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COLLEGE OF SCIENCE

COMMUNITY DIVERSITY, STRUCTURE AND NATURAL REGENERATION OF TREES IN TROPICAL FOREST: EFFECTS OF HUMAN DISTURBANCE

A THESIS SUBMITTED TO THE DEPARTMENT OF ENVIRONMENTAL SCIENCE IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF THE MASTER OF SCIENCE (MSC.) DEGREE IN ENVIRONMENTAL SCIENCE

BY

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DECLARATION

I hereby declare that this submission is my own work towards the MSc. and that, to the best of my knowledge, it contains neither material previously published by another person nor material which has been accepted for the award of any other Degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

The study was undertaken to determine community diversity, structure and natural regeneration of trees in tropical forest: effects of human disturbance at Terchire (Teekyere) in the Brong Ahafo Region of Ghana. Based on the intensity of human disturbance, the study area was stratified into three sites namely heavily disturbed forest (HDF), intermediately disturbed forest (IDF) and a reference forest (RF) to serve as a control. Data was collected between the months of November and December 2010.

A total of 49 tree species belonging to 21 families and containing 532 individual adult trees were recorded in the three sites studied. Tree abundance was highest in the intermediately Disturbed forest (IDF) whiles Species richness was comparable to the IDF and the RF. Considering the high Tree abundance and species Riches in the IDF, it indicates that IDF can help maintain plant diversity. Though both the heavily disturbed forest and intermediately disturbed forests have experienced disturbance, the species richness of the former was similar to that of the Reference forest. This supports the intermediate disturbance hypothesis on species diversity. Species richness of both seedling and sapling also showed the same trend in the reference forest. The step-wise multiple regression analysis also revealed that the soil parameters analyzed showed high percentage of variation in the seedlings and saplings structure except for species richness that has very low percentage. Effective Cation Exchange capacity (ECEC) indicated the overall fertility of the soil which affects the structure of seedlings and saplings. From The study it is evident that different levels of human disturbance had varying effects on tree species, regenerating capacity, diversity, and structure.

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CHAPTER ONE

1.0 Introduction

Forest disturbance can alter environmental conditions by changing light availability and soil conditions (Fredericksen and Mostacedo, 2000). Disturbance also influences processes that can either augment or erode the ecological functions of a forest community (Sagar *et al*., 2003). Both natural and human disturbances influence forest dynamics and tree diversity at local and regional scales (Hong *et al*., 1995; Hubbell *et al*., 1999; Sheil, 1999; Ramirez-Marcial *et al*., 2001). However, the biology of specific species (such as their life history traits, physiology and behavior) also influences post-disturbance forest regeneration (Lawes *et al*., 2007). Understanding tropical forest succession is critical for the development of tropical forest conservation strategies worldwide, given that tropical secondary forests can be considered the forests of the future (Wright, 2005; Sanchez-Azofeifa *et al.*, 2005).

Past and present rates of tropical land conversion clearly indicate that most mature tropical forests will eventually disappear leaving behind a complex landscape consisting of a matrix of agricultural fields and forest patches under different levels of succession. Generally, post-disturbance changes in regeneration, dominance and diversity of forested species are related to characteristics of the overall disturbance regime, including the intensity, frequency and scale of disturbances (Kennard, 2002; Mori and Takeda, 2004; Zhu *et al*., 2007). Frequently, however individual disturbance factors (e.g., selective logging) have been highlighted in attempts to explain the structural attributes of forests (Vetaas, 1997; Nagaike *et al*., 1999; Ramirez-Marcial *et al*., 2001; Sapkota *et al*., 2009). Despite multiple factors simultaneously altering ecosystem functioning, frequent and fluctuating disturbance factors (e.g., grazing, browsing, fuel-wood and fodder collection) have often been overlooked in explanations of post disturbance changes in forest ecosystems. Connell (1978) highlighted the spatio-temporal fluctuations observed in disturbance e.g., 'type' and 'intensity' of disturbance. He linked community richness with 'time since', 'frequency of' and 'size of' disturbance and proposed that disturbance of moderate intensity may support species diversity. Excessive disturbance leads to the loss of late-successional species, whereas too little leads to competitive exclusion of species adapted to colonize sites immediately following a disturbance. Therefore, an intermediate disturbance regime enables species to co-exist (Molino and Sabatier, 2001; Sheil and Burslem, 2003).

The need to understand how forest communities regenerate after human disturbances and how the species behave in the successional process of colonization of these areas is very important for degraded area recovery projects. The successful regeneration of a tree species is dependent on its ability to produce large number of seedlings as well as the ability of these seedlings and saplings to survive and grow. However, the presence of sufficient numbers of seedlings, saplings and young trees is greatly influenced by the interaction of biotic and abiotic factors in the environment (Harper *et al.*, 1965).

Furthermore, it should be pointed out that forest fragments close to the degraded areas are important sources of seeds and are therefore definers of the floristic composition and natural regeneration structure. Thus these fragments should be preserved and monitored in the planning of actions to exploit natural resources (Rodrigues and Gandolfi, 2000). The transformation of forest lands by human actions represents one of the great forces in global environmental change and one of the great drivers of biodiversity loss. Forest is cleared degraded and fragmented by timber harvest, conversion to agriculture, road-building, etc. causing a permanent loss of the forest cover and its transformation into another land use. Land degradation is becoming one of the severest environmental issues in the world especially in developing nations. It is usually accompanied by soil erosion which always results in decrease or complete loss of land productivity and produces onsite and off-site pollution to soil and water. Regeneration is a critical phase of forest management due to the fact that it is responsible for maintaining the desired species composition and stocking following a disturbance. Therefore, monitoring of regeneration should be made an integral part after a disturbance hence the need to examine the patterns of tree regeneration species in a disturbed area. The success of tree regeneration is determined by successful completion of several events in the tree life cycle such as seed production and dispersal to safe sites, germination and seedling emergence, establishment and onward growth. Seed production may be limited by various extrinsic factors such as resource availability, pollination failure, predation on flowers, fruits and leaves, and by climatic conditions, as well as by intrinsic factors such as age and size of the plant, and its genetic constitution (Dalling *et al.,* 1997).

The pattern of seed production differ among populations of the same species that are adapted to different microhabitats and individual trees within a population also vary enormously in the size of their fruit crop. Seed production among a population also varies due to differences in both the number of fruiting individuals and the number of seeds produced per reproductive individual. The interplay between seed predation and dispersal is an important determinant of seed establishment. Environmental factors such as nutrients, moisture, sunlight, wind, temperature, soil characteristics and certain plant and animal species can have an effect on tree reproduction.

1.1 Justification

Regeneration is a critical phase of forest management due to the fact that it is responsible for maintaining the desired species composition and stocking following a disturbance. Therefore knowledge of the community diversity, structure and natural regeneration of the study is critical in this direction. However, little is known about factors affecting plant communities and their regeneration in tropical forests. Ecological data obtained in this regard would be useful for the application of sound management practices in the forest. This study was therefore, carried out to determine community diversity structure and natural regeneration of trees in tropical forest in relation to the effects of humans disturbances.

1.2 Objectives

The main objective of this study was to determine the diversity, structure and regeneration capacity of Newmont forest in relation to human disturbance.

The specific objectives of this study are:

- To identify tree species in the forest types,
- To identify seedlings and saplings of tree species in the forest types,
- To determine the abundance of tree species in the forest types,
- To determine the abundance of seedlings/saplings in the forest types,
- To determine the structure of seedlings and saplings in the forest types, and
- To determine soil physicochemical properties which affect seedling and saplings in the forest types.

CHAPTER TWO

2.0 Literature Review

Botanical assessments such as floristic composition and structure studies are essential in view of their value in understanding the extent of plant biodiversity in forest ecosystems [World Conservation Monitoring Centre (WCMC), 1992]. Knowledge of floristic composition and structure of forest reserves is also useful in identifying important elements of plant diversity, protecting threatened and economic species, and monitoring the state of reserves, among others (Tilman, 1988; Segawa and Nkuutu, 2006). Thus, the study of floristic composition and structure of tropical forest becomes more imperative in the face of the ever increasing threat to the forest ecosystem. Studies have shown that composition and structure of forests are influenced by a number of factors (Klinge *et al.*, 1995; Haugaasen *et al.*, 2003; Wittmann and Junk, 2003).

Prominent among these factors are disturbances which are thought to be key aspects, and the cause of local species variation within forests based on their intensity, scale and frequency (Hill and Curran, 2003; Laidlaw *et al.*, 2007). Disturbances can alter the successional pattern and subsequent composition, diversity, and structure of the forest (Doyle, 1981; Busing, 1995). Logging which has immediate and direct effects on composition and structure also creates canopy openings which may cause regeneration problems, especially in exposed conditions where soils dry out rapidly and nutrient loss through run-off becomes common (Parthasarathy, 2001). Canopy openings readily support the growth of invasive weeds and other herbaceous plants which usually interfere with regeneration and impede recovery of trees and shrubs (Epp, 1987; Hawthorne, 1993, 1994; Madoffe *et al.*, 2006).

Invasive weeds threaten biodiversity by displacing native species and disrupting community structure (Parker *et al.*, 1999; Richardson *et al.*, 2000; Sala *et al.*, 2000; Stein *et al.*, 2000). Soil water availability is also considered a key factor for the regeneration, survival and growth of seedling communities (Lieberman and Lieberman, 1984; Ceccon *et al.*, 2002). Light conditions influence regeneration pathways strongly (Haugaasen *et al.*, 2003) and ultimately affect the composition and structure of forest. It has been reported that light limitation alone may prevent seedling survival regardless of other resource levels (Tilman, 1982). Flooding as a limiting factor influences seedling and sapling species distribution, and establishment (Klinge *et al.*, 1995; Wittmann and Junk, 2003), probably as a result of physiological stress from highly anoxic conditions, as well as physical flood disturbance (Haugaasen and Peres, 2006).

2.1 Forest Disturbance

The forest canopy is a mosaic of gaps, patches of juvenile trees in former gaps and mature forests (Whitmore, 1986). The effect of different types of disturbance on rainforest will depend on the disturbance regime within which it has evolved. Disturbance which is unusual to a particular forest type will have a far greater impact than that which falls within the usual disturbance regime (Hopkins, 1981). Base on the intensity of disturbance,Webb, (1977) classified them into three grops: large scale Dissturbance which maybe due to natural or man-made; cyclones, landslips, volcanic activity, tectonic plate movement, flooding,wildfires and logging, especially clear-felling regimes. The size of the disturbance can be from several hectares to several hundred hectares or up to many square kilometers (Webb, 1977). Medium scale disturbance which covers an area from 5 square kilometers to approximately 10 hectares. Logging roadways through rainforest, windthrows, and downdraughts associated with cyclones, local landslips and small firesmay cause this scale of disturbance and Small Scale Disturbance which is usually the result of falling branches of a single tree or the death of a single tree (Webb, 1977).

2.2 Regeneration and Succession

Succession is the process through which regeneration is achieved. Succession expresses the differences in colonising ability, growth and survival of organisms adapted to a particular set of conditions on an environmental gradient (Smith, 1980). The replacement of one of several species or groups of species by others results from interspecific competition and the interaction of herbivores, predators and disease.

The nature of succession in a given area will depend on seed availability, conditions for germination and liberation of suppressed saplings in relation to fortuitous formation of canopy gaps, changes in microclimate and predation (Webb and Tracey, 1981).

