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EFFECTS OF SELECTIVE LOGGING ON ADVANCED REGENERATION OF TIMBER SPECIES IN THE ASENANYO RIVER FOREST RESERVE, GHANA

A Thesis submitted to the Department of Theoretical and Applied Biology in partial fulfillment of the requirement for the award of the Master of Science degree in Environmental Science

By:

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DECLARATION

I hereby declare that this work entitled "EFFECTS OF SELECTIVE LOGGING ON ADVANCED REGENERATION OF TIMBER SPECIES IN THE ASENANYO RIVER FOREST RESERVE, GHANA" is a true account of my own research work under supervision with the exception of references which have been dully acknowledged.

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DEDICATION

I dedicate this dissertation to my mother and son, Mrs. Christiana Sefah Boateng and Enoch Owusu Boateng Jnr.

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ABSTRACT

Selective logging is the most commonly adopted method for the extraction of timber resources from natural forests in most tropical countries including Ghana. This low intensity logging system results in less damage to the residual forest and soil, and ensures sufficient regeneration but is often associated with adverse impacts on advanced regeneration and soil due to the use of heavy logging machines. However, such effects have received little scientific scrutiny. In this study, the composition and structure of advanced regeneration of timber species, and soil physico-chemical properties at varied levels of disturbance were investigated in the Asenanyo River Forest Reserve to provide insights into the effects of logging, and to help inform sustainable management of production reserves. Floristic and soil samples were collected from forty 25 m × 25 m plots randomly laid in five habitats representing three disturbance levels (i.e., undisturbed, slightly and heavily disturbed sites) and two post-logging times (i.e., 5 and 15 years). Shannon and Simpson diversity indices were somewhat higher in the slightly disturbed habitat compared to the other habitats. Means of basal area and density were significantly higher in the undisturbed and slightly disturbed sites, respectively ($P < 0.05$). Soil properties analyzed did not differ significantly among studied habitats with the exception of water holding capacity. Post-logging time had the highest explanatory power for the diversity indices whilst the level of disturbance best explained the evenness and density of advanced regeneration in the reserve. The basal area of advanced regeneration best explained by interaction of site and post-logging time. A non-metric multidimensional scaling ordination showed considerable similarities in species composition among the studied habitats except between the undisturbed and the heavily disturbed (15 year postlogging). Results generally suggest minimal effects of selective logging on advanced regeneration of timber species and soil physico-chemical properties. However, a slight improvement in the composition and structure of advanced regeneration in the slightly disturbed habitats reflects a positive impact of moderate disturbances in line with the intermediate disturbance hypothesis. Reducing logging disturbances that result from movements of machinery such as skidders and timber trucks, and training staff to ensure minimal adverse effect on soil and advanced regeneration, and promote sustainable timber production.

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ABBREVIATIONS

AAC	Annual Allowable Cut
AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
ASEN	Asenanyo River Forest Reserve
CEPIL	Centre for Public Interest Law
dbh	Diameter at Breast Height
FAO	Food and Agriculture Organization
FC	Forestry Commission
FD	Forestry Department
FMU	Forest Management Unit
FSD	Forest Services Division
GDP	Gross Domestic Product
GHI	Genetic Heat Index
GSBA	Globally Significant Biodiversity Areas
HFZ	High Forest Zone
IDH	Intermediate Disturbance Hypothesis
ISSER	Institute of Statistical, Social and Economic Research
ITTO	International Tropical Timber organization
IUCN	International Union for Conservation of Nature
KC	Messrs. Kumi and Company Limited
MSSE	Moist Semi-Deciduous South-East subtype
MSNW	Moist Semi-Deciduous North-West subtype
MOP	Manual of Procedure

NTFPs	Non Timber Forest Products
RIL	Reduce Impact Logging
SD	Standard Deviation
SRA	Social Responsibility Agreement
SRI	Soil Research Institute
TUC	Timber Utilization Contract
TUP	Timber Utilization Permit
WD	Wildlife Division
YAF	Yield Allocation Formula

CHAPTER ONE

INTRODUCTION

1.1 Background

The tropical rainforest is believed to be the oldest and most complex land-based ecosystem on earth containing over 30 million species of plants and animals, it contains half of the Earth's wildlife and at least two-thirds of its plant species (Peres, Barlow & Laurance, 2006). In addition to its high biodiversity, the tropical rainforest absorbs carbon dioxide and produces oxygen, stabilizes climate, maintains the water cycle and protects against flood, drought, and soil erosion (Peres *et al.,* 2006). The rainforests are a source of medicine, food, fuel, shelter, clothing, and also provide revenue and foreign exchange through the exploitation of timber and ecotourism. A significant percentage of Africans reside in rural areas, where forests and trees perform a range of economic, ecological and sociocultural functions, which are critical to their wellbeing (FAO, 2010).

Despite the numerous benefits, tropical rainforest resources are being depleted at an alarming rate throughout the world. According to the FAO (2010), Africa has the second highest rate of deforestation worldwide—with 3.4 million hectares of forest lost annually. The situation is not different in Ghana, where degradation of forests and the loss of biodiversity through deforestation have increased sharply in recent decades (Dixon, Perry, Vanderklein & Hiol, 1996). It has been estimated that Ghana's high forest, which forms part of the Upper-Guinean Forest and covered an area of 8.2 million hectares at the turn of the last century, had dwindled to about 1.7 million hectares by the mid-1980s (Hall & Swaine, 1981), and about one million hectares by the mid-1990s (FSD, 1996). The principal causes of deforestation and forest degradation in Ghana are agriculture expansion, harvesting of wood/timber, population and development pressures, and mineral exploitation and mining (IUCN, 1992; Agyarko, 2001).

Today, both legal and illegal timber exploitation is recognized to have major impact on forest area and structure in Ghana (FSD, 1996). The same applies to forest reserves, which were originally established to promote environmental stability and to serve as a basis for sustainable timber production (Hawthorne & Abu-Juam, 1995; Agyeman, Swaine & Thompson, 1999). The major proportion of closed forest cover in Ghana is found inside forest reserves as much of the forest in unprotected areas (off-reserve areas) has been lost through various anthropogenic activities (Agyarko, 2001).

Selective timber extraction has consequently been proposed as a more sustainable, low-impact alternative to clear-cut logging in Ghana and other tropical countries (Agyarko, 2001). In Ghana, timber is harvested on a polycyclic selection system; using a 40-year cutting cycle aimed at reducing logging damages and increasing production volume (FD, 1995; Marfo, 2010). Tree selection for logging is based on the interim yield allocation formula (YAF), which incorporates the health and regenerative capacity of the forest as well as the economic relevance of the harvestable tree species (FD, 1995). Consequently, the number of harvested trees per hectare has become generally been reduced; however, damage to remaining trees remains considerable (Johns, Barreto & Uhl, 1996; Johns, 1988; Putz, Blate, Redford, Fimbel & Robinson, 2001).

Several studies indicate that logging directly affects species composition and structure of the forests ecosystem (Silva, De Carvalho, De Lopes, De Almeida, Costa, De Oliveira, Vanclay & Skovsgaard, 1995; Hall, Harris, Medjibe & Ashton, 2003; Okuda, Suzuki, Adachi, Quah, Hussein & Manokaran, 2003; Asase, Asiatokor, & Ofori-Frimpong, 2014). Although logging may encourage a new balance of regeneration of timber species, most of the vegetation present at the time of logging—the advanced regeneration (Ashton, 1990)—is often destroyed (Sandra & Lugo, 1990; Mwima, Obua, & Oryem-Origa, 2001). The distribution of trees may become less uniform, with gaps separating unlogged patches (Johns, 1988; Johns *et al*., 1996). Stimulated by increased light levels, rapidly growing shrubs frequently become dominant, attracting seed predators like rodents and insects, and herbivores that tend to influence timber species regeneration (Johns, 1988). Construction of forest roads and activities of logging machines may cause erosion and runoff, compact soil, and remove topsoil and seedlings, resulting in limited regeneration and change in vegetation composition (Johns, 1988). On the other hand, decomposition of debris including remains of the felled trees release nutrients for the development of the residual stand (Jonkers, 1987). As a consequence, the advanced regeneration of timber species, and thus the quantity and the quality of timber resources may be affected.

1.2 Problem statement

Despite the associated collateral damage and extensive disturbance of the forest stand (Asner, Keller, Pereira, Zweede & Silva, 2004), selective logging is generally expected to have a positive influence on the natural regeneration (Makana & Thomas, 2005). For example, harvested trees and the activities of machines used in logging create larger canopy gaps, thus enhancing light availability in the forest and hence natural regeneration and juvenile growth (van Ulft, 2004). The extent of logging impacts varies for different tree size classes. According to Mwima *et al*. (2001) small trees are much more vulnerable to destruction as they suffer severe injury than larger ones. Thus, selective logging may increase the frequency and intensity of disturbance to juvenile trees (van Ulft, 2004). The extraction of logs by skidders destroys much of the vegetation in logging gaps and on skid trails, removing the advanced regeneration which forms the majority of the successful regeneration of timber species in natural gaps (Johns 1988). Beside the effect of logging on vegetation, activities of logging machines such as skidders and loading trucks also disturb forest soils, through compaction and erosion which in turn hinder natural regeneration (Johns, 1988).

Through fragmentation and the opening of the forest to illegal hunting activities, logging can affect animal populations that disperse and consume seeds, (Chiarello, 1999). A reduction in the population of animals which disperse fruits and nuts in forest would negatively affect natural regeneration of tree species.

The natural regeneration of desired timber species in a sufficient abundance and frequency is crucial for sustainable forest management to compensate for the extraction of those species and guarantee adequate timber yields on future harvests (Poorter, Bongers, Van Rompaey & De Klerk, 1996). In general, despite the many direct and indirect effects of logging on forest ecosystems, this subject has received little attention among foresters in Ghana.

1.3 Justification/Significance of Study

Understanding the relation between natural regeneration of trees and selective logging is necessary for regulating and maintaining the high tree species diversity and ecological processes in the tropical rainforests (van Ulft, 2004). This knowledge is critical as pressure on forest imposed by logging mounts. Information on responses of advanced regeneration of timber species to logging would greatly assist in defining forest management strategies that promote sustainable timber extraction and minimize the effects on species diversity (van Ulft, 2004). However, there is a dearth of information on the effects of logging operations on natural

regeneration (especially timber species) in Ghana (Agyeman *et al*., 1999). Further, the few studies on this subject have produced conflicting results. Sapkota, Tigabu & Oden (2009), for example, observed an increase in the relative seedling density of tree species with gap size, suggesting enhanced timber trees regeneration. On the contrary, Hawthorne, Marshall, Abu-Juam & Agyeman,
(2011) and Wiafe (2014) showed that forest stands logged between 10 and 30 years had lower densities of timber trees in disturbed areas than in the unlogged areas.

1.4 Objectives

The aim of this study was to assess the effect of selective logging disturbance on advanced regeneration of timber species in Asenanyo River Forest Reserve in the Ashanti Region of Ghana.

Specific objectives were:

i. To assess the effects of selective logging disturbance and post-logging time on composition and structure of the advanced regeneration in the Asenanyo River Forest Reserve.
ii. To determine the effect of logging disturbance and post-logging time on the conservation status of the advanced regeneration of the Asenanyo River Forest Reserve.
iii. To investigate the responses of soil physico-chemical properties to logging disturbance and post-logging time.

It was hypothesized that the composition and structure of the advanced regeneration would differ among forest stands that experienced different levels of selective logging disturbance, and with respect to the time after logging. The Genetic Heat Indices (GHIs) were expected to differ among the studied sites of different disturbance levels and post-logging time. Soil physico-chemical properties were also predicted to vary among sites that differed in disturbance levels and post-logging time.

CHAPTER TWO

LITERATURE REVIEW

2.1 Forest Resources in Ghana

Ghana is divided into three (3) main vegetation zones, which run approximately parallel to the equator, a phenomenon largely attributed to climatic factors, notably rainfall and temperature (Hawthorne, 1995a). Ghana's total forest cover stands at 1.6 million hectares comprising of both forest reserves and off-reserves areas (Hawthorne, 1995b). The high forest zone (HFZ) mainly in the southwestern part occupies a third of the country (about 34 percent of land area) and consists of forests ranging from wet evergreen to dry semi-deciduous (Appiah, Blay, Damnyag, Dwomoh, Pappinen & Luukkanen, 2009). It is the region with the highest precipitation in the country, where rainfall may reach 2300 mm in the wettest parts (wet evergreen zone).

The high forest zone falls within the Biodiversity Hotspot of the Upper Guinean forests of West Africa, one of the 36 most important biodiversity areas in the world (Affum-Baffoe, 2010). The savannah region, the driest area of Ghana covers approximately two-thirds of the country and the third zone is a relatively small area of the transition zone, which lies between the High Forest and the Savannah Zones (Affum-Baffoe, 2010). There is also an extensive coastal area in Ghana, which hosts a variety of wetlands (FAO, 2001).

The two (2) main categories of protected areas in Ghana are the forest reserves and the wildlife reserves. There are 282 Protected Areas covering a total area of 22,754 km^2 with 216 of them located within the high forest zone (FAO, 2001). The Forest Services Division (FSD) and the Wildlife Division (WD) manage the forest and wildlife reserves, respectively. The forest reserves are categorized into Production (about 80 percent) and Protection (about 20 percent) reserves (AffumBaffoe, 2010). Controlled extractive activities such as logging are permitted in the Production reserves but the Protection reserves are established for conservation purposes. Thirty (30) forest reserves in the HFZ covering an area of 1,034.52 km^2 found to have a high concentration of biological resources of global conservation importance have been designated as Globally Significant Biodiversity Areas (GSBAs) where logging and other extractive activities are prohibited (Affum-Baffoe, 2010).

The management of the wildlife reserves is aimed at biodiversity conservation. Therefore access and use of the natural resources are limited (FAO, 2001). Ghana has seven (7) national parks, one (1) strict nature reserve, six (6) resources reserves, two (2) wildlife sanctuaries and five (5) Wetlands of International Importance (Ramsar sites; excluding the Owabi wildlife sanctuary; FC, 1994).

2.1.1 Importance of Ghana's Forest

The tropical high zone forest plays a crucial role in defining the cultural identity and traditional beliefs of Ghanaians (Hawthorne, 1995b). Major areas of importance include the following:

2.1.1.1 Economic importance

Forest and wildlife resources have long been major contributors to Ghana's economic development, formal and informal employment, livelihoods and export earnings. Forestry and logging accounted for 3.7 percent of GDP and contributed 7.6 percent of total export earnings in 2009 (FAO, 2001). The timber industry is the third most important foreign exchange earner and one of the fastest growing manufacturing units in the country (ITTO, 2006). It is estimated that forest and wildlife serve as a source of livelihood for about 2 million people (ITTO, 2006). A wide mix of actors and rural households depend on forest resources for their livelihoods, ranging from small scale carpentry, hunting, and woodfuel collection to the gathering and commercialization of diverse non-timber forest products (NTFPs) (ITTO, 2006).

2.1.1.2 Importance to energy supply

According to the Energy Commission of Ghana (2006), the primary indigenous energy sources in Ghana are from the forestry sector. Biomass in the form of firewood and charcoal dominates the total energy consumed in the country averaging 67 percent in 2008.

2.1.1.3 Sociocultural benefits

Most of the rural population depends on the forest for their survival. Forest plays significant roles in the provision of food, clothing, potable water, herbal medicines and bushmeat (Aduse-Poku, Nyinaku, Atiase, Mensah, Nyantakyi, Owusu & Agyenim-Boateng, 2003). In some cases, specific forest resources serve as cultural symbols, linking people to their past. Ntiamoa-Baidu (1987) found that

Chlorophora excelsa and *Ceiba pentandra* are sacred trees in most parts of the West African region—the trees are associated with fertility, birth and ancestral spirits. Asamoah (1985) noted that in the Volta region of Ghana, bark and leaves of *C. pentandra* are believed to expel evil spirits. Trees also serve as physical boundary markers that define property and provide evidence of ownership rights in judicial disputes (Ntiamoa-Baidu, 1987). Most people are strongly linked with forest, associated trees and animals for they serve as the dwelling place of gods (dwarfs), serve as sacred groves and "arbre a palabre" and totems (Asamoah, 1985; Oyakhilome, 1985). Sacred groves are sites of ancestral burials and ritual healings while "arbre a palabre" is a venue usually under a big tree where political, judicial, and social decisions are made by elders of a community/village (Oyakhilome, 1985; Aduse-Poku *et al.*, 2003).

2.1.1.4 Biodiversity/research/educational importance

The biological diversity of Ghana's high forest zone is considerably high and accounts for most of the country's biological diversity (FAO, 2001). Ghana's forest hosts about 3725 higher plant species including 730 tree species, 225 mammals and 724 resident birds (FAO, 2001). Ghana has some 1185 known species of amphibians, birds, mammals and reptiles of which about 0.8 percent are endemic (FAO, 2001). The forests provide grounds for many scientific researches/studies into health, food/agriculture, and hydrological works (Aduse-Poku *et al.*, 2003).

2.1.1.5 Ecotourism benefits

Most of Ghana's forest reserves, including the national parks, resource reserves, wildlife sanctuaries, strict nature reserve and coastal wetlands serve as ecotourism centres in the country (FAO, 2001). These forest habour many unique natural and cultural resources with endemic species such as *Talbotiella gentii*, historical caves, beautiful rock formations and waterfalls, which serve as major attractions to tourists (Asamoah, 1985; FAO, 2001).

2.1.1.6 Environmental benefits

The forest also provides environmental services such as carbon dioxide sequestration, production of oxygen, nutrient cycling improvement, soils regeneration, maintenance of local and regional climate, soil organisms, water cycle, rainfall levels and protection of waterbodies and soils (Amisah, Gyampoh, Sarfo-Mensah & Quagraine, 2009).

2.2 Forest Degradation and Deforestation

Ghana, like many tropical countries, continues to lose its remaining closed forests at an alarming rate. Between 1990 and 2005, Ghana has lost about 1.9 million hectares of forest with an annual deforestation rate of 2.0 % (FAO, 2005). It is estimated that about 20,000 hectares of the reserved area are lost to agriculture, bush fires and other human activities each year (IUCN, 1992). Through deforestation and forest degradation, most of the forests have lost their pristine interior habitats that are critical for the protection of vulnerable species (FAO, 2001). Deforestation as defined by Williams (2006) is the removal of a forest or stand of trees where the forestland is thereafter converted to a non-forest use such as farms and ranches while forest degradation refers to the deterioration/decline of the structure and/or the species composition of a forest stand as a result of disturbance (FAO, 2005). In 1992, it was estimated that only about 1.5 million ha of "intact closed forest" remained in Ghana (Agyarko, 2001).

In Ghana, commercial agriculture is the most important driver of deforestation, followed by subsistence agriculture (IUCN, 1992; Agyarko, 2001). Commercial logging/timber exploitation is also a major cause of forest destruction. Logging is a key export activity in Ghana, which is one of the top world exporters of veneer and tropical sawnwood (Appiah *et al.*, 2009). Though commercial logging in this country is mainly selective, the activity leads to the depletion of certain tree species while creating significant damage to remaining stands (FAO, 2001). Other factors causing deforestation and degradation of forests in Ghana include annual bushfires, surface mining and infrastructural development (FAO, 2010). Underlying these degradation and deforestation include poverty, forest policy failures, unrealistic forest fee regimes, and higher foreign prices of timber, weak institutional structures, and population pressures (FAO, 2010).

2.3 Logging Procedures in Ghana

The general aim of forest management in most tropical countries is "the sustainable production of timber while maintaining environmental quality and social responsibility" (Hawthorne *et al*., 2011). Timber production is an important component of Ghana's economy as the timber industry is the third most important foreign exchange earner of the country. This industry is one of the fastest growing manufacturing units, generating employment and income to a majority of Ghanaians (ISSER, 1992). The Forestry Commission (FC) under the Ghana's 1992 constitution has the mandate to protect, manage and develop the nation's forest and wildlife resources (FC, 1994).

Large-scale timber exploitation has been controlled since colonial times through the allocation of cutting rights, where a legally defined area of forest is granted by the state to a private sector concessionaire for a given period of time (CEPIL, 2009). These cutting rights give the concessionaire the right to harvest and market the timber obtained under a regulatory regime that is set and overseen by the FSD (CEPIL, 2009). About some 762,000 ha has been allocated for timber production in forest reserves excluding production areas in off-reserves, permanent protection and convalescence areas (Marfo, 2010). The Annual Allowable Cut (AAC) for forest reserves and off-reserves has been set at 500,000 m^3 each to give a national figure for the total AAC of one million m^3 (Adam, 1999). In Ghana, timber is harvested under a polycyclic selection felling system using a cutting cycle of 40years (Marfo, 2010).

The procedure for obtaining timber rights is regulated by the Timber Resource Management Act, 1998 (Act 547) and the Timber Resources Management Regulations, 1998 (L.I. 1649; Adam, 1999). The right to harvest timber is obtained through a process of competitive tendering and the issuance of a longterm Timber Utilization Contract (TUC) or temporary permits such as Timber Utilization Permit (TUP) and salvage permits. TUPs are intended for noncommercial timber harvest from the forest such as the supply of timber for community development projects even though there is ample evidence of their abuse and use for commercial purposes (Marfo, 2010). The TUCs seek to tighten the planning controls on timber utilization and ensure that the interests of the communities and land owners are fully taken into account through the definition of the Social Responsibility Agreements (SRAs) (Adam, 1999).

According to the Manual of Procedure (MOP) of the Ghana Forest Services (1998), the procedures for timber production can be summarized into three broad activities: (a) identification of TUC/timber harvestable area; field checks, demarcation of boundaries, etc., (b) preparation of the contract; advertisement of TUC, SRAs, evaluation and award of contract, etc., and c) management of the TUC area; stock survey, yield estimation, exploitation, compartment closure.

A TUC may be suspended or terminated on the grounds of (CEPIL, 2009): (a) breach of the terms or conditions of the contract (b) loss of means to manage the resource (c) area of contract not suitable for timber utilization and (d) holder charged or convicted of a forest offence.

2.3.1 Impacts of Selective Logging

Though Ghana practices selective logging system, which involves felling of few trees per hectare, several trees are destroyed and soil is exposed due to the use of heavy machinery for extraction (Johns, 1988; Cannon, Peart, Leighton & Kartawinata, 1994).

