship for the seedling density and species composition to the distance to the forest stand ranged from an r-value of 0 to 0.94 (Table 4.2).

Ceiba pentandra seedlings were present in 14 % of the plots and were scattered over the site (Figure 4.3). *Piptadeniastrum africanum* and *Triplochiton scleroxylon* seedlings were present in only 2 and 10 % of the plots, respectively (Figures 4.4 and 4.5). The seedlings of *Triplochiton scleroxylon* were common only in the South Eastern side of the site (Figure 4.5).

Table 4.1: Species composition and density of seedlings (seedlings / ha) and frequency of distribution (*i.e.* percentage of plots in which the species was present) in a degraded Dry Semi-Deciduous forest in Ghana.

Species	Common Name	Family	Density	Frequency
Afzelia africana	Papao	Caesalpinaceae	148	6
Afzelia bella♠	Papao-nua	Caesalpinaceae	18	1
Albizia zygia♠	Okoro	Mimisaceae	334	12
Antiaris toxicaria♠ ♣	Kyenkyen	Moraceae	426	18
Bersama abyssinica	Esonodua	Melianthaceae	38	2
Blighia sapida	Akye	Spindaceae	166	7
Blighia unijugata	Akyebiri	Spindaceae	1,112	30
Buchholzia coriacea♠ ♣	Esonobese	Caparaceae	18	1
Ceiba pentandra♠ ♣	Onyina	Bombaceae	334	15
Celtis mildbraedii ♣	Esa	Ulmaceae	38	2
Celtis wightii♠	Esafufuo/Prempresa	Ulmaceae	186	6
Celtis zenkeri♣	Esakoko	Ulmaceae	112	4
Christiana africana	Sesedua	Tiliaceae	18	1
Chrysophylum pruniforme♠	Duatadwe	Sopotaceae	38	2
Cola caricifolia♠	Ananseaya	Sterculiaceae	56	3
Cola gigantia♠ ♣	Watapuo	Sterculiaceae	500	6
Cordia millenii♠ ♣	Tweneboa-nini	Boraginaceae	38	2
Cynomentra ananta♠	Ananta	Caesalpinaceae	92	3
Daniella ogea	Ehyedua	Caesalpinaceae	18	1
Distemonanthus benthamianus♠ ♣	Bosamdua	Caesalpinaceae	18	1
Duboscia viridiflora♠	Akokoragyehini	Tiliaceae	56	2
Erythrina mildbraedii ♣	Osorowa	Papilionaceae	18	1
Ficus exasperata♣	Nyankyerene	Moraceae	852	26
Ficu sur♣	Nwadua/Domini	Moraceae	112	4
Greenwayodendron oliveri♠	Duabiri	Annonaceae	296	13
Hildegadia barteri♠	Akyerekyewewa	Sterculiaceae	74	3
Holarrhena floribunda	Sese	Apocynaceae	38	2
Lecaniodicus cupanioides♠	Dwindwera	Sapindaceae	278	13
Lonchocarpus sericeus♠	Sante	Papilionaceae	556	16
Macaranga barteri♣	Opam	Euphorbiaceae	18	1
Maesopsis eminii ♣	Onwamdua	Rhamnaceae	240	1
Mallotus oppositifolius♠	Anyanyanforowa	Euphorbiaceae	666	13
Maranthes chrysophylla♠	Kajabiri	Chrysobalanaceae	538	19

Table 4.1 Continued).

Species	Common Name	Family	Density	Frequency
Margaritaria discoidea♣	Pepea	Euphorbiaceae	18	1
Microdesmis puberula♠	Ofema	Pendaceae	74	4
Milicia exelsa♠♣	Odum	Moraceae	352	13
Morinda lucida	Konkroma	Rubiaceae	38	2
Nesorgodonia papaverifera♠♣	Danta	Sterculiaceae	612	13
Newbouldia laevis♠	Sesemasa	Bignoniaceae	92	4
Piptadenistrum africanum♠♣	Dahoma	Mimosaceae	222	4
Ravolfia vomitoria♠	Kakapenpen	Apocynaceae	592	20
Ricinodendron heudelotii♠♣	Wama	Euphorbiaceae	18	1
Scytopetalum tieghemii♠	Oprim	Scytopetalaceae	18	1
Solanum erianthrum♠	Pepediawuo	Solanaceae	112	4
Spathodea campanulata♠	Akuakuo-ninsuo	Bignoniaceae	92	5
Steculia rhinopetala♠♣	Wawabima	Sterculiaceae	166	6
Steculia tragacantha	Sofo	Sterculiaceae	482	8
Treculia africana	Brebretim/Ototim	Moraceae	18	1
Trema orientalis♠	Sesea	Ulmaceae	166	6
Tricalysia discolor♠	Kwaekofi	Rubiaceae	278	7
Trichilia monadelpha	Tanuro	Meliaceae	18	1
Trichilia prieuriana♠	Kakadikuro	Meliaceae	462	12
Trilepisium madagascariense♠♣	Okure	Moraceae	148	6
Tripochiton sclerozylon♠♣	Wawa	Sterculiaceae	334	13
Vitex furruginea	Otwentorowa	Verbenaceae	18	1

♠Seedlings found in the adjacent forest stands.

♣ Seed production trees in the adjacent forest stands. Additional seed production trees that were present in the adjacent forest stands were *Alstonia booni* (Sirono), *Anogeisus leiocapus* (Kane), *Antrocaryon micraster* (Aprokuma), *Chrysophyllum perpulchrum* (Atabene), *Hannoa klaineana* (Fotie), *Macarranga bateri* (Opam), *Pterygota marcrocarpa* (Kyereye), *Strombosia glaucescens* (Afena), and *Terminalia superba* (Ofram).

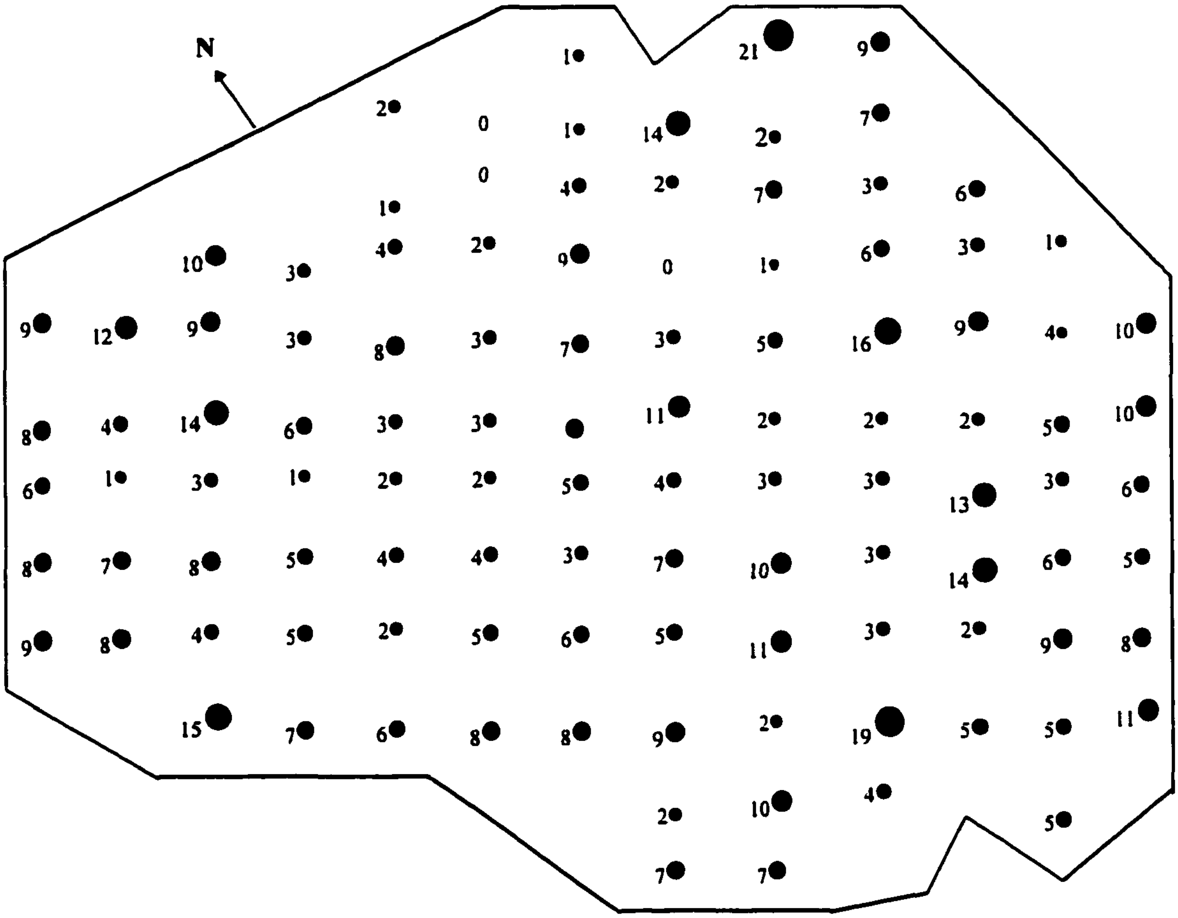

Figure 4.1: Spatial distribution of tree seedlings in the degraded forest area. The relative size of the dot "•" indicates the number of seedlings in 5 m^2 plots. The actual numbers are printed beside the dots. "0" indicates there were no seedlings in that plot.

Table 4.2: Linear relationship of seedling density and species composition (number of species) to distance along the direction of the prevaling wind to adjacent natural forest. The regression model is Y = a + bX, where Y is either seedling density or species composition, X is the distance from the plot to the edge of the forest, a and b are regression coefficients.

Transects	n	Seedling Density						Species Composition					
		a	P_a	b	P_b	r	SE	a	P_a	b	P_b	r	SE
1	5	8.00	0.04	0.00	1.00	0.00	1.41	5.00	0.11	-0.10	0.67	0.26	1.37
2	5	3.90	0.65	0.03	0.76	0.19	4.71	6.50	0.06	-0.04	0.19	0.70	1.30
3	7	8.75	0.17	0.01	0.92	0.05	5.42	6.32	0.04	-0.01	0.69	0.19	2.23
4	7	6.96	0.01	-0.03	0.19	0.56	1.87	5.49	0.00	-0.02	0.01	0.94	0.45
5	9	4.86	0.04	-0.01	0.49	0.26	2.31	4.78	0.00	-0.02	0.08	0.62	1.25
6	9	8.00	0.00	-0.04	0.00	0.91	1.09	6.24	0.00	-0.03	0.00	0.92	0.77
7	10	8.15	0.00	-0.02	0.11	0.53	2.46	5.13	0.00	-0.02	0.04	0.66	1.18
8	11	5.45	0.06	0.00	0.87	0.05	4.49	4.91	0.02	-0.01	0.71	0.13	2.97
9	11	5.77	0.11	-0.01	0.73	0.11	5.96	4.35	0.00	-0.01	0.51	0.21	1.91
10	11	7.04	0.10	-0.00	0.95	0.02	6.03	3.05	0.09	0.00	0.61	0.18	2.49
11	8	7.67	0.15	-0.00	0.84	0.09	5.13	3.29	0.22	0.01	0.80	0.11	2.59
12	8	7.32	0.00	-0.03	0.11	0.60	1.99	5.21	0.00	-0.02	0.10	0.62	1.28
13	6	8.08	0.06	0.00	0.93	0.04	2.71	5.00	0.12	0.00	1.00	0.00	2.24

Note : P_a = probability for a, P_b = probability for b, r = correlation coefficient, and SE = standard error.

