

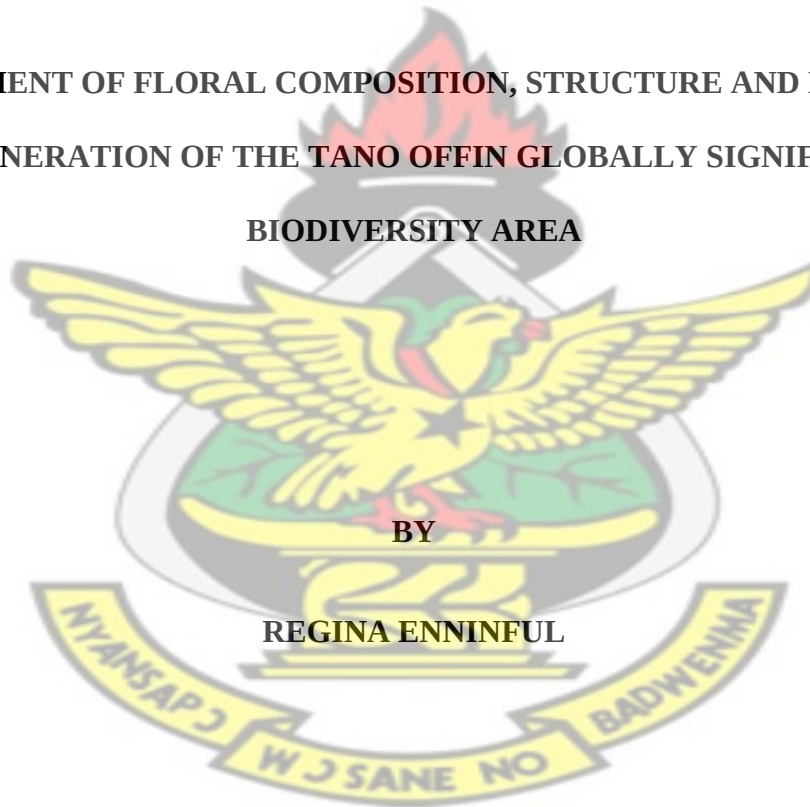
KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF SCIENCE

DEPARTMENT OF THEORETICAL AND APPLIED BIOLOGY

KNUST

**ASSESSMENT OF FLORAL COMPOSITION, STRUCTURE AND NATURAL
REGENERATION OF THE TANO OFFIN GLOBALLY SIGNIFICANT
BIODIVERSITY AREA**



KNUST

MAY, 2013

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**A THESIS SUBMITTED TO THE DEPARTMENT OF THEORETICAL AND APPLIED
BIOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF MASTER OF
PHILOSOPHY DEGREE IN BIOLOGICAL SCIENCE**

BY

REGINA ENNINFUL

DECLARATION

“I hereby declare that I have wholly undertaken this study reported therein under the supervision of Dr. Ebenezer J. D. Belford and that except portions where references have been duly cited, this thesis is the outcome of my research”.