The intensity of disturbance caused by selective logging is in general related to the number of trees harvested and the logging equipment used (Webb, 1998). This disturbance has been considered by some to produce little effect on forest structure, composition and dynamics (Webb, 1998). However, others researchers have reported considerable changes in species composition (Silva *et al*., 1995), forest structure (Hall *et al*., 2003; Okuda *et al*., 2003), nutrient cycling (Congdon & Herbohn, 1993; Asase *et al*., 2014) and genetic diversity (Jennings, Brown, Boshier, Whitmore & Lopes, 2001; Asase *et al*., 2014).

Silva *et al*. (1995) revealed that logging significantly reduced the number of shade tolerant species but stimulated the germination and growth of light demanding species in the Amazonia. Hall *et al.* (2003), reported substantial alteration in the composition of Central African forest after selective logging—trees with diameter at breast height (dbh) greater than 10 cm, lianas, and re-sprouting stumps were more abundant in plots 10 years after logging compared to unlogged areas. Okuda *et al.* (2003) also reported greater mean canopy height in primary forest (27.4 m) than in disturbed areas (24.8 m), as was the variance in height and the number of emergent canopy trees with heights of or greater than 40 m. Also, the mean canopy surface area and mean crown size in primary forest were nearly 1.5 times and twice the corresponding values in disturbed forest in Malaysia (Okuda *et al*., 2003).

Species richness was significantly higher in gaps than in control areas, and there was more diversity in species composition among gaps (Jennings *et al*., 2001). However, Jennings *et al.*, (2001) also found that there was a low recruitment rate per gap, which explains why gaps differed in species composition—2-3 % for pioneer species and 3-6 % for shade-tolerant and intermediate species–suggesting that most species could not take advantage of gaps. Asase *et al.* (2014) recorded significantly higher mean Shannon diversity index in post-logged than unlogged forest in southwest Ghana but there were no significant differences in tree density, dominance, or dbh size class distributions between these forest types. Also, soil physico-chemical properties such as pH, bulk density, available phosphorus, exchangeable potassium and total nitrogen contents were all similar in the two forests types (Asase *et al*., 2001).

Congdon and Herbohn (1993) and McNabb, Miller, Lockaby, Stokes, Clawson, Stanturf & Silva, (1997) found out that most disturbed areas such as roads and loading sites had the litter biomass removed hence reduced soil carbon (C), nitrogen (N), phosphorus (P), particularly organic P and C but higher soil moisture, pH, calcium (Ca), potassium (K) and Magnesium (Mg). McNabb *et al.*

(1997) attributed the relatively lower values of C, N and P to reduced biological inputs due to persistent soil compaction. McNabb *et al.* (1997) also attributed the higher exchangeable cations to the replacement of dominant species by lightdemanding, fast-growing *Cecropia* species that act as Ca and Mg "pumps", reducing conditions in compacted areas and freeing exchange sites to retain Ca and Mg after logging in the Amazonian rainforest.

Despite the associated problems, these disturbances are generally presumed to be essential to maintain the high biodiversity of tropical rain forests (Brokaw, 1985, van Ulft, 2004) as many canopy tree species fully depend on large gaps for successful regeneration (Denslow, 1980). The felling and extraction of selected timber creates canopy gaps and this increases the light availability on the forest floor which is essential for the growth and establishment of advanced regeneration (Cannon *et al.*, 1994).

2.3.2 Reduce Impact Logging

Reduced impact logging (RIL) technology is a collective term that refers to the use of scientific and engineering principles, in combination with education and training, to improve the application of labour, equipment and operating methods in the harvesting of industrial timber (Pinard and Putz, 1996). This technology came about as a result of the numerous adverse effects associated with conventional logging techniques on the environment (Pinard and Putz, 1996). Putz *et al*. (2008)

suggested the following activities to ensure that RIL has minimum impact on the environment:

(a) Make a pre-harvest inventory and mapping of individual crop trees
(b) Plan the movements of logging machinery
(c) Cut vines two years prior to logging as this ensures that when trees are cut, other trees connected to them by vines are not pulled down
(d) Train loggers in the use of appropriate felling and bucking techniques including directional felling, cutting stumps low to the ground, optimal crosscutting of tree stems, etc.
(e) Monitor and assess the condition of the forest in terms of canopy, seedling availability, and biodiversity, and
(f) Conduct post-harvest assessments to evaluate the degree to which RIL guidelines were adhered to.

2.4 Forest Regeneration

Forest regeneration is the act of renewing tree cover by establishing young trees either by natural or artificial means after a disturbance such as fire, logging and storm (Brown, 1993). An essential part of forest stewardship involves the careful planning and management of young trees and seedlings (Okuda *et al*., 2003). When an opening has been created in the forest canopy, there is an opportunity to influence what plants or trees will become established and thrive (Brown, 1993). In some situations, regeneration will occur in the opening when nearby trees drop seeds—natural regeneration—whilst in other situations, planting seedlings may be of value—artificial regeneration. Ensuring adequate regeneration and sustained productivity is at the heart of any scientific silvicultural system (Denslow, 1980). Exploitation of tropical forest for timber causes canopy opening, leading to changes in microclimate, which influence the remaining trees (Brown, 1993; Okuda *et al.*, 2003). Reduced competition, principally for light, not only increases growth rates of some of the remaining trees, but also mortality of shade-tolerant trees (Brown, 1993; Putz, Sist, Fredericksen & Dykstra, 2008). For tree seedlings, similar effects occur, but with greater magnitude (Putz *et al.,* 2008). The manner and the intensity of logging operations can have a profound influence on the recovery of the forest as microclimatic changes vary with the size of canopy openings (Chapman and Chapman, 1997). According to Denslow (1980), the extent of forest regeneration is determined by site conditions such as soil nutrients, moisture, pH and light regime. At any moment in the regeneration process, an individual tree may die, for example, following predation or due to adverse microclimatic conditions. The failure of a species to regenerate will ultimately result in its (local) extinction (Denslow, 1980). Different tree species have developed different regeneration strategies over millions of years of evolution. Some trees produce many, small seeds and depend upon wind for their dispersal. Other trees produce a few, large seeds and depend upon animals for their dispersal while others sprout from stumps and roots (Brokaw, 1985). Some tree seeds need little light or heat in order to germination while others needs much heat and light (Denslow, 1980; Brokaw, 1985).

2.4.1 Natural Regeneration

Natural regeneration is 'the renewal of a forest crop by self-sown seed or by coppice of root suckers (Pariona, Fredericksen & Licona, 2003). Forests depend on adequate regeneration of tree species to be healthy and sustainable (Chapman and Chapman, 1997). The presence of young trees in the forest understory is necessary to sustain forest development after timber harvest or natural disturbances that create canopy gaps (Mwima *et al.,* 2001).

Natural regeneration relies entirely on natural seed sources or sprouting and little on human interventions (seedbed preparation, seed selection; Bahati, 1995). Natural regeneration can be an effective means of regenerating the forest when conditions are right. Although natural regeneration is usually reliable and ensures that only the trees suited to the site (the species already on the site) are established, the time delays in achieving regeneration can be long (Bahati, 1995). Successful natural seeding requires among other conditions: (a) the presence of a seed source such as healthy mature individuals in or near the area to be regenerated, (b) supply and germination of sufficient numbers of healthy, viable seed, and (c) a site favorable for germination. According to Bahati (1995), a number of optional management interventions may be required, depending on the respective site conditions for successful natural regeneration. These interventions include seedbed preparation (e.g., scarification), vegetation control (e.g., herbicide), game control (e.g., fencing) and pest control (e.g., repellents). Natural regeneration may also be established using various methods including all continuous cover silvicultural systems (e.g., shelterwood selection), seed tree retention cutting, small-scale clear-cutting with seed trees in the vicinity, or coppicing (Bahati, 1995).

Some merits of natural regeneration according to Pariona *et al.* (2003) are: (a) Less heavy equipment and labor is required as land preparation is usually not necessary, (b) Seedlings are naturally hardened-off—seedlings have naturally shaped root system unlike seedlings which have been grown in a nursery, and (c) Provides better conservation of local biodiversity and amelioration of ecosystems. According to Pariona *et al.* (2003), some demerits associated with natural regeneration are: (a) Seedlings or seeds may not survive due to high competition from surrounding vegetation for nutrients, soil moisture, light and pests/diseases, (b) Sole dependence on fructification and seed production, and (c) Long risk period as a successfully regenerated site may take longer period to reach harvest than with direct seeding or planting.

2.5 Forest Succession after Logging Disturbances

Succession is an ecological process that changes the biotic community structure towards a more stable, diverse community structure after an initial disturbance to a community (Connell & Slatyer, 1977). Succession expresses the differences in colonizing ability, growth and survival of organisms adapted to a particular set of conditions on an environmental gradient—the process through which regeneration is achieved (Smith, 1980).

When gaps are formed in a forest canopy, growth of advanced regeneration within gaps is promoted and/or new seedlings colonize these gaps. Seedlings of shadeintolerant/pioneers species are often established in larger gaps with exposed mineral soils, while in smaller gaps advanced regeneration of shade-tolerant species is dominant (Swaine & Whitmore, 1988). The patterns of tree seedling establishment in gaps have been studied in relation to seedling responses to various microsite environments (such as light and moisture) within gaps (Brokaw, 1985; Swaine & Whitmore, 1988; Whitmore, 1989).

According to Wong (1989), three (3) ecological guilds/groups of species can be observed in the tropics on the basis of sunlight requirements: a) Pioneer species—light demanders that require full sunlight to enable their seeds to germinate and establish. Pioneer species regenerate abundantly after a forest disturbance such as logging, b) Non-pioneer light demanders which germinate in the shade of undisturbed forest but die in few years if the canopy remains undisrupted and c) Shade-bearers/shade tolerant species which are found in understory and flourish in unlogged/undisturbed forest. There are also cryptic pioneers which although regenerate in gaps under canopy tolerate shade later in life and have been misclassified with shade-bearers in practice (Hawthorne, 1993).

Natural regeneration of tropical trees varies from species to species (Swaine & Whitmore, 1988). The sizes of gap created during logging determine the type of species and the extent of natural regeneration (Swaine and Whitmore, 1988).

Felling gaps and skid trails create medium sized openings which favour the natural regeneration of most economic timber species—many of which are nonpioneer light demanders—compared to other gaps such as forest roads and loading bay (Hawthorne, 1993; Swaine, Agyeman & Adam, 1998). Small and large gaps (such as single tree fall, multiple tree fall, haulage roads and loading bays) results in reduced regeneration and a decline in the economic value of tropical high forests of Ghana (Hawthorne, 1993; Swaine *et al*., 1998). Swaine *et al*. (1998) opined that logging disturbances markedly reduced the pre-existing tree seedlings in felling gaps and skid trails. However, regeneration in small gaps and skid trails was enhanced three (3) years in Bia-South Forest Reserve (Hawthorne, 1993) and 15 years after logging in wet and dry forests (Appiah *et al*., 1998). This underscores the importance of disturbances/gaps created as a result of logging in natural regeneration of economic timber species (Whitmore, 1989).

2.6 Species Conservation Star Rating

The star rating system is "a category of conservation priority assigned to each forest species of vascular plant in Ghana" (Hawthorne, 1993). The star rating system assesses the conservation value of plant species by their global distribution such that the more widely a species is distributed, the less merit accorded in conservation rankings and species that are rare and/or endemic and threatened are more valuable than others (Hawthorne, Grut & Abu-Juam, 1997). Plant species are ranked as green, pink, red, scarlet, blue, gold or black stars in increasing order of conservation importance (Table 1) (Hawthorne & Abu-Juam, 1995). However, the star ratings did not cover weedy species or savannah species and was also poor for epiphytes as there is scanty knowledge on its local distribution and ecology (Hawthorne, 1993).

The presence of rare star-rated species in a forest is one of the important indicators of high biodiversity or richness of the forest (Swenson, 2009). It also indicates the level of management of the forest since they cannot withstand wildfires and forest degradation (Swenson, 2009). The abundance of star-rated species determines the Genetic Heat Index (GHI) of the forest hence a high GHI signifies that the area is relatively rich in rare species (Hawthorne and Abu-Juam, 1995) and therefore degradation of the area would represent a highly significant erosion of genetic resources. The following GHI values are defined by Hawthorne (1996) for the various conservation classes: Very high conservation value for GHI > 200; High conservation value (150 ≤ GHI ≤ 200); Moderate conservation value (100 ≤ GHI < 150); Low conservation value (50 ≤ GHI < 100) and very low conservation value (GHI < 50).

Table1: Conservation Star Rating for Ghanaian Plant Species with their respective weight of Genetic Heat Index (GHI)

Colour	Weight of GHI	Description
Black	27	Highly significant in context of global biodiversity; Rare globally and not widespread in Ghana.
Gold	9	Significant in context of global biodiversity; fairly rare globally and/or nationally.
Blue	3	Mainly of national biodiversity interest; e.g. globally widespread, nationally rare; or globally rare but of no concern in Ghana due to commonness.
Scarlet	1	Common and widespread commercial species with potential seriously threatened by overexploitation.
Red	1	Common and widespread commercial species; under significant pressure from exploitation.
Pink	1	Common and widespread commercial species; not currently under significant pressure from exploitation.
Green	0	Species common and widespread in tropical Africa; no conservation concern.
Others	0	Unknown, or non-forest species e.g. ornamentals or savannah plants.

Sources: Hawthorne and Abu-Juam (1995); Vermeulens and Koziell (2002)

2.7 Soil Nutrients and Forest Regeneration after Timber Harvesting Soil is the support medium in which tree seedlings remain attached, sprout from, and subsequently depend upon for further growth (Uhl & Clark, 1983). This implies that the status of forest soil largely affects the germination/establishment and regenerative capacities of seeds/tree seedlings. Most soils suitable for tree seedlings growth in the tropics have a well-balanced soil nutrients, exchangeable cations (Ca, Mg, K and Na), optimum pH levels (usually from 6.0 to 7.0), low bulk densities, higher levels total nitrogen, organic carbon and organic matter (Brown & Lugo, 1982).

Forest disturbances such as logging cause forest degradation, which increases losses of carbon, nitrogen, phosphorus, and sulfur from the forest ecosystems (Congdon & Herbohn, 1993; McNabb *et al*, 1997). Where reforestation programmes rather than conversion other than forest land uses follow degradation, the effects of disturbances on soil may be magnified. The major causes of organic carbon losses are harvesting of trees, burning of forest residue, and erosion (John, Dalling, Harms, Yavitt, Stallard, Mirabello, Hubbell, Valencia, Navarrete, Vallejo & Foster, 2007). Nitrogen and sulphur are lost by the same pathways; aside leaching of nitrate and sulphur to streams and groundwater and by the anaerobic production of nitrogen and sulphur containing gases (John *et al*.,

2007). Phosphorus is lost primarily through harvest and erosion (John *et al*., 2007). Losses of these elements following deforestation are most rapid in sites with high decomposition rates, especially in the tropics. The interactions of carbon, nitrogen, phosphorus, and sulphur cycles affect losses of many elements through nutrient limitations to biological transformations, ratios of element availability, which cause either biological mobilization or immobilization, and anion/anion interactions in the soil solution (Brown & Lugo, 1982).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location and Extent

The Asenanyo River Forest Reserve lies between latitudes $6^{\circ} 17'$ and $6^{\circ} 36'$ north and longitudes $1^{\circ} 50'$ and $2^{\circ} 16'$ west, and about 70 km from Kumasi. The reserve is currently under the Forest Management Unit (FMU) 37. The Asenanyo River Forest Reserve is a continuous block covering an area of 22792 hectares (Appendix II; Figure 1) in three district assemblies (namely, Atwima Nwabiagya, Atwima Mponua and Amasie West) and divided by the Kumasi-Bibiani road into two unequal halves. The reserve shares a common boundary with the Tano-Offin Forest Reserve to the north along a stretch of about 5.58 km. The Asenanyo River Forest Reserve has a total of 204 compartments (FC, 2010). The forest reserve comprises of productive area (15991.97 ha), unproductive area (5751.03 ha), admitted farms and village (1049.00 ha; Appendix II Figure 1; FC, 2010). The unproductive area includes sites under research, protection, convalescence, conversion, plantation and teak (*Tectona grandis*) seed orchard.

3.1.2 Status and Property/Communal Rights

Ownership of the reserve is vested in the Golden Stool for which the stools of Nkawie Kuma, Nkawie Panin, Nyinahin, Domi Keniago, Manso-Nkwanta and Akwamu all act as caretakers. Under the Ashanti Rule No. 6 of 1940 made by the

Asantehene and his councilors, the forest reserve was selected and maintained as such and published in Gazette No. 35 of 18/5/40 (Reserve Settlement Commissioners Report, 1940). The reserve was constituted under the Kumasi Native Authority Rules of 15th December, 1949 and approved by the then Governor-in-Council.

Individual and communal rights in the forms of admitted farms and natural benefits respectively are permitted in the reserve. In this regard, the fringe communities have domestic user right over a variety of NTFPs such as foods (snails, bush meat, mushrooms, fruits), medicine (tree bark, herbs, leaves), building materials (poles, bamboo) and household goods (pestles, brooms, mats).

Hunting of game is regulated by the Wildlife Division (WD) of the FC through the issuance of permits. Currently, Messrs Kumi and Company (with the property mark 'KC') has the right of timber harvesting in the whole reserve with the exception of Akota village.

3.1.3 Climate and Physical Features

There are two well-defined seasons: a rainy season from April to October, and a dry season from November to March. The reserve lies in the two-peak rainfall belt, with the maximum during May-June and the minimum during SeptemberOctober. The Asenanyo River Forest Reserve lies in the 1250-1500 mm isohyets zone (Hall & Swaine, 1981). However, figures from the nearest meteorological station at Bibiani indicate average rainfall from 2005-2009 as 1051-1522 mm.

The mean monthly temperature of the area for the period 2005-2009 was 27.9 ºC and the mean annual relative humidity recorded is about 84 %. The southwesterly wind which is the prevailing wind experienced during the rainy season changes to northeasterly (Hamarttan) during the dry season (FC, 2010).

The land is undulating over the greater part of the reserve with an average height of 152-198 m above sea level. There are hill ranges trending north-west in the southern tip of the reserve; these ranges average 259 m to over 305 m. A conspicuous hill among them is the Sumtwitwi Bepo which rises to 546 m (FC, 2010). These ranges are associated with differential erosion of the constituent rocks. The reserve forms part of Tano-Offin watershed (FC, 2010).

3.1.4 Flora and Fauna

Taylor (1960) classified the Asenanyo reserve as belonging to the *CeltisTriplochiton* association, whilst Hall and Swaine (1981) put the reserve within Moist Semi-Deciduous North-West subtype (MSNW). The area of the Asenanyo River Forest Reserve to the north of the Asenanyo River falls under the Moist Semi-Deciduous South-East subtype (MSSE; Addey & Baker, 1995). Taylor (1960) and Hall and Swaine (1981) further described the structure of the reserve as consisting of three distinct storeys—the upper, middle, and lower canopies with tall emergent trees exceeding 50 m and sometimes 60 m. In the central portions of the reserve, *Turraeanthus africanus* is found in patches, while marsh or swamp forests with raphia palms are frequently observed. The reserve could be described as an open forest. The gaps are evenly spread over the entire reserve, with wider openings in recently logged areas where the undergrowth is dense. Hence, the forest in the northern and southern portions can generally be considered as secondary while the central portion can be described as primary albeit in a collapsing condition.

A total of 192 tree species have been recorded in the reserve of which 66 are timber species (Hall & Swaine, 1981). This figure falls far below the MSNW vegetation zone estimate, which stands at 335 trees species. Timber species such as *Celtis mildbreadii, Triplochiton scleroxylon, Corynanthe pacheyceas, Pterygota macrocarpa, Antiaris toxicaria, Nesogordonia papaverifera, Sterculia oblongata, Turraeanthus africanus* and *Piptadeniastrum africanum* are well represented above 70 cm dbh (more than 20 stems per 100 ha) in the reserve (FC, 2010). The stocking levels for *Celtis zenkeri, Cola gigantea, Petersianthus macrocarpus, Sterculia rhinopetala, Entandrophragma angolense, Mansonia altissima* and *Terminalia superba* are moderately low while that of *Cylicodiscus gabunensis, Guarea cedrata, Albizia adianthifolia and Tieghemella heckelii* are low compared to the ecological zone (FC, 2010).

The dominant families occurring in the reserve include Moraceae, Sterculiaceae, Ulmaceae, Rubiaceae, Bombaceae and Combraceae. Generally, floristic diversity and life-form categories in the reserve include large trees capable of exceeding 30 m in height, small trees, large climbers, small understorey climber, shrubs, herbs, pteridophytes and epiphytes (FC, 2010).

Very limited information on faunal components of the reserve exist, but recent studies have revealed the presence of twenty nine (29) species covering mammals (*Cercopithecus mona, Civettictis civetta, Potamochoerus porcus* and *Tragelaphus scriptus*), birds (*Melanerpes formicivorus, Cyanomitra obscura* and *Tropicranus albocristatus*), and reptiles (*Dendroaspis viridis*) (FC, 2010).

3.2 Sampling Design

3.2.1 Plot Layout

Out of 138 compartments under production (FC, 2010), three (3) compartments were used in the study; comprising of two (2) logged/disturbed compartments (52 and 109) and an unlogged/undisturbed compartment (27). Compartments 52 and 109 of the reserve were logged 5 and 15 years ago, respectively. Compartment 27 (unlogged) was used as a reference site for this study. The logged/disturbed areas within compartments 52 and 109 were identified and categorized as Heavily Disturbed (HD) and Slightly Disturbed (SD) areas according to the level/degree of disturbance (Hawthorne, 1993). The HD sites consisted of logging roads and loading stations/bays, whereas the SD sites consist of skid trails and stump/felled tree gaps. Roads are the main roads providing access for logging up to the loading stations, skid trails are narrow meandering roads from felled tree gaps on which logs are hauled to the loading bays, which are areas where logs extracted from the forest are sorted and stored for subsequent loading to the mill (Hawthorne, 1993). The disturbed habitats were further categorized on post-logging times (i.e., 5 years and 15 years). Thus, five studied habitats were surveyed in all, namely undisturbed (UD), SD_5, SD_{15}, HD_5, and HD_{15} (subscript figures indicate postlogging times). Eight plots measuring 25 m × 25 m were randomly laid in each studied habitat making a total of 40 sampling plots. Plots were demarcated with the aid of prismatic compass, 50 m linen tapes and ranging poles.