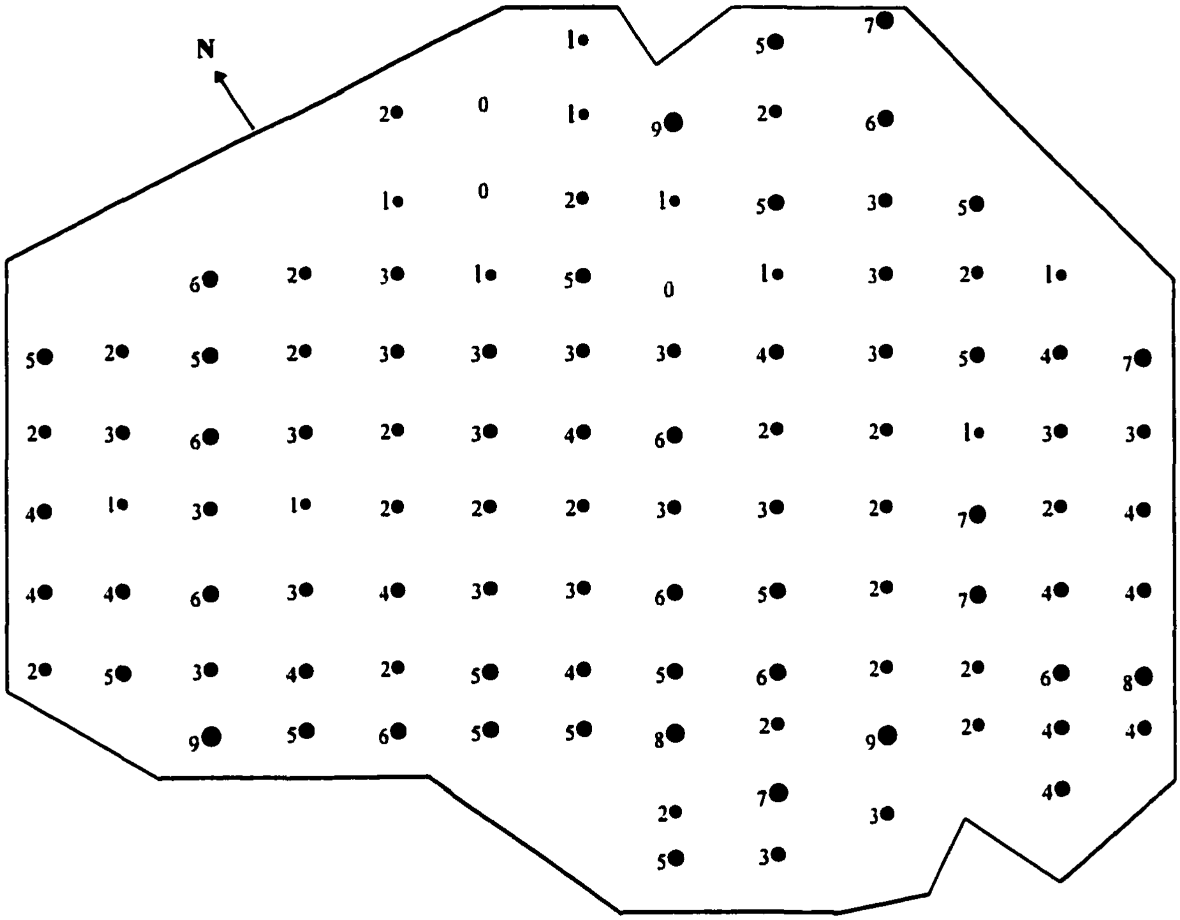

Figure 4.2: Spatial distribution of species composition of tree seedlings in the degraded forest area. The relative size of the dot "•"indicates the number of species in 5 m^2 plots. The actual numbers are printed beside the dots. "0" indicates there were no species in that plot.

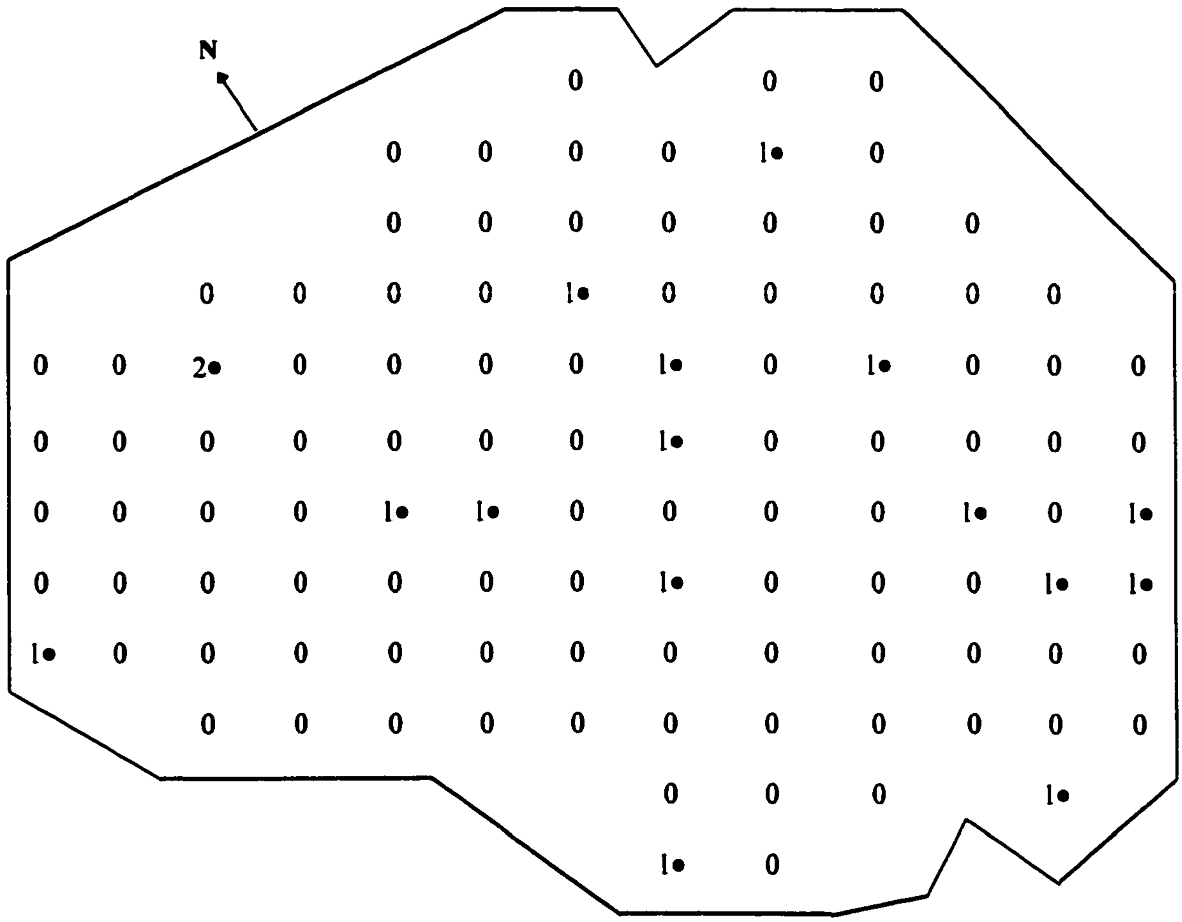

Figure 4.3: Spatial distribution of *Ceiba pentandra* seedlings in the degraded forest area. The relative size of the dot "•" indicates the number of seedlings in 5 m^2 plots. The actual numbers are printed beside the dots. "0" indicates there were no seedlings in that plot.

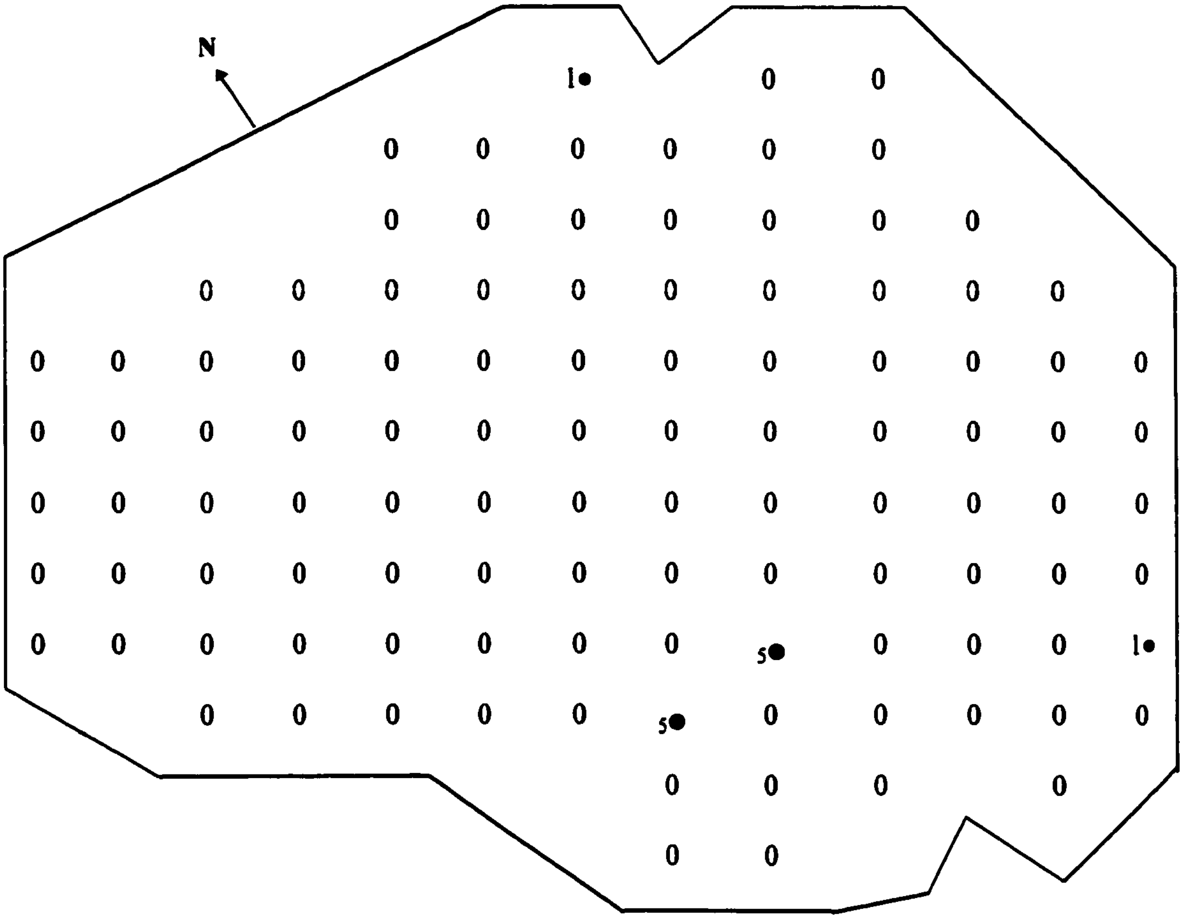

Figure 4.4: Spatial distribution of *Piptadeniastrum africanum* seedlings in the degraded forest area. The relative size of the dot "●" indicates the number of seedlings in 5 m^2 plots. The actual numbers are printed beside the dots. "0" indicates there were no seedlings in that plot.

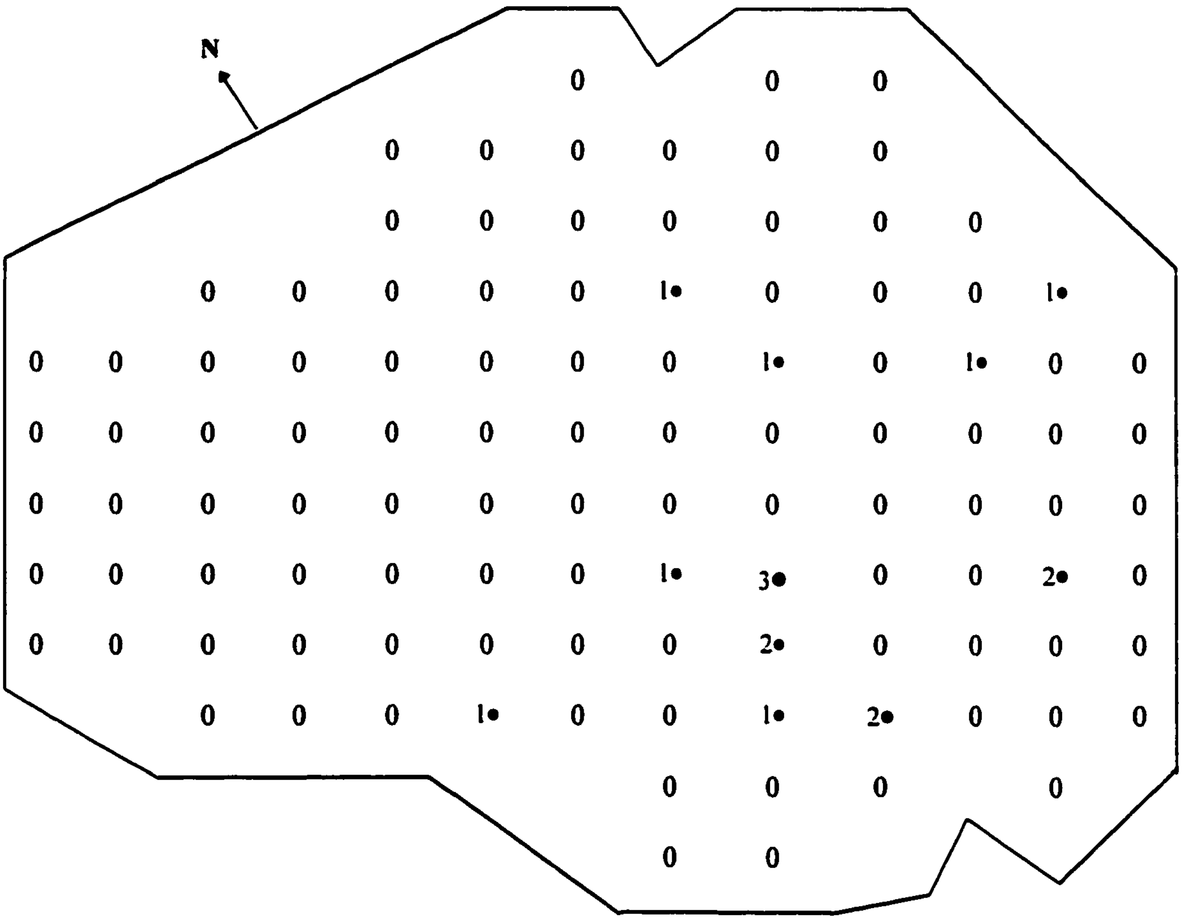

Figure 4.5: Spatial distribution of *Triplochiton scleroxylon* seedlings in the degraded forest area. The relative size of the dot "•" indicates the number of seedlings in 5 m^2 plots. The actual numbers are printed beside the dots. "0" indicates there were no seedlings in that plot.