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Student's Name

Signature

Date

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Supervisor's Name

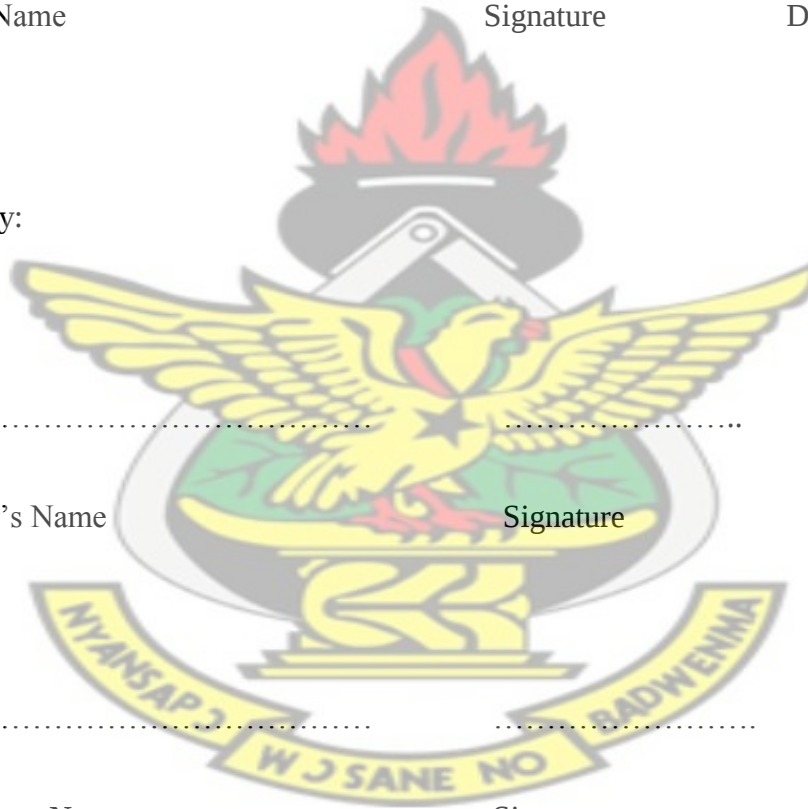
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ABSTRACT

Tano Offin Globally Significant Biodiversity Area (GSBA - 178.34 km²) is a reserve within the Tano Offin Forest Reserve in the Ashanti Region of Ghana. The reserve which experiences occasional wildfires has been logged and mined for bauxite in the past. Current menace of forest degradation presents the need to generate information on the current state of the floristic patterns of the forest. To address conservational needs of the reserve, a study was carried out in the GSBA to assess the floristic composition, structure, natural regeneration, canopy closure as well as to evaluate the influence of elevation and invasive species on the aforementioned. Ten 50 m x 50 m plots were demarcated for the assessment of diameter and height of all trees, lianas and shrubs with dbh ≥ 10 cm as well as the identification of other plant life forms. These individual plots varied in invasiveness and altitude: ranging from 264 m – 623 m. A 10 m x 10 m plot was located within each of the 50 m x 50 m plots where diameter of trees and other plant life forms of dbh < 10 cm were identified and measured. Quadrats (1 m x 1 m) were laid at the corners of the 50 m x 50 m plots and its centre for canopy closure and natural regeneration assessments. Plant species (240) belonging to 59 families were identified. These comprised of 171 trees, 41 lianas, 11 shrubs, 7 herbs, 7 herbaceous climbers, 1 epiphyte, 1 grass and 1 fern. Fabaceae was the predominant family in terms of species richness. Species diversity (H') of the tree layer, shrub and herb layers were 2.55, 2.54 and 2.48 respectively. Trees and other plant life forms of dbh ≥ 10 cm were grouped into six diameter classes and four height classes; the number of plants in these groups was decreasing as the group size increased so that the highest-size group had the least number of plants. Basal area of the GSBA was 28.36 m²/ha and average tree height of the emergent layer was 46.19 m. Floristic diversity did not differ significantly ($P > 0.05$) in the tree, shrub and herb layers of all three forest types namely, lowland, transition and highland forests. *Celtis mildbraedii* was both the most significant species among trees and other plant life forms with dbh ≥ 10 cm in general, and in all three forests types. *Rinorea welwitschii* was also both the most significant species among trees and other plant life forms with dbh < 10 cm, and at the shrub layer of highland and lowland forests. *Hymenostegia afzelii* was the most significant species for the shrub layer at the transition area though *Rinorea welwitschii* was completely absent from this zone. Basal area for trees and other plant life forms with dbh ≥ 10 cm increased with increasing elevation. Generally, there was increase in the number of taller trees with increase in elevation. Areas with invasive species recorded lower mean basal area at both the tree and shrub layers. Invasive species were present only at the transition area which had the lowest percentage of shade bearers and non-pioneer light demanders but the highest with pioneers. A total of 75 plant species were found regenerating as saplings and seedlings. Eight species of the regeneration flora were absent from the adult community. For the lowland forests, 50.94 % of the adult tree population were regenerating while 46.74 % were regenerating in the transition area and 42.86 % at the highlands. Pioneer saplings were absent from lowland forests. Invasiveness had significant influence ($P < 0.05$) on the species diversity of seedlings. There was a decline in canopy closure with respect to decreasing altitude, measuring 89.06 %, 87.84 % and 84.9 % for the highlands, transition area and the lowland forests respectively. It is revealing that the GSBA is under exploitation especially in lowland forests. The information generated on species composition, structure and regeneration should be useful in designing conservation measures for the Tano Offin GSBA.