Hopkins *et al.*, 1977; divided the species of humid subtropical rainforest into four major groups, describing their survival strategies and their role in the successional process.Pioneer Species which is Short lived, shade tolerant perenniials that grow up to eight meters high. They begin the regeneration process in areas of medium to large scale disturbance. Examples are *Rubus rosifolius* and the naturalised *Solanum mauritianum.* The second type is Early Secondary Species which require environmental modification to predominate and form a closed canopy. They are fast growing perennial trees (10-25 m high) living for 15-50 years. Examples are *Euodia micrococca* and *Alphitonia excelsa.*The third type is late secondary which has mature phase species with a canopy present. These are more favouured by the altered conditions. Examples of species are *Brachychiton acerifolium* and *Diploglottis*, The 'tolerance' model allows for any species present before disturbance to be able to colonise the area after the disturbance. This model is commonly used to describe succession in small gaps. Opportunistic species often exploit the changed environment first, but not in every case in this model. They do not provide for more advantageous condition for later species. Later species will only grow if they can tolerate lesser levels of resources. As in the facilitation model, the successional end point is reached when the most shade tolerant species occupy and retain the site (Smith, 1980). Delayed or arrested succession is described by the 'inhibition' model. Here , early colonists prevent the invasion of subsequent colonists or suppress growth of already exsisting species. This is often the case when trees and shrubs have few seeds or propagules in the soil. Succession may proceed at a later date if the dominant pioneer species is destroyed or damaged by herbivores, fires, pathogens or herbicides (Hopkins *et al.*, 1977).

2.3 Outcomes of Successional Process

2.3.1 Restoration of the Original Community

Following disturbance, secondary succession eventually restores the original community. Webb and Tracey (1981) emphasise that disturbance must not be too extensive or too frequently repeated, and disturbed areas should be able to maintain patchiness in space and variety of serial stages in time to allow for the total display of all species available. Adequate seed sources of the original community must remain available, either stored in the soil or dispersed from adjacent living plants. Deflected Community occurs where partial intermittent destruction is accompanied by environmental changes persistently unfavourable for the return of the original community (Webb and Tracey, 1981). Hybrid Community In which destruction is more complete and sustained, so that some environmental changes become permanently unfavourable and seed sources become more limited. The disturbed area is colonised by pioneer species. Gradually with sloaw changes in local climatic and soil conditions, the original community becomes fragmentary and relict (Webb and Tracey, 1981). New Community Complete destruction of the original community and its seed sources takes place and there are many changes in the physical environment. The site is colonised by a new community depending on the proximity of seed sources of other community types and few of the original species are able to adapt and survive in competition with them.The process of succession stops (unless delayed or arrested) when the climax stage is reached. This is the point where the community is stable and self-replicating and barring disturbances will persist indefinately (Smith, 1980). Community restoration can take up to 800 years after a widespread disturbance (Hopkins *et al.,* 1977).

2.3.2 Role of Pollinators in Flowering and Fruiting

Plants with a large flower crop tend to be pollinated by large unspecialized pollinators, for example, birds, bats and moths, and tend to flower in synchrony over a short period (Pomeroy and Service, 1986). Bawa and Krugman (1986) have suggested that pollinators probably switch from one species to another as the floral resources of one species decline and that of the other increase.

An alternative strategy is to produce a few flowers at a time over a long period, for pollination by specific animal species. Theses pollinators tend to be birds, butterflies, large moths or large bees (Pomeroy and Service, 1986).

Loss of food resources for pollinators or removal of that pollinator from the community may influence pollinator guilds and consequently plant guilds that depend upon these pollinators (Bawa and Krugman, 1986). Management strategies require an understanding of pollination modes and the extent to which various plant species are dependent upon particular pollinators. Unfortunately, very little is known about pollination biology in tropical or subtropical forests.

2.4 Reproduction

Four processes interact to generate the seed 'shadow' that finally produces a seedling 'shadow', namely, seed production, predation, dispersal and dormancy (Janzen and Vasquez-Yanes, 1986). There is a great variation in these mechanisms from pioneer to mature phase species.

2.4.1 Seed Production

Seed production by pioneer species and early secondary species occurs regularly. Large numbers of well dispersed seeds have long viability and comprise the majority of seeds in the seed bank just below the soil surface. Tree species differ in the quantity and frequency of seed production (Richards, 1996). Some species produce seeds regularly whiles others produce seeds irregularly. Sometimes empty seeds are formed (Albrecht, 1993). A large proportion of seeds reaching the ground are dispersed by seed predators like insects and small animals (Janzen, 1970). Seeds may also become infected by fungi (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 agents to form a seed bank (Richards, 1996). Tree species may also enhance survival by producing abundant seeds at long and regular intervals.

Late secondary species fruit most years with seed viability mostly limited to several months, although some species can survive up to two years (Hopkins and Graham, 1984). Mature phase species are characterized by infrequent gregarious flowerings which produce massive quantities of fruit (Hopkins, 1975). Seeds are of a short lifespan, surviving from several weeks to several months. The time intervals between these large fruiting is usually greater than three years. In the intervening periods, many individuals sporadically produce smaller quantities of fruit. Such gregarious flowering and fruiting appears to be general among rainforest tree species. (Hopkins, 1975). During periods of gregarious fruiting, seed predation can be high. The soil seed bank, according to Janzen and Vasquez-Yanes (1986) contains representatives of only a tiny fraction of the species of trees in tropical and subtropical forests. The seeds are in haphazard proportions having little to do with any forest structure. Hence dispersal agents are essential links in the establishment of seed shadows.

2.4.2 Seed Predation

Seed predation shows no particular pattern. It can vary markedly from year to year, tree to tree and habitat to habitat. Different species have different susceptibilities to different seed predators (Janzen and Vasquez-Yanes, 1986). Mammals and insects are the main seed predators in humid subtropical rainforest. Evidence does show that animal predation directly affects the survival and pattern of distribution of seedlings of particular rainforest species (Janzen, 1971; Wilson and Janzen, 1972, in Hopkins 1975). Hopkins (1975) feels that there is little doubt that damage by plant predators and parasites, whether animal, fungi, bacterial or viral, can be a controlling factor affecting the establishment and survival of plants.

2.4.3 Seed Dispersal

Seed dispersal is an integral part of successional and regenerative processes in tropical ecosystems (Hardwick *et al.,* 2004). Early successional areas lacking nuclear trees most frequently are colonized by wind dispersed species (Janzen, 1988). Successful colonization by particular species within early successional areas depends not only on many microclimatic factors (Holl, 1999), but also on species' ability to disperse. The seed dispersal distances of tropical trees ranges from 10 m to 1000 m (Fox, 1973). Tropical trees disperse their seeds by means such as wind, birds, insects, and other animals. Wind dispersal is the most common in overstorey tree species (Richards, 1996).

Various agents act as seed dispersers. These include wind, water, gravity, birds, bats and other small mammals. Seed dispersal is an essential process in maintaining forest diversity and regenerating disturbed areas to the original forest structure. Seed dispersal also provides new inputs of genetic material into isolated remnant areas.

The main dispersal agents in subtropical areas are wind, birds and gravity (sometimes assisted by mammals). Water and bats have lesser roles but in particular areas, can be important contributors (Hopkins, 1975).

Wind dispersed species are: pioneer and early secondary species, taller canopy (Mature phase) species, vines, epiphytes, orchids and ferns. These species have a distinct advantage in medium-large gaps where animal dispersal is diminished. Wind dispersal may move offspring away from an infected parent tree or from soils infected by pathogens. In this way it may reduce the mortality of subsequent seedling during establishment stages. Janzen (1970) believed that the wind dispersal of seeds was the reason for widely scattered distribution of many species features of the tropical trees. The ability of most species to disperse is more limited than generally realized, so dispersal can limit colonization (Fuller and Del Moral, 2003). Isolation favors colonization by species with small, buoyant seeds. If the seed rain is sparse, then chance plays a role in species assembly and alternative compositions in similar habitats can develop (McEuen and Curran, 2004; Svenning and Wright, 2005).

Birds are attracted to certain colors of fruit. Blue-black and black-red are favored over red (Floyd, 1976). Fruit eating birds can be divided into opportunists and specialists, fruits devoured by opportunists are usually small (5-10 mm), many-seeded, often showy and usually juicy. Large fruits attract specialists, and contain few or single seeds. These fruits typify pioneer and climax species respectively (Whitmore, 1983). This situation has implications for isolated communities where specialist migratory birds are needed for seed dispersal. Seed dispersal by animals often involves enrichment of the seed by the animal to increase its ability to germinate and also leaching of germination inhibitors.

Sites that have been severely damaged often have a depleted seed bank with little chance of replenishment. Landscape permeability, that feature which resists or promotes dispersal, varies greatly. Some habitats are impermeable to some species, but not to others. Barriers and inhospitable habitats reduce permeability and therefore can limit the diversity of functional types that reach a site unaided. Restoration activities can eliminate dispersal problems by planting most species expected in the community. This is rarely successful because residual species resist the newly planted species and swarms of invading alien species can overwhelm the site. Many species that could be effective in a particular project, even though they may not be present in local examples of the target vegetation, are valid candidates for planting.

2.4.4 Seed Dormancy and Germination

Seeds of subtropical plants have variable dormancy periods. Germination may occur quickly when the seed is moistened or delayed until the hard seed coat is broken down. Bird ingestion and excretion can accelerate the germination process by several months, as in the case of *Cryptocarya glaucescens* (three months if ingested; six months if not). Many of the short-lived fast growing early secondary species have hard seed coats, which remain buried in the soil for many years (Floyd, 1976).

In subtropical rainforests with a definite dry season, seeds may remain dormant if the fruits mature in the dry season. Once the rainy season begins, germination commences (Janzen and Vasquez-Yanes, 1986).

Strocker (1988) examined the role between fruiting, seed predation and germination in shade-tolerant species. He felt that with the favorable establishment environment for shade-tolerant species and the effects of predation on large seeds of this group, immediate rather than delayed germination has evolved. Water; oxygen and temperature are the key factor controlling tree seed germination in the tropics (Swaine *et al.,* 1997). Seed of most tropical trees germinate immediately after dispersal if they land on moist soils (Swaine *et al.,* 1997). Room (1973) found that seed germination, establishment and growth of seedling were more successful in full sunlight than in shade. Seed dormancy for tropical tree species, which is rare, is often resulted by lack of suitable conditions for germination (Swaine *et al.*, 1997).

2.5 Seedling Reservoir and Mortality

The abundance of tree seedlings depends on micro-site conditions, disturbances and the availability of viable seeds (Richards, 1996). The rate of growth and pattern of tree seedlings depend on the micro-environmental condition including light, temperature and moisture (Kwasiga *et al.*, 1986). Seed mortality as well as seed bank and seedling reservoir must be considered if one wants a good picture of the regeneration potential of an area. Not every seedling survives and grows to a matured tree. Mortality can result by many factors including inability to compete with weeds and attack by pathogens (Ashton, 1990; Richards, 1996). Seedlings vary in their vulnerability to specific pathogens (Burdon and Chilvers, 1976) but their vulnerability decreases as their cell wall thickens and lignifies (Walker, 1969). Mortality is high for seedling of shade intolerant species when they grow under canopy of competing species (Richards, 1996). Seedling mortality is particularly high in the early stages, so that species composition is often determined during the juvenile stage (Swaine and Hall, 1988).

2.6 Tropical Forest Resources of Ghana

The total area of Ghana is divided into two main ecological zones; high forest zone and the savanna zone. The high forest zone is found in the south-western part of the country extending northwards to reach the evergreen areas of Ashanti region and western parts of Brong-Ahafo region (FAO, 2005a). The remaining land represents the savanna zone and the transition zone where the high forest zone and savanna zone converge. The high forest zone is further divided into Wet Evergreen forest, Moist Evergreen forest, Moist Semi-Deciduous and Dry Semi -Deciduous forest. The high forest zone is noted for commercial logging. More desirable timber species can be found in the drier Semi-Deciduous zones. The tropical forest of Ghana contains a countless number of resources that perform economic, ecological, social and cultural functions. The resources include many varieties of trees, herbs, shrubs, many invertebrates, insects, birds, mammals, amphibians and reptiles. Ghana's forest soils are also home to minerals, nutrients and micro-organisms.

Ghana's high forest contains approximately 2100 species of trees shrubs and herbs. Trees found in the forest of Ghana include; Triplochiton scleroxylon (Wawa), Mansonia altissima (Mansonia), Nesogordonia papaverifera (Danta) and Khaya ivorensis (Mahogany) (FAO, 2005b). Mineral elements such as Gold, Manganese etc. are found in some soils of Ghana's forest, together with nutrients such as Carbon (C), Nitrogen (N), Phosphorus (P), Potassium (K), and Calcium (Ca).