There was no pattern in relation to the distance to any side of the site for *Ceiba pentandra* and *Piptadeniastrum africanum* (Figures 4.3 and 4.4).

4.2. **Viable Seeds**

Germination of seeds started five days after the start of the test and no germinants appeared in the 16 controls. There were generally more viable tree seeds in the bottom layer than the upper layer (Figure 4.6) but the difference was not statistically significant ($p = 0.8522$). The total number of viable tree seeds recorded in each germination tray ranged from 0 to 16 per tray (Figure 4.7). At the end of the germination test, 46,000 viable tree seeds ha^{-1} were recorded (Table 4.3, Figure 4.6). Germination was completed after 75 days (Figure 4.6).

Tree seeds were found in only 39 % of the plots (Figure 4.7). The total number of tree species ranged from 0 to 3 species per tray (Figure 4.8). At the end of the germination test, a total of 7 species was recorded (Table 4.3). *Solanum erianthrum* was the dominant tree species (24,000 seeds ha^{-1}, 52 % of all tree species) for both the upper and bottom soil layers (Table 4.3). All tree species recorded in the seed bank were present in the seedling stocks and 57 % were present in the seed producing trees (Tables 4.1 and 4.3).

There were significantly more viable seeds of *Chromolaena odorata* in the upper layer than the bottom layer ($P = 0.0000$, Figure 4.9). The total number of *Chromolaena odorata* viable seeds in the upper layer ranged from 75 to 6,336 seeds per tray with an average of 1,649 seeds per tray. The total number of *Chromolaena odorata* viable

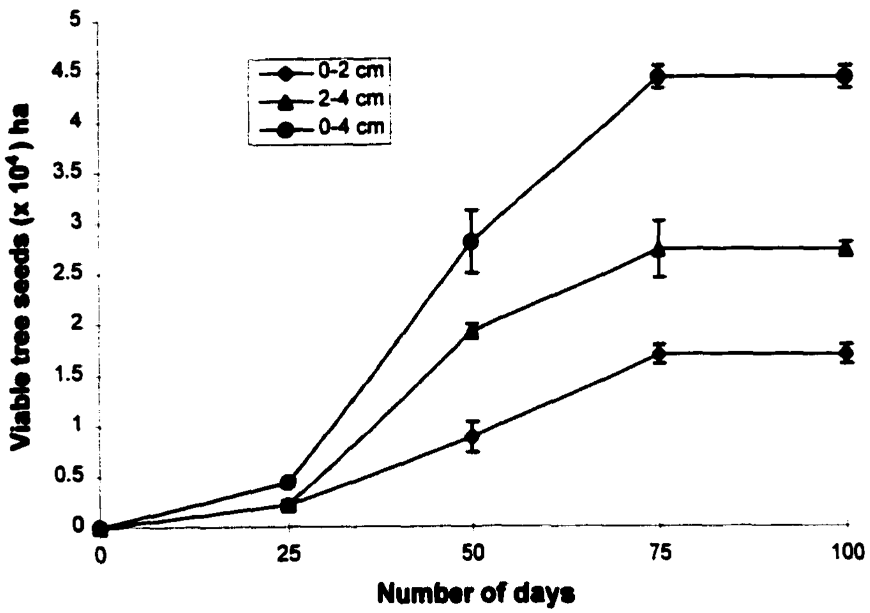

Figure 4.6: Cumulative germination of tree seeds at two depths in the degraded forest area. The number of viable seeds was estimated by the number of germinants in a 100-day germination test. Bars represent standard errors of the mean.

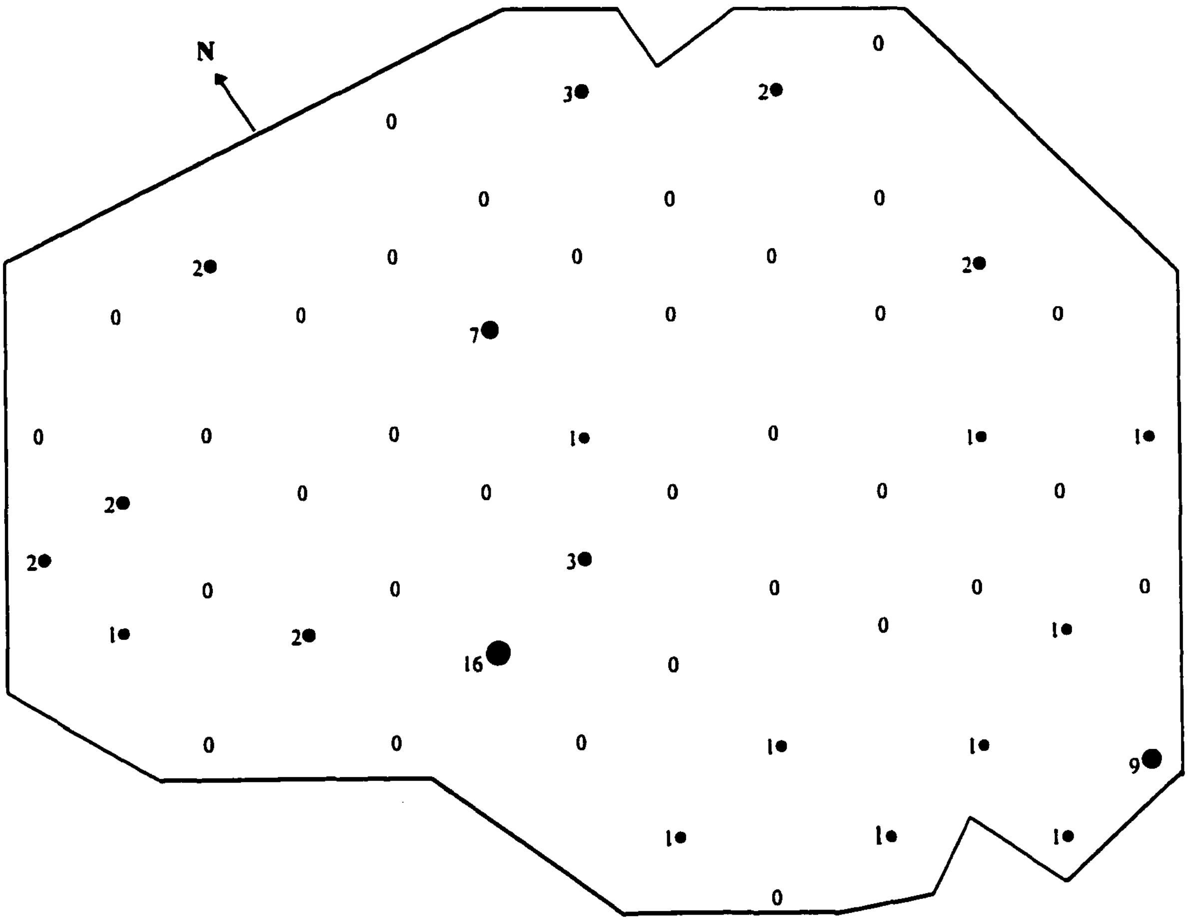

Figure 4.7: Spatial distribution of tree seeds in the degraded forest area. The relative size of the dot "●" indicates the number of viable seeds in 0.25 m^2 plots. The actual numbers are printed beside the dots. "0" indicates there were no seeds in that plot.

Table 4.3: Density of viable seeds as estimated from the number of germinants during a 100-day germination test of the soil sample from a degraded forest area.

Species	Number of viable seeds ha^{-1}
Celtis mildbraedii	1,000
Ceiba pentandra	2,000
Ficus exasperata	8,000
Ficu sur	9,000
Solanum erianthrum	24,000
Trema orientalis	1,000
Trichilia prieuriana	1,000
Herb and climber species	153,000
Chromolaena odorata	73,892,000

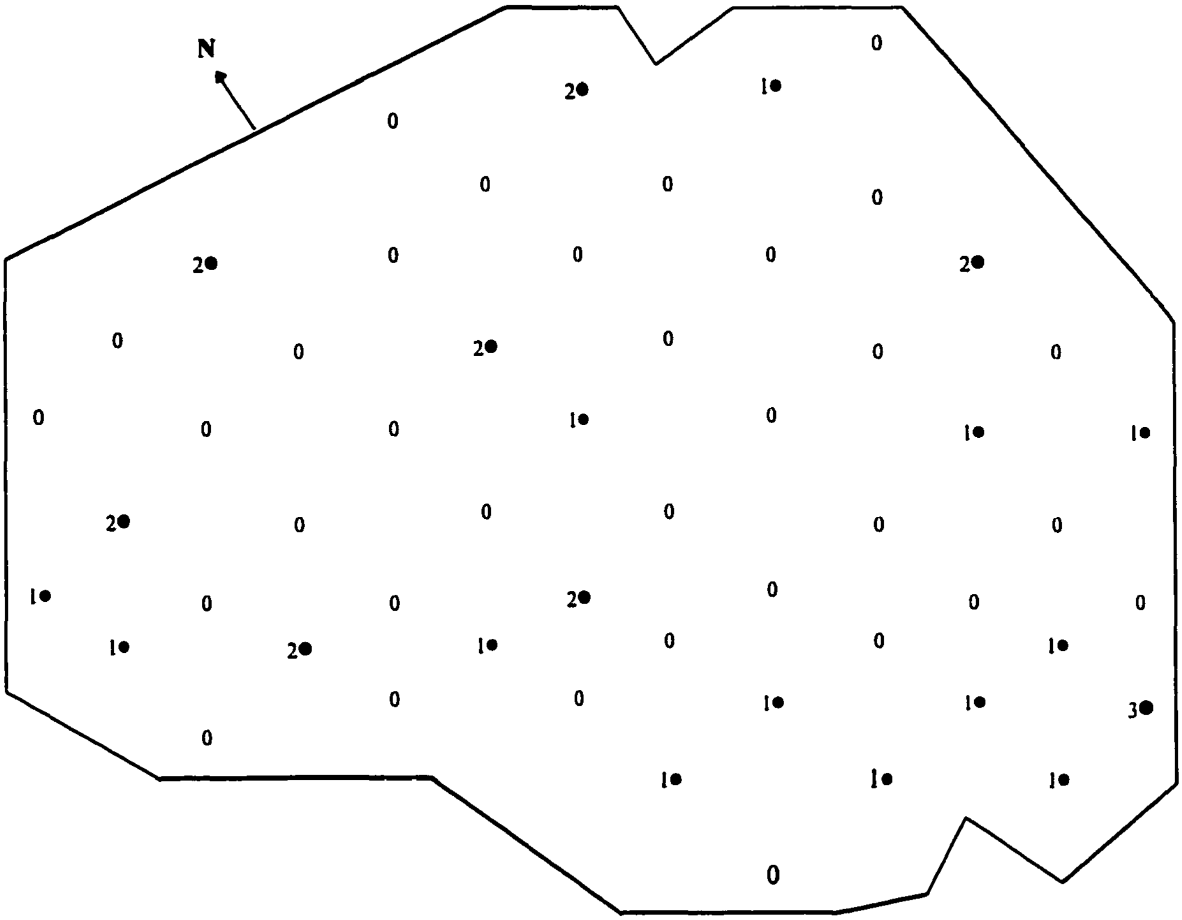

Figure 4.8: Spatial distribution of species composition of tree seeds in the degraded forest area. The relative size of the dot "●" indicates the number of species in 0.25 m^2 plots. The actual numbers are printed beside the dots. "0" indicates there were no species in that plot.