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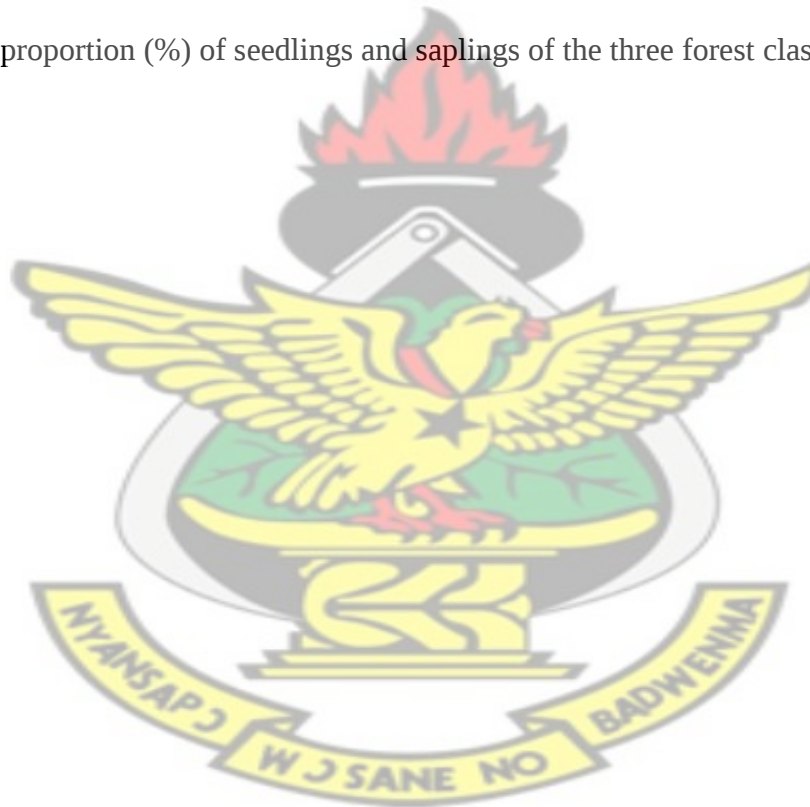
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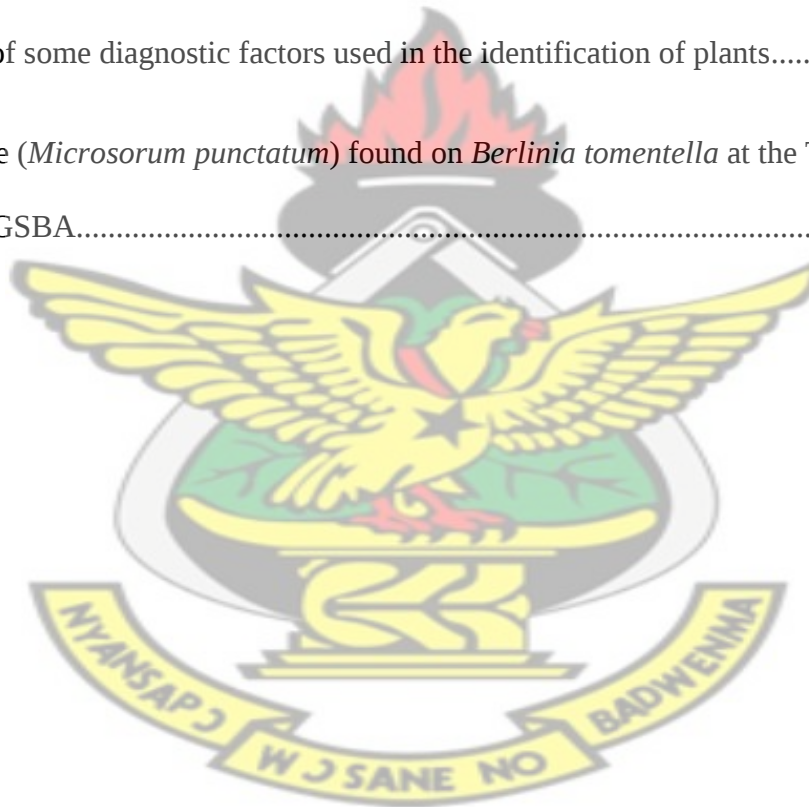