2.7 The Potential for Forest Based Livelihoods

Many of the world's poor depend directly on forests for sustenance. Timber and other forest products provide 350 million people living in or around tropical forests with 50 percent or more of their household needs and also directly providing 10 percent of jobs in developing countries.

The potential for the forest resources to support a wide range of forest-based livelihoods and to reduce poverty has been discussed in detail. These include income generation, employment and recreational opportunities, as well as providing support services for agriculture in the rural areas. The forests are also the source of a variety of foods that supplement and complement what rural households obtain from agriculture, and of a wide range of medicines and other products that contribute to health and hygiene.

2.8 Multiple use of Forest Lands

People have very different interests in tropical forests. Whilst some assert that forests are needed to store carbon, others are looking to carve off a piece of forests to convert into farm. Interests in forests range from those which are central to an individual's livelihood or a corporation's viability, to the opinions and aesthetic preferences of those who live far away from the forest. Interests in the forests may be backed by strong political influence, legal rights and resources, or by none of these. In many countries, forest management strategies have often concentrated on timber production to the detriment of non-timber forest benefits.

The result has been a gradual loss of cultural assets and knowledge and loss of livelihood of forest dependent groups, particularly poorer groups who depend on forests for their social security. Today, this trend can no longer be continued in forest management because we have moved from a time of natural resources abundance and a low population to a time of resource scarcity and a rapidly growing population. Getting forest management right is to manage the forest resources for multiple benefits to meet the demands and needs of the rapidly growing population on sustainable basis. Integrated natural forest management for multiple uses of natural forests therefore becomes important to the natural resource manager.

2.9 Concept of Multiple Uses of Forest Lands

Multiple use is the conscious and deliberate use of forest land for the concurrent production of more than one product or service (Gregory, 1955). Bernard (1960) defines it as the accommodation of maximum of other compatible uses with the highest single use of the forest land. The concept of multiple use as applied to forests is based on the recognition that a variety of goods and services can be produced from the same land, either simultaneously or serially, and that such management can greatly increase the net value of the forest. Multiple use management does not imply that all possible forest uses should occur in the same place at the same time. Forest In situations where potential conflict exists between incompatible uses, the forests could be zoned to avoid the conflicts. Examples of major management zones are Timber Production Zone, Plantation Development Zone, Fire Protection Zone, Water Resources Protection Zones, etc. Multiple use of forests begun in the United States (US) when recreational use of the national forests grew steadily during the pre-World War II years but never reached parity with timber production as an objective of forest management. The Forest Service adopted the multiple use concepts to manage the forest lands for several uses including grazing, wildlife, recreation and timber. The vehicle for the concept was the Multiple Use-Sustained Yield Act of 1960.

Through this act the US Congress directed that the national forests should be managed for outdoor recreation, range, timber, watershed protection, and wildlife and fish purposes. Accordingly, these five categories came to be known as multiple uses and the degree to which forestlands are managed for any one of these multiple uses depends on the goals of ownership (Guldin, 1990). However, the concept of multiple use of natural forests is not new in Ghana having been practiced by traditional communities who derived food, medicine, building materials, water, etc. from the forests. All natural forests are to some extent, potentially multiple use forests, as they yield a variety of products and services. The problem lies in assigning values to these potential uses in order to determine to what extent each of them should be planned for and encouraged when different uses compete with or enhance each other. Determining the optimal mix of differing uses on a single forest land requires that the costs and benefits of each be considered when designing management practices. Management problems can arise because multiple uses of the same forest area may also involve multiple users, multiple and conflicting management objectives, multiple time frames, and negative interactions among uses (Panayotou and Ashton, 1992). In devising a multiple use management plans for natural forests, several factors need to be considered. Knowledge concerning the ecology and economics of a forest is necessary, but not sufficient. Information about relevant institutions, customs, and political factors is equally important in assuring the overall success of multiple-use forest management (Panayotou and Ashton, 1992).

Thus multiple use forest management should be based on complete understanding of all the social, economic, political, environmental, and ecological parameters that are involved. In multiple use of natural forests water protection and biodiversity conservation functions of forests should also be given similar priority as other uses of the forests. Management objectives should indicate the desired ecological state the forest should attain and be maintained, for optimal benefits.

The right of access to the forest is an important requirement for multiple-use of forestlands. This important requirement needs to be addressed in policies affecting the natural resources. The 1994 Forest and Wildlife policy recognizes the need for multiple use of the forest resources and thus provides the platform for forest managers to develop and integrate management practices to derive multiple benefits from the forests.

2.10 Multiple-Use Potential of Forests in Ghana

Ghana's natural forests have the potential resources that could be managed to provide multiple benefits to both the Ghanaian populace and the international community. The Wildlife Protected Areas have tremendous potential for tourism. Some forest reserves have been managed and are still being managed to provide multiple benefits in this regard. Other potentials include waterfalls areas and monkey sanctuaries in the forest areas that could be managed to provide multiple uses. Multiple use of sacred groves has become possible in Ghana as a consequence of the relationship that local residents have with their environment.

An example is the establishment of a monkey sanctuary at Boabeng-Fiema in Brong-Ahafo Region. Themona monkey Cercopithecus mona and western black-and-white colobus Colobus polykomos are revered and protected. These species cannot be hunted, access to and use of their habitat is restricted and offences are dealt with by the traditional council (Nuhu, 1986). This harmonious relationship between the local residents and the environment has resulted in a stable ecosystem and an area of growing interest to national and international visitors alike as an ideal site for tourism. The distribution and strategic locations of the forests in Ghana enhance its potential to be used for multiple benefits.

The permanent protection areas consist largely of hill sanctuaries, but also include swamp sanctuaries, shelter belts, special biological protection areas, intact forest sanctuaries, provenance and fire protection areas. Of this area, 69% is inaccessible for logging (except at very high cost) and 16% is degraded. Only 15% (which is protected on grounds of genetic diversity) is well stocked and accessible (Kotey *et al.,* 1998). Hawthorne (1990) estimated that less than 1% of forest cover is found outside forest reserves, much of it in small, scattered patches in swamps and sacred groves. In view of this, certain forests present the opportunity to be managed for watershed protection, biodiversity conservation, erosion control, etc. The forests support a wide diversity of plant and animal species making it possible to derive multiple benefits from them. Most people living in and around forests rely on the forest resources for food, medicine, fuel, fodder, building materials and household items. To meet these needs will be to manage the forests on sustainable basis. Though the forest resources have great potential to be managed for multiple benefits, forest management strategies need to integrate these benefits on the same management unit. To be successful, multiple-use forest management requires sound judgment, an intimate knowledge of the resources being managed and the relationship between them, infinite patience in dealing with people (Edward, 1960), and a clearly defined property rights and security of tenure.

2.11 Benefits of Ghana's forest

2.11.1 Economic benefits

The forests of Ghana contain many valuable timber species and non-timber forest products, the exploitation of which has supported the economy considerably. The forestry sector has for many years been ranked the fourth most important foreign exchange earner for Ghana after minerals, cocoa and tourism. The sector contributes 11% of Ghana's foreign exchange earnings. The timber industry alone contributes 6% of Gross Domestic Product (GDP) and Provides employment to 104,000 persons and livelihood for about two million people (Appiah, 1998; Gene-Birikorang *et al.*, 2001). Wild meat, non woody forest products also constitute significantly to the economy. The contribution of the forest sector to tourism promotion has not been quantified, although it is believed to be quite important. Forest areas may also be managed for major products such as timber, poles, firewood, fodder, bamboo and rattan and minor products such as extractives (dyes, gums, latexes, oils, resins), and food (fruits, honey, nuts, spices, snails) as well as services such as water, recreation and tourism, erosion control, and protection against high and low temperatures.

2.11.2 Environment and Ecological Benefits

The forest and trees of Ghana are important environmentally and ecologically resources which provide valuable environmental services and help maintain local, regional and global natural ecosystem. Forest and trees protect watersheds from drying out, provide habitat for numerous flora and fauna and generally maintain biodiversity (Oduro, 2002). They retard soil loss and erosion especially in areas of high rainfall, and retain moisture in the soil, ensuring a gradual supply of water to streams and rivers. Trees outside forest areas also provide environmental services. For example, a shelterbelt of trees across farmlands protects the soil against the drying effects of winds. In Ghana most farmers leave trees on their farms to maintain soil fertility by preventing erosion of the topsoil and by recycling nutrients through litter fall (Oduro, 2002).

2.11.3 Social and Cultural Benefits

The forest of Ghana contributes significantly to both rural and urban life, providing food, medicine, building materials, cultural symbols, ritual, artifacts, sacred sites. In many parts of Ghana forest products also feature in many cultural practices and ceremonies. For example traditional stools are a symbol of the Asante chieftaincy (Oduro, 2002). They are usually curved with a particular sacred tree woods. Drums are also made from specific woods and skins of animals. For example duiker skin is widely sought after, for use in the production of local drums (Falconer, 1992a).

2.11.4 Forest Resources Potential for Forest-Based Livelihoods

2.11.5 Timber Resources

Timber resources play an indispensable role in the Ghanaian economy. According to Gene-Birikorang*et al.,* (2001) the forest industry in 1999 contributed approximately 470 billion cedis to the provisional estimate of nominal GDP of 20,580 billion cedis. In economic value terms, the report estimated the forest industry's contribution at 280 billion cedis. These figures do not include the contribution of illegal chainsaw activities. The industry also contributed approximately US$ 179 million (8%) to Ghana's foreign exchange earnings. The timber industry provides employment to 104,000 persons and 'livelihood for about 2 million people' (Appiah, 1998). The ability of the timber industry to continually contribute its quota to the socioeconomic development of any country however depends on the availability of timber resources in the forest and on efficient utilization of these timber resources. This calls for sustainable management of the forest resources. Sustainable timber production from the forest could provide employment, income and other livelihoods to the surrounding communities. This would be possible if logging companies employ labor from the surrounding communities during logging operations and also fulfill their social responsibility agreement as required by the Timber Utilisation Contract.

2.11.6 Non-Timber Forest Products

The interest in non-timber forest products (NTFPs) that has built up over recent decades in conservation and development circles has its origins in a number of propositions: NTFPs, and much more than timber, contribute in important ways to the livelihoods and welfare of populations living in and adjacent to forests; providing them with food, medicines, other material inputs, and a source of employment and income, particularly in hard times.

Exploitation of NTFPs is less ecologically destructive than timber harvesting and therefore provides a sounder basis for sustainable forest management. Increased commercial harvest of NTFPs adds to the perceived value of the tropical forest, at both local and national levels, thereby increasing the incentive to retain the forest resource, rather than conversion of the land for agriculture or livestock (Arnold and Ruiz-Perez, 1998). Valuations of forest sites indicate that the potential income from sustainable harvesting of certain NTFPs could be considerably higher than timber income as well as income from agricultural or plantation uses of the forest sites. This has led to initiatives to expand and provide markets for more locally produced NTFPs, in order to tap an increasing share of this apparent cornucopia of sustainably harvestable wealth in tropical forests (Arnold and Ruiz-Perez, 1998).

Trade in NTFPs is an important economic activity in all corners of the high forest zone in Ghana, involving a great number of people including gatherers, producers, and wholesale and retail traders, often operating within complex trading channels (Falconer, 1992a). Commonly traded NTFPs include: Foods (snails, bush meat, mushrooms, fruits and seeds), Spices Chewing sticks, Chewing sponge (made from the stems of forest climbers), Cola nut Charcoal/firewood, Medicines Canes used in building and to make baskets furniture and other products. Household goods (sponges, mortars, pestles, utensils, wooden trays and grinders, food wrapping leaves, and tool handles (Abbiw, 1990; Falconer, 1992a). These products supplement and complement what rural households obtain from agriculture, and also contribute to health and hygiene (Arnold and Ruiz Perez, 1998). There is also a group of NTFPs that are produced naturally by plants and emerges from injured tissues, such as exudates, viscous liquid compounds or others, and which are mainly for industrial use. These include essential oils, tannins and dyes, which are often obtainable only with the aid of chemical solvents or steam distillation (Parren and de Graaf, 1995). The opportunity exists for local communities to gather and sell these products to industries.