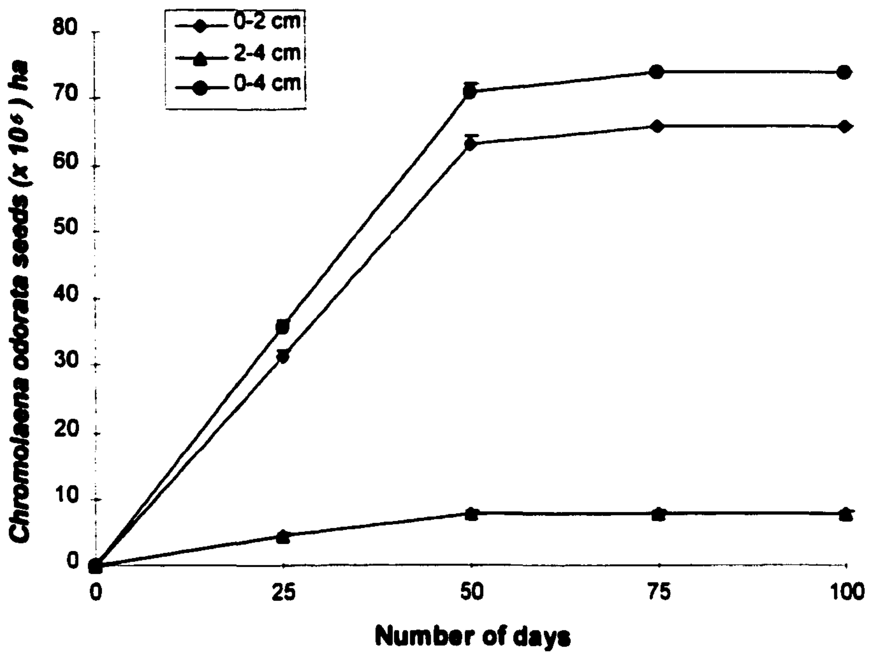

Figure 4.9: Cumulative germination of *Chromolaena odorata* seeds at two depths in the degraded forest area. The number of viable seeds was estimated by the number of germinants in a 100-day germination test. Bars represent standard errors of the mean.

seeds in the bottom layer ranged from 36 to 735 seeds per tray with an average of 199 seeds per tray with the exception of one plot, which had 2,284 seeds. There were 1,606 times more *Chromolaena odorata* seeds than tree seeds (Table 4.3).

Two hundred and seven other herb and climber species were also recorded at the end of the test but were not included in the analysis because they were not the focus of this study (Table 4.3). The competing vegetation and tree species were the main concern of the study. The germination of *Chromolaena odorata* seeds was almost completed in 75 days and very few germinants appeared afterwards (Figure 4.9).

4.3. **Height increment**

The height increment was significantly greater in the released than in the unreleased seedlings for all species together (Figure 4.10, Appendixes 1 and 2, P = 0.000). The height increment of released seedlings (all species) was generally three times that of the unreleased seedlings, three months after the release treatment (Figure 4.10, Appendixes 1 and 2). The level of response, however, varied with species. The height increment (species mean) of released seedlings ranged from 1.6 to 13.5 cm while that of unreleased seedlings ranged from 0.6 to 4.5 cm (Figure 4.10, Appendixes 1 and 2). *Steculia tragacantha* (Sttr) showed the largest response among all species (Figure 4.10, Appendix 1). *Celtis zenkeri* (Ceze) showed the lowest response among the species that responded significantly to the treatment (Figure 4.10, Appendix 1).

All the released seedlings of Class 1 species had significantly higher height increment than their unreleased counterparts and the difference ranged from 1.0 to 8.5 cm

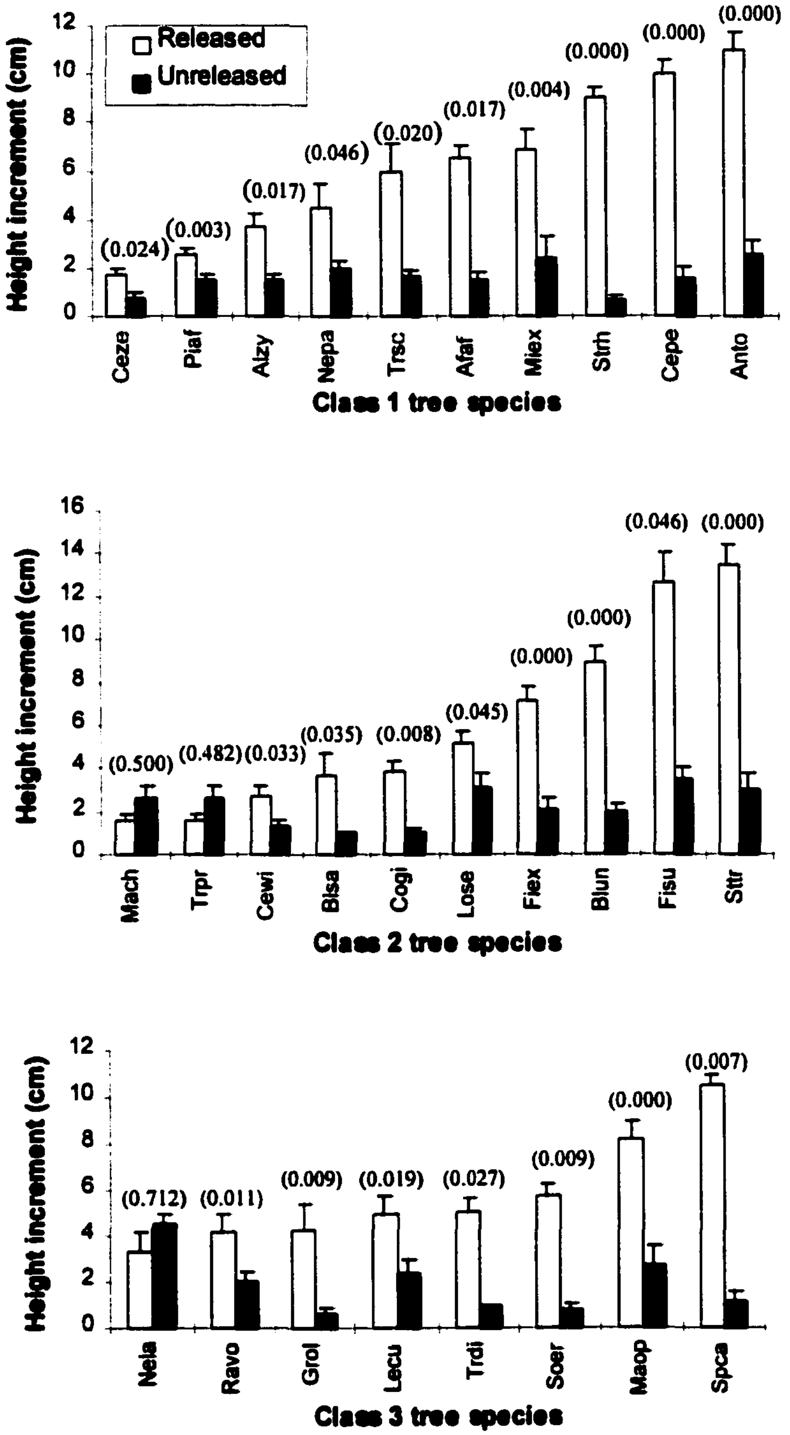

Figure 4.10: Height increment in released and unreleased tree seedlings in the degraded area three months after the release treatment (mean + 1 S.E., n = 2 - 29). Numbers in parentheses represent probabilities of the Covariance Analysis. Tree species were coded by the first two letters of their generic and species names.

(Figure 4.10, Appendixes 1 and 2, $P \leq 0.04$). All the Class 2 species had significant higher height increment than their unreleased counterparts ($P \leq 0.04$) except *Trichilia prieuriana* (Trpr) and *Maranthes chrysophylla* (Mach; $P \geq 0.48$) and the difference ranged from 1.4 to 10.5 cm (Figure 4.10, Appendixes 1 and 2). The height increment of all Class 3 species were significantly higher than their unreleased counterparts ($P \leq 0.02$) except *Newbouldia laevis* (Nela; $P = 0.71$) and the difference ranged from 2.2 to 9.3 cm (Figure 4.10, Appendixes 1 and 2).

4.4. **Increase in number of leaves**

The released seedlings grew significantly more new leaves than the unreleased ones for all species combined (Figure 4.11, Appendixes 3 and 4, $P = 0.000$). The increase in number of leaves per seedling (all species) was generally three times more in released seedlings than the unreleased ones three months after the release treatment (Figure 4.11, Appendixes 3 and 4). The increase in number of leaves in released seedlings ranged from 1.5 to 7.6 while that of unreleased seedlings ranged from 0.0 to 3.7 (Figure 4.11, Appendixes 3 and 4). The level of response varied with species. *Mallotus oppositifolius* (Maop) showed the highest response among all species while *Celtis zenkeri* had the lowest response among the species that showed a significant response (Figure 4.11, Appendix 3).

All the released seedlings of Class 1 species had significantly more leaves than their unreleased counterparts and the difference ranged from 0.9 to 4.2 (Figure 4.11, Appendixes 3 and 4, $P \leq 0.04$). All the Class 2 species had significantly more new leaves

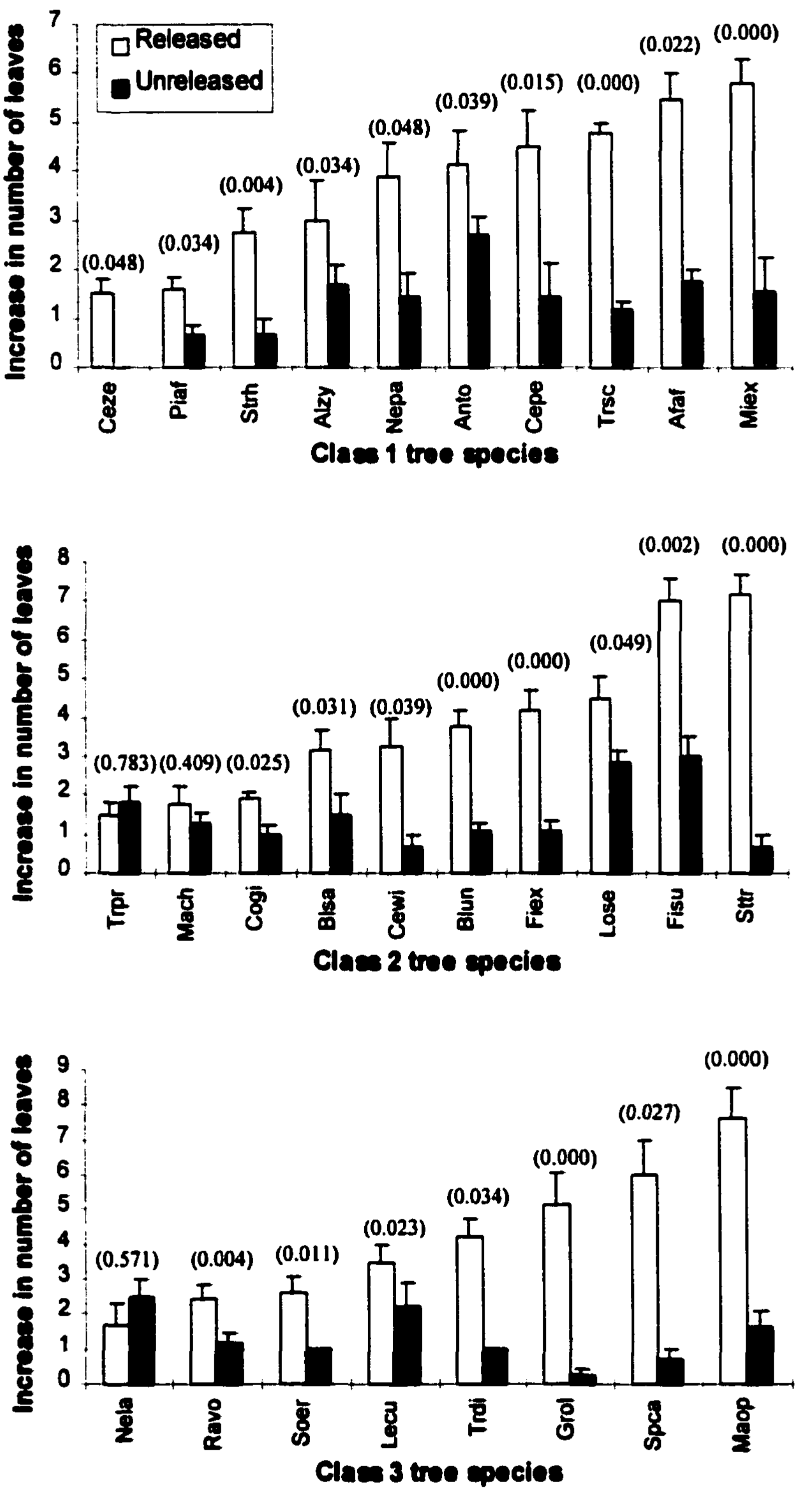

Figure 4.11: Increase in number of leaves per seedling in released and unreleased tree seedlings in the degraded area three months after the release treatment. See Figure 1 for more explanations.

than their unreleased counterparts ($P \leq 0.04$) except *Maranthes chrysophylla*, and *Trichilia prieuriana* ($P > 0.41$) and the difference ranged from 0.9 to 4.2 (Figure 4.11, Appendixes 3 and 4). All the released seedlings of Class 3 species had significantly more new leaves than their unreleased counterparts ($P \leq 0.03$) except *Newbouldia laevis* ($P > 0.57$) and the difference ranged from 1.3 to 6.0 (Figure 4.11, Appendixes 3 and 4).