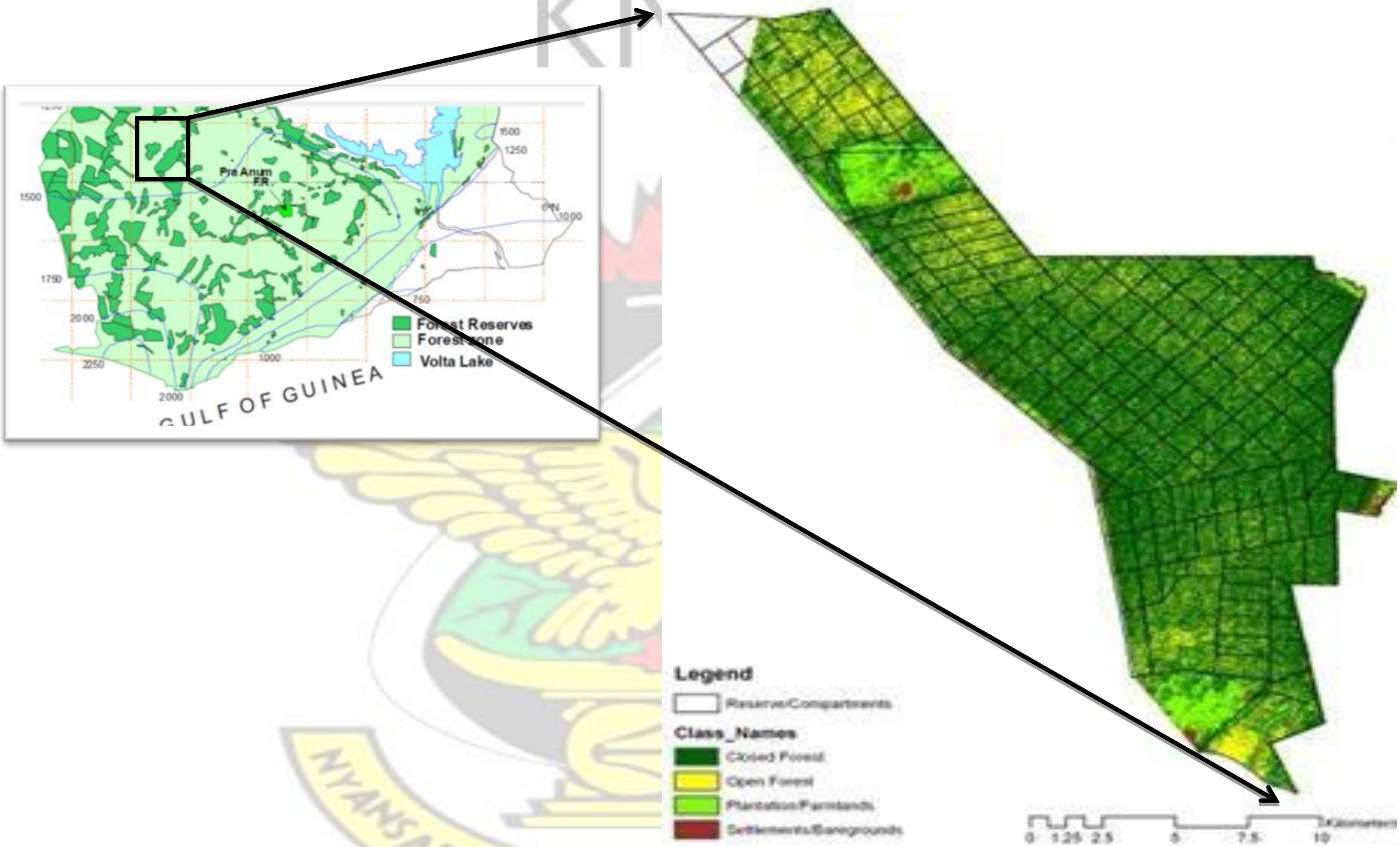

Figure 1: Asenanyo River Forest Reserve (right) with arrows showing its location on map of southern Ghana (left) [49]

3.3 Data Collection Procedures

3.3.1 Floristic Sampling

To assess composition and structure of advanced regeneration of timber species in the various habitats, all tree size classes from saplings (≥ 3.0 cm dbh < 5.0 cm), poles (≥ 5.0 cm dbh < 10.0 cm) and small trees (≥ 10.0 cm dbh ≤ 15.0 cm) were identified, measured and recorded in each of the forty (40) sampled plots. Enumerated trees were tagged to avoid double enumeration. All measurements were recorded on a standardized data sheet (Appendix IV). Nomenclature followed Hutchinson and Dalziel (1954-1972) and JSTOR Global Plants.

3.3.2 Soil Sampling

To test for physico-chemical properties of soils, five (5) soil cores were collected from each plot (0-30 cm; one core at each corner and one core at the centre of a plot; (Dassonville, Vanderhoeven, Vanparys, Hayez, Gruber, & Meerts, 2008) with a soil auger. The five cores were mixed into a single composite sample and a sub-sample taken into a sample bag, labeled, and taken to the Soil Research Institute (SRI), Kwadaso Agric College for laboratory analysis.

Soil samples were air-dried and sieved using a 2 mm sieve. The following soil physico-chemical properties were determined for each sample; pH, electrical conductivity, soil organic matter, exchangeable cations (Na, K, Ca and Mg), total nitrogen and carbon, available phosphorus and water holding capacity.

Determination of Soil pH

To measure pH, 1:1 in water method was employed. In this method, the 1:1 proportions of soil and deionized water suspension was stirred vigorously for 20 minutes and left to stand for 30 minutes before measurement with pH electrode (Black, 1965; Page, Miller & Keeney, 1982).

Determination of Organic Carbon

Soil organic carbon was measured by the wet oxidation (modified Walkley-Black) method (Walkley & Black, 1934; Allison, 1960). Soil samples were treated with 1:2 proportions of 1M $K_2Cr_2O_7$ and H_2SO_4 after which 200 ml deionized water was added. Unreacted $K_2Cr_2O_7$ was determined by titrating with $FeSO_4$ solution.

Determination of Exchangeable Cations

Exchangeable cations (Na, K, Ca and Mg) were extracted in ammonium acetate by shaking for one hour and filtering the supernatant after centrifuging for analysis. Na and K were read on the flame photometer and Ca and Mg were read by atomic absorption spectroscopy (Moss, 1961).

Determination of Total Nitrogen

Total nitrogen (N) determination was based on the Kjeldahl (block digestion) method using steam distillation and titration.

Determination of Electrical Conductivity

Electrical conductivity was measured by treating 10.0 g of soil with 10 ml of deionized water and the suspension stirred for 1 hour and allowed to settle for 30 minutes. The conductivity meter was calibrated using KCl reference solution at the temperature of the suspension and with the electrodes dipped in the supernatant and the readings were taken (Black, 1965).

Determination of Soil phosphorus

Available phosphorus was determined by shaking 7 ml Bray solution:1 g soil for 1 minute and transferring to a centrifuge to spin at 6000 rpm for 5 minutes. A 0.5 ml supernatant:2.0 ml reagent (0.53 g of L-ascorbic acid in 70.0 ml of Bray solution bulked with deionized water to 500 ml) was dispensed into a colorimeter tube and the absorbance of sample measured at 882 nm wave length (Menage & Pridmore, 1973; Bartlett, Craze, Stone & Crouch, 1994).

Determination of Water Holding Capacity

Water holding capacity (plant available water) was calculated using the relation:

Water holding capacity = field capacity water content-wilting point water content.

The field capacity water content was obtained by saturating the dry pulverized soil sample in a porous plate with water and leaving it overnight to equilibrate and then placing the soil in the plate under 1/3 atmosphere of pressure for 24 hours. The soil sample was then weighed, placed in an oven at 105 °C for 2 hours and weighed again. Wilting point was determined by saturating the dry pulverized soil sample in a porous plate with water and leaving it overnight to equilibrate and then placing the soil in the plate under 15 atmosphere of pressure for 48 hours. The soil sample was then weighed, placed in an oven at 105 °C for 2 hours and weighed again.

3.4 Data Analysis

3.4.1 Floristic and Soil Data Analysis

The data collected from the field (both floristic and soil data) were entered into Microsoft Excel and screened for data entry errors. The following abundance measurements were made:

$$\text{Relative density} = \frac{\text{Number of individuals of a species} \times 100}{\text{Total number of individuals of all species}}$$

$$\text{Relative frequency} = \frac{\text{Frequency of a species} \times 100}{\text{Sum of frequencies of all species}}$$

$$\text{Relative dominance} = \frac{\text{Total basal area of a species} \times 100}{\text{Total basal area of all species}}$$

The basal areas of all trees were determined from their respective diameters as follows:

Basal area (BA; m^2) = π $DBH^2/4(10000)$, with DBH in cm (Avery & Burkhart, 2002).

The Cottam and Curtis' Importance Value Index (IVI) which measures the relative importance of species (van Andel, 2003) was computed for all trees as follows:

IVI = relative density + relative frequency + relative dominance.

To find out the diversity and the evenness of advanced regenerations of timber species, the Shannon diversity index (H′) and evenness (*E*) were also calculated for each plot as follows (Begon, Harper & Townsend, 1996; Cox, 2002):

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

$$E = \frac{H}{\ln S}$$

Where; p_i = proportion of all individuals in same

species. ln p_i = natural log of p_i.

E = evenness or equitability.

S = total number of species in the sample (species richness).

The Simpson's index of diversity (1 – D; Magurran, 1988; Begon *et al*., 1996) was also calculated for each plot, where:

$$D = \sum_{i=1}^{s} {p_i}^2$$

A star rating system, based on the work of Hawthorne and Abu-Juam (1995) in Ghana, and Tchouto, De Boer, De Wilde, van Der Maesen, Yemefack & Cleef (2004) in Cameroon, was used to define the conservation status of each species recorded from which the Genetic heat Index (GHI) of each habitat was calculated. The GHI of the various studied habitats was calculated as (Hawthorne & Abu-Juam, 1995; Vermeulens & Koziell, 2002):

$$GHI = \frac{[(Bk \times BkW) + (Gd \times GdW) + (Bu \times BuW) + (Rd \times RdW)]}{N} \times 100$$

Where;

Bk = Number of black star species

Gd = Number of gold star species

Bu = Number of blue star species

Rd = Number of scarlet, red and pink star species

BkW = Weight for black star species

GdW = weight for gold star species

BuW = Weight for blue star species

RdW = Weight for scarlet, red or pink star species

N = Total number of species in a sample (including green star species)

Analysis of variance (ANOVA) was performed on the basal area, density, Shannon diversity and evenness, Simpson's index of diversity, and soil physicochemical parameters to investigate the effects of post-logging time and site (intensity of disturbance).

The non-metric multidimensional scaling ordination technique was also used to visualize the distances among the sites based on the density of the tree species. The information theoretic approach (Burnham & Anderson, 2002) was used to assess the relative effects of sites and time since logging on diversity indices and abundance of the advanced regeneration. The information theoretic approach allows data-based selection of a "best" model and a ranking and weighting of the remaining models in a pre-defined set (Burnham & Anderson, 2002). The approach also allows formal inference to be based on more than one model (multimodal inference)—such procedures lead to more robust inferences in many cases (Salton & Buckley, 1990). Models were fitted using the simple linear regression, and compared with the Akaike Information Criterion (AIC) values. All field and laboratory analyses were done at 5 % significant level, using the R software (R Core Team, 2014).

CHAPTER FOUR

RESULTS

4.1 Floristic Composition and Structure of the Asenanyo River Forest Reserve

The general floristic characteristics of the Asenanyo River Forest Reserve as observed in this study are presented in Table 2, with the details provided in Table 3. A total of 1392 individual plants distributed into 108 species, 275 genera and 140 families were documented in the forty (40) plots sampled. Means of basal area and densities differed significantly ($P < 0.05$) while Shannon diversity index (H′), evenness (E) and Simpson's index of diversity (1-D) did not differ among studied habitats. The conservation value of the advanced regeneration in the reserve was generally low (GHI = 71.88).

Overall, the composition and conservation status of the advanced regeneration in the slightly disturbed habitats were comparatively better than those of the undisturbed and heavily disturbed habitats. The slightly disturbed habitats (SD_5 and SD_{15} for habitats logged 5 and 15 years, respectively) recorded the highest number of individual plants of 357 and 330 respectively. The undisturbed habitat (UD) had 278 whilst the heavily disturbed habitats had 225 and 205 individual plants for HD_{15} (logged 15 years ago) and HD_5, (logged 5 years ago) respectively.

Similarly, species richness was highest for the slightly disturbed habitats (75 and 64 for SD_{15} and SD_5, respectively), lowest for the UD (54). The heavily disturbed sites had virtually the same number of species—64 for HD_{15} and 63 for HD_5.

Thirty (30) different plant families were found in SD_{15} whilst SD_5, HD_5 and HD_{15} had 29 families each, with UD recording the least number of 23 families. Mean basal area was highest in undisturbed habitat (3.54 m^2/ha; $P < 0.05$) whilst habitats logged 5 years back (SD_5 and HD_5) recorded the minimum values of 1.08 m^2/ha and 0.64 m^2/ha, respectively. The mean basal areas were 2.86 m^2/ha for SD_{15} and 1.48 m^2/ha for HD_{15}. Significantly higher mean densities ($P < 0.05$) were encountered in the slightly disturbed habitats (SD_5 = 44.63 /ha and SD_{15} = 41.2/ha) whilst the undisturbed habitats (UD) recorded 34.75/ha ($P < 0.05$). Heavily disturbed habitats—HD_{15} and HD_5— had lower mean densities of advanced regeneration of 27.75/ha and 25.63/ha, respectively. Shannon diversity index (H′) was insignificantly high in habitats logged 15 years ago (SD_{15} = 2.61; HD_{15} = 2.51) and least in the undisturbed habitat (H′ = 2.22). Distribution of advanced regeneration was fairly equal for all studied habitats (between 0.91 and 0.93). Simpson index was also insignificantly high for the slightly disturbed habitats and the HD_{15} (0.90) compared to the HD_5 (0.89) and the undisturbed habitat (0.88).

As shown in Table 3, some species were unique to some particular habitats in the studied area. *Xylopia staudtii*, *Macaranga hurifolia*, *Protomegabaria stapfiana* and *Scytopetalum tieghemii* were found only in SD_{15} whereas *Berlinia tomentella*, *Erythrophleum ivorense*, *Harungana madagascariensis*, *Mammea africana*, *Memecylon lateriflorum*, *M. rhodantha* and *M. altissima* were unique to HD_5. *M. arboreus*, *Khaya grandifoliola*, *Calpocalyx brevibracteatus* and *Synsepalum afzelii* were found only in UD as *Strephonema pseudocola*, *Anthocleista vogelii* and *Anopyxis klaineana* were recorded only in SD_5. Likewise *Lovoa trichilioides*, *Treculia africana*, *Lonchocarpus sericeus* and *Chrysophyllum perpulchrum* were unique to HD_{15}. In all the five studied habitats in ASEN, 108 plant species were recorded.

The five most dominant families in all the studied habitats accounted for more than 50 % the total number of individual plants recorded in a particular habitat (Figure 2). Sterculiaceae and Ulmaceae were the two most dominant families in all studied habitats. Other families of importance were Meliaceae (52 individuals) and Caesalpiniaceae (25) in UD, Caesalpiniaceae (24) and Mimosaceae (23) in SD_5, and Euphorbiaceae (13) and Caesalpiniaceae (10) in HD_5. The SD_{15} habitat was also dominated by Mimosaceae (27) and Meliaceae (24), whereas Rubiaceae (17) and Moraceae (16) were the third and fourth abundant families in HD_{15}, respectively. On the basis of species richness, Sterculiaceae and Ulmaceae again emerged the most important families in both the slightly disturbed habitat and the undisturbed habitat (Figure 3). Caesalpiniaceae (8 species) and Meliaceae (7 species) were the most dominant families in HD_5 and HD_{15}.

Table 2: General floristic characteristics of the studied habitats within the Asenanyo River Forest Reserve (ASEN).

Attribute	Habitats Undisturbed (UD)	Slightly disturbed after 5 years of post-logging (SD_5)	Slightly disturbed after 15 years of postlogging (SD_{15})	Heavily disturbed after 5 years of post-logging (HD_5)	Heavily disturbed after 15 years of postlogging (HD_{15})
Number of individuals	278	357	330	205	222
Number of species	54	64	75	63	64
Number of genera	47	54	65	55	54
Number of families	23	29	30	29	29
Mean basal area (m^2/ha)	3.54 ± 0.24^{a}	1.08 ± 0.06^{bc}	2.86 ± 0.20^{a}	0.64 ± 0.06^{b}	1.48 ± 0.29^{c}
Mean density (per ha)	34.75 ± 1.69^{ac}	44.63 ± 2.84^{b}	41.25 ± 1.74^{ab}	25.63 ± 1.13^{d}	27.75 ± 1.41^{cd}
Mean Shannon diversity index (H')	2.22 ± 0.06	2.45 ± 0.01	2.61 ± 0.18	2.38 ± 0.07	2.51 ± 0.11
Mean Shannon evenness (E)	0.93 ± 0.01	0.93 ± 0.01	0.93 ± 0.01	0.91 ± 0.02	0.92 ± 0.02
Mean Simpson's index of diversity (1-D)	0.88 ± 0.01	0.90 ± 0.01	0.90 ±0.02	0.89 ± 0.01	0.90 ± 0.01

Different letter superscripts indicate significant differences among means at 5 % significant level. Measures of dispersion are standard errors of the means.

Table 3: Comprehensive list of advanced regeneration of timber species observed in the five studied habitats of the Asenanyo River Forest Reserve and their successional classes/ecological guild and conservation star ratings

Family	Species	Succ. Class	Star Cat.	Occurrence				
				UD	5yrs after logging		15yrs after logging	
					SD5	HD5	SD15	HD15
Anacardiaceae	*Lannea welwitschii* (Hiern) Engl.	P	Green	-	+	+	+	+
Annonaceae	*Cleistopholis patens* (Benth.) Engl. & Diels	P	Green	-	+	-	+	+
	Duguetia staudtii (Engl. & Diels) Chatrou	SB	Green	+	-	-	-	+
	Hexalobus crispiflorus A. Rich.	SB	Green	+	+	-	+	-
	Xylopia staudtii Engl. & Diels	SB	Green	-	-	-	+	-
Apocynaceae	*Alstonia boonei* De Wild.	P	Green	+	-	+	-	-
	Funtumia elastica (P.Preuss) Stapf	P	Green	-	+	-	+	+
	Holarrhena floribunda (G. Don) Dur. & Schinz	P	Green	+	+	+	+	+
	Pleioceras barteri Baill.	P	Green	+	-	+	+	+
Bignoniaceae	*Spathodea campanulata* P.Beauv.	P	Green	-	-	+	-	+
	Stereospermum acuminatissimum K.Schum.	P	Green	-	-	+	+	+
Bombacaceae	*Bombax buonopozense* P.Beauv.	P	Pink	+	+	+	+	+
	Ceiba pentandra (Linn.) Gaertn.	P	Red	-	+	-	+	-
	Rhodognaphalon brevicuspe (Sprague) Roberty	P	Red	-	+	+	-	+

Boraginaceae	*Cordia millenii* Bak.	P	Pink	-	+	+	+	+

Table 3 continued

Family	Species	Succ. Class	Star Cat.	Occurrence				
				UD	5yrs after logging		15yrs after logging	
					SD_5	HD_5	SD_{15}	HD_{15}
	Cordia platythyrsa Bak.	P	Pink	-	+	-	-	+
Burseraceae	*Canarium schweinfurthii* Engl.	P	Red	-	+	-	-	-
	Dacryodes klaineana (Pierre) H. J. Lam	SB	Green	-	-	+	-	+
Caesalpiniaceae	*Amphimas pterocarpoides* Harms	NPLD	Green	+	+	+	-	-
	Berlinia tomentella Keay	SB	Green	-	-	+	-	-
	Bussea occidentalis Hutch.	NPLD	Green	-	+	+	+	-
	Copaifera salikounda Heck.	SB	Red	-	-	+	+	-
	Cynometra ananta Hutch. & Dalziel	SB	Pink	+	-	+	+	+
	Daniellia ogea (Harms) Rolfe ex Holl.	P	Red	+	+	-	+	-
	Dialium aubrevillei Pellegr.	SB	Pink	-	-	+	+	-
	Distemonanthus benthamianus Baill.	P	Red	+	+	+	+	+
	Erythrophleum ivorense A. Chev.	NPLD	Pink	-	-	+	-	-
	Guibourtia ehie (A.Chev.) J.Leonard	NPLD	Scarlet	+	+	-	+	+

Cecropiaceae	*Musanga cecropioides* R. Br.	P	Green	+	+	-	+	-
	Myrianthus arboreus P. Beauv.	SB	Green	+	-	-	-	-
Chrysobalanaceae	*Parinari excelsa* Sabine	NPLD	Green	-	-	+	+	+
Combretaceae	*Strephonema pseudocola* A.Chev.	SB	Blue	-	+	-	-	-

Table 3 continued

Family	Species	Succ. Class	Star Cat.	Occurrence				
				UD	5yrs after logging		15yrs after logging	
					SD_5	HD_5	SD_{15}	HD_{15}
	Terminalia ivorensis A.Chev.	NPLD	Red	+	+	+	+	+
	Terminalia superba Engl. & Diels	P	Red	+	+	+	+	+
Euphorbiaceae	*Bridelia micrantha* (Hochst.) Baill.	P	Green	-	+	+	+	+
	Discoglypremna caloneura (Pax) Prain	P	Green	-	-	+	+	+
	Macaranga hurifolia Beille	P	Green	-	-	-	+	-
	Margaritaria discoidea Baill. G.L. Webster	P	Green	+	-	+	-	-
	Protomegabaria stapfiana (Beille) Hutch.	SB	Green	-	-	-	+	-
	*Ricinodendron heudeloti*i (Baill.) Pierre ex Pax & Hoffm.	P	Pink	+	+	-	+	-
Flacourtiaceae	*Homalium letestui* Pellegr.	NPLD	Green	-	+	+	+	+
Guttiferae	*Allanblackia parviflora* A. Chev.	SB	Pink	-	-	+	+	-
	Harungana madagascariensis Lam. ex Poir.	P	Green	-	-	+	-	-
	Mammea africana Sabine	SB	Blue	-	-	+	-	-
Humiriaceae	*Sacoglottis gabonensis* (Baill.) Urb.	NPLD	Blue	-	+	+	+	+
Irvingiaceae	*Klainedoxa gabonensis* Pierre ex Engl.	NPLD	Pink	+	+	-	+	+
Lecythidaceae	*Petersianthus macrocarpus* (P Beauv.) Liben	P	Pink	+	+	+	+	+