2.11.6.1 Medicine

Medicinal usage of NTFPs tends to overlap with that of forest foods; indeed particular items added to foods serve both to improve palatability and act as a health tonic or prophylactic. There are also strong links between medicinal use and cultural values. For example, where illnesses are thought to be due to the spirits, plants have acquired symbolic importance as treatments. Such values often underlie the division between use of traditional and modern medicines that is widely observed at the present time (Falconer, 1994).

2.11.6.2 Bushmeat

Bushmeat is consumed regularly by a large portion of the Ghanaian population (Asibey, 1986). The Wildlife Division of the Forestry Commission estimated that game is the main source of meat for 80% of the rural population (Asibey, 1987).

2.11.6.3 Canes

Canes, which are derived from the stems of various climbing palm species, are widely used to produce household and commercial goods. The most common products are baskets (Kotey *et al.*, 1998); Falconer (1992b) estimated that over 90% of all households in southern Ghana owned an average of 3.4 baskets. The market for cane furniture is ever increasing.

2.11.6.4 Fuelwood and charcoal

These account for more than 75 percent of all energy consumed in Ghana and an even higher percentage of energy for household cooking and water heating in rural and urban areas alike (Owusu *et al.,* 1989). Women collect most of the fuelwood in rural household in the high forest zone from farm and fallow lands. There is high demand for fuel wood for processing of palm oil or distillation of "akpeteshie" gin (Mayers and Kotey, 1996).

The World Bank (1988) estimated that fuelwood consumption in Ghana was 15.9 million m^3 in 1988. A study in Sierra Leone found that fuelwood selling provided the first cash income from land cleared for rice production. Subsequently fuelwood collection for the market was concentrated during the off-peak agricultural period, providing cash income in a period when food supplies were generally at their lowest (Kamara, 1986).

2.11.7 Forest-Based Livelihoods and Poverty Alleviation

Non-timber forests products have attracted the attention in recent years for their potential to generate income through value-added processing and innovative marketing. There is the need for a systematic approach to assessing NTFPs as a basis for sustainable development (Belcher, 1998). It is evident that the forest resources have the potential for a wide range of forest-based livelihoods to benefit local populations and to reduce poverty. These include income generation, employment and recreational opportunities, as well as providing support services for agriculture in the rural areas. The forests are also the source of a variety of foods that supplement and complement what rural households obtain from agriculture, and of a wide range of medicines and other products that contribute to health and hygiene. Over the years the communities have collected these NTFPs from the forests. It has now become important that the communities begin to cultivate some of these resources on their own to ensure their continued supply. This will provide self-employment for individuals who will cultivate and on a small scale collect NTFPs for sale.

2.11.8 Other Potential Livelihoods

The Ghanaian forests have the potential to generate income from recreational facilities. For example, the Kakum National Park in the Central Region and Bobiri Forest Reserve in the Ashanti Region, have the potential to attract tourists. Kakum National Park is endowed with wildlife as well as 'canopy walkway' and the Bobiri Forest Reserve has a butterfly sanctuary and other rare species that could attract tourists to these sites. Maintenance of natural forest also helps to protect the soil and watershed areas. Most farming communities depend on this for increased productivity of their farm.

2.12 Biodiversity

Over 2,100 plant species have been found in the high forest zone, 23 of them endemic (Hall and Swaine, 1981). In total 730 tree species have been recorded from the drier Southern Marginal Forest is the poorest closed forests (Hawthorne, 1989). The Wet Evergreen Forest is floristically the richest while the Moist Evergreen and Moist Semi deciduous Forest types are the most important for commercial timber species. The fauna of the forest zone includes over 200 species of mammals, many of which are rare or endangered (Mensah-Ntiamoah, 1989). The high forest zone also supports 74 species of bats, 37 species of rodents, and a variety of reptiles and over 200 species of birds (IUCN, 1992).

2.13 Preservation of Forest Reproduction

There is little information on the reproductive patterns of valuable non-domesticated tropical species. Therefore, many individual trees may be harvested prior to maturity. If near-adult organisms are taken before they produce seeds, that species may become endangered. The timing of harvesting is also important, as fruiting and setting seed are seasonal for many species. Harvesting should be done after the reproductive season for that species is over. For example, in the Amazon, mahogany is usually cut at the end of the dry season, although it reproduces early in the rainy season which follows. This is a most destructive practice. Also, any species which are keystone species or extremely important in the ecosystem should not be harvested frequently, if at all. For instance, the fruits of figs and palms are essential foods for many animals. Just as critical is the capacity of a species for reproduction. Some species can regenerate by sprouting from stumps and thereby survive cutting. Other species, such as bamboo and some palms, reproduce only after many sterile years and then die, thus cutting them prior to reproduction is fatal for that population.

2.14 Allowing Natural Regeneration

Natural regeneration is required for sustainable forestry. Regeneration in a natural way requires some gaps in the forest, although these cannot be too extensive. This mimics the natural course of events, where the death of trees or wind or fire opens gaps in the canopy. It is also necessary to know something of the requirements of seeds for germination and of seedlings for development. In the tropics seedlings of any particular species are often at a low density, and seeds may have only a short period of viability. Many seeds need to pass through an animal gut or to be exposed to heat or moisture in order to germinate. Then, too, many species fruit only sporadically. Thus there are many requirements for adequate reproduction, which vary according to species. The low density of individuals of any one species in tropical forests and their frequently poor capacity for reproduction is a problem in sustainable forestry. Seedlings of the desired species may be planted, but it is often not economically viable to do so, as a great deal of forest may have to be opened for light (as in the case of mahogany), or extensive and labor-intensive weeding may need to be done.

2.15 Maintaining Ecosystem Functions and Biodiversity

Forestry is generally thought to be incompatible with the preservation of ecosystem function and natural biodiversity. Natural forest areas need to be maintained for this purpose, a need often ignored by farmers, logging companies, and government planners. Careful management is required to prevent land degradation. Where logging is done so as to minimize erosion and soil compaction, nutrient losses can be replaced during natural regeneration. The use of heavy equipment must be used very sparingly, if at all, and logging roads must be carefully designed to take into account soil type and land topography. Especially, the harvesting cycle must be lengthy enough to allow for complete regeneration.

Immediately after logging, biodiversity drops precipitously. It can rebound to some extent, although the species returning may not be the same as in the original forest.

Forest exploitation may be diversified to minimize damage to these areas. For example, sensitive areas should be preserved untouched, and areas which are to be logged can be dispersed and kept as restricted as possible. "Cluster-cutting" from nuclei or "strip-cutting" clear-cutting narrow strips may permit more natural regeneration than traditional cutting. Some areas may be managed intensively for production, others modestly for conservation and ecosystem preservation. If logged areas are converted to agricultural systems, much biodiversity is lost forever, although some may be maintained if many native species are planted. Agroforestry may be useful, although even when local plants are used, biodiversity is much reduced from that in primary forest areas.

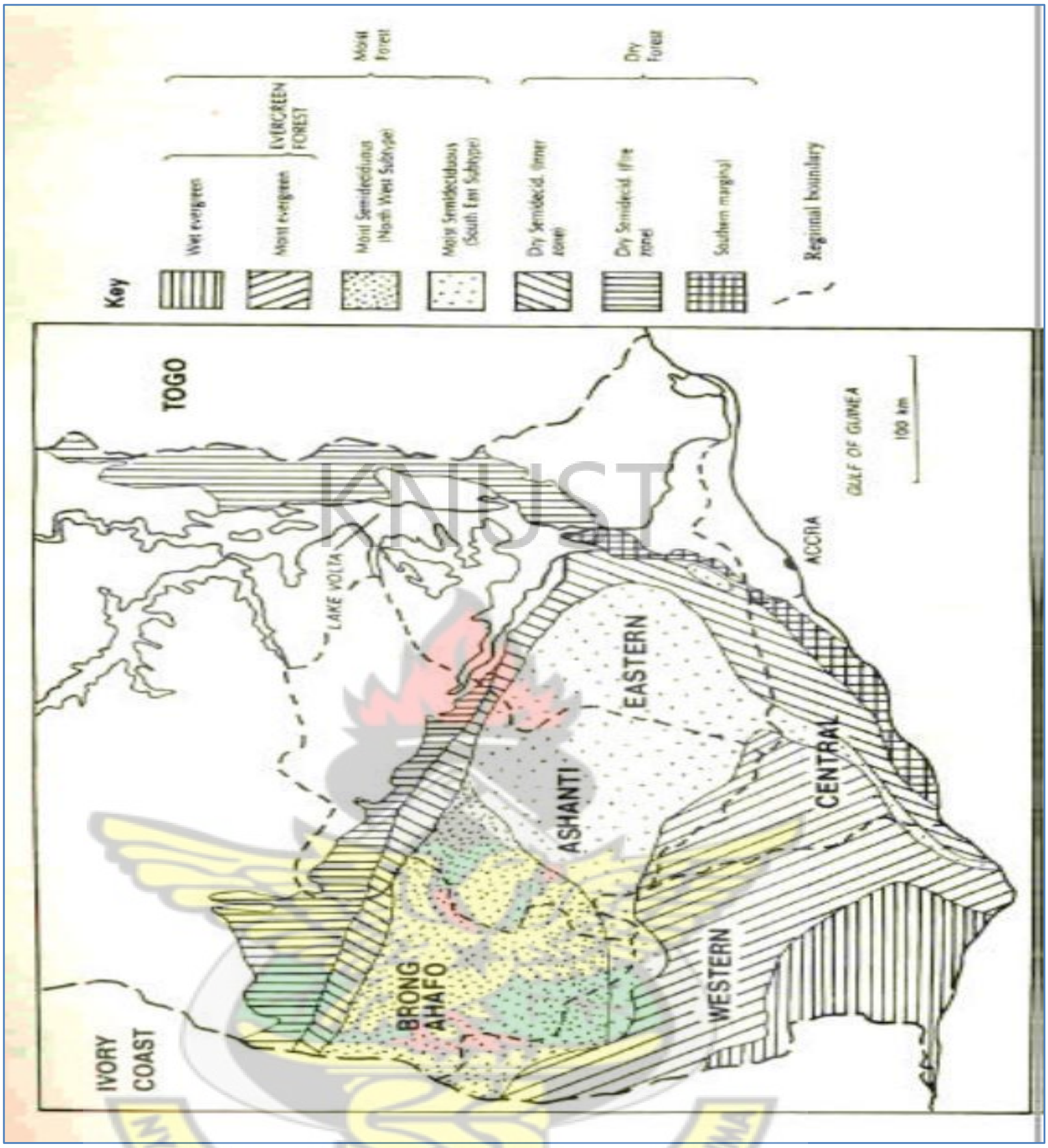

Figure 1: Southern Ghana with forest zones and regions

2.16 Forest Regeneration in Ghana

Regeneration, being either artificial or natural, depends on the production and survival of seeds and seedlings by the parent trees (Honu, 1999), but natural regeneration largely depends on the production of seed. However information on the flowering and fruiting of Ghanaian trees is limited (Swaine *et al.,* 1997). Natural regeneration process in the tropical and the temperate forest are similar in some ways, but tropical forests are more complex and more diverse due to their greater variety in tree species (Richards, 1996). Natural regeneration of the tropical trees vary from specie to specie and depend on four regeneration sources: (a) seeds produced locally (b) seeds dispersed from parent tree (c) seed bank and (d) sprouting conditions (Richards, 1996). Sprouting conditions include the presence of fertile soil which supports emerging seedlings in their growth. The seed bank is the principal sources of seeds for regeneration, for most species (Swaine *et al.*, 1997). According to a study conducted by members of the geographic institute, University of Mainz, titled, "Soil properties and tree growth along an altitudinal transect", soil properties change with an increase in altitude, and there is a decrease in tree growth.

The study showed that the macronutrient concentration correlated significantly negatively with altitude, as well as forest stature, tree basal area and tree growth. Regression analyses from another study conducted on the effects of size, competition and altitude on tree growth, indicated that competition for light was a strong limiting factor for the growth of smaller trees whereas competition for nutrients was not limited, but rather a limiting factor for trees of all sizes. The study also showed that tree growth and the intensity of competition for light decreased with an increase in altitude (Coomes *et al.*, 2007).