4.5. **Mortality**

Seedling mortality was observed only in unreleased plots and the rate of mortality varied from species to species. In general, faster growing species suffered higher mortality (Figures 4.10 and 4.12, Appendixes 1 and 5). Seedling mortality was highest in Class 1 trees and lowest in Class 3 tree species (Figure 4.12, Appendix 5). The seedling mortality of Class 1 species ranged from 0 to 45 % (Figure 4.12, Appendix 5). All the Class 1 species but *Celtis zenkeri* suffered mortality with an average mortality of 28 % (Figure 4.12, Appendix 5). Seedling mortality of Class 2 species ranged from 0 to 33 % (Figure 4.12, Appendix 5). Sixty percent of the Class 2 species suffered mortality with an average of 12 % (Figure 4.12, Appendix 5). Only three out of eight Class 3 species suffered mortality (Figure 4.12, Appendix 5). Symptoms of pathogen infection were not observed on dead tree seedlings.

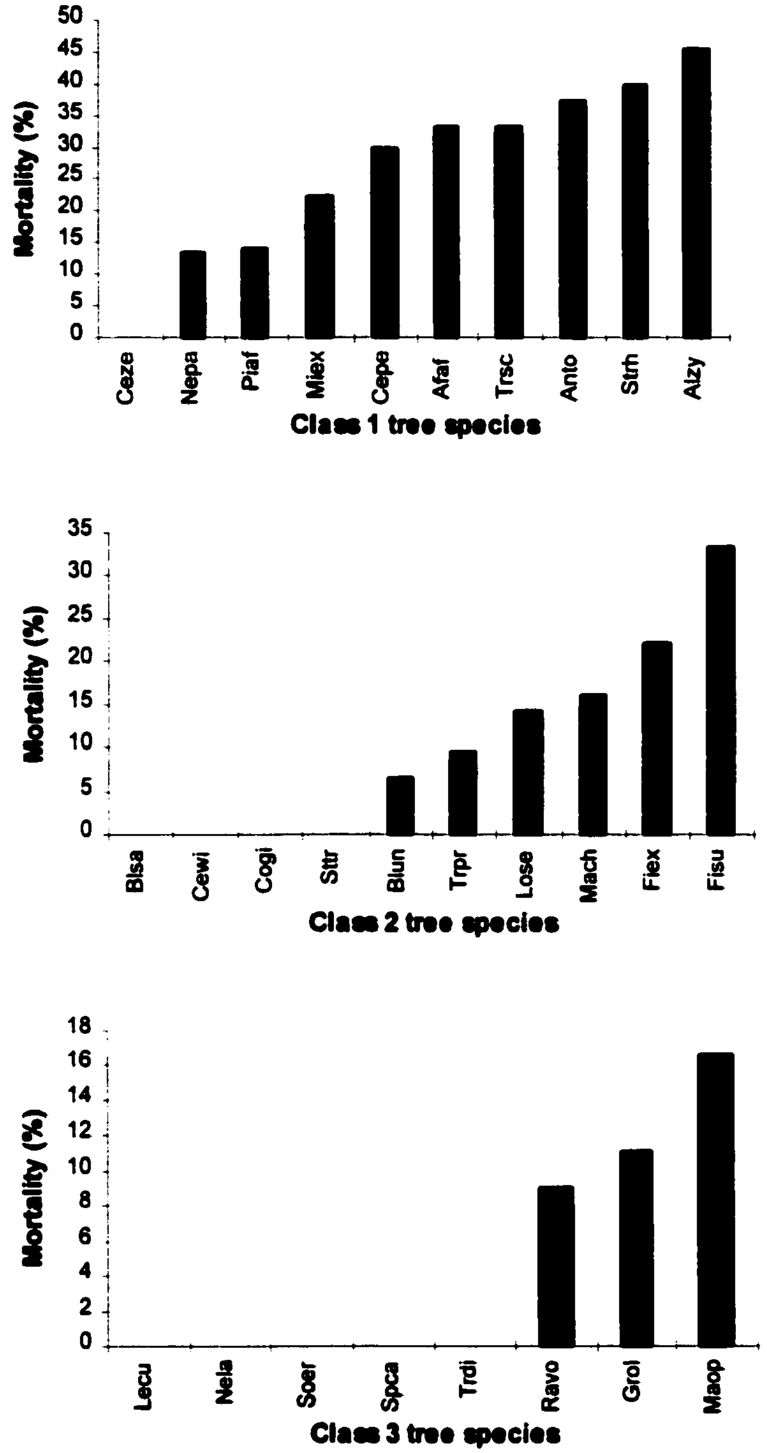

Figure 4.12: Mortality (%) of tree seedlings in unreleased plots. Tree species are coded by the first two letters of their generic and species names. No mortality was observed in the released plots.

5.0. DISCUSSION

5.1. DISTRIBUTION AND SPECIES COMPOSITION OF SEEDS AND SEEDLINGS OF TREES AND COMPETING VEGETATION

The restoration of degraded forests in Ghana is currently concentrated on converting degraded areas to mainly teak plantation. Natural regeneration or human-assisted natural regeneration is generally not considered because there is no information on the distribution of tree seeds and seedlings in degraded areas. This study shows that tree species in the degraded forest have enough seedling stock under the canopy of *Chromolaena odorata* (Figures 4.1 and 4.2). This suggests that tree seedlings have the ability to survive the unfavorable conditions created by *Chromolaena odorata* and have the potential to regenerate the area back to forest. However, the high density of *Chromolaena odorata* and its abundant seed supply may present a major obstacle for the future survival and growth of tree seedlings. Therefore, it may be necessary to artificially remove *Chromolaena odorata* to facilitate the growth of trees.

This study provides further evidence to support the finding of Swaine *et al.* (1997) that degraded forest soils contain few tree seeds compared to *Chromolaena odorata*, a strong competitor to tree seedlings. The amount of tree seeds found in this study (46,000 seeds ha^{-1}) is even lower than the 26 million seeds ha^{-1} found by Swaine *et al.* (1997). It is possible that some seeds in the upper layer germinated in the field during the rainy season before samples were taken. The early rainfalls may be enough to wet the upper layer of the soil and induce seed germination but not enough to wet deeper layers. Additionally, the amount of seeds produced during the year may have been small. These may be the explanations why there were more seeds in the bottom layer than the upper layer (Figure 4.6). This trend is in contrast to the findings that the seed bank content generally decreases with increasing depth from the ground surface (Enright 1978).

There were significantly more *Chromolaena odorata* viable seeds in the upper layer than the bottom layer (P = 0.0000, Figure 4.9) which is in an agreement with Enright (1978). The seed density of *Chromolaena odorata* is also in agreement with the results of Swaine *et al.* (1997). Seed germination was almost completed in 75 days, which is very close to what Hall and Swaine (1980) found in an intact forest. They reported that few seeds germinated after 70 days. More than 96 % of the seeds germinated before 51 days from the start of the experiment. There were 1,606 times more *Chromolaena odorata* seeds in the soil seed bank than tree seeds. Such an abundant seed supply of *Chromolaena odorata* gives this species a significant competitive advantage over trees (Table 4.3).

The density of tree seedlings was 3.8 times lower than tree seeds (Tables 3.1 and 3.3). This difference may have resulted from a lower germination rate of tree seeds under the field conditions or a low survival rate of germinants under the canopy of *Chromolaena odorata*. There was also no clear relationship between the distribution of the tree seedlings and seeds (Figures 4.1 and 4.7). Tree seedlings were absent in 3 % of the plots and tree seeds were absent in 61 % of the plots in this study (Figures 4.1 and 4.7). Such uneven distribution of tree seeds is difficult to explain. Normally, the density of wind dispersed seeds decreases with increasing distance from the mother tree. However, the tree seed density, seedling density and species composition only had a weak relationship to the distance and direction of the adjacent natural forests. There might be several reasons for the even distribution of seeds and seedlings and the poor relations: 1) seeds may have been dispersed into the area from more than one direction, 2) the small size of the area (4 ha) may have caused turbulent air flow, and 3) the seeds may have been dispersed by other agents as well as wind. More studies are necessary to investigate factors influencing the distribution of seeds and seedlings.

The species composition of tree seedlings was 7.8 times higher than the species composition of the seeds (Tables 3.1 and 3.3, Figures 4.2 and 4.8). Tree species were present in 97 % of the seedling plots and were well distributed (Figure 4.2). Such a difference suggests that the seedlings were probably accumulated over a period of several years. Those plots that did not contain tree seedlings were generally located in waterlogged areas, suggesting that tree seedlings are intolerant to waterlogging. While the total seedling density and species composition of the tree seedlings suggest there is a great potential to regenerate the degraded area naturally, the seed density and species composition of the tree seeds suggest it may take a long time for natural regeneration process to restore a newly disturbed area back to a productive forest.

There were sufficient (11,780 seedlings ha^{-1}) and well-distributed tree seedlings in the degraded area to restore the area back to forest (Figure 4.1). Planting distance depends on the tree species, however, the average planting distance used in Ghana is 3 m x 3 m. Therefore, the number of seedlings found per hectare in the degraded area is 10 times more than what a 1 ha plantation planted at 3 m x 3 m can contain. The even distribution of the seedlings may however change over time. The density of *Antiaris toxicaria*

(Anto), *Blighia unijugata* (Blun), *Cola gigantia* (Cogi), *Ficus exasperata* (Fiex), *Lonchocarpus sericeus* (Lose), *Mallotus oppositifolius*, *Maranthes chrysophylla*, *Nesorgodonia papaverifera*, *Ravolfia vomitoria* (Ravo), *Steculia tragacantha*, and *Trichilia prieuriana* were found to be over 400 seedlings per ha and the frequency of distribution over 5 % (Table 4.1). These species, therefore, may form the future forest.

Solanum erianthrum was found to be a dominant tree species in the soil seed bank (Table 4.3). Other researchers (*e.g.*, Swaine *et al.* 1997) reported similar results. This study shows that 43 % of the species present as seed and 64 % of the species present as seedlings had no corresponding seed production trees (Tables 3.1 and 3.3). A possible explanation is that seeds of these species may have arrived at the site by various forms of seed dispersal agents (Harper 1977; Hall and Swaine 1980).

5.2. RESPONSES OF TREE SEEDLINGS TO THE REMOVAL OF *CHROMOLAENA ODORATA* LINN (ACHEAPONG).

This study shows there is a great potential to restore the degraded area back to productive forest by removing *Chromolaena odorata*. Most tree species responded positively and significantly to the removal of *Chromolaena odorata*, the competing species (Figures 4.10 and 4.11, Appendixes 1 - 4). The seedlings obtained greater height growth and more new leaves after being released from *Chromolaena odorata* (Figures 4.10 and 4.11, Appendixes 1 - 4). The increase in number of leaves per seedling was positively related to height increment ($r = 0.70$, $P = 0.0000$, $SE = 1.90$). The significant increase in these two parameters suggest that release from competition greatly increased the growth momentum of those trees. According to the height increment of the released seedlings during the study period (3 months), it may take the trees up to 2.5 years to grow taller than the maximum height of *Chromolaena odorata*. However, the increased growth momentum will most likely produce even greater growth in those trees in the future, suggesting that the tree species may grow taller than the mean height of *Chromolaena odorata* (2 m) in less than 2.5 years. It should be pointed out that this is a preliminary study and longer-term observations may be necessary before a more concrete recommendation can be made to forest managers. Additionally, *Chromolaena odorata* is very intolerant of shade and can not grow under the canopy of trees. Therefore, *Chromolaena odorata* will no longer be a concern once the trees form a certain coverage. The critical level of coverage, however, needs to be examined in future research.

Chromolaena odorata is widespread in degraded forest areas in Ghana. It is a high shade intolerant species and has a great capacity to invade and dominate the degraded areas. One of the possible reasons for the aggressive invasion is the abundant number of viable seeds produced by this species (Section 4.2). The light weight of the seed gives this species an additional advantage for the wide range dispersal by wind. It grows very fast and can grow to about 2 m in height (Riddoch 1991). This species forms such a dense woven canopy that it is almost impossible for the tree seedlings to penetrate. The flux density of photosynthetically active radiation under the *Chromolaena odorata* canopy is only 7 % of the ambient level (Section 3.1).