Table 3 continued

Table

Family	Species	Succ. Class	Star Cat.	Occurrence				
				UD	5yrs after logging		15yrs after logging	
					SD_5	HD_5	SD_{15}	HD_{15}
	Scytopetalum tieghemii A.Chev. ex Hutch. & Dalziel	SB	Pink	-	-	-	+	-
Loganiaceae	*Anthocleista vogelii* Planch.	SB	Green	-	+	-	-	-
Melastomataceae	*Memecylon lateriflorum* (G Don) Brem.	SB	Green	-	-	+	-	-
Meliaceae	*Entandrophragma angolense* (Welw.) C.DC.	NPLD	Scarlet	+	+	+	+	+
	Entandrophragma candollei Harms	NPLD	Scarlet	-	+	-	-	+
	Entandrophragma cylindricum (Sprague) Sprague	NPLD	Scarlet	-	-	+	+	-
	Entandrophragma utile (Dawe & Sprague) Sprague	NPLD	Scarlet	-	+	-	+	-
	Guarea cedrata (A Chev.) Pellegr.	SB	Red	+	+	-	+	+
	Khaya anthotheca (Welw.) C DC	NPLD	Scarlet	+	+	-	-	+
	Khaya grandifoliola C DC.	NPLD	Scarlet	+	-	-	-	-
	Khaya ivorensis A Chev.	NPLD	Scarlet	+	+	+	+	+
	Lovoa trichilioides Harms	NPLD	Red	-	-	-	-	+
	Turraeanthus africanus (Welw. ex C.DC.) Pellegr.	SB	Pink	+	-	+	+	+
Mimosaceae	*Albizia glaberrima* (Schumach. & Thonn.) Benth.	P	Green	-	+	-	+	+

3 continued

Family	Species	Succ. Class	Star Cat.	Occurrence				
				UD	5yrs after logging		15yrs after logging	
					SD_5	HD_5	SD_{15}	HD_{15}
	Albizia zygia (DC.) J.F.Macbr.	P	Pink	+	+	+	+	+
	Calpocalyx brevibracteatus Harms	SB	Green	+	-	-	-	-
	Cylicodiscus gabunensis Harms	NPLD	Pink	+	+	-	+	+
	Parkia bicolor A. Chev.	NPLD	Green	-	+	+	+	+
	Piptadeniastrum africanum (Hook.f.) Brenan	NPLD	Red	+	+	+	+	-
	Xylia evansii Hutch.	NPLD	Blue	-	-	-	+	+
Moraceae	*Antiaris toxicaria* Leschen.	NPLD	Red	-	+	-	+	+
	Milicia excelsa (Welw.) Berg.	P	Scarlet	+	+	+	+	+
	Milicia regia (A.Chev.) Berg	P	Scarlet	-	-	+	-	+
	Morus mesozygia Stapf	P	Green	-	+	+	+	+
	Treculia africana Desc.	NPLD	Green	-	-	-	-	+
	Trilepisium madagascariense DC.	P	Green	+	-	+	-	+
Myristicaceae	*Pycnanthus angolensis* (Welw.) Warb.	NPLD	Red	+	+	+	+	-
Myrtaceae	*Syzygium guineense* (Willd.) DC.	SB	Blue	-	+	+	-	+

Table 3 continued

Table

Family	Species	Succ. Class	Star Cat.	Occurrence				
				UD	5yrs after logging		15yrs after logging	
					SD_5	HD_5	SD_{15}	HD_{15}
Ochnaceae	*Lophira alata* Banks ex Gaertn. f.	P	Red	+	-	+	+	+
Olacaceae	*Ongokea gore* (Hua) Pierre	NPLD	Pink	+	+	-	+	-
	Strombosia pustulata Oliv.	SB	Pink	+	-	+	+	-
Pandaceae	*Panda oleosa* Pierre	SB	Green	+	-	-	+	-
Papilionaceae	*Lonchocarpus sericeus* (Poir.) HB & K.	SB	Green	-	-	-	-	+
	Millettia rhodantha Baill.	NPLD	Green	-	-	+	-	-
Rhizophoraceae	*Anopyxis klaineana (Pierre) Engl.*	NPLD	Pink	-	+	-	-	-
Rubiaceae	*Corynanthe pachyceras* K.Schum.	NPLD	Green	-	+	-	+	-
	Nauclea diderrichii (De Wild. & T.Durand) Merr.	P	Scarlet	+	+	+	+	+
	Psydrax subcordata DC. Bridson	P	Green	+	-	+	+	+
Rutaceae	*Zanthoxylum gilletii* (De Wild.) Waterm.	P	Green	-	+	-	+	+
	Zanthoxylum leprieurii Guill. & Perr.	P	Green	+	-	+	+	+
Sapindaceae	*Blighia sapida* K.D.Koenig	NPLD	Green	+	+	-	-	+
Sapotaceae	*Chrysophyllum albidum* G.Don	SB	Pink	+	+	-	+	+

3 continued

Family	Species	Succ. Class	Star Cat.	Occurrence: UD	5yrs after logging: SD$_5$	5yrs after logging: HD$_5$	15yrs after logging: SD$_{15}$	15yrs after logging: HD$_{15}$
	Chrysophyllum perpulchrum Mildbr. ex Hutch. & Dalziel	NPLD	Pink	-	-	-	-	+
	Pouteria altissima (A Chev.) Baehni	NPLD	Scarlet	-	+	+	+	+
	Synsepalum afzelii (Engl.) Pennington	SB	Green	+	-	-	-	-
	Tieghemella heckelii Pierre ex A.Chev.	NPLD	Scarlet	-	+	+	+	+
Simaroubaceae	*Hannoa klaineana* Pierre ex Engl.	P	Green	-	+	+	+	+
Sterculiaceae	*Cola gigantea* A Chev.	SB	Green	+	+	-	+	+
	Heritiera utilis (Sprague) Spague	SB	Red	+	+	+	+	-
	Mansonia altissima (A Chev.) A Chev.	NPLD	Red	-	-	+	-	-
	Nesogordonia papaverifera (A.Chev.) Capuron ex N.Hallé	SB	Pink	+	+	+	+	+
	Pterygota macrocarpa K. Schum.	NPLD	Scarlet	+	+	-	+	+
	Sterculia oblonga Mast.	P	Pink	-	-	+	+	-
	Sterculia rhinopetala K. Schum.	NPLD	Pink	+	+	+	+	-

Table 3 continued

	Sterculia tragacantha Lindl.	P	Green	+	+	-	+	-
	Triplochiton scleroxylon K. Schum.	P	Scarlet	+	+	+	+	+
Tiliaceae	*Duboscia macrocarpa* Bocq.	NPLD	Green	+	-	-	+	+
Ulmaceae	*Celtis adolfi-friderici* Engl.	P	Pink	+	+	+	+	-
	Celtis mildbraedii Engl.	SB	Pink	+	+	+	+	+
	Celtis philippensis Blanco	SB	Pink	+	+	+	+	+
	Celtis zenkeri Engl.	NPLD	Pink	+	+	+	+	+

. + = present, - = absent

T. scleroxylon dominated all five habitats studied (Figure 4, Appendix 1 Table 1A). Relative important value of this species ranged from 16.12 % in the HD_5 (Appendix I Table 1D) to 13.34 % in the SD_5 (Appendix I Table 1C). *C. mildbraedii* was the second most important species recording relative IVI values between 11.51 % in UD (Appendix I Table 1B) and 6.08 % in HD_5 (Appendix I Table 1D). *C. zenkeri* and *C. pentandra* had 3.79 each in SD_5 and HD_{15} habitats respectively. Aside these four species, *K. anthotheca*, *G. ehie*, *C. gabunensis*, *C. millenii*, *N. diderrichii*, *K. ivorensis* and *B. micrantha* were also within the five most important species of the various habitats (Figure 4, Appendix I Tables 1B,
1C and 1D). The five most important plant species in the ASEN (Appendix I Table 1A) had Importance Value Index (IVI %) of 48.65 % whilst the remaining 103 plant species had a total IVI of 51.38. *T. scleroxylon,* the most important species, recorded IVI of 29.06, followed by *C. mildbraedii* (9.78 %), *C. zenkeri* (4.29 %), *N. diderrichii* (3.07 %) and *C. philippensis* (2.45 %). The relative dominance of *T. scleroxylon* for all the studied habitats in the reserve was 62.92 % (Appendix I Table 1A). This was followed by *C. mildbraedii* (15.67 %), *C. zenkeri* (4.18 %) and *N. diderrichii* (2.49 %).

Thirteen (13) species recorded IVIs between 1 % and 2.00 %, whilst the remaining 90 species had IVIs less than 1 % (0.97 % ≥ IVI ≥ 0.08 %). Among the least important species recorded in the studied habitats were *S. rhinopetala, Myrianthus arboreus, Albizia glaberrima, Funtumia elastic, Alstonia boonei, Millettia rhodantha, N. papaverifera* and *Terminalia ivorensis.*

Rank abundance (based on IVI) distributions of timber species indicated that a fewer number of species were dominant, whereas many species were rare in all habitats studied (Figure 5).

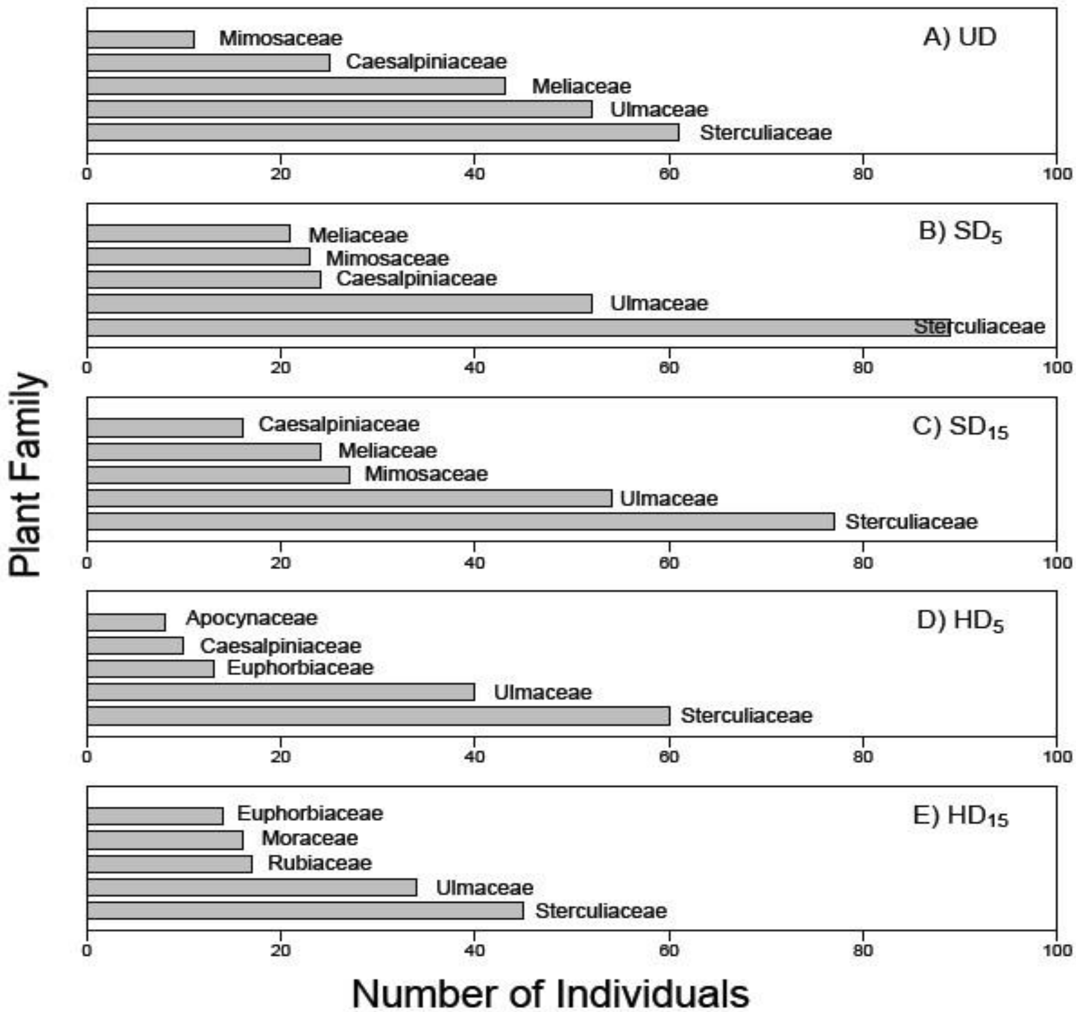

Figure 2: Comparison of dominant families of flora based on the number of individuals at the studied habitats of the Asenanyo River Forest Reserve.

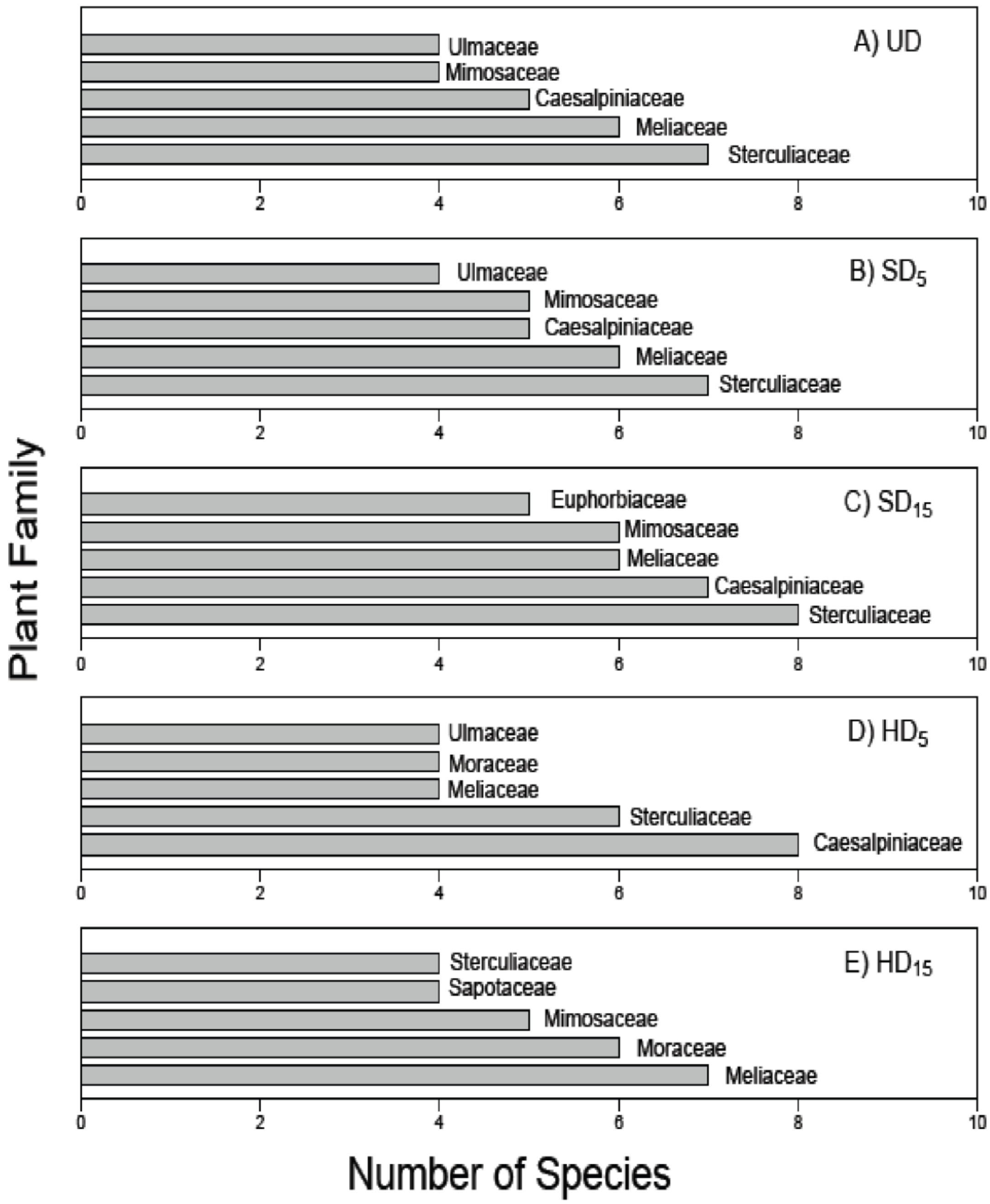

Figure 3: Comparison of dominant families of flora based on the number of species at the studied habitats of the Asenanyo River Forest Reserve.

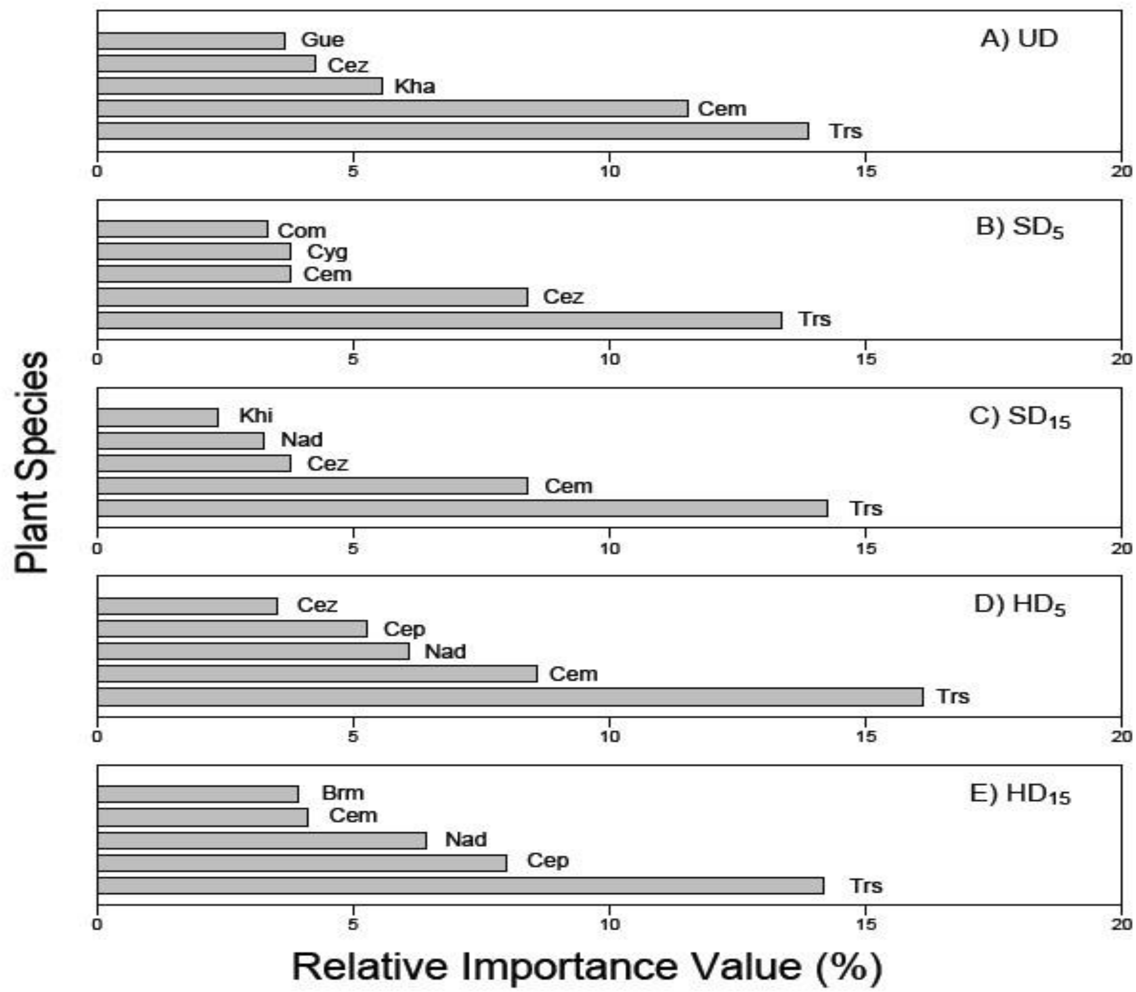

Figure 4: Most important plant species for the five habitats studied in the Asenanyo River Forest Reserve. Trs = *T. scleroxylon*, Cep = *C. pentandra*, Cez = *C. zenkeri,* Cem = *C. mildbraedii*, Nad = *N. diderrichii*, , Brm = *B. micrantha*, Khi = *K. ivorensis*, Kha = *K. anthotheca*, Cyg = *C. gabunenses*, Com = *C. millenii*, and Gue = *G. ehie*

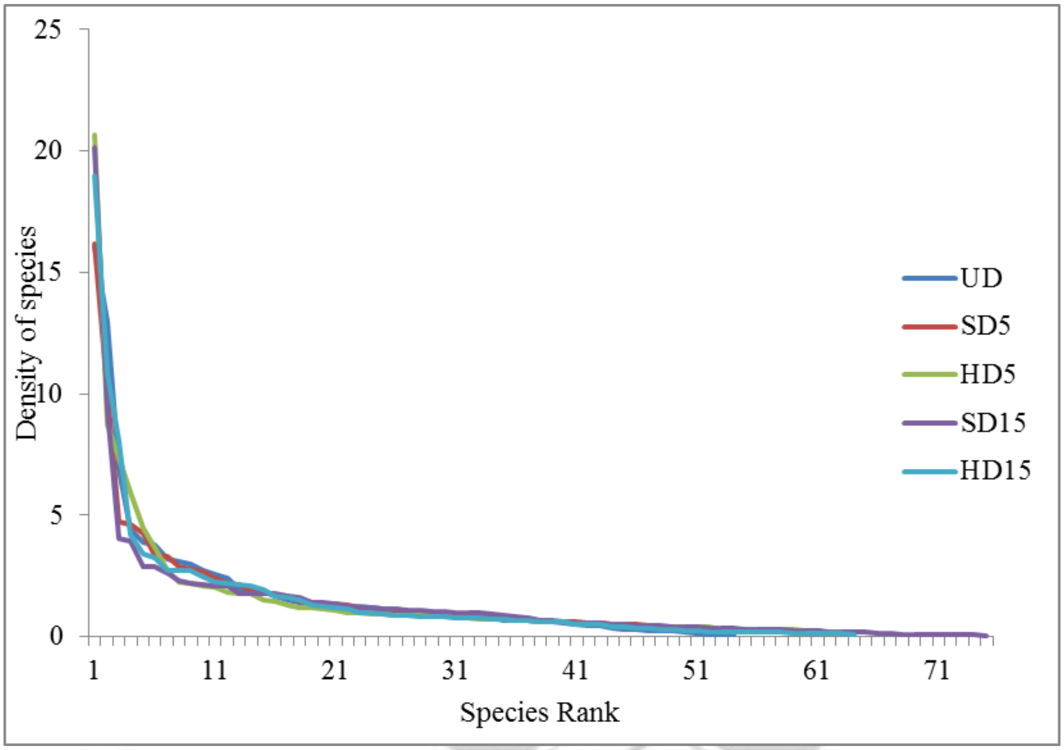

Figure 5: Rank abundance distribution of species observed in the five studied habitats of the Asenanyo River Forest Reserve.