The light requirement of tropical trees varies widely (Richards, 1996). Light demanding trees can develop to maturity only in canopy gaps (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 species) and their seedling may survive and reach maturity under unbroken canopies (Richards, 1996).

When forest openings are created, they are often invaded by upper canopy species (Richards, 1996). Seeds and seedlings of tree species which do not exist in the upper canopy may also invade gaps. The majority of the tree species in Ghana have sufficient natural regeneration capability (Hawthorne, 1995) and the mother tree of most species in the under-storey can be found in the same area (Swaine and Hall, 1988). Seedlings of light-demanding species are virtually absent in the under-storey (Poorter *et al.*, 1996), so that it seems that these species are disappearing from the community (Richards, 1996). Restoration starts with the desire to improve degraded and destroyed landscapes or ecosystems. Land can be returned to utility through enhancing fertility, by reversing the long-term effects of agriculture, mining, or logging or by ameliorating toxicity. Plant communities also can be modified to resemble their former condition in an effort to provide conservation benefits (Van Andel and Aronson, 2006).

2.17 Improvement of Forest Management

Obviously, as far as forests are concerned, the best management practice would be to leave them untouched. However, with the current demand for forest products, and with rapidly increasing human populations in tropical regions, this is an unlikely prospect for the majority of large tracts of forest. For most, some sort of management will be required to prevent their complete demolition. There are a wide variety of forest management practices, often with differing and even incompatible goals. Management for ecosystem and genetic resource protection as a primary goal will coexist uneasily with management for sustainable commercial production. As greenhouse gases in the atmosphere increase and carbon sequestration by forests becomes an important issue, and as populations swell in tropical countries, the tension between these goals will increase. Even when the goals are oriented toward conservation, there are different ways of approaching them. Improving the productivity of managed forests is essential, since increasing the yield of timber and other forest products in such forests is far preferable to removing more virgin forest. By far the most important management practice at present is "sustainable forestry," often allied with "selective logging" practices. Sustainable forestry has been touted as a way to reconcile the demand for tropical woods with preservation of forests.

By carefully removing only as many of the trees or other products as can be replaced relatively quickly and leaving others untouched, and, in addition, planting tree seedlings of desirable species, it is thought that forest ecosystems can be maintained so as to provide many crops of timber or other forest products. After an initial harvest, the forests would be left alone for an extended period of time, after which they could again be harvested for valuable products. In order for this system to be effective, there are several imperative preconditions: One, that the populations of organisms in the forest are able to produce a reproductive surplus; two, that there be adequate relatively undisturbed habitat; three that soil fertility be maintained; and fourth, that erosion, runoff and road construction be kept to a minimum.

In some contexts, the term "sustainable forestry" is equivalent to "sustained-yield logging," that is, a system in which the harvesting of timber occurs at a rate such that timber will continue to be produced at an equitable rate, or, as Vincent (1995) puts it, sustainability is to "harvest forests to produce an even flow of timber over time." These methods have been used for many years in European temperate forests, where trees are planted and harvested on regular schedules. This gives a sustained yield of timber, but may not be equivalent to "sustainability" of the forest *per* forest. Nor are these forests in any sense "natural" forests. In general, forestry in temperate countries operates to replace complex natural ecosystems with ecologically simplified forests managed strictly for maximum timber production. They are timber plantations, not true forests. Alternatively, the goal of sustainable forestry can be not just to provide a constant yield of timber, but to maintain the diversity of forests and to ensure that their ecological services remain intact. In this case, sustainable forestry means that timber is extracted in such a way that the forest can regenerate after logging into a complex ecosystem with most of its former components.

2.18 Soil Physical and Chemical Properties

Soil serves as a supporting medium in which tree seedlings remain attached, sprout from and subsequently depended upon for further growth. This implies that soil greatly affects germination and regenerative capability of tree seedlings. Soils are complex, in terms of physical and chemical properties however, most suitable soils for tree seedling growth are characterized by a balance of soil nutrients, optimum pH and low bulk density. In general, the best soil for growth of tropical trees seedling must have pH that ranges from 6.0-7.0, high organic carbon and organic matter content, relatively low bulk densities (low soil compaction, and high porosity for soil aeration). Honu (1999) points out that natural regeneration of Ghana's forest remains, and option to regenerate degraded forest is available, only when barriers to regeneration like invasive competitive weeds such as *Chromolaena odorata* are removed. Other schools of thought believe that this is not a reliable option because the long fallow period to suitably regenerate a forest by this means will affect revenue gains.

2.19 Renewal of Soil Nutrients

One of the most important preconditions of ecosystem rehabilitation in degraded areas is the process of soil development. The soil has to be restored in these degraded areas with all its properties such as water holding and sorption capacity, nutrient content and availability, soil bulk density, buffering capacity, etc. Accumulation of organic carbon (organic C) in the surface layers of the degraded land and the activation with organisms are of crucial importance in the soil development process in degraded areas. Even though microorganisms form only about 2 - 4% of the soil organic matter (SOM), we can consider their activity as one of the principal processes of soil formation, because of their high turnover rate and its irreplaceable role in organic matter (OM) transformation The quantity and activity of microorganisms represent sensitive indicators related to soil development processes (Powlson *et al.*, 1987).

The metabolic quotient (respiration-to-biomass ratio), based on Odum's theory of ecosystem succession (Odum, 1969), may be used as an index for assessing the ecological efficiency of the soil microbial community (Insam and Haselwandter, 1989). The rate of soil development and re-colonisation of degraded lands soil microorganisms depends, among others, on the quality of the spoil substrate and the type of vegetation. The main input of OM into the soil is provided by vegetation; litter fall and root exudation.

The rate of plant material decomposition relates to temperature, moisture, pH (Odum, 1966; Szegi, 1988; Gildon and Rimmer, 1993), nitrogen (N) amount and activity of available soil biota and also quality of plant material. Substrates rich in N, i.e. with lower C/N ratio, are more easily decomposable than substrates low in N (Szegi, 1988; Begon *et al.,* 1996). Alder litter with low C/N ratio and low lignin content is decomposed more quickly than needle litter, in which high C/N and protective waxes on the needle surface make decomposition more difficult.

CHAPTER THREE

3.0 Material and Methods

3.1 Study Area

The study was conducted at Newmont Ghana Gold Ltd – Ahafo North project at Terchire (Teekyere) in Tano – North District of Brong – Ahafo Region. An area noted for its semi deciduous vegetation with an average annual rainfall of about 73-90 mm, most of which occurs during rainy season (April – August). The Project area is located approximately 300 km north-west of the capital city, Accra, 107 km northwest of Kumasi, and 40 km south of the regional capital of Sunyani (EIS, Newmont Ghana Gold Ltd, March 2005). The area was a borrow – pit which was created as a result of the Kumasi – Sunyani highway construction in the early 1980's the top soil was stripped and the subsoil was taken for road construction leaving the area bare. As part of Newmont's stewardship towards the environment and to leave a positive legacy for the communities, Newmont Ghana Gold Ltd in 2002 continued the good work started by its predecessor Normandy Ghana Gold in 1998. The good environmental practice has returned 75 acres of degraded area into one that is rich in biodiversity and over 60 endangered species have been re-introduced into the area of study.

3.2 Data collection

Data was collected between the months of November and December 2010. Based on the intensity of human disturbance, the study area was stratified into three sites namely heavily disturbed forest (HDF), intermediately disturbed forest (IDF), and a reference forest (RF) to serve as control .Ten plots of 20 m x 20 m size were set up randomly in each of the forest types for sampling. The forest types were selected to represent the various degrees of disturbances taking place within the study area. In each of the three forest types all trees with diameter at breast height (dbh) ≥ 10 cm were identified and counted. Additionally, tree seedlings and saplings (2 m high with dbh < 10cm) were identified and counted. The height of the seedlings and saplings were also measured using a calibrated height tape. Plant species were identified with the help of a plant taxonomist, and with reference to field guides, manuals and herbarium specimens. Unidentified specimens were placed in a plant press and brought to the KNUST herbarium for proper identification.

Plate 1: Identification of seedlings and saplings

Plate 2: Measurement of tree diameter at breast height

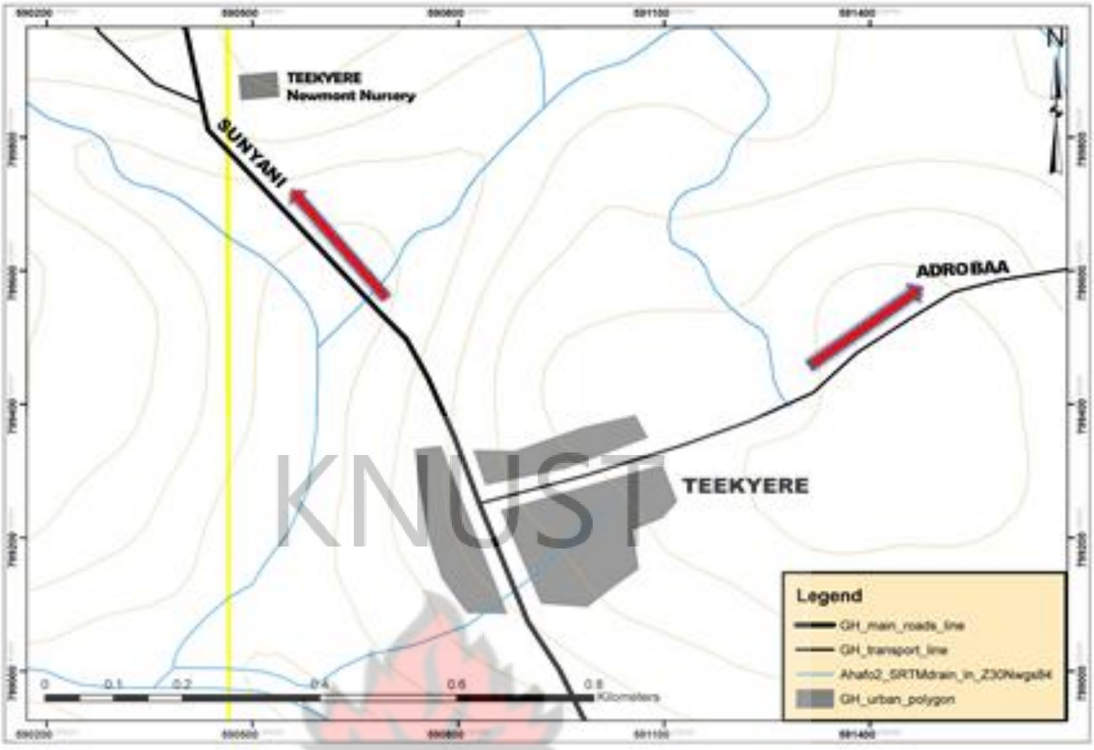

Figure 2: Location of study area at Terchire (Teekyere) in the Brong-Ahafo Region

3.3 Collection and Analysis of Soil Samples

Soil samples from each of the 20 m x 20 m plot in all the sites were collected with the aid of a soil auger and hand trowel. Soil samples were taken at the depth of 0-30 cm and 30- 60 cm. For each depth, soil samples were taken from three different points within each plot. The soil samples collected were then composited to get a single soil sample for each plot. Soil parameters were determined at the CSIR-Soil Research Institute, Kwadaso, Kumasi.

The following soil parameters were determined following standard Scientific Analysis procedures:

pH

Organic content

Organic Carbon

Sodium

Magnesium

Calcium

Soil Moisture

N (Nitrogen)

P (Phosphorus)

K (Potassium)

Percent base saturation

Exchangeable acidity

ECEC (Effective Cation Exchangeable Capacity)

3.4 Determination of the Various Soil Parameters

3.4.1 Soil pH

Soil pH was determined in 1:2.5 suspensions of soil and water using a pH meter. Twenty (20) grams soil sample was weighed into 100ml polythene bottles. To this, 50 ml distilled water was added and the bottle shaken for two hours. After calibrating the pH meter with buffer solutions of pH 4.0 and 7.0 and 10.0, the pH was read by immersing the glass electrode into the upper part of the suspension.