The results of this study suggest that the natural tree seedlings have the potential to restore the degraded forest back to high value, high quality forests after *Chromolaena* *odorata*, the competing vegetation is removed. The height increment of released Class 1 seedlings ranged from 225 to 625 % of that in unreleased seedlings (Figure 4.10, Appendixes 1 and 2). Similarly, the increase in the number of new leaves of the Class 1 seedlings ranged from 228 to 400 % of that in unreleased seedlings (Figure 4.11, Appendixes 3 and 4). It was found in Section 4.1 that the density of these Class 1 species at the site ranges from 112 to 612 seedlings per ha and the frequency of occurrence ranges from 4 to 18 %. Additionally, the Class 1 species form 50 % of the tree species that had a response of more than 6 cm in height growth (Figure 4.10, Appendix 1). Moreover, they constitute 44 % of the species that produce an average of more than 4 new leaves per species (Figure 4.11, Appendix 3). Such a significant response shown by the Class 1 species suggests that they have a great potential to be the dominant species in the future forest after being released from *Chromolaena odorata*. *Steculia rhinopetala* (Strh), *Ceiba pentandra* (Cepe), *Antiaris toxicaria*, *Milicia exelsa* (Miex), *Afzelia africana* (Afaf), and *Triplochiton sclerozylon* (Trsc) are the most important Class 1 species in the country. They are fast growing species and require high light conditions (Taylor 1960a; Taylor 1962; Hawthorne 1990; Riddoch *et al.* 1991; Molofsky and Augspurger 1992). This may explain why their height and leaf response were very high (Figure 4.10 and 4.11, Appendixes 1 and 3). The dominance of such species ensures a high growth rate and high value of forest products in the future. This in the long term has the potential to increase the revenue base of the forest industry. On the other hand, the growth response shown by *Celtis zenkeri*, *Piptadenistrum africanum* (Piaf), *Albizia zygia*

(Alzy), and *Nesorgodonia papaverifera* (Nepa), suggests that they have slow seedling growth (Figures 4.10 and 4.11, Appendixes 1 and 3).

The height growth and number of new leaves produced by Class 2 species did not increase as much as of Class 1 species did in response to the release. The height growth of released Class 2 species ranged from 167 to 450 % of that in unreleased seedlings (Figure 4.10, Appendixes 1 and 2). The Class 2 species represent 33 % of the tree species that had a response of more than 6 cm in height growth (Figure 4.10, Appendix 1). Similarly, the increase in number of new leaves of the Class 2 seedlings ranged from 190 to 1,028 % of that in unreleased seedlings (Figure 4.11, Appendixes 3 and 4). They form only 28 % of the species that produce an average of more than 4 new leaves per species (Figure 4.11, Appendix 3). These Class 2 species had 112 to 1,112 seedlings per ha at the site and the frequency of occurrence ranges from 4 to 30 % (Section 4.1). These species have the potential to form the second stratum of the future forest. Although these species currently do not have much economic value as Class 1 species do they can provide significant ecological functions (*e.g.*, watershed protection). Moreover, some of these species may become Class 1 species in the future. For example, *Pericopsis elata* was not an economic species before 1985 but later became one of the highly priced timber species (FAO 1985; Hawthorne and Abu-Juam 1995). The height and leaf response of *Steculia tragacantha*, and *Ficus sur* (Fisu) were very high (Figure 4.10 and 4.11, Appendixes 1 and 3), suggesting that they may be high light demanding species and very fast growing tree species. Similarly, *Blighia unijugata* and *Ficus exasperata* may also be fast growing light demanding species. On the other hand, the growth response shown by *Celtis wightii*

(Cewi), *Blighia sapida* (Blsa), *Cola gigantia*, and *Lonchocarpus sericeus* indicates that they have slow juvenile growth (Figure 4.10 and 4.11, Appendixes 1 and 3).

The height increment of released Class 3 species ranged from 46 to 333 % of that of unreleased seedlings (Figure 4.10, Appendixes 1 and 2). These species form only 17 % of the trees that had a response of more than 6 cm in height growth (Figure 4.10, Appendix 1). Similarly, the increase in number of new leaves of the Class 3 seedlings ranged from 154 to 1,700 % of that in unreleased seedlings (Figure 4.11, Appendixes 3 and 4). But they represent only 28 % of the species that produce an average of more than 4 new leaves per species (Figure 4.11, Appendix 3). The seedling density of these Class 3 species at the site ranges from 92 to 666 per ha and the frequency of occurrence ranges from 4 to 20 % (Section 4.1). These results suggest that the Class 3 trees do not have the potential to form a significant part of the future forest. The height and leaf respose of *Spathodea campanulata* (Spca), and *Mallotus oppositifolius* were very high (Figures 4.10 and 4.11, Appendixes 1 and 3), suggesting that they may be light demanding and fast growing tree species. On the other hand, the growth response shown by *Newbouldia laevis*, *Ravolfia vomitoria* (Ravo), *Greenwayodendron oliveri* (Grol), and *Lecaniodicus cupanioides* (Lecu), *Tricalysia discolor* (Trdi), and *Solanum erianthrum* (Soer) suggests that they have slow seedling growth (Figures 4.10 and 4.11, Appendixes 1 and 3).

The results of this study suggest that *Chromolaena odorata* is primarily responsible for the poor regeneration of trees in degraded areas. The high mortality in unreleased seedlings and no mortality in released seedlings suggest that those tree species generally cannot tolerate the shade created by the *Chromolaena odorata* canopy. Seedlings of light demanding species are fast growing and intolerant of shade and can survive and grow only in gaps (Taylor 1962; Swaine and Hall 1988; Hawthorne 1989). Mortality was greatest in Class 1 trees and lowest in Class 3 trees (Figure 4.13). This suggests that the light demanding characteristics of the tree species is strongest in the Class 1 trees and weakest in Class 3 trees. *Chromolaena odorata* must be removed in order to regenerate the degraded area.

6.0. GENERAL CONCLUSIONS AND RECOMMENDATIONS

The study has showed that there are enough tree seeds and tree seedlings to restore the degraded area back to forest. In summary:

(1) There were 11,780 tree seedlings ha^{-1} of 55 species under the canopy of *Chromolaena odorata* in the degraded area. This suggests that tree seedlings are able to survive the unfavorable conditions created by *Chromolaena odorata.*

(2) There were 46,000 tree seeds ha^{-1} of 7 species in the degraded area. There were less seeds in the upper layer than the bottom layer.

(3) The density of tree seeds was 3.8 times higher than tree seedlings and tree seeds were absent in 61 % of the plots. On the other hand, the species composition of tree seedlings was 7.8 times higher than the species composition of the seeds. Tree species were present in 97 % of the seedling plots and were well distributed.

(4) There were more than 73 million seeds ha^{-1} of *Chromolaena odorata* in the degraded area. More seeds were found in the upper layer than the bottom layer.

(5) *Chromolaena odorata* seeds in the soil seed bank were 1,606 times more abundant than tree seeds. The plenteous seed supply of *Chromolaena odorata* gives this species a significant competition advantage over trees.

The study also showed that tree seedlings responded positively to the removal of *Chromolaena odorata*. In summary:

(1) Released seedlings had an average height growth of 6.64 cm three months after the release treatment.

(2) Unreleased seedlings had an average height growth of 2.13 cm three months after the release treatment.

(3) The average height increment was three times greater in released seedlings than the unreleased ones three months after the release treatment.

(4) Released seedlings had an average of 4.3 new leaves three months after the release treatment.

(5) Unreleased seedlings had an average of 1.4 new leaves three months after the release treatment.

(6) The average increase in number of leaves was three times greater in released seedlings than the unreleased ones three months after the release treatment.

(7) Sixty four percent of the species suffered various levels of mortality in the unreleased plots, but all the seedlings of all the species survived in the released plots three months after the release treatment.

The study suggests that *Chromolaena odorata* is primarily responsible for the poor regeneration of trees in the degraded area. *Chromolaena odorata* must be removed in order to regenerate the degraded area back to a productive forest.

It is recommended that a long term study be conducted to determine 1) what the growth rates of the tree species will be in later years after the release treatment, 2) the economics of weeding the released plots until canopy closure of trees, 3) the critical level of coverage of the tree species, and 4) factors responsible for the uneven distribution of tree seeds.

7.0. LITERATURE CITED.

Adu, S.V. 1992. Soils of Kumasi Region, Ashanti Region, Ghana. Soil Resource Institute, Memoir, No. 8, Kwadaso-Kumasi, Ghana. 141 pp.

Akanbi, M.O. 1980. Preliminary notes *on Trizomia lamboni* (Newstead)(Hem., Psylidae), a potential dangerous pests of *Antiaris africana.* Entomologist's Monthly Mag. 116: 1392 - 1395.

Albrecht, J. 1993. Tree Seed Handbook of Kenya. GTZ Forestry Seed Center Muguga, Kenya, German Development Cooperation, Kenyan Forestry Research Institute/GTZ, Kenya. 264 pp.

Anonymous, 1973. Munsell Soil Color Charts. Munsell Color, MacBeth Division of Kollmorgen Corp., Baltimore Maryland, Publ. 21218.

Ashton, P.M.K. 1990. Methods for the evaluation of advanced regeneration in forest types of South and Southeast Asia. For. Ecol. Mgmt. 36: 163-175.

Augspurger, C. K. 1984a. Seedling survival of tropical tree species: Interaction of dispersal distance, light gaps, and pathogen. Ecology. 65: 1705 - 1712.

Augspurger, C. K. 1984b. Light requirements of neotropical tree seedlings: A comparative study of growth and survival. J. Ecol. 72: 777 - 795.

Augspurger, C. K., and Kelly, C. K. 1984. Pathogen mortality of tropical tree seedlings: experimental studies of the effects of dispersal distance, seedling density, and light conditions. Oecologia 61: 211 - 217.

Avoka, C. 1999. Interview with He Mr. Cletus Avoka, Minister of Lands and Forestry, Ghana. In ITTO Tropical update. ANUTECH, Pty Ltd., Canberra, Australia. Edited by Prebble C. pp 16-17.

Barbour, M.G., and Lange R.T. 1967. Seed population in some natural Australian top soils. Ecology 48: 153-155.

Borota, J. 1991. Tropical Forests: Some African and Asian Case Studies of Composition and Structure. University College of Forestry and Wood technology, Zvolen, Czechoslovakia. 274 pp.

Brookman-Ammisah, J. 1981. Trends in Ghanaian Forestry Practice. In Woodpower: New perspectives on Forest Usage. Pergamon Press, New York. pp 129 - 136.

Burdon, J. J., and Chilvers G. A. 1976. Epidemiology of *Pythium*-Induced Damping-Off in Mixed Species Seedling Stands. Ann. Appl. Biol. 82: 233 - 240. Chapman and Hall, London, U.K. 147 pp.

Carson, W.P. and Abbiw D.K. 1990. The vegetation of a fire protection site on the northern Accra plains, Ghana. African J. Ecol. 28: 2, 143-146.

Cochran, W.G. 1997. Sampling Techniques. Third Edition. John Wiley & and Sons. New York. 428 pp.

Cujoe, F.S. 1967. A key to the family Steculiaceae in Ghana. Tech. Note No. 7. Forest Products Inspection Bereau. Kumasi, Ghana. 21pp.

Enright, N.H. 1978. Effect of logging on regeneration and nutrient budget of *Araucaria cunninghamii* dominated tropical rainforest in Papua New Guinea. Malay. Forester 41: 303-318.

FAO. 1956. Tree Planting Practices in Tropical Africa. Forestry Development Paper No. 8. Food and Agriculture Organization of the United Nations. Rome, Italy. 302 pp.

FAO, 1985. Incentive Multiple-Use Forest Management in the Tropics: Analysis of Case Studies from India, Africa, Latin America and the Caribbean. Food and Agriculture Organization of the United Nations, Rome, Italy. 180 pp.

FAO, 1986. Forest Legislation in Selected African countries. Food and Agriculture Organization of the United Nations, Rome, Italy. 180 pp.

FAO, 1996. Forest Resource Assessment 1990. Survey of Tropical Forest Cover and Study of Change Processes. Food and Agriculture Organization of the United Nations, Rome, Italy. Forestry Paper No. 130. 154 pp.

Forest Resource Use Management Project (FORUM), 1996. Fire report in project areas. Volta Region, Ghana. 7 pp. (Internal Report).

Foster, H. 1995. Forest inventory results. Kabo River Forest Reserve. Forest Protection and Resource Used management Project (FORUM), Volta Region, Ghana. (Internal Report).

Fox, J. E. D. 1973. Dipterocarp seedling behavior in Sabah. Malay. Forester 36: 205-514.

Garwood, N. C. 1983. Seed germination in a seasonal tropical forest in Panama: A community study. Ecol. Monogr. 53: 159 - 181.

Ghana Forestry Department (GFD). 1991. Annual Report. Accra, Ghana. 13 pp. (Internal Report).

Ghana Forestry Department (GFD). 1993. A strategy for the plantation development in the High Forest Zone of Ghana. Planning Branch, Kumasi, Ghana. 24 pp. (Internal Report).

Ghana Forestry Department (GFD). Undated. Forest Reserves in the Volta Region. Planning Branch, Kumasi, Ghana. (Internal Report).

Ghartey, K.K.F. 1989. Results of the inventory. In Forest Inventory Project Seminar Proceedings, 29-30 March, 1989, Accra, Ghana. Edited by Wong J.L.G. 101 pp.