Majority of the species encountered were pioneer species (136) followed by nonpioneer light demanding species (112) and shade-bearers (72). Most of the pioneer species were found in habitats logged 15 years ago (SD_{15} and HD_{15} had 32 and 29, respectively). The unlogged habitat recorded the least number of pioneer species (21) whilst habitats logged 5 years back (SD_5 and HD_5) had 27 pioneer species each (Figure 6). The slightly disturbed habitats—SD_5 and SD_{15}— had higher numbers of NPLD species of 26 and 25, respectively. Again, the undisturbed habitat recorded the least number of NPLD species (17) whereas the HD_{15} and HD_5 had 23 and 21, respectively. Shade-bearer species were relatively higher in SD_{15} (18), followed by UD (16) and SD_5 (11; Figure 6). In each studied habitats, the number of pioneers exceeded that of NPLDs while the number of NPLDs exceeded the number of shade-bearers.

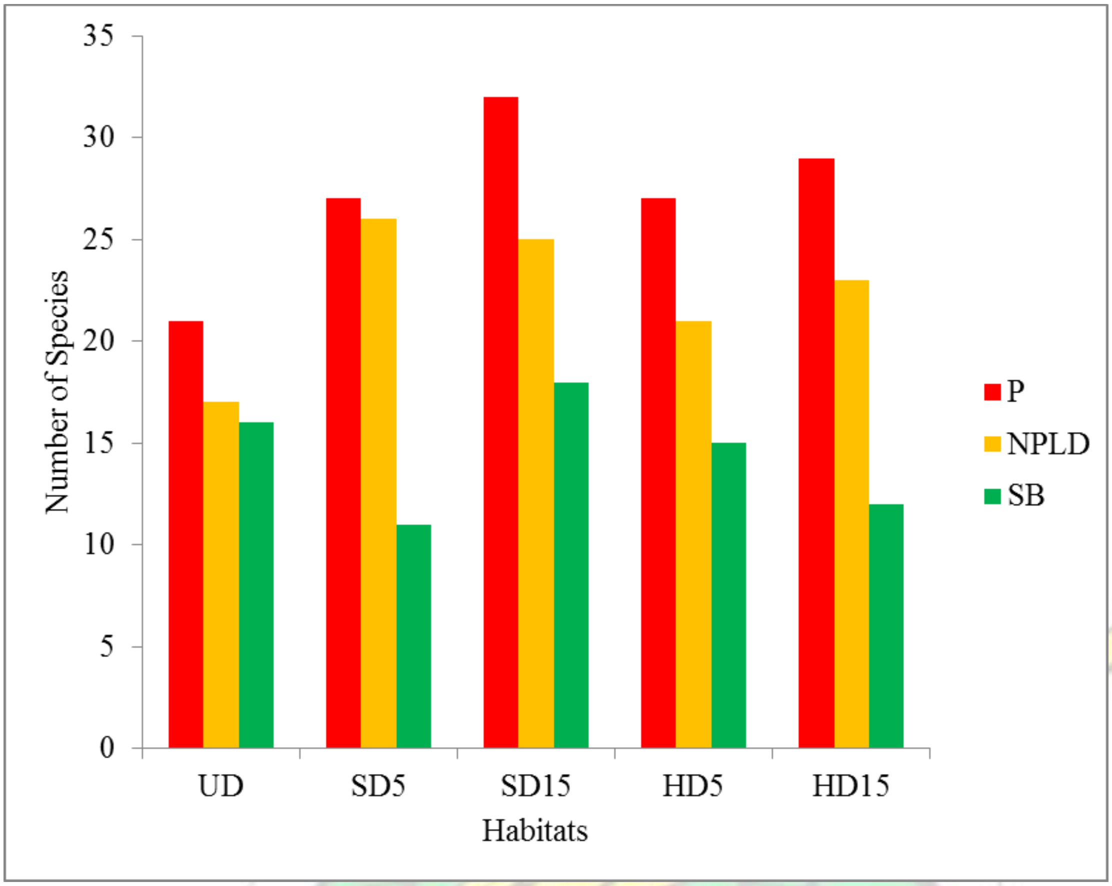

Figure 6: Successional classes/ecological guilds of timber species in the five studied habitats of the Asenanyo River Forest Reserve.

Non-metric multi-dimensional scaling ordination based on densities of individual plants indicated overlaps among the five habitats studied (Figure 7), indicating considerable similarities among these habitats. However, the composition of HD_{15} and UD habitats appeared to be distinct from each other.

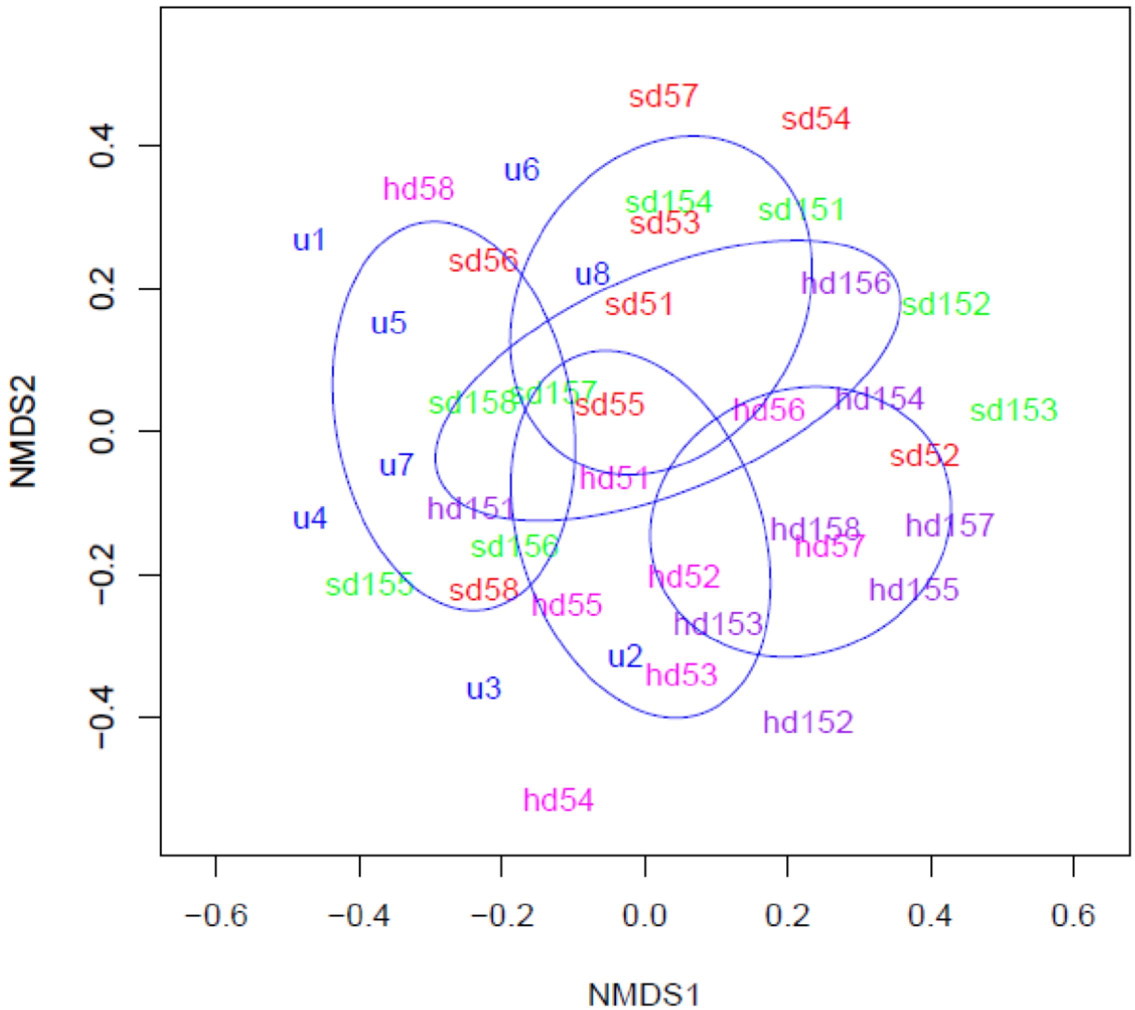

Figure 7: Non-metric multidimensional scaling of the studied habitats based on species density.

The mean basal area of the advanced regeneration in the ASEN was 1.92 m^2/ha. Highly significant differences existed among the mean basal areas of the habitats ($P < 0.001$). The mean basal areas of ASEN were greatly influenced by both post-logging time and levels of disturbance—significant differences existed between UD and SD_5, UD and HD_5, UD and HD_{15}, SD_5 and HD_5, SD_{15} and HD_5, SD_{15} and HD_{15}, and HD_5 and HD_{15} ($P > 0.05$). The highest mean basal area was obtained for UD (3.54 m^2/ha ± 0.24). Relatively higher mean basal areas were recorded for habitats logged 15 years ago (2.86 m^2/ha ± 0.20 and 1.48 m^2/ha ± 0.29 for SD_{15} and HD_{15} respectively) followed by habitats logged 5 years ago (1.08 m^2/ha ± 0.06 and 0.64 m^2/ha ± 0.06 for SD_5 and HD_5 respectively; Table 2).

Out of the 1392 individual plants recorded for the entire habitat, 727 saplings, 491 poles and 174 small trees were obtained. Habitats logged 5 years ago had the greatest number of saplings (278 for SD_5 and 152 for HD_5), followed by those logged 15 years back (131 and 98 for SD_{15} and HD_{15} respectively), whilst the undisturbed habitats (68; Figure 8) recorded the fewest saplings. SD_{15} (143) had more poles followed by UD (118) and HD_{15} (99). Habitats logged 5 years ago recorded the least number of poles—SD_5 had 78 whiles HD_5 recorded 53 poles. The undisturbed habitat recorded more small trees of 92 than all other habitats. Small trees were relatively fewer in habitats logged 5 years back as SD_5 recorded 1 and none (0) were found in HD_5. Habitats logged 15 year back—SD_{15} and HD_{15}—recorded relatively higher numbers of small trees (56 and 25 respectively) compared to habitats logged 5 years ago (SD_5 and HD_5; Figure 8).

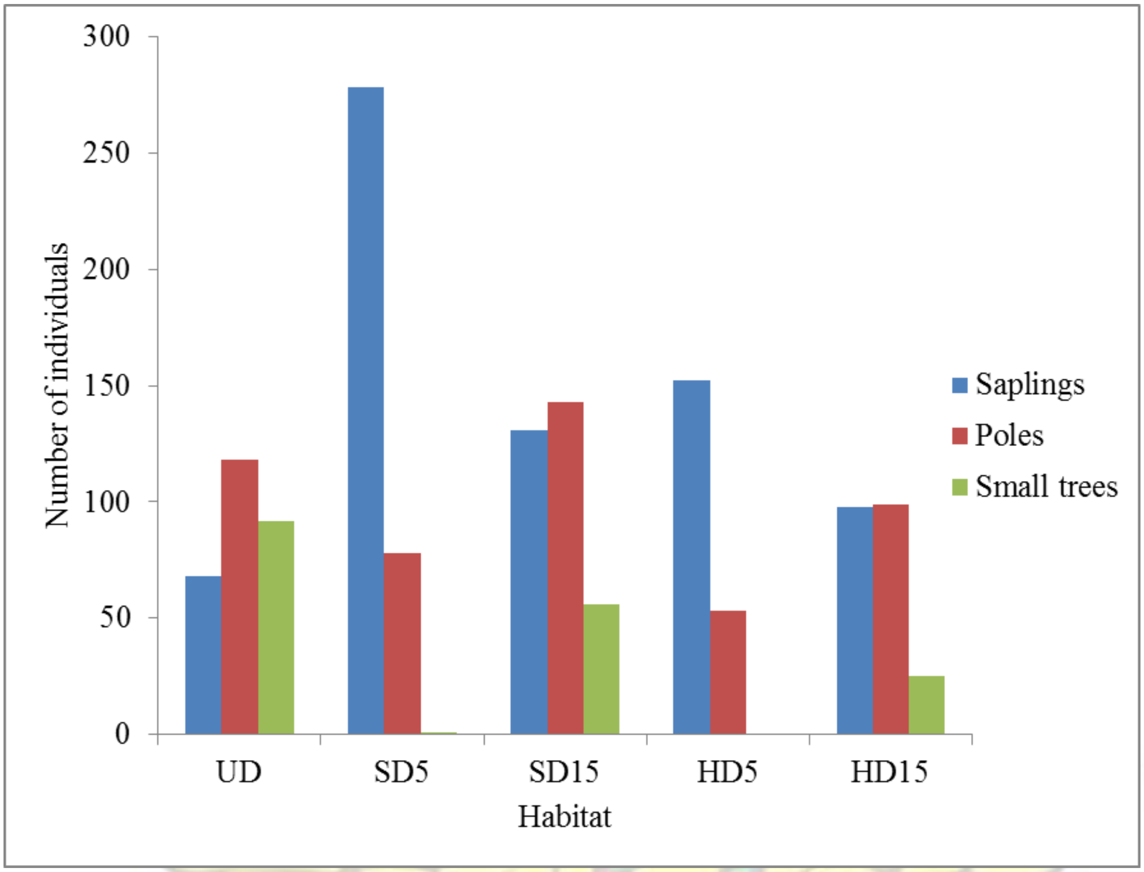

Figure 8: Stem size class distribution of trees in the studied habitats of the Asenanyo River Forest Reserve.

Post-logging time had the highest explanatory power on the alpha diversity indices (Shannon and Simpson's diversity indices) of the advanced regeneration (Table 4). On the contrary, the level of disturbance best explained the evenness and density of advanced regeneration in the reserve. The basal area of advanced regeneration of timber species changed most with interaction of level of disturbance and post-logging time.

Table 4: Model comparison to determine the relative effects of site (habitat) and time since harvesting on diversity indices and abundance of advanced regeneration. Models were fitted using the simple linear regression, and compared with the Akaike Information Criterion (AIC) values. Best models are in boldface.

Model	Form	AIC	R^2
1	$y\ (H^1) = \alpha + \beta(\text{Site} \times \text{Time}) + \varepsilon$	27.65	0.16
2	$y\ (H^1) = \alpha + \beta(\text{Site} + \text{Time}) + \varepsilon$	25.67	0.16
3	$y\ (H^1) = \alpha + \beta\ \text{Site} + \varepsilon$	25.55	0.12
4	$\boldsymbol{y\ (H^1) = \alpha + \beta\ \textbf{Time} + \varepsilon}$	**24.25**	0.15
1	$y\ (E) = \alpha + \beta(\text{Site} \times \text{Time}) + \varepsilon$	-150.62	0.06
2	$y\ (E) = \alpha + \beta(\text{Site} + \text{Time}) + \varepsilon$	-152.18	0.06
3	$\boldsymbol{y\ (E) = \alpha + \beta\ \textbf{Site} + \varepsilon}$	**-154.06**	0.04
4	$y\ (E) = \alpha + \beta\ \text{Time} + \varepsilon$	-152.44	0.01
1	$y\ (1-D) = \alpha + \beta(\text{Site} \times \text{Time})+$	-149.21	0.09
2	$y\ (1-D) = \alpha + \beta(\text{Site} + \text{Time})+$	-151.14	0.09
3	$y\ (1-D) = \alpha + \beta\ \text{Site} + \varepsilon$	-152.47	0.07
4	$\boldsymbol{y\ (1-D) = \alpha + \beta\ \textbf{Time} + \varepsilon}$	**-152.78**	0.08
1	$y\ (\text{Density}) = \alpha + \beta(\text{Site} \times \text{Time}$	252.81	0.69
2	$y\ (\text{Density}) = \alpha + \beta(\text{Site} + \text{Time})$	253.25	0.67
3	$\boldsymbol{y\ (\textbf{Density}) = \alpha + \beta\ \textbf{Site} + \varepsilon}$	**251.37**	0.67
4	$y\ (\text{Density}) = \alpha + \beta\ \text{Time} + \varepsilon$	296.01	0.01
1	$\boldsymbol{-\ \beta(\textbf{Site} \times \textbf{Time}) + \varepsilon}$	**71.97**	0.82
2	$y\ (\text{Basal area}) = \alpha + \beta(\text{Site} + \text{Tin}$	76.23	0.79
3	$y\ (\text{Basal area}) = \alpha + \beta\ \text{Site} + \varepsilon$	104.11	0.56
4	$y\ (\text{Basal area}) = \alpha + \beta\ \text{Time} + \varepsilon$	91.52	0.68

4.2 Conservation Status of the Advanced Regeneration in the Asenanyo River Forest Reserve

Majority of species found in the entire studied area of the Asenanyo River Forest Reserve were of green star species (112) followed by pink (92), scarlet (54), red (51) and blue (11). No black or gold star species were encountered in the reserve. GHI values ranged between 64.82 (UD) and 79.69 (SD_5). Heavily disturbed habitats (HD_5 and HD_{15}) and SD_5 all had three (3) blue star species whilst SD_{15} recorded two (2) blue star species (Figure 9). No blue star species was found in the undisturbed habitat. Some blue star species encountered in the study were *M. africana*, *S. gabonensis*, *X. evansii* and *S. pseudocola*. The number of scarlet star species was ranged between 9 (UD) and 12 (both SD_5 and HD_{15}). HD_{15} recorded the least number of red star species whilst slightly disturbed habitats (SD_5 and SD_{15}) recorded the highest (12). The number of pink star species varied from 16 to 23 for HD_{15} and SD_{15} correspondingly. The highest number of green star species was recorded in SD_{15} whilst both UD and SD_5 recorded the least.

In general, the SD_5 (GHI = 79.69) was richer in species of high conservation priorities compared to other studied habitats while undisturbed habitats (GHI =

64.82) had less species of conservation priorities (Figure 10). The heavily disturbed habitats recorded relatively higher GHI values (HD_5 = 74.60 and HD_{15} = 70.31) compared to SD_{15} (69.33).

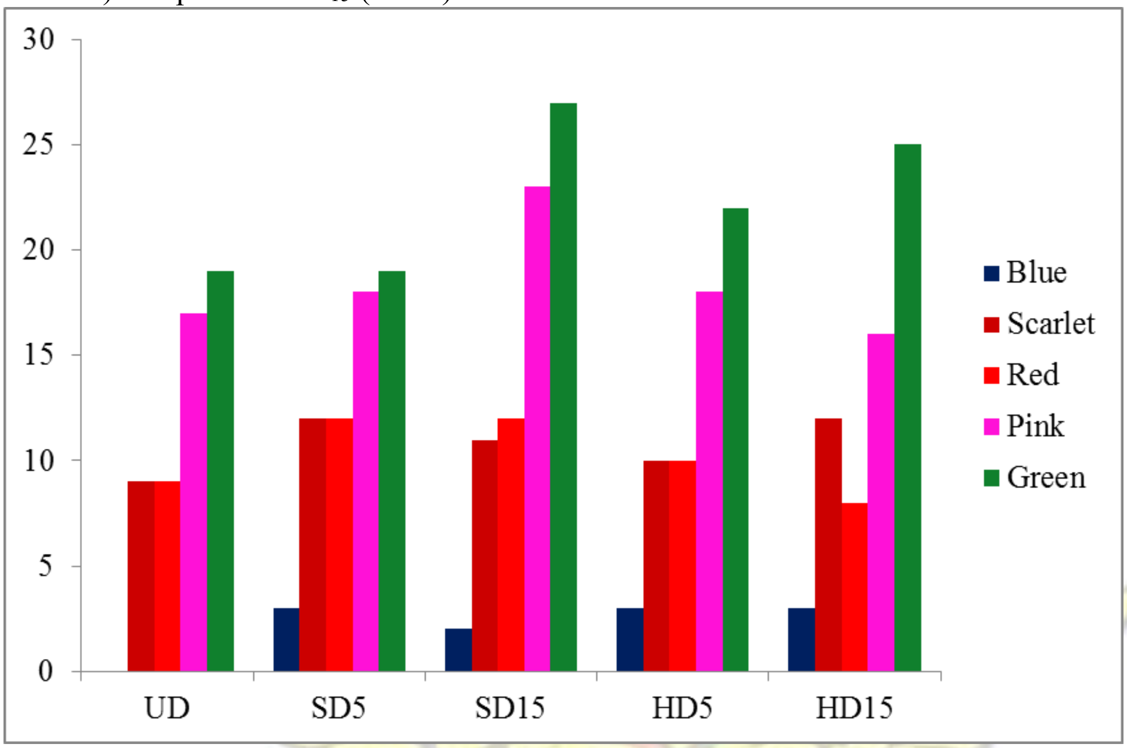

Figure 9: Conservation star categorization of trees in the five studied habitats of the Asenanyo River Forest Reserve.