3.4.2 Organic Carbon

Organic Carbon was determined by the Walkley and Black wet combustion method. 0.5 g duplicate soil sample was weighed into a 500 ml Erlenmeyer flask.

10 ml of 1.0 N of Potassium dichromate ($K_2Cr_2O_7$) solution was added using pipette. This was swirled gently to ensure contact with all the soil particles.

20 ml conc. H_2SO_4 was then added and swirled gently for a minute. The flask was allowed to stand on an asbestos sheet for 30 minutes to cool. After 30 minutes of standing the contents of the flask was diluted with 200 ml of distilled water, swirled again to ensure thorough mixing.

10 ml of H_3PO_4, 0.2 g NaF and 1 ml of diphenylamine indicator was added.

The excess $K_2Cr_2O_7$ was back titrated with 0.5 M ferrous solution to a green endpoint. A Blank titration was carried out in an identical manner using the same reagents but omitting the soil. The organic Carbon was calculated using the formula in Appendix I (i) (Nelson and Sommers, 1982).

3.4.3 Total Nitrogen

Total Nitrogen was determined by the modified Kjeldahl digestion method. In this method, 0.5 g o f soil sample was weighed into a digestion flask. One point one grams (1.1 g) of catalyst and 3.0 ml of conc. H_2SO_4 were added. The flask was gently heated on a block digester until frothing subsides and the heat gradually increased to 380^oC and digested for 2 hours. On completion of digestion, it was allowed to cool until just warm and then diluted to 100 ml with distilled water. An aliquot of the digested sample was transferred to the reaction chamber through the trap funnel. Ten (10) ml of alkaline mixture was added and distillation was commenced immediately and about

40 ml of the distillate was collected. The distillate was titrated against M/140 HCl from green to the initial colour of the indicator (wine red).

The digestion blanks were treated the same way and subtracted from the sample titre value. Total Nitrogen was calculated using the formula in Appendix I (ii) (Okalebo *et al*., 1993).

3.4.4 Available Phosphorus

One (1) g of soil sample was weighed into 15 ml centrifuge tube and 10ml of the extracting solution added, shaken for 10 minutes and filtered. Two (2) ml aliquots of the extract were pipetted into a 25 ml volumetric flask. From the stock solution of P 100 ml 5µgP/ml was prepared. From the 5µgP/ml solution a set of working standards of P containing 0, 0.1, 0.2, 0.4, 0.6, 0.8 and 1.0 g was prepared into 25 ml volumetric flask. Standard and sample were treated the same way. Ten (10) ml of distilled water was added to each flask. Four (4) ml of reagent blank was added and made up to the volume with distilled water. The colour was allowed to develop for 15 minutes and the absorbance determined on the spectrophotometer at 882nm.

Available Phosphorus was calculated using the formula in Appendix I (iii)
(Bray and Kurtz, 1945; Olsen and Sommers, 1982).

3.4.5 Effective Cation Exchange Capacity (ECEC) Determination

Effective Cation Exchange Capacity was determined by the sum of exchangeable bases (Ca2+, Mg2+, K+ and Na+) and exchangeable acidity (Al^3+ and H^+)

3.4.5.1 Percent (%) Base Saturation Determination

Percent (%) Base Saturation was determined by dividing Total Exchangeable Bases (TEB) by Effective Cation Exchange Capacity (ECEC), multiplied by 100. Percent (%) Base Saturation determination was calculated using the formula in Appendix I (iv) (Okalebo *et al*., 1993).

3.4.5.2 Exchangeable Acidity

Exchangeable acidity is defined as the sum of Al and H. The soil sample was extracted with unbuffered 1.0 M KCl and the sum of Al and H was determined by titration. Fifty (50) g of soil sample was put in a 200ml plastic bottle and 100 ml of 1.0 M KCl solution added. The bottle was capped and shaken for 2.0 hours and then filtered. Fifty (50) ml portion of the filtrate was taken with a pipette into a 250 m Erlenmeyer flask and 2-3 drops of phenolphthalein indicator solution added. The solution was titrated with 0.1 M NaOH until the colour just turned permanently pink. A blank was included in the titration. Exchangeable Acidity determination was calculated using the formula in Appendix I (v) (Okalebo *et al*., 1993).

3.4.5.3 Determination of Calcium Only

A 20 ml portion of the extract was transferred to a 250 ml Erlenmeyer flask and the volume made to about 50 ml with distilled water. Hydroxylamine hydrochloride (1.0 ml), Potassium cyanide (1.0 ml of 2% solution) and Potassium ferrocyanide (1.0 ml of 2%) were added. After a few minutes, 4 ml of 8.0 M potassium hydrochloride and a spatula of mureoxide indicator added. The solution obtained was titrated with 0.01 M EDTA solutions to a pure blue colour. Twenty (20) millilitres of 0.01 M calcium chloride solution was titrated with 0.01 M EDTA in the presence of 25 ml 1.0 M ammonium acetate solution to provide a standard pure blue colour. Calcium determination was calculated using the formula in Appendix A6 (Okalebo *et al.*, 1993).

3.4.5.4 Exchangeable Potassium and Sodium Determination

Potassium and sodium in the percolate were determined by flame photometry. A standard series of potassium and sodium were prepared by diluting 1000 mg/l of potassium and sodium solutions to 100 mg/l. This was done by taking a 25 ml portion of each into one 250 ml volumetric flask and made to volume with water. Portions of 0, 5, 10, 15, and 20 ml of the 100 mg/l standard solution were put into 200 ml volumetric flasks respectively. One hundred milliliters of 1.0 M NH_4OAc solution was added to each flask and made to volume with distilled water. The standard series obtained was 0, 2.5, 5.0, 7.5, 10.0 mg/l for Potassium and Sodium. Potassium and sodium were measured directly in the percolate by flame photometry at wavelengths of 7666.5 and 589.0 nm respectively. Exchangeable Potassium and Sodium determination was calculated using the formula in Appendix A7 (Okalebo *et al.*, 1993).

3.4.5.5 Exchangeable Cations

Exchangeable bases (calcium, magnesium, potassium and sodium) in the soil were determined in 1.0 M ammonium acetate (NH4OAc) solution at pH 7 and the exchangeable acidity (hydrogen and aluminium) was determined in 1.0 M KCl extract (Okalebo *et al*., 1993).

3.4.5.6 Extraction of Exchangeable Bases

Ten grams (10 g) sample was transferred into a leading tube and leached with 250 ml of buffered 1.0 M ammonium acetate (NH_4OAc) solution at pH 7 and the protocol by (Okalebo *et al*., 1993) was followed.

3.4.5.7 Determination of Calcium and Magnesium

For the determination of calcium plus magnesium, a 25 ml portion of the extract was transferred into an Erlenmeyer flask and the volume made to 50 ml with distilled water. A 10 ml portion of hydroxylamine hydrochloride, 1 ml of 2.0 %t potassium cyanide (from a burette), 1.0 ml of 2.0 % ferrocyanide, 10.0 M EDTA (ethylene diamine tetra acetic acid) to a pure turquoise blue colour. A 20 ml of 1.0 M magnesium chloride solution was also titrated with 0.01 M EDTA in the presence of 25 ml of 1.0 M ammonium acetate solution to provide a standard blue colour for the titration (Okalebo *et al*., 1993).

3.5 Data analysis

In order to show the relationship between richness, density and basal area of regenerating species, and soil physicochemical factors stepwise multiple regression analysis was run using the regeneration plant attributes and the environmental factors (mentioned above) as the dependent and independent variables respectively. The stepwise multiple regression analyses were conducted with the Minitab 15 software. All the analyses were conducted at a significance level of 5%.

CHAPTER FOUR

4.0 Results

4.1 Species diversity and abundance of mature trees

A total of 86 tree species belonging to 43 families and containing 532 individual adult trees were recorded in the three forest types (Table 1). Species richness was highest in the reference forest (33 species) followed by the intermediately disturbed forest (32 species) and then the heavily disturbed forest (21 species). *Morinda lucida* was the most dominant species in the reference forest whereas *Leucaena glauca* dominated in both the heavily disturbed forest and intermediately disturbed forest. In terms of abundance, the intermediately disturbed forest recorded most individuals of trees (266 individuals) followed by the heavily disturbed forest (165 individuals) and then the reference forest (101individuals).

Table 1: Summary of the Composition of Tree Species in the Study Plots on the heavily disturbed forest (HDF), intermediately disturbed forest (IDF) and Reference Forest (RF).

Characteristics of Species	HDF	IDF	RF	Overall
Number of individual trees	165	266	101	532
Number of Species	21	32	33	86
Number of families	12	14	17	43

4.2 Species Diversity and Structure of Regeneration Species

A total of 1884 individuals of seedlings and saplings were identified in the study area. They belonged to 93 species and 31 families (Appendix II table (I and ii)) Species richness was found to be higher in the intermediately disturbed forest (62 species) relative to the reference forest (58 species) and the heavily disturbed forest (56 species). Regenerating species were more abundant in the intermediately disturbed forest (816 individuals) compared to the other habitats (656 and 414 individuals in the intermediately and heavily disturbed forests respectively). The overall proportion of seedlings to saplings was in ratio 1:1 with 954 seedlings and 932 saplings identified within the habitats. More families occurred in the intermediately disturbed forest (22) in relation to the other habitats.

The heavily disturbed forest was most balanced in proportion of seedlings to saplings with a ratio of almost 1:1 (399 seedlings: 417 saplings). The reference forest was least proportional, having 140 seedlings and 274 saplings, with the ratio of seedlings to saplings being 1:2. The most abundant species in the heavily disturbed forest was *Ceiba pentandra* (83 individuals), whereas *Alophylus afrcanus* and *Ceiba pentandra* were the most dominant species in the intermediately (76 individuals) and reference forest (42 individuals) respectively. Overall, the families *Fabaceae* and *Malvaceae* were the dominant in terms of species richness (13 species). This was followed by the families *Moraceae* (8) Rubbiaceae (7), *Apocynaceae* and *Sapindacea*e (6 species each).

Mean height, dbh, and basal area of saplings were highest in the HDF compared with the other forest types (Table 2). Due to the fact that the HDF had the least canopy cover, thus receiving the highest amount of sunlight thereby affecting the structure of the saplings in the HDF.

Table 2: Summary of the mean Height, DBH and Basal Area of saplings

Characteristics	HDF	IDF	RF
Mean Height (m)	0.98	0.84	0.79
Mean DBH (cm)	1.53	1.27	1.34
Mean Basal area (cm^2)	3.59	1.87	2.21

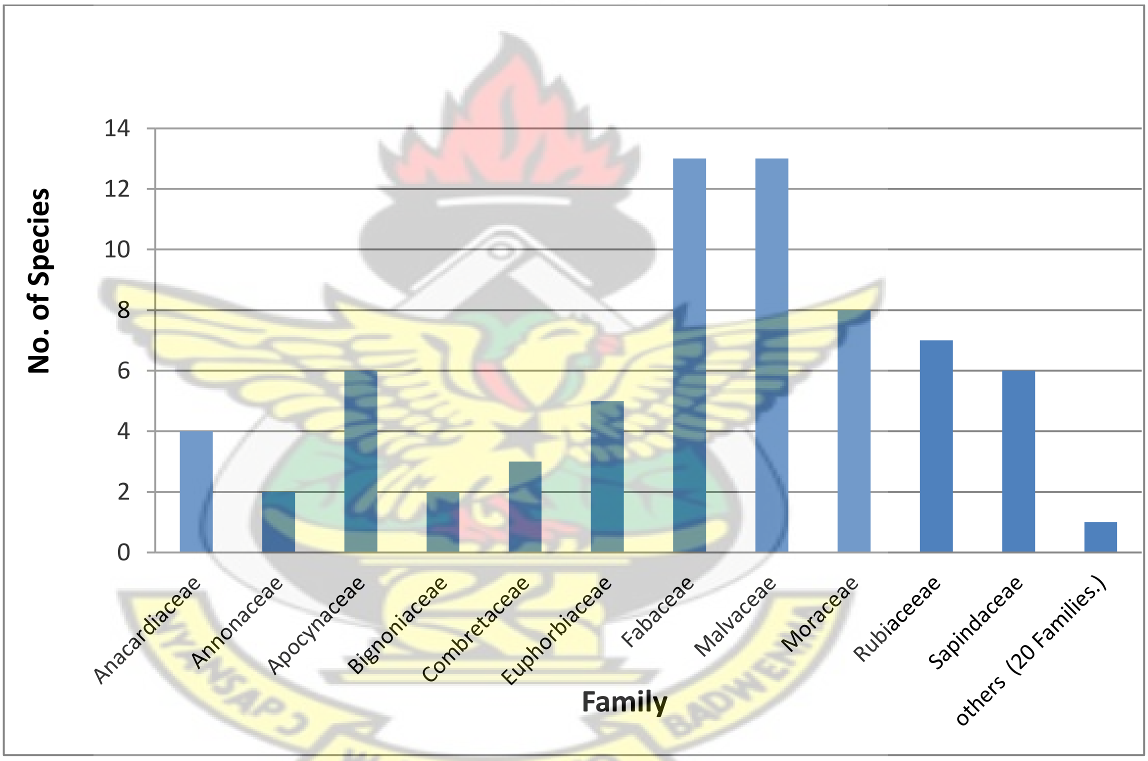

Figure 3: Distribution of regeneration species within the families

4.3 Effects of soil physicochemical factors on sapling and seedling species diversity and structure

Most of the soil physicochemical factors were highest in the reference forest followed by the intermediately disturbed forest and then the heavily disturbed forest (Table 3).