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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	- Analysis of variance
D/ha	- Density/hectare
DM	- Dominance
FAO	- Food and Agriculture Organization
FC	- Forestry Commission
FRNR	- Faculty of Renewable Natural Resources
FORIG	- Forest Research Institute of Ghana
FOSA	- Forestry Outlook Study for Africa
FRA	- Forest Resource Assessment
FREQ	- Frequency
GDP	- Gross Domestic Product
GSBA	- Globally Significant Biodiversity Area
IUCN	- International Union for Conservation of Nature
IVI	- Importance Value Index
N/A	- Not Available
NBSG	- National Biodiversity Strategy for Ghana
NTFP	- Non-Timber Forest Product
PSU	- Portland State University
USAID	- United States Agency for International Development

ACKNOWLEDGEMENT

I am forever grateful to Canadian International Development Agency (CIDA) for funding this study through the APERL (Agroforestry Practices to Enhance Resource-poor Livelihoods) project. I wish to acknowledge Prof. William Oduro (FRNR) and Prof. Naresh Thevathasan (University of Guelph, Canada) who have been very supportive in immeasurable ways.

My deepest appreciation goes to Prof. Yeboah-Gyan for doing the initial supervision and to Dr. Ebenezer J. D. Belford for the final supervision. I am thankful to Dr. Kyereh Boateng (FRNR) and Mr. Patrick Addo Fordjour for their valuable advice and also thankful to Mr. Jonathan Dabo (FORIG) and Mr. Emmanuel Manu (FORIG) for their technical assistance on the field. I am greatly indebted to Seth Kankam Nuamah and Dominic Amuzu for computing assistance.

My appreciation goes to the following for granting interviews and for assisting at the preliminary of this study: Dr. Mrs. Mary Apetogbor, Mrs. Gloria Djablatey and Dr. S. Adu-Bredu, all of FORIG; Dr. K. Essilfie and Prof. A. A. Oteng-Yeboah (Botany Dept. University of Ghana); Mr. Kofi Affum Baffoe and Mr. Richard Ninnoni, both of RMSC – Forestry Commission of Ghana, Kumasi and staff of Nkawie District of the Forestry Commission.

For the prayers, support and encouragement, I would like to say ‘thank you’ to Rev. Dr. Seth F. Coleman of the A. M. E. Zion church, my mum Madam Juliana Sackey, Madam Joana Ameyaw (FRNR), my brothers: Richmond Mensah and the Enninfuls (Joe, Abekah, Abam and Yaw); Mr. Isaac Oppong (Pelican Hostel) and the following friends: Samuel Okai Kudjo, Godfred Bonnah Nkansah, Nehemiah Odjer-Bio, Michael Essel, Benjamin Obeng, John Wiafe and Eunice Amo. To Yahweh-Nissi - belongs all the glory.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

The total forest area in the world is about 4 billion hectares (FRA, 2010) with the tropical forests covering about 10 % of the earth surface (Lewis, 2006). The diversity of the tropical forest provides resources which are both tangible and intangible (Antwi, 1999) and these could be considered as ecological, environmental, cultural and socio-economic benefits (Abeney, 1999). In Ghana, the forestry sector contributes about 6 % to the GDP, accounts for 11 % of export earnings, employs a labour force of 100, 000 people, and it provides and supports livelihoods of about 2.5 million rural folks (FAO, 2002; FOSA, 2002).