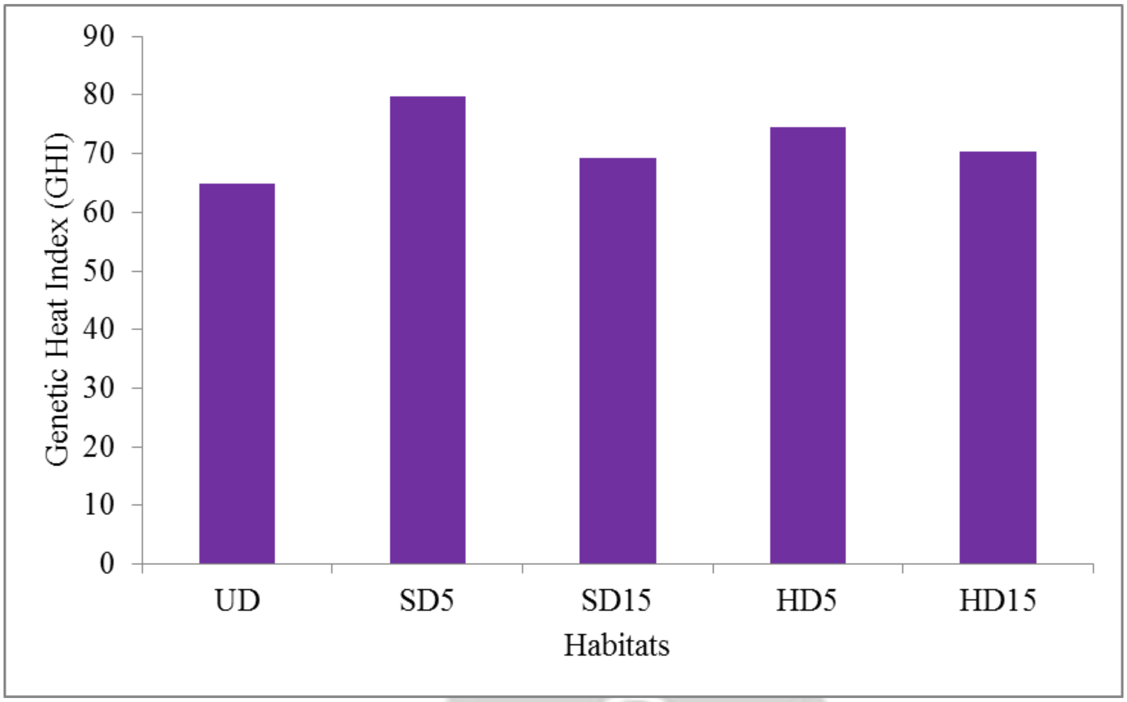

Figure 10: Genetic Heat Index (GHI) of the five studied habitats of the Asenanyo River Forest Reserve.

4.3 Soil Physico-chemical Properties

The results of soil physico-chemical analysis are indicated in table 5. All soil physico-chemical properties except for water holding capacity (%) did not differ among studied habitats when analyzed statistically ($P < 0.01$). The slightly disturbed habitats recorded significant higher water holding capacities (27.10 ± 5.14 and 27.21 ± 2.99 for SD_5 and SD_{15} respectively) compared to the heavily disturbed habits (15.77 ± 3.76 and 20.26 ± 0.93 for HD_5 and HD_{15} respectively). The undisturbed habitat recorded the least water holding capacity of 11.37 ± 1.43. However, the water holding capacity did not differ between habitats that had experienced similar level of disturbance.

The total carbon (%), nitrogen (%), electrical conductivity (µS/cm), organic matter content (%), exchangeable calcium and magnesium (meq/100g) were insignificantly higher in soils from the slightly disturbed habitats (SD_5 and SD_{15}) followed by heavily disturbed habitats (HD_5 and HD_{15}) and lower in the undisturbed habitat when analyzed (Table 5). Total carbon was ranged from 0.70 % to 3.10 % while total nitrogen varied from 0.06 to 0.26 % for UD and SD_5 habitats, respectively. SD_{15} and HD_{15} recorded total carbon of 2.07 % and 1.61 % respectively, while that of HD_5 was 1.41 %. SD_{15} had total nitrogen of 0.71 %, HD_{15} had 0.13 % while HD_5 recorded 0.12 %. Organic matter content differed from 1.22 % to 5.35 % for UD and SD_5, respectively. Organic matter contents for SD_{15}, HD_{15} and HD_5 were 3.28 %, 2.78 % and 2.43 %, respectively. Likewise, electric conductivity varied from 188.38 µS/cm for UD to 330.74 µS/cm for SD_5 while SD_{15}, HD_{15} and HD_5 recorded 294.50 µS/cm, 216.76 µS/cm and 200.14 µS/cm, correspondingly. Exchangeable Mg differed from 1.42 meq/100g to 3.77 meq/100g for UD and SD_{15}, respectively. Levels of exchangeable Mg recorded in SD_5, HD_{15} and HD_5 were 3.04 meq/100g, 2.19 meq/100g and 1.82 meq/100g correspondingly. Exchangeable calcium (Ca) varied from 1.71 meq/100g to 11.96 meq/100g for UD and slightly disturbed habitats (SD_5 and SD_{15}), with HD_5 and HD15 recording 4.33 meq/100g and 3.85 meq/100g, respectively.

The carbon-nitrogen ratio (C/N) was ranged from 12.03 to 12.35 for habitats logged 15 years ago (HD_{15} and SD_{15} respectively), with the HD_5, UD and SD_5 recording 11.50, 11.45 and 11.40 correspondingly. Exchangeable sodium (Na) levels was ranged from 0.06 meq/100g to 0.07 meq/100g for habitats logged 15 years ago (HD_{15} and SD_{15} respectively), with HD_5, SD_5 and UD recording 0.05 meq/100g, 0.04 meq/100g and 0.03 meq/100g correspondingly. Exchangeable potassium (K) varied from 0.04 meq/100g to 0.14 meq/100g for UD and HD_5 respectively. Exchangeable potassium recorded in SD_{15}, HD_{15} and SD_5 were 0.11 meq/100g, 0.09 meq/100g and 0.05 meq/100g correspondingly. The levels of available phosphorus (P) ranged from 6.94 ppm to 9.82 ppm for HD_5 and SD_{15}, respectively. UD, SD5 and HD_{15} recorded available phosphorus of 8.26 ppm, 7.53 ppm and 7.22 ppm, respectively. The soil of the entire studied habitat was virtually neutral when analyzed for pH levels especially for SD_5 which recorded a mean pH level of 6.00. The pH levels of the remaining four sites decreased marginally (UD = 5.95, HD_5 =5.92, HD_{15} = 5.85 and SD_{15} = 5.76).

Table 5: Comparison of soil physico-chemical properties for the five studied sites in the Asenanyo River Forest Reserve.

Property	Habitats					
	Undisturbed (UD)	Slightly disturbed after 5 years of postlogging (SD_5)	Slightly disturbed after 15 years of postlogging (SD_{15})	Heavily disturbed after 5 years of postlogging (HD_5)	Heavily disturbed after 15 years of post-logging (HD_{15})	*P*-value
pH	5.95 ± 0.30	6.00 ± 0.14	5.76 ± 0.36	5.92 ± 0.10	5.85 ± 0.16	0.7108
Total carbon (%)	0.70 ± 0.31	3.10 ± 1.37	2.07 ± 0.52	1.41 ± 0.37	1.61 ± 0.10	0.1995
Total nitrogen (%)	0.06 ± 0.03	0.26 ± 0.11	0.17 ± 0.05	0.12 ± 0.03	0.13 ± 0.10	0.1792
C/N	11.45 ± 0.71	11.40 ± 0.52	12.35 ± 0.42	11.50 ± 0.38	12.03 ± 0.25	0.5583
Organic matter (%)	1.22 ± 0.54	5.35 ± 2.35	3.28 ± 0.89	2.43 ± 0.64	2.78 ± 0.17	0.1995
Electrical conductivity (µS/cm)	188.38 ± 51.74	330.74 ± 58.20	294.50 ± 88.77	200.14 ± 34.78	216.76 ± 29.49	0.3284
Exchangeable Ca (meq/100g)	1.71 ± 0.25	11.96 ± 5.23	11.96 ± 7.53	4.33 ± 1.28	3.85 ± 0.76	0.2825
Exchangeable K (meq/100g)	0.04 ± 0.01	0.05 ± 0.02	0.11 ± 0.06	0.14 ± 0.05	0.09 ± 0.03	0.307
Exchangeable Mg (meq/100g)	1.42 ± 0.17	3.04 ± 0.93	3.77 ± 1.66	1.82 ± 0.45	2.19 ± 0.33	0.3674
Exchangeable Na (meq/100g)	0.03 ± 0.01	0.04 ± 0.01	0.07 ± 0.03	0.05 ± 0.01	0.06 ± 0.01	0.5255
Available phosphorus (ppm)	8.26 ± 0.90	7.53 ± 1.91	9.82 ± 2.44	6.94 ± 1.01	7.22 ± 2.16	0.795
Water holding capacity (%)	11.37^{b} ± 1.43	27.10^{a} ± 5.14	27.21^{a} ± 2.99	15.77^{ab} ± 3.76	20.26^{ab} ± 0.93	0.0082

Numbers with different letters denote significant difference at α = 0.05.

CHAPTER FIVE

DISCUSSION

5.1 Effects of Logging and Post-logging Time on Composition and Structure of Advanced Regeneration

The purpose of this study was to understand the composition and structure of the advanced regeneration of timber species in the Asenanyo River Forest Reserve following selective logging disturbances. Results indicated that diversity and abundance of the advanced regeneration of the reserve were altered by logging intensity and post-logging time. Numbers of individual plants, species, genera, families, alpha diversity indices and evenness were higher in the slightly disturbed habitats compared to the undisturbed and heavily disturbed habitats. These findings are consistent with the general notion that the recovery of forests after logging normally takes years and the resulting forest differ considerably in species composition, diversity and structure from the original forest (Johns *et al.,* 1996; Kinjanjui, Karachi & Kennedy, 2013; Wiafe, 2014). The average of 64 species per hectare recorded in this study is lower than those obtained in studies conducted in other tropical forests of Ghana and beyond (Parthasarathy, 2001; Nartey, 2013 unpublished; Vordzogbe, Attuquayefio & Gbogbo, 2005 cited in Adigbli, 2014, unpublished) apparently due to focus on only the advanced regeneration of timber species between the diameter of 3 cm to 15 cm in this study. Nonetheless, species richness recorded in the present study was higher than that reported by Wiafe (2014) in the same reserve.

The higher species abundance and diversity of advanced regeneration in the slightly disturbed habitats relative to the undisturbed and heavily disturbed habitats is in line with the intermediate disturbance hypothesis (Cornell, 1978), which predicts higher diversity of species when disturbances are intermediate on the scales of frequency, intensity and size. Moderate disturbances just as observed in the slightly disturbed sites in this study are known to mimic natural gaps in undisturbed environment (Gormley, 1997) and promote recruitment and growth of new species. On the other hand, a more stable closed canopy (Huston, 1979; Ofosu-Asiedu, Ofori & Adam, 1993; Sheil & Burslem, 2003) leading to a competitive exclusion in the undisturbed site might have contributed to its lower abundance and diversity of advanced regeneration compared to the slightly disturbed site. Extremely high level of disturbance, including removal of topsoil (i.e., seed bank) and organic matter during construction of forest roads and loading sites, increased soil compaction and erosion, damages of existing vegetation by logging machines, and increased evaporation of soil moisture (Tachie-Obeng, 1994; Mwima *et al*., 2001; Putz *et al.,* 2001; Kinjanjui *et al.,* 2013), might have contributed to the generally low abundance and diversity of advanced regeneration in these sites. This view reflects the strong correlation of logging damage with intensity of logging and its associated operations (Pinard & Putz, 1996; Hawthorne *et al.,* 2011). Agyemang, Turnbull & Swaine (1995), for example, reported a greater number of tree damage associated with haulage road and skid trail constructions than with felling in two moist forests of Ghana (i.e., Bura and Draw River Forest Reserves). Similarly, Sekercioglu (2002) recorded significantly lower densities of advanced regeneration in logged sites of Kibale National Park, Uganda. In the present study, significantly high mean basal area was recorded in the undisturbed habitats, most likely due to the prohibition of timber harvesting.

The more equitable distribution of species in the slightly disturbed and undisturbed habitats can also be attributed to the moderate disturbance pressures in these sites. In general, many of the floristic attributes analyzed seemed to be better for the slightly disturbed habitats, in agreement with most previous studies on post-logging effects in tropical forests (Collins & Glenn,
1997; Molino & Sabatier, 2001; Mackey & Currie, 2001; Sheil & Burslem, 2003; Kinjanjui *et al.,* 2013; Wiafe, 2014).

Taylor (1960) classified the Asenanyo River Forest Reserve as belonging to the *Celtis-Triplochiton* association. The relatively higher importance values (more than 40% of the total relative IVI in the reserve) for these species (i.e., *T. scleroxylon* and *C. milbraedii, C. zenkeri, C. philippensis,* and *C. adolfi-friderici*) recorded in this study (Appendix I Table 1A) supports this classification. However, earlier findings in the same reserve by Wiafe (2014) showed that *Trema orientalis* and *C. mildbraedii* were the predominant species in the heavily disturbed sites, whereas *T. scleroxylon* and *C. mildbraedii* dominated the slightly disturbed and undisturbed sites. This disparity in relative importance of species between these two studies may be attributed to differences in sampling effort. Wiafe (2014) sampled all individual tree species (including non-timber species) older than germinating seeds but less than 10 cm dbh compared to the timber species (dbh between 3 and 15 cm) sampled in the current study.

It is an established fact that few species dominate forest ecosystems that experience prolonged absence or frequent occurrences of high intensity disturbances (Cornell, 1978; Sheil & Burslem, 2003; Kinjanjui *et al.,* 2013). This pattern was evident in

the results of the present study, which showed a much higher importance value for the five most dominant species in the heavily disturbed habitats compared to the slightly disturbed habitats. Similar results have been observed in the tropics (Todaria, Uniyal, Pokhriyal, Dasgupta & Bhatt, 2010; Nartey, 2013 unpublished; Wiafe 2014), though other studies have produced contradictory results (Muhanguzi, Obua & Oryem-Origa, 2007;
Chazdon, Finegan, Capers, Salgado-Negret, Casanoves, Boukili & Norden, 2010).

With time, the importance of the dominant species diminished in the studied habitats as within the same disturbance category all sites logged five years back had higher IVIs for the five most dominant species than their respective sites logged 15 years ago. These results conform to earlier observations that a disturbed forest will 'heal' itself with time; though this time may depend on many factors including soil nutrients, disturbance regime, species, and micro/macroclimates
(Cornell, 1978; Skorupa & Kasenene, 1984; Swaine *et al*., 1998; Thompson, Mackey, Mcnulty & Mosseler, 2009).

Resistance is the inherent ability of a forest to remain unaffected or absorb moderate disturbances (Thompson *et al.,* 2009). According to Belote, Jones & Weiboldt, (2012), forest resistance decreases with increasing timber-harvesting disturbance when these researchers found that compositional stability was lower in most disturbed plots of forests in the Appalachian Mountains of North America. Thus, the dominance of the slightly disturbed and undisturbed sites by the same families in the present study reflects high resistance to moderate logging disturbance, coupled with their relatively high diversity.

According to Thompson *et al.* (2009), resistance is enhanced by increase diversity of a forest ecosystem. The dominance of Sterculiaceae and Ulmaceae in all studied sites in terms of number of individual plants is attributed to great abundance of *T. scleroxylon* and *Celtis* species in the reserve. The inclusion of Euphorbiaceae, Rubiaceae and Moraceae among the five most dominant families in the heavily disturbed sites is not surprising because most species in these families such as *Nauclea diderrichii, Antiaris toxicaria, Milicia excelsa* and *Bridelia micrantha* are either pioneers or non-pioneer light demanding species (Duah-Gyamfi, Kyereh, Adam, Agyeman & Swaine, 2012).

The close resemblance of the rank-abundance curves for all studied habitats suggests relatively minimal effect of logging, in terms of species commonness or rarity, on advanced regeneration. Hawthorne (1993) concluded that logging operations showed few signs of adverse effect on regeneration after observing a similar pattern of distribution after logging disturbance in the Bia South Game Production reserve of Ghana.

The higher representation of pioneers and NPLDs in disturbed habitats compared to undisturbed habitats can be attributed to the openings of canopy gaps and higher incidence of sunlight on the forest floors as a result of logging disturbance (Hawthorne, 1993; Swaine *et al*., 1998; Molino & Sabatier, 2001). This result is in line with the observations by Tchouto *et al*. (2004) in Cameroonian forest that herbaceous species, pioneer species and climbers increase with the degree of disturbances. Similarly, Felton, Felton, Wood & Lindenmayer, (2006) found significantly higher proportion of regenerated pioneers in logged sites compared to unlogged sites in a Bolivian subtropical forest. Following disturbances, pioneers and NPLDs densities are expected to increase whilst those of shadebearers decline with time until the canopy closes (Duah-Gyamfi *et al.,* 2012). However, the time required for this successional shift may vary depending on the intrinsic responses of the guilds to changes in the microhabitat, particularly light (Thompson *et al.,* 2009; Duah-Gyamfi *et al.,* 2012). The relatively higher numbers of pioneers recorded in habitats logged 15 years ago compared to habitats logged 5 years suggest that more time may be required for the expected compositional shifts to take place, though the number of shade-bearers increased with time in the slightly disturbed habitats. However, Duah-Gyamfi *et al*. (2012) reported a reduction in the proportion of understory pioneer species after 33 months of selective logging in Pra Anum Forest Reserve of Ghana.

The greater basal area of species in the undisturbed and slightly disturbed habitats compared to the heavily disturbed habitats (for a particular post-logging time) provide further evidence of the effects of logging on advanced regeneration in the Asenanyo River Forest Reserve. Sekercioglu (2002), Rasingam and Parathasarathy (2009) and Wiafe (2014) reported similar results in Kibale National Park, Uganda, Little Andaman Island, India, and Asenanyo Forest Reserve, Ghana, respectively. Also, Kinjanjui *et al*. (2013) recorded higher basal area in unlogged sites followed by moderately disturbed sites and least in heavily disturbed sites for trees with diameter greater or equal to 40 cm. Higher basal area of advanced regeneration encountered in the undisturbed sites can be attributed to the absence of disturbances which often remove large trees or cause serious damage to undergrowths (Agyemang *et al*., 1995). However, other investigators have reported higher basal areas following disturbances in different forests (e.g., Latty, Canham & Marks, 2004; Sefah, unpublished). Sefah (unpublished), for example, found significantly higher mean basal area of seedlings and saplings in heavily disturbed forests compared with intermediately and undisturbed forest types in Ghana, and concluded that this might be due to the sufficient light availability resulting from the low canopy cover.

In most forests, the number of trees typically decrease with increasing diameter (Parren, 2003), but most habitats in this study (except for habitats logged 5 years back) had relatively fewer plants in the lower diameter classes than in the higher diameter classes. The "irregular" pattern in diameter distribution within the disturbed habitats could be explained by the fact that this study did not sample very small trees—understory layer. The higher number of saplings but lower number of small trees in the disturbed forest compared to undisturbed forest is probably due to the removal of large trees by logging disturbances as also reported by Kinjanjui *et al.* (2013) in Mau Forest complex, Kenya. Similar pattern observed between habitats logged five years back and those logged 15 years ago could be explained by age/time factor. It is reasonable to expect most saplings to develop into poles and subsequently into small trees (Kinjanjui *et al.,* 2013), provided there are no further disturbances to these habitats (SD_5 and HD_5).

5.2 Effects of Logging and Post-logging time on Conservation Status of the Habitats

Most forest ecosystems in Ghana are dominated by green star species (Hawthorne & Abu-Juam, 1995; IUCN, 2004; Hawthorne & Gyakari, 2006). According to the IUCN (2004), for example, green star species account for almost half of Ghana's forest species. Hawthorne & Gyakari (2006) revealed further that these species are common in Ghana and are of no particular conservation concern. Thus, the predominance of green star species in all studied habitats (making up of 32.0 % of identified star-rated species) was not unexpected. The absence of black and gold species, and much fewer blue species in the entire studied habitats could be due to the generally rare nature of these species in the studied area and Ghana as a whole (Hawthorne and Gyakari, 2006; FC, 2010). The blue species existed only in the disturbed habitats, suggesting the importance of disturbance to the maintenance of high biodiversity in tropical forests (Cornell, 1978).

The average GHI of 71.8 % obtained in this study is low compared with the documented values of 301 (Ankasa Conservation Area) and 269 (Neung North Forest Reserve) and places the ASEN forest in the low conservation/bioquality category (Hawthorne & Abu-Juam, 1995; Hawthorne, 1996). This result is not surprising because, even under pristine conditions, the moist semi-deciduous forest zone, including the current study area, tends to have low to moderate GHI values compared to the wet evergreen forests and southern dry forests (Hawthorne & Abu-Juam 1995; Hawthorne, 1996). The comparatively lower GHI value recorded in the undisturbed site relative to the disturbed sites may suggest an improvement in the conservation status of the reserve following logging disturbances. However, it is important to note that this study did not cover all growth forms of plants.

5.3 Effects of Logging and Post-logging Time on Soil Physico-chemical Properties

Considering the lack of statistical differences in most soil properties among habitats of varied logging disturbance intensities and post-logging times, one can hardly argue that logging operation significantly affected soil nutrients (Hooper, Chapin, Ewel, Hector, Inchausti, Lavorel, Lawton, Lodge, Loreau, Naeem, Schmid, Setälä, Symstad, Vandermeer & Wardle, 2005). However, the relatively higher values of most soil nutrients analyzed in the slightly disturbed habitat (although insignificant) may partially account for the somewhat improved diversity and abundance of advanced regeneration in this habitat compared to the other studied habitats (Webb, 1998; Jennings *et al*., 2001). Tropical forest soils are generally known to be poor in nutrient and much of the nutrients are held in the aboveground vegetation. In this regard, the slight increase in soil nutrients from logged habitats compared to unlogged habitats are not surprising. An increase in the rate of litterfall deposition, direct uptake of nutrients from rainfall and from the air by means of nitrogen-fixing organisms and efficient litter decomposition mechanisms associated with the logging disturbances (Uhl & Clark, 1983; Islam & Well, 2000 cited in Kinjanjui *et al.,* 2013) may be responsible for the relatively higher nutrient levels recorded in the slightly disturbed habitats. For example, Tachie-Obeng (1994) observed significant increase in most tested soil nutrients in felled gaps and secondary skid trials compared to haulage roads, attributing this change to the presence of branches, leaves and almost 50 % of standing tree volume left in slightly disturbed forest as residue. On the contrary, Kinjanjui *et al. (*2013) recorded reductions in organic matter, total nitrogen and available phosphorus (P) with increasing forest disturbances but similar concentrations of K, Ca, Mg and Na in both logged and unlogged forests of Mau Forest complex, Kenya. Loss of organic matter by erosion or loss of top soil (resulting from forest road and loading bay constructions), accelerated oxidation, higher day time temperatures and reduced day time humidity through open canopy probably accounted for the low soil nutrient levels in heavily disturbed habitats (Uhl & Clark, 1983; Congdon & Herbohn, 1993; McNabb *et al.,* 1997; Hawthorne *et al.,* 2011; Kinjanjui *et al.,* 2013).