Species richness and structure of seedlings and saplings were influenced by a number of soil physicochemical factors (Table 4). Soil properties explained significant portion of variation in most of the parameters of seeding and sapling structure (34.9 to 78.5 %). However, they accounted for a small portion of variation in sapling abundance (10.5 %). Sapling abundance, height, dbh and basal area were affected by total Exchangeable Bases (TEB) and Effective Cation Exchangeable Capacity (ECEC) in addition to other factors. Sapling species richness was influenced by % Base Saturation and available K. Seedling abundance was predicted by pH, moisture and Mg.

Table 3: Comparison of Average Concentrations and Amounts of Chemical Properties of Soil sampled from the selected study plots within the habitat; heavily disturbed forest (HDF), Intermediate disturbed Forest (IDF) and Reference Forest (RF)

Soil physicochemical Factors	HDF	IDF	RF
pH	*5.35*	*5.41*	*6.27*
Organic Carbon (%)	2.56	2.37	2.98
Total Nitrogen (%)	0.22	0.2	0.27
Organic Matter (%)	4.42	4.02	5.17
Calcium (me/100g)	9.29	9.18	14.35
Magnesium (me/100g)	3.04	3.13	4.64
Potassium (me/100g)	0.62	0.43	0.56
Sodium (me/100g)	0.16	0.14	0.21
TEB	13.12	12.92	19.83
Exch.A (Al+H)	0.73	0.7	0.38
E.C.E.C (me/100g)	12.77	13.07	19.88
Base sat. %	93.97	94.16	98.5
% Moisture	12.65	10.57	12.8
Phosphorus (ppm)	8.81	8.21	8.81
Potassium (ppm)	99.77	91.75	108.94

Table 4: Multiple regression analyses on the effects of soil properties on species richness and structure of saplings and seedlings in the 30 forest plots. Only variables with significant influence were included in the final models.

Dependent Variable	Model R^2 (%)	Independent variable	p-value	parameter estimate	Standard error
Saplings					
Abundance	34.9	TEB	0.001	-3.559	0.456
		ECEC	0.022	2.438	0.449
		% Base saturation	<0.0001	6.658	0.022
Species richness	10.5	% Base saturation	<0.0001	7.337	0.041
		Available K	0.039	-2.167	0.038
Plant height	43.2	Na	0.002	3.420	3.059
		TEB	0.009	2.809	0.063
		ECEC	0.000	-4.281	0.059
Dbh	58.7	TEB	0.000	4.457	0.076
		ECEC	<0.0001	-5.311	0.073
		Available P	0.001	3.596	0.038
Basal area	78.5	Na	0.010	2.783	32.237
		TEB	<0.0001	6.309	0.580
		ECEC	<0.0001	-8.831	0.542
		Available P	0.005	3.057	0.321
Abundance*	50.5	pH	0.045	-13.13	6.14
		Moisture	0.025	-2.119	0.876
		Mg	0.020	-3.05	1.20

CHAPTER FIVE

5.0 Discussions

Studies on floristic and structure in the forest are instrumental in the sustainability of forests since they play a major role in the conservation of plant species and the management of forest ecosystems as a whole (Tilman, 1988; Ssegawa and Nkuutu, 2006).

5.1 Adult flora

Species richness of adult trees was comparable to the reference forest and the intermediately disturbed forest. However, far lower species richness was obtained in the heavily disturbed forest compared with the other forests. Though both the intermediately and heavily disturbed forests have experienced disturbance, the species richness of the former was similar to that of the natural forest. This supports the intermediate disturbance hypothesis on species diversity (Wilkinson, 1999). The study also demonstrates that higher disturbance could lead to species decline. This finding is similar to a study conducted by Bongers *et al*., (2009) in which species were lost at higher disturbance levels.

The presence of *L. glauca* in the intermediately and heavily disturbed forests as the most abundant species calls for a serious concern as it is a highly invasive species. In the intermediately disturbed forest, this species accounted for 45 % of the number of individuals whereas it made up about 50 % of tree abundance in the heavily disturbed forest. The choice of species for rehabilitation of degraded areas should be carefully done so as not to defeat the whole purpose. If this species is not checked, it will grow quickly to form dense thickets which would crowd out any native vegetation (Yau-Lun, 2003). In effect, this species poses a serious threat to the native biodiversity in the area. The call for the control of the spread of this species is more relevant considering the fact that the species is yet to colonise the reference forest. There is thus, a window of opportunity to protect native biodiversity in the forest.

5.2 Natural Regeneration

Both seedling and sapling diversity remained the same in all the forest types indicating that human disturbance did not have much influence on them. Species richness of both seedling and sapling also showed the same trend in the forest. Seedling and sapling abundance varied significantly in the forest types, being lower in the non-disturbed forest in relation to the other forest types. The difference could be related to differences in canopy gaps in the intermediately and heavily disturbed forests, and the non-disturbed forest. Human disturbance created gaps in the canopy allowing the necessary light penetration for seedling germination, and seedling and sapling growth in the disturbed forests as was reported by Van der Meer *et al*., (1999) and Stephenson *et al*., (2006).

The finding of this study is contrary to a similar study conducted in the "Tinte Bepo" forest reserve, Ghana in which human disturbance impacted negatively on tree seedlings (Addo-Fordjour *et al*., 2009). Though human disturbance seemed to be a favourable factor in influencing liana seedling and sapling abundance in this study, it is important to state that the disturbance in these forests have stopped in the past five years. Thus, currently, seedling and sapling growth and development are not being hampered by human activities. This explains the difference between the findings of this study and that of Addo-Fordjour *et al*., (2009) stated above. Apart from human disturbance, soil properties played important role in seedling and sapling abundance, with soil pH, moisture and magnesium on one hand and soil TEB, ECEC and percent base saturation on the other hand making significant influence on seedling and sapling abundance respectively.

Apart from abundance, all the other structural attributes of tree saplings were controlled by some soil properties. The important role of soil properties in natural regeneration of trees has also been reported in some studies (Modry *et al*., 2004). Although many soil properties were selected as the best predictors of sapling structure in the regression analysis, ECEC influenced all the structural attributes. Effective cation exchangeable capacity is very important because it is said to be an indicator of overall soil fertility (Lines-Kelly, 1993). Therefore, tree sapling structure in this study can be said to have been influenced by soil fertility. Human disturbance in the forest could have altered the soil in such a way to create differences in soil properties in the various plots.

Despite the high abundance of an invasive species, *L. glauca*, in the adult tree flora, it was poorly represented in the seedling and sapling flora in intermediate and heavily disturbed forests. This is very surprising in view of its adult abundance and invasive capability. The low regeneration capacity of this species at the moment gives hope for the possible control of the species in the forest.

CHAPTER SIX

6.0 Conclusion and Recommendations

6.1 Conclusion

Natural regeneration is very effective means of restoring a disturbed land and helps maintain the desired species and stocking following a disturbance.

From The study it is evident that different levels of human disturbance had varying effects on tree species, Natural regenerating diversity and structure.

It is also evident that the soil physicochemical properties determined have influence on the seedlings and saplings diversity and structure.

6.2 Recommendations

Non-invasive pioneer species should be encouraged in human disturbed forest to condition the soil for regeneration. The pressure of human disturbances on the forest should be relieved or significantly minimized in order to facilitate natural regeneration of trees.

The level of human disturbance on the forest could be minimized to help maintain tree species and regenerating diversity and structure.

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APPENDICES

APPENDIX I

(i). ORGANIC CONTENT

% Organic Carbon = ((B-S) × Molarity of Fe^{2+} × 0.003) / (weight of soil sample)× (100/77) × 100

Where:

B = Blank titre value

S = Sample titre value

0.003 08 = 12 / 4000 = milliequivalent weight of carbon

100 / 77 = the factor converting the carbon actually oxidized to total carbon

100 = the factor to change from decimal to percent

(ii). TOTAL NITROGEN

N (%) = (S-B) × solution volume /10^2 × Aliquot sample weight

Where:

B = Blank titre value

S = Sample titre value.

(iii). AVAILABLE PHOSPHORUS

P (mg/kg) = (a – b) × 20 × 6 × mcf / S

Where:

a = mg/l P in sample extract

b = mg/l P in blank

S = sample weight in (g)

Mcf = moisture correcting factor

20 = ml extracting solution

6 = ml final sample solution

(iv). PERCENT (%) BASE SATURATION DETERMINATION

% Base Saturation = TEB x 100 / ECEC

(v). EXCHANGEABLE ACIDITY

Exchangeable acidity (c mol/kg soil) = (a – b) x M x 2 x 100 x *mcf / S*

Where:

a = ml NaOH used to titrate with sample

b = ml NaOH used to titrate with blank

M = molarity of NaOH solution

S = air-dried soil sample weight in gram

2 = 100/50 (titre / pipette volume)

mcf = moisture correcting factor (100 + %moisture)/ 100)

(vi). DETERMINATION OF CALCIUM

The calculation of the concentration of calcium + magnesium or calcium follows the equation

Ca + Mg (or Ca) (c mol/ kg soil) = 0.01 x (Va – Vb) x 1000 / 0.1 x W

Where:

W = weight in grams of air-dried soil extracted

Va = ml of 0.01M EDTA used in the titration

Vb = ml of 0.01M EDTA used in blank titration

0.01 = concentration of EDTA used

(vii). EXCHANGEABLE POTASSIUM AND SODIUM DETERMINATION

Exchangeable K (c mol/kg soil) = (a-b) x 250 x mcf / 10 x 39.1 x S

Exchangeable Na (c mol/kg soil) = (a-b) x 250 x mcf / 10 x 23 x S

Where:

a = mg/l of K or Na in the diluted sample percolate

b = mg/l of K or Na in the diluted blank percolate

S = air-dried sample weight of the soil in gram

mcf = moisture correcting factor

39.1 = molar mass for potassium

23 = molar mass for sodium

APPENDIX II

(i). Table showing a summary of Abundance of seedlings in the various forest habitat of the study