Gillis, M. Peprah, I. and Mescher M. Undated. Foreign investment in the forest based sector in Africa. Harvard University, Cambridge, Massachusetts. (Cited in Repetto1988).

Gyimah, A. 1986. Flowering and fruiting periods of some indigenous trees. Tech. Bull. Forest Products Inspection Bureau. Kumasi, Ghana. 6: 1-8.

Hall, J.B. and Swaine, M.D. 1976. Classification and ecology of closed canopy forest in Ghana. J. of Ecol. 64: 913-951.

Hall, J.B. and Swaine, M.D. 1980. Seed stocks in Ghanaian forest soils. Biotropica 12: 256-263.

Hall, J.B. and Swaine, M.D. 1981. Distribution and Ecology of Vascular Plants in a Tropical Rain Forest. Forest Vegetation in Ghana. The Hague, London, UK. 383 pp.

Harper, J.L. 1977. Population Biology of Plants. Academic Press, New York, USA. 892 pp.

Hawthorne, W.D. 1989. The Flora and Vegetation of Ghana's Forests. In Forest Inventory Project Seminar Proceedings, 29-30 March, 1989, Accra, Ghana. Edited by Wong J.L.G. 101 pp.

Hawthorne, W. 1990. Field Guide to the Forest Trees of Ghana. Natural Resource Institute, for the Overseas Development Agency, London, UK. Ghana Forestry Series 1. 278 pp.

Hawthorne, W. D. 1995. Ecological Profiles of Ghanaian Forest Trees. Tropical Forestry Papers 29, Oxford Forestry Institute, Oxford. (Cited in Swaine *et al.* 1997).

Hawthorne, W. D. and Abu-Juam M. 1993. Forest Protection in Ghana: With Particular Reference to Vegetation and Plant Species. Forest Inventory and Management Project, ODA and Forestry Department, Kumasi, Ghana. (Cited in Prah 1994).

Hawthorne, W. D. and Abu-Juam, M. 1995. Forest Protection in Ghana. IUCN, Gland, Switzerland and Cambridge. UK. 203 pp.

IIED, 1992. Environmental Synopsis of Ghana. International Institute for Environment and Development, Overseas Development Agency. 28 pp.

ITTO/IIED 1993. Study of incentive for the sustainable management of the tropical high forests of Ghana. Government of Ghana, International Tropical Timber Organization and International Institute for Environment and Development (Cited in Prah 1994).

IUCN, 1988. Ghana: Conservation of Biological Diversity. Conservation Monitoring Center, Cambridge, UK. 17 pp.

Janzen, D.H. 1970. Herbivores and the number of tree species in tropical forests. Amer. Nat. 104: 501-528.

Jones N. 1974. Records and comments regarding the flowering of *Triplochiton scleroxylon*, K. Schum. Commonw. For. Rev. 53: 52 - 6.

Jones N. 1975. Observations on *Triplochiton scleroxylon*, K. Schum. Flower and fruit development. Nigeria, Federal Development of Research: Proceedings of the symposium on variation and breeding systems of *Triplochiton scleroxylon*, K. Schum. 21-28 April, 1975. Pages 28 - 37.

Jones, N., and Howland, P. 1974. Federal Department of Forest Research, Ibadan, West African Hardwoods Improvement Project. Nigeria. Commonw. For. Rev. 53: 190-194.

Jones, N., and Kudler, J. 1970. A survey on fruiting of *Triplochiton scleroxylon*, K. Schum. and insects pests in 1969 - 1970. Ghana. J. Sc. 10: 93-106.

Korem, A. 1985. Bush Fire and Agricultural Development in Ghana. Ghana Publishing, Tema. 220 pp.

Kwasiga, F.R., Grace, J., Sandford, A.P. 1986. Some photosynthetic characteristics of tropical timber trees as affected by the light regime during growth. Ann. Bot. 58: 23-32.

Lamprecht, H. 1989. Silviculture in the Tropics. Technical Cooperation, Federal Republic of Germany, Eschborn, Germany. 296 pp.

Lawson, G.W., Armstrong-Mensah, K.O., and Hall, J.B. 1970. A catena in tropical moist semi-deciduous forest near Kade, Ghana. J. Ecol. 58: 371-98.

Leakey, R. R. B., Ferguson, N. R., and Longman K. A. 1981. Precocious and reproductive biology of *Triplochiton scleroxylon*, K. Schum. Commonw. For. Rev. 60: 117 - 126.

Legg, J.T., and Lockwood, G. 1981. Resistance of cocoa swollen-shoot virus in Ghana. Field trials. Ann. of Appl. Bio. 97: 75-89.

Lowe, R.G. 1968. Periodicity of a tropical rain forest tree *Triplochiton scleroxylon*, K. Schum. Commonw. For. Rev. 47: 150-163.

Meteorological Station Rainfall Report (MSRR), Jasikan, Ghana. 8 pp. (Internal Report).

Ministry of Lands and Forestry (MLF), 1996. Medium Term Forestry Development Plan 1996 - 2000. Accra, Ghana. (Internal Report).

Molofsky, J., and Augspurger, C.K. 1992. The effect of leaf litter on early seedling establishment in a tropical forest. Ecology. 73: 68-77.

Myers, N.1980. Conversion of Tropical Moist Forest: Review of a Recent Survey. In Tropical Forest Utilization and Conservation. Yale University Printing service. pp 48-66.

Norusis, M.J. 1993. SPSS For Windows Base System Users Guide Release 6.0. SPSS Inc., Michigan, USA. 828 pp.

Nsenkyire, E.O. 1992. Ghana-progress towards the year 2000. Sustainable management of tropical forests. Accra, Ghana. (Internal Report).

Perera, A.H. 1986. An Evaluation of Regeneration Potential in Pinus Plantation in the Central Region of Sri Lanka. Ph.D. Thesis, the Pennsylvania State University. 137 pp.

Philip, M.S. 1983. Measuring Trees and Forests. A text book written for students in Africa. Division of Forestry, University of Dar es Salaam, Tanzania. 388 pp.

Poore, D. and Sayer J. 1991. The Management of Tropical Moist Forest Lands: Ecological Guidelines. Second edition. IUCN, Gland, Switzerland and Cambridge, UK. 78 pp.

Poorter, L., Bongers, F., van Rompaey, R.S.A.R., and de Klerk, M. 1996. Regeneration of canopy trees at five sites in West Africa moist forests. For. Ecol. Mgmt. 84: 61 - 69.

Prah, E. A. 1994. Sustainable Management of the Tropical High Forest of Ghana. Commonwealth Secretariat Marlborough House, Pall Mall, London. 73 pp.

Repetto, R. 1988. The Forest for the Trees? Government Polices and the Misuse of the Forest Resources. World Resources Institute, Washington, DC, USA. 105 pp.

Richards, P.W. 1996. The Tropical Rain Forest. Second edition. Cambridge University Press. 575 pp.

Riddoch, J.C., Fasehun, F.E., Riddoch, B., and Lapido, D.O. 1991. Photosynthesis and successional status of seedlings in a Tropical Semi-Deciduous Rain Forest in Nigeria. J. Ecol. 79: 491-503.

Ridley, H.N. 1930. The dispersal of plants throughout the world. Lovell Reeve, Ashford, Kent. (Cited in Richards 1996).

Roberts, H.A. 1981. Seed Banks in Soils. In Advances in Applied Biology Vol. 6. Academy press, New York, USA. pp 1-55

Room, P.M. 1973. Ecology of the mistletoe *Tapinanthus bangwensis* growing on cocoa trees in Ghana. J. Ecol. 61: 729-742.

Steel, R.G.D, and Torrie, J.H. 1980. Principles and Procedures of Statistics. Second Edition. McGraw-Hill, New York, USA. 633 pp.

Sudhakara, K., Mammen, W., Santoshkumar, A.V., Ashokan, P.K., and Mammen, W. 1995. Effect of seed size, rooting medium and fertilizer on containerized seedlings of *Ceiba pentandra*. India Forester. 121: 1135-1142.

Swaine, M.D., and Hall, J.B. 1983. Early succession on cleared forests in Ghana. J. Ecol. 71: 602-627.

Swaine, M.D., and Hall, J.B. 1988. The mosaic theory of forest regeneration and determination of forest composition in Ghana. J. Trop. Ecol. 4: 253-269.

Swaine, M.D., and Hall, J.B., and Alexander, I.J. 1987. Tree population dynamics at Kade, Ghana (1968-1982). J. Trop. Ecol. 3: 331-345.

Swaine, M.D., Agyeman, V.K., Kyere, B., Orgle, T.K., Thomson J., and Veenendaal, E.M. 1997. Ecology of Forest Trees in Ghana. ODA Forestry Series No. 7, London, UK. 76 pp.

Taylor, C. J. 1960a. Senecology and Silviculture in Ghana. Thomas Nelson & Sons Ltd., Edinburgh, UK. 418 pp.

Taylor, C. J. 1960b. The vegetation zones of the Gold Coast. Government Printer, Accra, Ghana. pp 1-12.

Taylor, C. J. 1962. Tropical Forestry with Particular Reference to West Africa. Oxford University Press, New York. 163 pp.

Timber Export Development Board (TEDB), 1997. Ghana Hardwoods Trade Directory. Second Edition. TEDB, Unit 4, Granard Business Center, London, UK. 64 pp.

United Nations Conference on Environment and Development (UNCED), 1992. Statement made by head of state or government at the summit segment of the conference. Rio de Janeiro, 3 - 14 June 1992. Vol. III.

Walker, J. C. 1969. Plant Pathology . McGraw-Hill, New York. 819 pp.

Weetman, G., and Vyse, A. 1990. Natural Regeneration. In Regenerating British Columbia's Forest. University of British Columbia Press, Vancouver, Canada. pp 118-129.

World Commission on Environment and Development (WCED), 1987. Our Common Future. Oxford University Press, Oxford. 383 pp.

Webber, M.L. 1934. Fruit dispersal. Malay For. 3: 18-19. (Cited in Richards 1996).

Weber, G. F. 1973. Bacterial and Fungal Diseases of Plants in the Tropics. University of Florida Press, Gainesville, Florida. 673 pp.

Whitemore, T. C. 1982. On pattern and process in forests. In the Plant Community as a Working Mechanism. Brit. Ecol. Special Pubn, Blackwell, Oxford. pp 45 - 59

Whitemore, T. C. 1989. Canopy gaps and two major groups of forest trees. Ecol. 70: 536-538.

Whitemore, T. C. and Sayer, J.A. 1992. Tropical Deforestation and Species Extinction. Chapman and Hall, London. 147 pp.

Zaimeche, S. E. 1994. The Consequences of rapid deforestation: A North African Example. Ambio. 23: 2, 136-140.

APPENDIX 1: HEIGHT INCREMENT OF RELEASED TREE SEEDLINGS IN THE DEGRADED AREA THREE MONTHS AFTER THE RELEASE TREATMENT.

Species	Common name	Family	n	Height growth (cm)		Mean (cm)	SE
				Min.	Max.		
Class 1 species							
Celtis zenkeri	Esakoko	Ulmaceae	4	1	2	1.8	0.25
Piptadenistrum africanum	Dahoma	Mimosaceae	5	2	3	2.6	0.24
Albizia zygia	Okoro	Mimisaceae	7	2	5	3.7	0.52
Nesorgodonia papaverifera	Danta	Sterculiaceae	11	1	12	4.5	1.00
Tripochiton sclerozylon	Wawa	Sterculiaceae	9	2	12	6.0	1.08
Afzelia africana	Papao	Caesalpinaceae	2	6	7	6.5	0.50
Milicia exelsa	Odum	Moraceae	10	4	12	6.9	0.84
Steculia rhinopetala	Wawabima	Sterculiaceae	4	8	10	9.0	0.41
Ceiba pentandra	Onyina	Bombaceae	8	8	12	10	0.63
Antiaris toxicaria	Kyenkyen	Moraceae	7	9	14	11	0.76
Class 2 species							
Maranthes chrysophylla	Kajabiri	Chrysobalanaceae	4	1	2	1.6	0.24
Trichilia prieuriana	Kakadikuro	Meliaceae	4	1	2	1.6	0.24
Celtis wightii	Esafufuo/Prempresa	Ulmaceae	4	1.5	3.5	2.8	0.43
Blighia sapida	Akye	Spindaceae	7	1	7	3.6	0.99
Cola gigantia	Watapuo	Sterculiaceae	21	1	8	3.8	0.47
Lonchocarpus sericeus	Sante	Papilionaceae	23	1.5	10	5.2	0.55
Ficus exasperata	Nyankyerene	Moraceae	19	4	14	7.1	0.63
Blighia unijugata	Akyebiri	Spindaceae	29	2	18	8.9	0.74
Ficu sur	Nwadua/Domini	Moraceae	3	10	14	12.7	1.33
Steculia tragacantha	Sofo	Sterculiaceae	20	7	20	13.5	0.96
Class 3 species							
Newbouldia laevis	Sesemasa	Bignoniaceae	3	2	5	3.3	0.88
Ravolfia vomitoria	Kakapenpen	Apocynaceae	10	1.5	9	4.2	0.80
Greenwayodendron oliveri	Duabiri	Annonaceae	7	1	9	4.3	1.49
Lecaniodicus cupanioides	Dwindwera	Sapindaceae	9	2	9	4.9	0.77
Tricalysia discolor	Kwaekofi	Rubiaceae	13	1	9	5.1	0.58
Solanum erianthrum	Pepediawuo	Solanaceae	4	5	7	5.8	0.48
Mallotus oppositifolius	Anyanyanforowa	Euphorbiaceae	24	4	15	8.2	0.76
Spathodea campanulata	Akuakuo-ninsuo	Bignoniaceae	2	10	11	10.5	0.50

APPENDIX 2: HEIGHT INCREMENT OF UNRELEASED TREE SEEDLINGS IN THE DEGRADED AREA THREE MONTHS AFTER THE RELEASE TREATMENT.