Cation exchange capacity (CEC) is a measure of the soil's ability to hold positively-charged ions (Dassonville *et al*., 2008). Large quantities of negative charges, resulting from increased soil organic matter content in a habitat, enhance CEC and promote nutrient retention in the topsoil (Dassonville *et al*., 2008). Hence, the higher organic matter content of the slightly disturbed habitat can explain its higher CEC, exchangeable Na, Ca, and Mg levels in comparison to that of the heavily disturbed and undisturbed habitats. The marginally higher total N and C contents of the slightly disturbed habitats can be connected with increased enrichment of litter in these sites, which provided substrates for nitrogen fixation, by soil microbes (Dassonville *et al*., 2008). Similarly, the relatively higher organic content recorded in the slightly disturbed habitats could be attributed to reduced soil microbial activities (other than nitrogen-fixing microorganisms) as electrical conductivity (EC) increased (Uhl & Clark, 1983).

In general, the best soil for growth of tropical trees seedling must have pH that ranges from 6.0-7.0 (McNabb *et al.,* 1997). All pH values obtained in this study were within this range. With the exception of SD_5, soils from the undisturbed habitat were more basic compared to that from the disturbed habitats. The trend in pH is in agreement with Kinjanjui *et al. (*2013), who reported a reduction in pH with increased forest disturbances in Mau Forest complex, Kenya. Contrarily, McNabb *et al*. (1997) and Olander, Bustamante, Asner, Telles, Prado & Camargo, (2005) found increase in soil pH, Ca, and Mg in an eastern Amazon forest after 16 years of logging in areas such as forest roads and loading bay with reducing conditions which may result from Fe reduction, freeing exchange sites that can retain these cations.

The significant higher water holding capacity in slightly disturbed habitats could be due to the higher organic contents and decreased bulk density, which might have led to a reduction in the number of pores among soil particles (Johns, 1988).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study was conducted to assess the effect of selective logging disturbances and post-logging time on advanced regeneration of timber species in a tropical rainforest of Ghana. Results generally indicated slightly better composition and structural characteristics (in terms, of alpha diversity, density, important values, etc.) of the advanced regeneration in the slightly disturbed habitats compared to the undisturbed and heavily disturbed habitats. These results suggest positive effects of intermediate level of disturbance in these forests, consistent with the intermediate disturbance hypothesis. However, mean basal area was significantly high in the undisturbed habitat. The relative importance indices of *T. scleroxylon* and *Celtis* species were the highest in all studied habitats, providing a quantitative support for the earlier classification of the Asenanyo River Forest Reserve as a *Celtis-Triplochiton* association (Taylor, 1960).

The Asenanyo reserve recorded a GHI of 71.8 % as green star species dominated the advanced regeneration of timber species. This GHI places the reserve in a low conservation priority area, and suggests that local environments probably do not support the survival of globally rare species. Notwithstanding, the GHI differed among studied habitats reflecting differences in logging intensity and postlogging time. The few blue star species encountered in the reserve were only found in the disturbed habitats.

In general, logging disturbances and the time since harvesting exerted minimal effects on the soil physico-chemical properties, except for significantly higher water hold capacity in the slightly disturbed habitats compared to the rest of the studied habitats. Nonetheless, the slightly lower values of most of the analyzed soil properties in heavily disturbed habitats relative to the slightly disturbed habitats reflects the intensity of the logging disturbance more than the time since timber harvesting. Furthermore, the results indicate that intermediate levels of logging may positively impact the soil physico-chemical properties in this tropical forest by facilitating the nutrients release from the aboveground biomass.

6.2 Recommendations

Based on findings from this study, it is recommended that both forest managers and timber companies must strategically plan logging operations—by adhering to the reduced impact logging techniques—to ensure minimal effect on advanced regeneration and soil physico-chemical properties. Forest roads and loading sites where much destruction occurs should be strategically located so that they can be re-used in different logging operations. Movement of logging machines (such as skidders and timber trucks) should be minimized as possible. Also, interventions such as enrichment planting in heavily disturbed areas (loading sites, roads, etc) should be embarked upon to improve the vegetation of such areas after logging operations.

Forestry Commission of Ghana must adopt and enforce simple and effective forestry codes as most current regulations are conflicting, confusing, and, seldom adhered to. For example, the widths of all main forest roads in the studied habitats were greater than the recommended width of 20 m (Ghana Forest Service, 1998). Furthermore, the size and number of most loading sites were greater than the required size and number (i.e., one quarter of a hectare and four loading sites per compartment, respectively; Ghana Forest Service, 1998). Companies found liable to forest and/or logging offences must be made to face the full rigor of the law. The over-exploitation of very few species as timber should be discouraged as this may lead to local extinction of some species.

Future research must integrate natural regeneration of all plant species and growth forms, not just the advanced regeneration of timber species, to fully understand the impacts of selective logging and post-logging time on forest composition, structure and dynamics in this reserve and others in Ghana. Such studies may also consider the influence of topographical features such as aspects, elevation, slope, etc. The impact of logging on fauna composition and diversity especially on insects, rodent and birds that aid in seed dispersal and pollination might also yield valuable information. Assessment of seed banks in logged and unlogged forest since most regenerated trees after logging come from this source is also highly recommended.

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APPENDICES Appendix I

Table 1A: Number of individuals, relative frequency, density, dominance and important value index (IVI) of timber species in the studied habitats of the Asenanyo River Forest Reserve.

Species	No. of individuals	R. Freq. (%)	R. Den. (%)	R. Dom (%)	IVI (%)
Triplochiton scleroxylon	242	6.87	17.39	62.92	29.06
Celtis mildbraedii	116	5.33	8.33	15.67	9.78
Celtis zenkeri	66	3.95	4.74	4.18	4.29
Nauclea diderrichii	53	2.92	3.81	2.49	3.07
Celtis philippensis	40	2.75	2.87	1.74	2.45
Bridelia micrantha	34	1.55	2.44	0.73	1.57
Entandrophragma angolense	22	2.23	1.58	0.53	1.45
Cordia millenii	25	1.89	1.80	0.50	1.40
Disemonanthus benthamianus	22	1.89	1.58	0.31	1.26
Khaya anthotheca	23	1.03	1.65	0.97	1.22
Antiaris toxicaria	22	1.55	1.58	0.44	1.19
Terminalia superba	21	1.72	1.51	0.32	1.18
Piptadeniastrum africanum	23	1.37	1.65	0.51	1.18
Cylicodiscus gabunensis	19	1.72	1.36	0.36	1.15
Albizia zygia	18	1.72	1.29	0.40	1.14
Khaya ivorensis	19	1.37	1.36	0.51	1.08
Tieghemella heckelii	18	1.72	1.29	0.24	1.08
Petersianthus macrocarpus	18	1.37	1.29	0.36	1.01

Morus mesozygia	17	1.55	1.22	0.14	0.97
Guibourtia ehie	17	1.20	1.22	0.48	0.97
Guarea cedrata	17	1.03	1.22	0.51	0.92
Sterculia rhinopetala	16	1.37	1.15	0.23	0.92
Pycnanthus angolensis	16	1.20	1.15	0.35	0.90
Blighia sapida	17	1.03	1.22	0.33	0.86
Cola gigantea	16	1.20	1.15	0.20	0.85
Nesogordonia papaverifera	13	1.37	0.93	0.23	0.85
Lannea welwitschii	13	1.20	0.93	0.22	0.79
Terminalia ivorensis	15	1.03	1.08	0.20	0.77
Pterygota macrocarpa	14	1.03	1.01	0.18	0.74
Holarrhena floribunda	13	1.03	0.93	0.18	0.71
Klainedoxa gabonensis	13	1.03	0.93	0.17	0.71
Milicia excelsa	9	1.20	0.65	0.16	0.67

Table 1A continued

Species	No. of individuals	R. Freq. (%)	R. Den. (%)	R. Dom (%)	IVI (%)
Bombax buonopozense	11	1.03	0.79	0.13	0.65
Sterculia tragacantha	9	1.20	0.65	0.10	0.65
Parkia bicolor	9	1.20	0.65	0.08	0.64
Amphimas pterocarpoides	14	0.52	1.01	0.29	0.60
Zanthoxylum leprieurii	9	1.03	0.65	0.12	0.60
Lophira alata	11	0.86	0.79	0.15	0.60
Daniellia ogea	11	0.86	0.79	0.09	0.58
Ceiba pentandra	11	0.86	0.79	0.08	0.58
Cynometra ananta	8	1.03	0.57	0.08	0.56
Celtis adolfi-friderici	10	0.86	0.72	0.09	0.55
Hannoa klaineana	8	1.03	0.57	0.05	0.55
Psydrax subcordata	11	0.69	0.79	0.12	0.53
Heritiera utilis	9	0.86	0.65	0.09	0.53
Sacoglottis gabonensis	7	1.03	0.50	0.04	0.52
Strombosia pustulata	8	0.86	0.57	0.08	0.51
Homalium letestui	8	0.86	0.57	0.04	0.49
Pleioceras barteri	9	0.69	0.65	0.09	0.47
Hexalobus crispiflorus	9	0.52	0.65	0.25	0.47
Ongokea gore	7	0.86	0.50	0.03	0.46
Funtumia elastica	8	0.69	0.57	0.11	0.46
Turraeanthus africanus	6	0.86	0.43	0.04	0.44
Pouteria altissima	6	0.86	0.43	0.03	0.44

Parinari excelsa	6	0.86	0.43	0.02	0.44
Stereospermum acuminatissimum	8	0.69	0.57	0.05	0.44
Trilepisium madagascariense	7	0.69	0.50	0.06	0.42
Chrysophyllum albidum	7	0.69	0.50	0.04	0.41
Zanthoxylum gilletii	6	0.69	0.43	0.06	0.39
Duboscia macrocarpa	5	0.69	0.36	0.13	0.39
Panda oleosa	7	0.52	0.50	0.14	0.39
Entandrophragma utile	6	0.69	0.43	0.03	0.38
Allanblackia parviflora	5	0.69	0.36	0.03	0.36
Ricinodendron heudelotii	6	0.52	0.43	0.08	0.34
Albizia glaberrima	4	0.69	0.29	0.03	0.33
Rhodognaphalon brevicuspe	4	0.69	0.29	0.01	0.33
Syzyguim guineense	4	0.69	0.29	0.01	0.33
Entandrophragma cylindricum	6	0.52	0.43	0.03	0.33
Copaifera salikounda	5	0.52	0.36	0.03	0.30
Musanga cecropioides	5	0.52	0.36	0.02	0.30

Table 1A continued

Species	No. of individuals	R. Freq. (%)	R. Den. (%)	R. Dom (%)	IVI (%)
Xylia evansii	5 0.3	0.52	0.36	0.02	0
Cleistopholis patens	5	0.52	0.36	0.02	0.30
Duguetia staudtii	6	0.34	0.43	0.07	0.28
Treculia africana	4	0.52	0.29	0.04	0.28
Cordia platythyrsa	4	0.52	0.29	0.01	0.27
Synsepalum afzelii	6	0.34	0.43	0.03	0.27
Margaritaria discoidea	3	0.52	0.22	0.01	0.25
Bussea occidentalis	3	0.52	0.22	0.01	0.25
Discoglypremna caloneura	3	0.52	0.22	0.01	0.25
Sterculia oblonga	5	0.34	0.36	0.01	0.24
Corynanthe pachyceras	4	0.34	0.29	0.01	0.22
Entandrophragma candollei	4	0.34	0.29	0.01	0.21
Mansonia altissima	4	0.34	0.29	0.01	0.21
Alstonia boonei	3	0.34	0.22	0.01	0.19
Milicia regia	3	0.34	0.22	0.01	0.19
Scytopetalum tieghemii	2	0.34	0.14	0.01	0.16
Dialium aubrevillei	2	0.34	0.14	0.00	0.16
Dacryodes klaineana	2	0.34	0.14	0.00	0.16
Spathodea campanulata	2	0.34	0.14	0.00	0.16
Canarium schweinfurthii	4	0.17	0.29	0.01	0.16

Khaya grandifoliola	3	0.17	0.22	0.02	0.14
Anopyxis klaineana	2	0.17	0.14	0.00	0.11
Xylopia staudtii	1	0.17	0.07	0.01	0.08
Calpocalyx brevibracteatus	1	0.17	0.07	0.00	0.08
Macaranga hurifolia	1	0.17	0.07	0.00	0.08
Lonchocarpus sericeus	1	0.17	0.07	0.00	0.08
Erythrophleum ivorense	1	0.17	0.07	0.00	0.08
Mammea africana	1	0.17	0.07	0.00	0.08
Protomegabaria stapfiana	1	0.17	0.07	0.00	0.08
Anthocleista vogelii	1	0.17	0.07	0.00	0.08
Harungana madagascariensis	1	0.17	0.07	0.00	0.08
Berlinia tomentella	1	0.17	0.07	0.00	0.08
Memecylon lateriflorum	1	0.17	0.07	0.00	0.08
Myrianthus arboreus	1	0.17	0.07	0.00	0.08
Chrysophyllum perpulchrum	1	0.17	0.07	0.00	0.08
Lovoa trichilioides	1	0.17	0.07	0.00	0.08
Millettia rhodantha	1	0.17	0.07	0.00	0.08
Strephonema pseudocola	1	0.17	0.07	0.00	0.08

Table 1B: Relative frequency, density, dominance and important value index (IVI) of timber species in undisturbed (UD) habitat studied in the Asenanyo River Forest Reserve.

Species	UD			
	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)

Albizia zygia	1.12	1.12	1.08	0.72	1.20	0.63
Alstonia boonei	1.12	1.12	2.52	1.44	3.77	2.75
Amphimas pterocarpoides	1.12	1.12	1.08	0.36	1.15	0.48
Blighia sapida	1.12	8.99	0.36		0.07	
Bombax buonopozense	3.37	5.62	12.59		12.95	
Calpocalyx brevibracteatus	1.12	1.12	1.80	3.96	1.02	3.22
Celtis adolfi-friderici	2.25	1.12	0.36	1.80	0.08	0.82
Celtis mildbraedii	1.12	1.12	0.72	1.08	0.64	0.98
Celtis philippensis	1.12	1.12	1.08	1.08	0.92	0.56
Celtis zenkeri	2.25	2.25	0.72	1.44	1.27	1.52
Chrysophyllum albidum	3.37	1.12	2.16	2.52	2.56	3.01
Cola gigantea	1.12	1.12	3.24	0.36	4.41	0.69
Cylicodiscus gabunensis	3.37	1.12	2.52	0.36	3.87	0.25
Cynometra ananta	1.12	2.25	6.47	1.08	6.87	1.23
Daniellia ogea	1.12	2.25	2.16	2.52	1.91	1.89
Disemonanthus benthamianus	1.12	1.12	0.36	0.72	0.38	0.45
Duboscia macrocarpa	1.12		0.72	0.72	1.37	0.31
Duguetia staudtii	1.12		0.36		0.07	
Entandrophragma angolense			0.36		0.22	
Guarea cedrata						
Guibourtia ehie						
Heritiera utilis						
Hexalobus crispiflorus						
Holarrhena floribunda						
Khaya anthotheca						
Khaya grandifoliola						
Khaya ivorensis						
Klainedoxa gabonensis						
Lophira alata						
Margaritaria discoidea						
Milicia excelsa						
Musanga cecropioides						
Myrianthus arboreus						
Nauclea diderrichii						

1.14
0.83
2.47
1.77
1.12
0.65
0.52
11.51
2.06
4.27
0.52
1.25
1.20
1.06
1.04
0.92
1.04
1.36
2.32
2.59
3.67
0.73

2.50
0.58
5.57
1.15
1.73
2.22
0.62
1.14
1.07
0.72
0.52
0.57

Table 1B continued

Species	UD			
	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)
Nesogordonia papaverifera	1.12	0.72	1.16	1.00

Ongokea gore	1.12	0.72	0.14	0.66
Panda oleosa	2.25	1.80	2.39	2.15
Petersianthus macrocarpus	1.12	0.72	0.85	0.90
Piptadeniastrum africanum	2.25	1.80	1.65	1.90
Pleioceras barteri	1.12	0.36	0.23	0.57
Psydrax subcordata	1.12	2.88	1.33	1.78
Pterygota macrocarpa	2.25	1.80	1.41	1.82
Pycnanthus angolensis	2.25	2.88	3.11	2.74
Ricinodendron heudelotii	1.12	0.36	0.68	0.72
Sterculia rhinopetala	1.12	0.36	0.28	0.59
Sterculia tragacantha	1.12	0.36	0.21	0.56
Strombosia pustulata	1.12	1.08	1.33	1.18
Synsepalum afzelii	2.25	2.16	0.81	1.74
Terminalia ivorensis	1.12	1.08	0.69	0.97
Terminalia superba	1.12	0.36	0.76	0.75
Trilepisium madagascariense	1.12	0.72	0.88	0.91
Triplochiton scleroxylon	8.99	16.55	16.09	13.88
Turraeanthus africanus	2.25	1.08	0.51	1.28
Zanthoxylum leprieurii	1.12	1.44	1.96	1.51

Table C: Relative frequency, density, dominance and important value index (IVI) of timber species in slightly disturbed habitats after 5 and 15 years of post-logging (SD_5 and SD_{15} respectively) studied in the Asenanyo River Forest Reserve.

Species	SD_5				SD_{15}			
	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)

Albizia glaberrima	0.88	0.28	0.15	0.44	1.39	0.61	1.04 1.38	1.01
Albizia zygia	1.75	0.84	0.52	1.04	1.39	0.91	1.10	1.23
Allanblackia parviflora	-	-	-	-	1.39	0.61	-	1.03
Amphimas pterocarpoides	0.88 0.88	1.68	1.09 0.57	1.22 0.67	-	-	-	-
Anopyxis klaineana	0.88 1.75	0.56	0.26 2.66	0.47 2.31	-	-	-	-
Anthocleista vogelii	2.63 0.88	0.28	2.76 0.26	2.82 0.57	-	-	2.08	-
Antiaris toxicaria	0.88 0.88	2.52	0.90 0.27	0.97 0.48	2.08	2.42	-	2.20
Blighia sapida	0.88 1.75	3.08	0.86 1.74	0.95 1.82	-	-	1.16 2.08	-
Bombax buonopozense	0.88 2.63	0.56	0.58 4.27	0.67 3.79	1.39	1.21	0.33	1.25
Bridelia micrantha	0.88 6.14	1.12	0.94	0.79 8.40	1.39	2.73	-	2.06
Bussea occidentalis	0.88 0.88	0.28	10.09	1.11 0.87	0.69	0.30	0.65 0.97	0.44
Canarium schweinfurthii	2.63	1.12	1.35 0.90	2.36	-	-	9.36 0.55	-
Ceiba pentandra	-	1.96	2.21	-	2.08	1.21	3.95 0.26	1.32
Celtis adolfi-friderici	3.51	0.56	-	3.32	1.39	1.52	0.05 0.18	1.29
Celtis mildbraedii		4.48	3.38		5.56	10.30	1.02	8.41
Celtis philippensis		0.56			1.39	0.61	2.62	0.85
Celtis zenkeri		8.96			3.47	3.94		3.79
Chrysophyllum albidum		1.12			0.69	0.30		0.42
Cleistopholis patens		0.84			0.69	0.30		0.35
Cola gigantea		2.24			0.69	0.30		0.39
Copaifera salikounda		-			1.39	1.21		1.21
Cordia millenii		3.08			1.39	2.73		2.24

Table 1C continued

Species	SD$_5$				SD$_{15}$			
	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)

Cordia platythyrsa	0.88	0.88	0.84	1.12	0.33	0.95	0.50	-	-	-		-
Corynanthe pachyceras	3.51		0.28	4.74		3.78		0.69	0.30	0.35	1.41	0.45
Cylicodiscus gabunensis	-		3.08	-		-		2.08	1.52	0.26	0.20	1.67
Cynometra ananta	2.63		-	2.16		2.06		0.69	0.30	0.22		0.42
Daniellia ogea			1.40					0.69	0.91			0.60
Dialium aubrevillei								0.69	0.30			0.41
Discoglypremna caloneura								0.69	0.30	0.07		0.36
Disemonanthus benthamianus	2.63		3.08	2.89		2.87		0.69	0.30	0.39	1.27	0.46
Duboscia macrocarpa	-		-	-		-		1.39	0.30	1.64		0.99
Entandrophragma angolense	1.75		1.68	1.06		1.50		2.78	1.52	-		1.98
Entandrophragma candollei	0.88		0.84	0.70		0.81		-	-	0.98	0.17	-
Entandrophragma cylindricum	-		-	-		-		1.39	1.52	2.87	2.30	1.29
Entandrophragma utile	1.75	0.88	0.84	1.38	0.24	1.33	0.47	0.69	0.61	0.81	0.57	0.49
Funtumia elastica	0.88	0.88	0.28	0.62	0.13	0.78	0.43	1.39	1.82	0.79	0.33	2.03
Guarea cedrata	1.75	0.88	0.84	0.42	0.81	0.91	0.75	0.69	1.21	1.80		1.40
Guibourtia ehie	0.88	0.88	0.28	0.71	1.03	0.62	0.92	1.39	1.52	0.07		1.24
Hannoa klaineana	0.88	0.88	0.56	0.68	0.53	0.80	0.75	1.39	0.91	-		0.95
Heritiera utilis	0.88	0.88	0.56	0.61	0.29	0.78	0.48	0.69	0.30	2.90	0.48	0.60
Hexalobus crispiflorus	0.88		0.28	0.83		0.94		0.69	0.30	1.67		0.44
Holarrhena floribunda			0.84					0.69	1.21			1.24
Homalium letestui			0.84					0.69	0.30			0.36
Khaya anthotheca			0.84					-	-			-
Khaya ivorensis			0.84					2.08	2.12			2.37
Klainedoxa gabonensis			0.28					1.39	1.21			1.03
Lannea welwitschii			1.12					1.39	1.52			1.52

Table 1C continued

Species	SD_5	SD_{15}

	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)

Lophira alata	-		-	-		-		1.39	2.12	2.18	0.27	1.90
Macaranga hurifolia	-		-	-		-		0.69	0.30	1.78	0.42	0.42
Milicia excelsa	0.88	2.63	0.28	0.24	1.82	0.47	2.32	1.39	0.91	0.43	4.03	1.36
Morus mesozygia	0.88	2.63	2.52	0.27	2.40	0.48	2.70	1.39	0.61	0.20	0.31	0.81
Musanga cecropioides	0.88		0.28	1.36		1.21		0.69	0.61	0.90	0.32	0.58
Nauclea diderrichii	1.75		3.08	0.63		1.08		2.08	3.64	1.10	0.62	3.25
Nesogordonia papaverifera	-		1.40	-		-		0.69	0.30	1.78	1.20	0.40
Ongokea gore	-		0.84	-		-		1.39	0.61	0.31	0.11	0.77
Panda oleosa	0.88	1.75	-	0.23	4.65	0.46	2.88	0.69	0.61	0.07	0.96	0.73
Parinari excelsa	1.75		-	1.19		1.64		1.39	0.91	0.43		0.87
Parkia bicolor	-		0.28	-		-		1.39	1.21	-		1.23
Petersianthus macrocarpus	0.88		2.24	0.53		0.66		0.69	0.91	1.77	0.09	0.74
Piptadeniastrum africanum	-		1.96	-		-		2.08	2.73	0.48	0.30	2.20
Pleioceras barteri	-		-	-		-		0.69	0.91	2.17		0.93
Pouteria altissima	0.88	1.75	0.56	0.48	1.08	0.73	1.23	1.39	0.61			0.77
Protomegabaria stapfiana	0.88	0.88	-	0.29	0.91	0.48	0.78	0.69	0.30			0.37
Psydrax subcordata	0.88		-	0.43		0.62		0.69	0.30			0.35
Pterygota macrocarpa	-		0.84	-		-		1.39	1.52			1.29
Pycnanthus angolensis			0.84					1.39	0.61			0.81
Rhodognaphalon brevicuspe	2.63		0.28	1.44		2.10		-	-			-
Ricinodendron heudelotii			0.56					0.69	0.91			1.13
Sacoglottis gabonensis			0.56					0.69	0.30			0.36
Scytopetalum tieghemii			-					1.39	0.61			0.83
Sterculia oblonga								0.69	0.91			0.64
Sterculia rhinopetala			2.24					2.08	1.52			1.92

Table 1C continued

Species	SD_5	SD_{15}

	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)
Sterculia tragacantha	1.75	0.84	1.32	1.30				
Stereospermum acuminatissimum	-	-	-	-				
Strephonema pseudocola	0.88	0.28	0.13	0.43				
Strombosia pustulata	-	-	-					
Syzyguim guineense	0.88 1.75	0.28	0.23 1.87	-				
Terminalia ivorensis Terminalia	1.75 2.63	2.80	3.29					
superba	7.02	2.24	1.69	0.46				
Tieghemella heckelii	0.88	1.96	16.21 0.24					
Triplochiton scleroxylon	-	16.81	-	2.14				
Turraeanthus africanus	-	0.28	-					
Xylia evansii	-	-	-	2.43				
Xylopia staudtii	-	-	-					
Zanthoxylum gilletii		-		2.09				
Zanthoxylum leprieurii		-						
				13.34				
				0.47				
				-				
				-				
				-				

Table 1D: Relative frequency, density, dominance and important value index (IVI) of timber species in heavily disturbed habitats after 5 and 15 years of post-logging (HD_5 and HD_{15} respectively) studied in the Asenanyo River Forest Reserve.