		Abundance		
Species Name	Family	HDF	IDF	RF
Albizia adianthifolia	Fabaceae	3	-	-
Albizia coriaria	Fabaceae	1	2	1
Albizia glaberrima	Fabaceae	-	1	-
Albizia zygia	Fabaceae	-	-	10
Alophylus afrcanus	Sapindaceae	17	62	2
Alstonia boonei	Apocynaceae	-	2	2
Amphimas pterocarpoides	Fabaceae	-	1	1
Anthocleista nobilis	Gentianaceae	2	-	-
Antiaris toxicaria	Moraceae	12	7	3
Antrcaryon micraster	Anacardiaceae	-	-	1
Azadilacta indica	Meliaceae	4	12	-
Baphia nitida	Fabaceae	1	4	-
Blghia sapida	Sapindaceae	3	9	4
Blighia unijugata	Sapindaceae	29	30	8
Blighia welwitschii	Sapindaceae	-	-	-
Bombax buonopozense	Malvaceae	7	12	16
Bridelia micrantha	Euphorbiaceae	2	5	1
Canarrium schweiinfurthii	Burseraceae	-	-	1
Carica papaya	Caricaceae	6	-	-
Ceiba pentandra	Malvaceae	57	43	14
Celtis zenkeri	Ulmaceae	-	-	1
Chidlowia sanguinea	Fabaceae	-	-	1
Chrysophyllum giganteum	Sapotaceae	-	1	-
Citropsis articulata	Rutaceae	2	1	-
Cleistopholis patens	Annonaceae	-	1	2
Cola gigantea	Malvaceae	-	-	5
Cordia millenii	Boraginaceae	3	-	-
Deinbollia grandifilia	Sapindaceae	4	2	-
Detarium senegalense	Fabaceae	1	-	-
Discoglypremna caloneura	Euphorbiaceae	-	-	1
Ficus craterostoma	Moraceae	2	-	-
ficus exasperata	Moraceae	-	4	2
Ficus urifolia	Moraceae	7	-	-
Funtumia africana	Apocynaceae	-	2	-
Funtumia elastica	Apocynaceae	-	2	2
Glyphaea brevis	Meliaceae	-	-	1
Griffonia simplicifolia	Fabaceae	1	-	-
Heritiera utilis	Malvaceae	-	-	-
Holarrhena floribunda	Apocynaceae	2	5	3
Khaya senegalense	Meliaceae	2	-	-

(i) Contd: Summary of Abundance of seedlings in the various forest habitat of the study area.

		Abundance		
Species Name	Family	HDF	IDF	RF
Lannea welwitschii	Anacardiaceae	-	-	1
Leucaena glauca	Fabaceae	1	6	-
Mangifera indica	Anacardiaceae	7	2	-
Mareya micrantha	Euphorbiaceae	2	1	1
Margaritaria discoidea	Euphorbiaceae	3	-	-
Milicia excelsa	Moraceae	3	5	2
Millettia zechiana	Fabaceae	25	19	3
Monodora myristica	Annonaceae	-	1	-
Morinda lucida	Rubbiaceae	9	9	5
Morus mesozygia	Moraceae	5	14	5
Nesogordonia papaverifera	Malvaceae	1	-	-
Newbouldia laevis	Bignoniaceae	39	13	1
Pseudospondias microcarpa	Anacardiaceae	2	-	5
psydrax parviflora	Rubiaceae	-	-	1
Pterygota macrocarpa	Malvaceae	2	4	3
Pycnanthus angolensis	Myristicaceae	-	2	1
Raphia palma-pinus	Palmae	-	3	-
Rauvolfia vomitoria	Apocynaceae	65	64	2
Rinorea kibbiensis	Violaceae	-	3	-
Rothmannia whitfieldii	Rubiaceae	13	-	-
Solanum erianthum	Solanaceae	15	11	-
Spathodea campanulata	Bignoniaceae	3	3	6
Sterculia oblonga	Malvaceae	-	-	1
Sterculia rhinopetala	Malvaceac	2	-	2
Sterculia tragacantha	Malvaceae	19	1	9
Strombosia pustulata	Olacaceae	1	-	-
Terminalia glaucesceus	Combretaceae	6	-	1
Terminalia ivorensis	Combretaceae	-	-	2
Terminalia superba	Combretaceae	6	11	2
Trichilia monadelpha	Meliaceae	-	-	3
Trichilia tessmannii	Meliaceae	-	4	2
Trichillia prieuriana	Meliaceae	-	-	1
Trlepisium madagascariese	Moraceae	-	3	6
Vernonia amygdalina	Asteraceae	20	12	-
Voacanga Africana	Apocynaceae	-	-	2

(ii). Table showing a summary of Abundance of saplings in the various forest habitat of the study area.

		Abundance		
Species Name	Family	HDF	IDF	RF
Albizia adianthifolia	Fabaceae	2	-	-
Albizia coriaria	Fabaceae	6	3	2
Albizia glaberrima	Fabaceae	-	5	3
Albizia zygia	Fabaceae	-	2	3
Alophylus afrcanus	Sapindaceae	3	14	8
Alstonia boonei	Apocynaceae	-	2	2
Amphimas pterocarpoides	Fabaceae	-	2	2
Antiaris toxicaria	Moraceae	19	12	11
Antrcaryon micraster	Anacardiaceae	5	-	6
Azadilacta indica	Meliaceae	1	1	-
Baphia nitida	Fabaceae	-	20	-
Blghia sapida	Sapindaceae	12	27	9
Blighia unijugata	Sapindaceae	13	16	3
Blighia welwitschii	Sapindaceae	-	1	-
Bombax buonopozense	Malvaceae	1	13	45
Bridelia micrantha	Euphorbiaceae	2	2	6
Broussonetia papyirefera	Moraceae	-	-	4
Canarrium schweiinfurthii	Burseraceae	-	6	-
Carica papaya	Caricaceae	5	1	-
Cassia fistula	Caesalpiniaceae	1	1	-
Cedrella ordoranta	Meliaceae	1	26	28
Ceiba pentandra	Malvaceae	26		4
Celtis zenkeri	Ulmaceae	-	9	-
Chrysophyllum giganteum	Sapotaceae	2	-	-
Citropsis articulata	Rutaceae	1	-	3
Cleistopholis patens	Annonaceae	-	2	24
Cola gigantea	Malvaceae	-	-	-
Cordia millenii	Boraginaceae	-	1	1
Deinbollia grandifilia	Sapindaceae	2	8	2
ficus exasperata	Moraceae	-	-	-
Ficus urifolia	Moraceae	4	1	-
Funtumia elastica	Apocynaceae	-	4	1
Glyphaea brevis	Meliaceae	-	-	-
Griffonia simplicifolia	Fabaceae	-	1	-
Heritiera utilis	Malvaceae	-	9	6
Holarrhena floribunda	Apocynaceae	4	-	-
khaya ivorensis	Meliaceae	4	-	4
Khaya senegalense	Meliaceae	1	-	2
Lannea welwitschii	Anacardiaceae	-	7	-
Leucaena glauca,	Fabaceae	3	7	4
Lonchocarpus sericeus	Fabaceae	-	-	-

(ii) Contd: Summary of Abundance of saplings in the various forest habitat of the study area.

Species Name	Family	Abundance		
		HDF	IDF	RF
Macaranga barteri	Euphorbiaceae	2	1	-
Mangifera indica	Anacardiaceae	3	5	1
Mansonia altissma	Malvaceae	-	8	5
Mareya micrantha	Euphorbiaceae	1	2	-
Margaritaria discoidea	Euphorbiaceae	-	1	-
Milcia regia	Moraceae	-	2	11
Milicia excelsa	Moraceae	2	15	2
Millettia zechiana	Fabaceae	11	1	-
Monodora myristica	Annonaceae	-	5	7
Morinda lucida	Rubbiaceae	8	4	7
Morus mesozygia	Moraceae	2	1	-
Nauclea diderrichii	Rubbiaceae	-	1	-
Nesogordonia papaverifera	Malvaceae	-	11	1
Newbouldia laevis	Bignoniaceae	3		5
Pseudospondias microcarpa	Anacardiaceae	2	-	1
Psidium gyajava	Myrtaceae	-	-	3
Psydrax parviflora	Rubiaceae	-	26	-
Pterygota macrocarpa	Malvaceae	7	6	4
Raphia palma-pinus	Palmae	1	11	15
Rauvolfia vomitoria	Apocynaceae	15	14	-
Rinorea kibbiensis	Violaceae	-	1	-
Rothmannia whitfieldii	Rubiaceae	5	-	1
Scottellia klaineana	Achariaceae	-	38	1
Solanum erianthum	Solanaceae	17	4	4
Spathodea campanulata	Bignoniaceae	6	4	2
Sterculia tragacantha	Malvaceae	2	5	-
Terminalia glaucesceus	Combretaceae	4	-	1
Terminalia ivorensis	Combretaceae	-	7	4
Terminalia superba	Combretaceae	6	1	-
Tieghemella heckelii	Sapindaceae	-	-	1
Tricalysia Coffeae	Rubiaceae	-	-	4
Trichilia monadelpha	Meliaceae	-	15	15
Trichilia tessmannii	Meliaceae	-	-	1
Triplochiton scleroxylon	Malvaceae	3	5	4
Trlepisium madagascariese	Moraceae	-	14	-
Vernonia amygdalina	Asteraceae	24	1	11
Voacanga Africana	Apocynaceae	-	1	6

(iii). Table showing a summary of Abundance of trees in the various forest habitat of the study area.

Species Name	Family	Abundance H DF	IDF	RH
Albizia adianthifolia	Fabaceae	1	1	1
Albizia coriaria	Fabaceae	3	11	4
Albizia glaberrima	Fabaceae	3	-	-
Albizia zygia	Fabaceae	-	-	8
Alsatonia boonei	Apocynaceae	4	5	4
Amphimas pterocarpoides	Fabaceae	-	1	-
Antiaris toxicaria	Moraceae	3	2	6
Azadilacta indica	Meliaceae	-	1	-
Baphia nitida	Fabaceae	-	3	-
Blghia sapida	Sapindaceae	-	22	6
Blighia unijugata	Sapindaceae	5	3	-
Bombax buonopozense	Malvaceae	-	-	1
Bridelia micrantha	Euphorbiaceae	3	2	3
Canarrium schweiinfurthii	Burseraceae	-	-	2
Cassia	Fabaceae	-	1	-
Cedrela odoranta	Meliaceae	-	2	-
Ceiba pentandra	Malvaceae	2	3	-
Cordia millenii	Boraginaceae	-	-	3
Delinbollia grandifolia	Spaindaceae	4	-	-
Ficus urifolia	Moraceae	7	-	-
Funtumia africana	Apocynaceae	-	2	-
Funtumia elastica	Apocynaceae	-	3	-
Glyphaea brevis	Meliaceae	-	-	1
Psidium gyajava	Myrtaceae	-	-	1
Holarrhena floribunda	Apocynaceae	1	3	3
Khaya senegalense	Meliaceae	1	-	-
leucaena glauca	Fabaceae	80	119	1
Lonchocarpus sericeus	Fabaceae	-	-	5
Mangifera indica	Anacardiaceae	-	3	-
Mansonia altissma	Malvaceae	-	-	1
Millettia zechiana	Bignoniaceae	-	5	1
Morinda lucida	Rubbiaceae	3	6	18
Newbouldia laevis	Bignoniaceae	1	2	1
Pseudospondias microcarpa	Anacardiaceae	-	1	2
Pterygota macrocarpa	Malvaceae	-	2	2
Raphia palma-pinus	Palmae	-	1	1
Rauvolfia vomitoria	Apocynaceae	21	-	1
Spathodea cappannulata	Sapindaceae	-	3	2

(iii) Contd: Summary of Abundance of trees in the various forest habitat of the study area

Species Name	Family	Abundance		
		HDF	IDF	RF
Sterculia tragacantha	Malvaceae	2	3	2
Tectona grandis	Verbenaceae	7	20	-
Terminalia ivorensis	Combretaceae	-	-	2
Terminalia superba	Combretaceae	1	7	5
Trema orientails	Ulmaceae	-	-	2
Trichilia monadelpha	Meliaceae	-	-	1
Triplochiton scleroxylon	Malvaceae	12	10	1
Trlepisium	Moraceae	-	17	11
Vernonia amygdalina	Asteraceae	1	-	-

APPENDIX III

(i)

Plate showing the collection of soil sample

(ii)

Plate showing the emptying of soil from the soil auger

(iii)

Plate showing the mixing of soil sample

(iv)

Plate showing a sapling in the study area

(v)

Plate showing the Reference Forest