Species	Common name	Family	n	Height growth (cm)		Mean	SE
				Min.	Max.		
Class 1 species							
Steculia rhinopetala	Wawabima	Sterculiaceae	3	0.5	1	0.7	0.17
Celtis zenkeri	Esakoko	Ulmaceae	2	0.5	1	0.8	0.25
Afzelia africana	Papao	Caesalpinaceae	4	1	2	1.5	0.29
Albizia zygia	Okoro	Mimisaceae	6	1	2	1.5	0.22
Piptadenistrum africanum	Dahoma	Mimosaceae	6	1	2	1.5	0.22
Ceiba pentandra	Onyina	Bombaceae	7	0	3	1.6	0.48
Tripochiton sclerozylon	Wawa	Sterculiaceae	6	1	2	1.7	0.21
Nesorgodonia papaverifera	Danta	Sterculiaceae	19	0	5	2.0	0.33
Milicia exelsa	Odum	Moraceae	7	0	6	2.4	0.90
Antiaris toxicaria	Kyenkyen	Moraceae	10	0	5	2.6	0.56
Class 2 species							
Blighia sapida	Akye	Spindaceae	2	1	1	1.0	0
Cola gigantia	Watapuo	Sterculiaceae	6	0	2	1.0	0.26
Celtis wightii	Esafufuo/Prempresa	Ulmaceae	6	1	2	1.3	0.21
Blighia unijugata	Akyebiri	Spindaceae	29	0	7	2	0.4
Ficus exasperata	Nyankyerene	Moraceae	21	0	11	2.1	0.56
Maranthes chrysophylla	Kajabiri	Chrysobalanaceae	21	0	9	2.6	0.58
Trichilia prieuriana	Kakadikuro	Meliaceae	19	0	11	2.6	0.60
Steculia tragacantha	Sofo	Sterculiaceae	6	0	5	3.0	0.73
Lonchocarpus sericeus	Sante	Papilionaceae	6	0.5	5	3.1	0.66
Ficu sur	Nwadua/Domini	Moraceae	2	3	4	3.5	0.50
Class 3 species							
Greenwayodendron oliveri	Duabiri	Annonaceae	8	0	2	0.6	0.26
Solanum erianthrum	Pepediawuo	Solanaceae	2	0.5	1	0.8	0.25
Tricalysia discolor	Kwaekofi	Rubiaceae	2	1	1	1.0	0
Spathodea campanulata	Akuakuo-ninsuo	Bignoniaceae	3	0.5	2	1.2	0.44
Ravolfia vomitoria	Kakapenpen	Apocynaceae	20	0	7	2	0.43
Lecaniodicus cupanioides	Dwindwera	Sapindaceae	6	0	4	2.3	0.67
Mallotus oppositifolius	Anyanyanforowa	Euphorbiaceae	10	0	9	2.7	0.84
Newbouldia laevis	Sesemasa	Bignoniaceae	2	4	5	4.5	0.50

APPENDIX 3: INCREASE IN NUMBER OF LEAVES PER SEEDLING OF RELEASED TREE SEEDLINGS IN THE DEGRADED AREA THREE MONTHS AFTER THE RELEASE TREATMENT.

Species	Common name	Family	n	Number of leaves		Mean	SE
				Min.	Max.		
Class 1 species							
Celtis zenkeri	Esakoko	Ulmaceae	4	1	2	1.5	0.29
Piptadenistrum africanum	Dahoma	Mimosaceae	5	1	2	1.6	0.24
Steculia rhinopetala	Wawabima	Sterculiaceae	4	2	4	2.8	0.48
Albizia zygia	Okoro	Mimisaceae	7	1	6	3.0	0.79
Nesorgodonia papaverifera	Danta	Sterculiaceae	11	1	7	3.9	0.69
Antiaris toxicaria	Kyenkyen	Moraceae	7	1	6	4.1	0.67
Ceiba pentandra	Onyina	Bombaceae	8	2	8	4.5	0.73
Tripochiton sclerozylon	Wawa	Sterculiaceae	9	4	6	4.8	0.22
Afzelia africana	Papao	Caesalpinaceae	2	2	6	5.5	0.50
Milicia exelsa	Odum	Moraceae	10	4	8	5.8	0.51
Class 2 species							
Trichilia prieuriana	Kakadikuro	Meliaceae	4	1	2	1.5	0.29
Maranthes chrysophylla	Kajabiri	Chrysobalanaceae	4	1	3	1.8	0.48
Cola gigantia	Watapuo	Sterculiaceae	21	1	4	1.9	0.18
Blighia sapida	Akye	Spindaceae	7	2	5	3.1	0.51
Celtis wightii	Esafufuo/Prempresa	Ulmaceae	4	1	4	3.3	0.71
Blighia unijugata	Akyebiri	Spindaceae	29	1	11	3.8	0.41
Ficus exasperata	Nyankyerene	Moraceae	19	2	8	4.2	0.53
Lonchocarpus sericeus	Sante	Papilionaceae	23	1	10	4.5	0.57
Ficu sur	Nwadua/Domini	Moraceae	3	6	8	7.0	0.58
Steculia tragacantha	Sofo	Sterculiaceae	20	2	14	7.2	0.50
Class 3 species							
Newbouldia laevis	Sesemasa	Bignoniaceae	3	1	3	1.7	0.67
Ravolfia vomitoria	Kakapenpen	Apocynaceae	10	1	6	2.4	0.45
Solanum erianthrum	Pepediawuo	Solanaceae	4	2	4	2.6	0.48
Lecaniodicus cupanioides	Dwindwera	Sapindaceae	9	1	6	3.4	0.53
Tricalysia discolor	Kwaekofi	Rubiaceae	13	1	7	4.2	0.51
Greenwayodendron oliveri	Duabiri	Annonaceae	7	3	8	5.1	0.91
Spathodea campanulata	Akuakuo-ninsuo	Bignoniaceae	2	1	7	6.0	0.99
Mallotus oppositifolius	Anyanyanforowa	Euphorbiaceae	24	2	13	7.6	0.83

APPENDIX 4: INCREASE IN NUMBER OF LEAVES PER SEEDLING OF UNRELEASED TREE SEEDLINGS IN THE DEGRADED AREA THREE MONTHS AFTER THE RELEASE TREATMENT.

Species	Common name	Family	n	Number of leaves Min.	Number of leaves Max.	Mean	SE
Class 1 species							
Celtis zenkeri	Esakoko	Ulmaceae	2	0	0	0.0	0
Piptadenistrum africanum	Dahoma	Mimosaceae	6	0	1	0.7	0.21
Steculia rhinopetala	Wawabima	Sterculiaceae	3	0	1	0.7	0.33
Tripochiton sclerozylon	Wawa	Sterculiaceae	6	1	2	1.2	0.17
Nesorgodonia papaverifera	Danta	Sterculiaceae	19	0	10	1.4	0.51
Ceiba pentandra	Onyina	Bombaceae	7	0	4	1.4	0.69
Milicia exelsa	Odum	Moraceae	7	0	4	1.6	0.69
Albizia zygia	Okoro	Mimisaceae	6	1	3	1.7	0.42
Afzelia africana	Papao	Caesalpinaceae	4	1	2	1.8	0.25
Antiaris toxicaria	Kyenkyen	Moraceae	10	2	5	2.7	0.37
Class 2 species							
Celtis wightii	Esafufuo/Prempresa	Ulmaceae	6	0	2	0.7	0.33
Steculia tragacantha	Sofo	Sterculiaceae	6	0	5	0.7	0.33
Cola gigantia	Watapuo	Sterculiaceae	6	0	2	1.0	0.25
Blighia unijugata	Akyebiri	Spindaceae	29	0	3	1.1	0.18
Ficus exasperata	Nyankyerene	Moraceae	21	0	5	1.1	0.24
Maranthes chrysophylla	Kajabiri	Chrysobalanaceae	21	0	4	1.3	0.26
Blighia sapida	Akye	Spindaceae	2	1	2	1.5	0.50
Trichilia prieuriana	Kakadikuro	Meliaceae	19	0	7	1.8	0.41
Lonchocarpus sericeus	Sante	Papilionaceae	6	2	4	2.8	0.31
Ficu sur	Nwadua/Domini	Moraceae	2	2	3	3.0	0.50
Class 3 species							
Greenwayodendron oliveri	Duabiri	Annonaceae	8	0	1	0.3	0.16
Spathodea campanulata	Akuakuo-ninsuo	Bignoniaceae	3	0	1	0.7	0.33
Solanum erianthrum	Pepediawuo	Solanaceae	2	1	1	1.0	0
Tricalysia discolor	Kwaekofi	Rubiaceae	2	1	1	1.0	0
Ravolfia vomitoria	Kakapenpen	Apocynaceae	20	0	5	1.2	0.26
Mallotus oppositifolius	Anyanyanforowa	Euphorbiaceae	10	0	4	1.6	0.50
Lecaniodicus cupanioides	Dwindwera	Sapindaceae	6	0	4	2.2	0.70
Newbouldia laevis	Sesemasa	Bignoniaceae	2	2	3	2.5	0.50

APPENDIX 5: MORTALITY (%) OF UNRELEASED TREE SEEDLINGS IN THE DEGRADED AREA THREE MONTHS AFTER THE RELEASE TREATMENT. NO MORTALITY WAS OBSERVED IN THE RELEASED PLOTS.

Species	Common name	Family	Seedlings			% Mortality
			Initial	Final	Mortality	
Class 1 species						
Celtis zenkeri	Esakoko	Ulmaceae	2	2	0	0
Nesorgodonia papaverifera	Danta	Sterculiaceae	22	19	3	13.6
Piptadenistrum africanum	Dahoma	Mimosaceae	7	6	1	14.3
Milicia exelsa	Odum	Moraceae	9	7	2	22.2
Ceiba pentandra	Onyina	Bombaceae	10	7	3	30
Afzelia africana	Papao	Caesalpinaceae	6	4	2	33.3
Tripochiton sclerozylon	Wawa	Sterculiaceae	9	6	3	33.3
Antiaris toxicaria	Kyenkyen	Moraceae	16	10	6	37.5
Steculia rhinopetala	Wawabima	Sterculiaceae	5	3	2	40
Albizia zygia	Okoro	Mimisaceae	11	6	5	45.5
Class 2 species						
Blighia sapida	Akye	Spindaceae	2	2	0	0
Celtis wightii	Esafufuo/Prempresa	Ulmaceae	6	6	0	0
Cola gigantia	Watapuo	Sterculiaceae	6	6	0	0
Steculia tragacantha	Sofo	Sterculiaceae	6	6	0	0
Blighia unijugata	Akyebiri	Spindaceae	31	29	2	6.5
Trichilia prieuriana	Kakadikuro	Meliaceae	21	19	2	9.5
Lonchocarpus sericeus	Sante	Papilionaceae	7	6	1	14.3
Maranthes chrysophylla	Kajabiri	Chrysobalanaceae	25	21	4	16
Ficus exasperata	Nyankyerene	Moraceae	27	21	6	22.2
Ficu sur	Nwamdua/Domini	Moraceae	3	2	1	33.3
Class 3 species						
Lecaniodicus cupanioides	Dwindwera	Sapindaceae	6	6	0	0
Newbouldia laevis	Sesemasa	Bignoniaceae	2	2	0	0
Solanum erianthrum	Pepediawuo	Solanaceae	2	2	0	0
Spathodea campanulata	Akuakuo-ninsuo	Bignoniaceae	3	3	0	0
Tricalysia discolor	Kwaekofi	Rubiaceae	2	2	0	0
Ravolfia vomitoria	Kakapenpen	Apocynaceae	22	20	2	9.1
Greenwayodendron oliveri	Duabiri	Annonaceae	9	8	1	11.1
Mallotus oppositifolius	Anyanyanforowa	Euphorbiaceae	12	10	2	16.7