Species	HD^5				HD_{15}			
	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)
					2.78	1.52	1.38	1.89
					0.69	0.30	0.13	0.38
	-	-	-	-				
					1.39	0.61	0.58	0.86
	-	-	-	-				
	0.69	0.30	0.50	0.50	1.39	0.91	0.53	0.94
					1.39	0.91	0.92	1.07
					5.56	16.97	20.15	14.23
	0.69	0.30	0.09	0.36	1.39	1.21	0.69	1.10
	0.69	0.30	1.16	0.72	1.39	0.91	1.19	1.16
	0.69	0.30	0.09	0.36				

Albizia glaberrima	-		-	-	-		0.81		0.45	0.52		0.59
Albizia zygia	2.70	1.80	1.95	1.78	2.15	1.38	1.61		2.25	2.71		2.19
Allanblackia parviflora	0.90		1.46	0.89	0.56		-		-	-		-
Alstonia boonei	0.90		0.49	0.30	0.59		-		-	-		-
Amphimas pterocarpoides	-		0.49	0.39	-		-		-	-		-
Antiaris toxicaria	0.90		-	-	0.59		3.23		2.25	2.74		2.74
Berlinia tomentella	-		0.49	0.39	-		-		-	-		-
Blighia sapida	0.90	1.80	-	-	0.56	3.12	1.61	0.81	0.90	1.18	0.18	1.23
Bombax buonopozense	0.90	0.90	0.49	0.30	0.56	1.23	3.23		0.45	2.74		0.48
Bridelia micrantha	6.31	4.50	3.90	3.66	8.59	5.28	-		5.86	-		3.94
Bussea occidentalis	3.60		0.49	0.30	3.51		-		-	-		-
Celtis adolfi-friderici	-		0.98	1.81	-		4.03	4.03	-	4.23		-
Celtis mildbraedii	-		10.73	8.74	-		1.61	0.81	4.05	10.87		4.11
Celtis philippensis	-		5.37	5.97	-		0.81	0.81	9.01	2.12	0.23	7.97
Celtis zenkeri	-		2.44	4.48	-		1.61		2.25	0.13	0.61	1.99
Chrysophyllum albidum	0.90		-	-	0.76		-		0.45	0.86		0.49
Chrysophyllum perpulchrum	1.80		-	-	1.19		2.42		0.45	-		0.46
Cleistopholis patens			-	-					0.45	0.43		0.62
Cola gigantea			-	-					0.90			1.12
Copaifera salikounda			0.49	0.88					-			-
Cordia millenii			0.98	0.78					1.35			1.40

Table 1D continued	HD5				HD15			
	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)
Species								
Cordia platythyrsa	-	-	-	-	1.61 0.81	1.35 0.45	0.89 0.32	
Cylicodiscus gabunensis	-	-	-	-	1.61	0.90	0.38	0.53
Cynometra ananta	1.80 0.90	0.98 0.49	2.02 0.30	1.60 0.56	0.81	0.45	0.52	0.96
Dacryodes klaineana	0.90 0.90	0.49 0.49	0.50 0.30	0.63 0.56	-	-	-	0.59
Dialium aubrevillei	1.80	0.98	0.88	1.22	0.81	0.45	0.68	-
Discoglypremna caloneura								0.65
Disemonanthus benthamianus					3.23	2.25	0.91	2.13
Duboscia macrocarpa	-	-	-	-	0.81 0.81	0.90 0.90	2.23 0.73	1.31
Duguetia staudtii	-	-	-	-	1.61	0.90	0.19	0.81
Entandrophragma angolense	2.70	1.46	1.32	1.83	0.81	0.45	0.29	0.90
Entandrophragma candollei	-	-	-	-	-	-	-	0.51
Entandrophragma cylindricum	0.90	0.49	0.22	0.54				-

	HD5				HD15			
	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)
Entandrophragma utile	0.90 0.90	0.49 0.49	0.74 0.74	0.71 0.71	-	-	-	-
Erythrophleum ivorense	-	-	-	-	-	-	-	-
Funtumia elastica	-	-	-	-	0.81 1.61	0.45 1.35	0.13 0.82	0.46
Guarea cedrata	-	-	-	-	0.81	0.90	0.77	1.26
Guibourtia ehie	0.90	0.49	0.39	0.59	0.81	0.90	0.83	0.83
Hannoa klaineana	0.90	0.49	0.41	0.60	-	-	-	0.85
Harungana madagascariensis								-
Heritiera utilis	1.80 0.90	2.44 0.98	2.10 0.69	2.11 0.86	-	-	-	-
Holarrhena floribunda	0.90	0.49	0.39	0.59	1.61	1.35	0.52	1.16
Homalium letestui					1.61	1.35	0.99	1.32

Table 1 D continued

Species								
Khaya anthotheca	-	-	-	-	1.61 1.61	0.90 0.90	1.49 0.98	1.33
Khaya ivorensis	0.90	0.49	1.20	0.86	0.81	0.45	0.13	1.17
Klainedoxa gabonensis								0.46

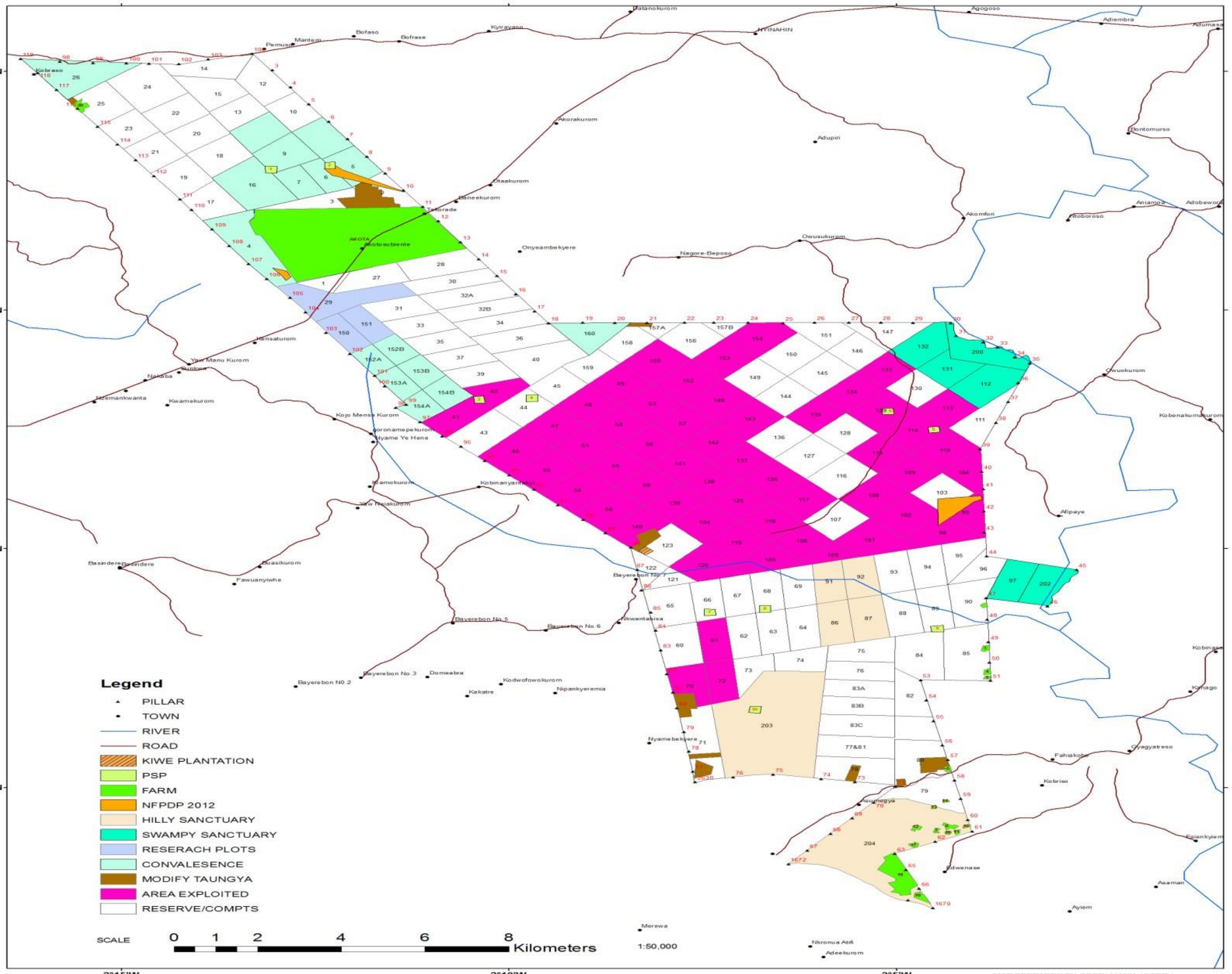
	HD5				HD15			
	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)
Lannea welwitschii	1.80	0.98	0.67	1.15	1.61 0.81	0.90 0.45	1.95 0.37	1.49
Lonchocarpus sericeus	-	-	-	-	0.81	0.45	0.22	0.54
Lophira alata	0.90	0.98	0.83	0.90	0.81	0.45	0.13	0.49
Lovoa trichilioides	-	-	-	-	-	-	-	0.46
Mammea africana	0.90 1.80	0.49 1.95	0.50 1.52	0.63 1.76	-	-	-	-
Mansonia altissima	0.90 0.90	0.49 0.49	0.30 0.39	0.56 0.59	-	-	-	-
Margaritaria discoidea	1.80 0.90	0.98 0.98	1.18 0.61	1.32 0.83	-	-	-	-
Memecylon lateriflorum	0.90 1.80	0.49 1.95	0.22 1.77	0.54 1.84	0.81	0.45	0.17	-
Milicia excelsa	4.50 0.90	6.34 0.49	7.38 1.00	6.08 0.80	0.81	0.45	0.72	0.48
Milicia regia	0.90	0.49 0.98	0.22 1.44	0.54 1.41	-	-	-	0.66
Millettia rhodantha		0.49 0.98	0.94 2.20	0.78 1.36	1.61 4.03	0.90 7.21	0.27 8.04	-
Morus mesozygia	0.90 0.90	0.49	0.61	0.67	3.23 1.61	1.80 0.90	3.23 0.81	0.93
Nauclea diderrichii	0.90	0.49	0.50	0.63	1.61	0.90	0.60	6.43
Nesogordonia papaverifera	0.90	-	-	-	2.42	1.80	2.45	2.75
Parinari excelsa	-				-	-	-	1.11
Parkia bicolor					0.81	1.80	0.77	1.04
Petersianthus macrocarpus					0.81	0.45	0.77	2.22
Piptadeniastrum africanum					-	-	-	-
Pleioceras barteri								1.13
Pouteria altissima								0.68
Protomegabaria stapfiana								-

Table 1 D continued

Species	HD^5 R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)	HD_{15} R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)
Psydrax subcordata	0.90	0.49	0.88	0.76	0.81	0.45	0.38	0.55
Pterygota macrocarpa	-	-	-	-	0.81	0.45	0.17	0.48
Pycnanthus angolensis	0.90 0.90	1.46 0.49	1.15	1.17 0.54	-	-	-	-
Rhodognaphalon brevicuspe	0.90 0.90	0.49 0.49	0.24	0.59 0.56	1.61 2.42	0.90 1.35	1.17 1.60	1.23
Sacoglottis gabonensis	0.90	0.98	0.39	0.80	0.81	0.45	0.13	1.79
Spathodea campanulata	0.90	0.98	0.30	0.94	-	-	-	0.46
Sterculia oblonga	-	-	0.52	-	-	-	-	-
Sterculia rhinopetala			0.93					-
Stereospermum acuminatissimum			-		2.42	3.15	2.16	2.58
Strombosia pustulata	1.80 1.80	1.46 0.98	0.99	1.42 1.17	-	-	-	-
Syzyguim guineense	0.90 3.60	0.49 2.93	0.75	0.59 2.93	0.81 0.81	0.45 0.90	0.22 2.18	0.49
Terminalia ivorensis Terminalia	2.70	2.93	0.39	2.79	0.81 1.61	0.45 0.90	0.19 1.23	1.30
superba	-	-	2.27	-	2.42	1.80	3.42	0.48
Tieghemella heckelii	1.80	0.98	2.75	1.13				1.25
Treculia africana Trilepisium			-		0.81	1.35	1.29	2.55
madagascariense			0.61					1.15

	HD^5				HD$_{15}$			
	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)	R. Freq (%)	R. Den (%)	R. Dom (%)	IVI (%)
Triplochiton scleroxylon	7.21	20.49	20.66	16.12	6.45 0.81	17.12	18.97	14.18
Turraeanthus africanus	0.90	0.49	0.88	0.76	0.81 0.81	0.45 0.45	0.60 0.10	0.62
Xylia evansii	-	-	-	-	1.61	0.90	1.70	0.45
Zanthoxylum gilletii	-	-	-	-		0.90	0.65	1.13
Zanthoxylum leprieurii	1.80	0.98	1.10	1.29				1.05

Appendix II



Courtesy of Ofori Manu Joseph (District Cartographer-Nkawie Forest District)

Figure 1: Progress map of Asenanyo River Forest Reserve

Appendix III

Calculation of Genetic Heat Index for the studied habitats of Asenanyo River Forest Reserve

$$GHI = \frac{(Bk \times BkW) + (Gd \times GdW) + (Bu \times BuW) + (Rd \times RdW)}{N} \times 100$$

Where;
Bk = Number of black star species
Gd = Number of gold star species
Bu = Number of blue star species
Rd = Number of scarlet, red and pink star (reddish) species
BkW = Weight for black star species
GdW = weight for gold star species
BuW = Weight for blue star species
RdW = Weight for scarlet, red and pink star (reddish) species
N = Total number of species in a sample (including green star species)

$$GHI \text{ for } UD = \frac{(0 \times 3) + (9 \times 1) + (9 \times 1) + (17 \times 1)}{54} \times 100 = 64.82$$

$$GHI \text{ for } SD_5 = \underline{(3 \times 3) + (12 \times 1) + (12 \times 1) + (18 \times 1)} \times 100 = 79.69 \; 64$$

$$GHI \text{ for } SD_{15} = \frac{(2 \times 3) + (11 \times 1) + (12 \times 1) + (23 \times 1)}{75} \times 100 = 69.33$$

$$GHI \text{ for } HD_5 = \underline{(3 \times 3) + (10 \times 1) + (10 \times 1) + (18 \times 1)} \times 100 = 74.60 \; 63$$

$$GHI \text{ for } SD_{15} = \frac{(3 \times 3) + (12 \times 1) + (8 \times 1) + (16 \times 1)}{64} \times 100 = 70.31$$

Details of Anova Results of Data

```
## Shannon diversity index >
anova(lm(H~site))
Analysis of Variance Table

Response: H
          Df Sum Sq  Mean Sq F value Pr(>F) site
4 0.6654 0.166344  1.6811 0.1764 Residuals 35
3.4632 0.098949



## Simpson diversity
> anova(lm(D~site))
Analysis of Variance Table

Response: D
          Df   Sum Sq    Mean Sq F value Pr(>F)
site       4 0.003965 0.00099125  0.8337  0.513
Residuals 35 0.041613 0.00118893

## Shannon evenness
> anova(lm(E~site))
Analysis of Variance Table

Response: E
          Df   Sum Sq    Mean Sq F value Pr(>F) site
4 0.002425 0.00060625  0.5282 0.7157 Residuals 35
0.040175 0.00114786



## Basal area
> anova(lm(BA~site))
Analysis of Variance Table

Response: BA
          Df Sum Sq Mean Sq F value    Pr(>F)     site
4 48.225 12.0562   40.23 1.249e-12 *** Residuals 35
10.489  0.2997

Signif. codes:  0 â€***â€™ 0.001 â€**â€™ 0.01 â€*â€™ 0.05
â€˜.â€™ 0.1 â€˜â€™ 1
> (TukeyHSD(aov(BA~site)))
  Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = BA ~ site)
 $site
                diff        lwr          upr     p adj hd5-
hd15  -0.8333738 -1.6203223 -0.04642527 0.0334747 sd15-hd15
1.3818736  0.5949251  2.16882214 0.0001286 sd5-hd15  -
0.3942520 -1.1812005  0.39269658 0.6065928 ud-hd15
```

```
2.0617221  1.2747736  2.84867066 0.0000001 sd15-hd5
2.2152474  1.4282989  3.00219594 0.0000000 sd5-hd5
0.4391219 -0.3478267  1.22607039 0.5046796 ud-hd5
2.8950959  2.1081474  3.68204446 0.0000000 sd5-sd15  -
1.7761256 -2.5630741 -0.98917702 0.0000017 ud-sd15
0.6798485 -0.1071000  1.46679706 0.1176052 ud-sd5
2.4559741  1.6690255  3.24292261 0.0000000
```

```
## Density of species

> anova(lm(density~site)) Analysis
of Variance Table

Response: density
          Df   Sum Sq Mean Sq F value     Pr(>F)
site       4 2176.15  544.04  19.747 1.394e-08 ***
Residuals 35  964.25   27.55
---
Signif. codes:  0 â€***â€™ 0.001 â€**â€™ 0.01 â€*â€™ 0.05
â€˜.â€™ 0.1 â€˜â€™ 1
> (TukeyHSD(aov(density~site)))
  Tukey multiple comparisons of means
95% family-wise confidence level

Fit: aov(formula = density ~ site)
 $site
            diff         lwr       upr     p adj hd5-
hd15  -2.125  -9.6703219  5.420322 0.9258894 sd15-hd15
13.500   5.9546781 21.045322 0.0000967 sd5-hd15  16.875
9.3296781 24.420322 0.0000020 ud-hd15    7.000  -
0.5453219 14.545322 0.0797871 sd15-hd5  15.625
8.0796781 23.170322 0.0000085 sd5-hd5   19.000
11.4546781 26.545322 0.0000002 ud-hd5     9.125
1.5796781 16.670322 0.0112472 sd5-sd15   3.375  -
4.1703219 10.920322 0.7013086 ud-sd15   -6.500 -
14.0453219  1.045322 0.1193061 ud-sd5    -9.875 -
17.4203219 -2.329678 0.0052336
```

Appendix IV

FIELD DATA SHEET

Compartment No.: ………………. Level of Disturbance: ……………… Type of Disturbance: …………..……….. Sheet No.: ……..…………………….

Plot No.: ……………………….…. Plot Dimension:……………………

No.	Species	Diameter/cm	Remarks
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			
13.			
14.			
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17.			
18.			
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21.			
22.			
23.			
24.			
25.			
26.			
27.			

28.			
29.			
30.			

Appendix V

Plate 1: A demarcation line through undisturbed site of ASEN dominated by climbers.

Plate 2: A slightly disturbed (stump site) of ASEN after 5 years of selective logging.

Plate 3: A slightly disturbed (stump site) of ASEN after 15 years of selective logging.

Plate 4: A slightly disturbed (Skid trails) site of ASEN after 5 years of selective logging.

Plate 5: A slightly disturbed (Skid trail) site of ASEN after 15 years of selective logging.

Plate 6: A heavily disturbed (forest road) site of ASEN dominated by grasses and other non-timber species after 5 years of selective logging.

Plate 7: A heavily disturbed (forest road) site of ASEN dominated by grasses and other weeds after 15 years of selective logging.

Plate 8: A heavily disturbed (Loading bay) site of ASEN dominated by non-timber species after 5 years of selective logging.

Plate 9: A heavily disturbed (loading bay) of ASEN dominated by grasses and other weeds after 15 years of selective logging.