Records reveal an 8.5 % increase in the rate of tropical deforestation from the 1990's to the period of 2000 – 2005 (Butler, 2009). Reports by the 2010 Global Forests Resources Assessment indicates a 2 % annual forest loss from 1990 – 2000 in Ghana (FRA, 2010). Forests in Ghana are being depleted at an alarming rate through several factors including excessive logging, mining and quarrying, developmental projects, charcoal production & firewood collection, bushfires, and unsustainable agricultural practices (FAO, 2000).

The impact of human activities on the environment is evident throughout the world and it includes remarkable changes in species composition, abundance, and diversity of organisms in various ecosystems including the tropical forest such as the Tano Offin GSBA (FRA, 2010; Kim & Byrne, 2006). Thus information on the current state of the Tano Offin GSBA is vital in

maintaining healthy plant diversity which should results in enhanced productivity of the forest, greater prospects for economic development, medical discoveries and an increased resiliency to environmental challenges (Shah, 2009).

1.2 Problem Statement

The deforestation of tropical forest threatens the sustainability of its biodiversity, demanding the conservation of remnant species of flora lest these may be subjected to extinction in the near future (Myers *et al.*, 2000). But how can the plant diversity of tropical forest be conserved if knowledge on the composition and abundance of the different kinds of species is lacking? In this regard, floristic assessment of the forest is indispensable in detecting the risk of extinction, arrival of invasive species and changes in plant diversity over time.

Relatively, limited work has been done in determining the floristic composition and structure of forests in Ghana (Hall & Swaine, 1981; Hawthorne, 1993; Vordzogbe *et al.*, 2005; Anning *et al.*, 2008; Addo-Fordjour *et al.*, 2009b; Pappoe *et al.*, 2010). In 1981, an extensive assessment of the distribution of vascular plants in Ghanaian forests was carried out by Hall and Swaine which included the Tano Offin Forest Reserve (Hall & Swaine, 1981). It has been decades now and thus the need to generate a carefully compiled up-to-date data on the floral composition of the reserve. Moreso, inventories by the Forestry Commission of Ghana in the reserve have focused mainly on timber species (Affum-Baffoe pers.comm) which is deficient for conservation purposes. Most imperatively on the GSBA, records indicate that no formal ecological research has been undertaken in the GSBA (FC, 2007; Affum-Baffoe pers.comm).

Notably, although 44.5 % of the reserve has been designated as a Globally Significant Biodiversity Area (GSBA), reports about the reserve and even the GSBA indicate activities of illegal logging and other forms of human disturbances (FC, 2007). The situation is that serious to the extent that when the then Minister of Lands and Natural Resources payed an unannounced visit to the Tano Offin Forest Reserve in May 2011, some illegal chainsaw operators were caught right on the act (The Chronicle, 2011).

Depending on the level and rate of infliction, disturbances such as logging in forest affect the composition, structure and light availability to the forest, eventually influencing natural regeneration process (Jennings *et al.*, 1999; Hale, 2004). In addition, canopy opening promotes growth of invasive species which alter the course of natural regeneration in the forest, restraining the resurgence of native trees (Vermeulen & Koziell 2002). Moreover, the Tano Offin GSBA has been a forest reserve of bauxite deposits which presents a potential threat to its forest diversity.

In addition, elevation acts as an important source of local variation and it determines rate of recovering, recruitment and eventually the floristic composition of a forest (Wang *et al.*, 2002; FAO, 2002; Joseph *et al.*, 2012). Thus, investigations on the influence of elevation on patterns of plant diversity is critical for this biodiversity rich area which sits on a mountainous range of the Nyinahin hills - Tano Offin forest reserve is cited as one of the three Upland Evergreen forests in Ghana (Hall & Swaine, 1981). A study with a focus on local patterns of plant diversity assists profoundly with local conservation practices and the management of localised biodiversity patterns (Kim & Bryne, 2006).

It is in this light that attempt is being made in this study to generate information on the current state of floristic patterns of the Tano Offin GSBA as well as the influence of elevation and invasive species on the GSBA. Plant species composition and stand structure serve as important indicators in the formulation of conservation measures (Lindenmayer *et al.*, 2000; Newton *et al.*, 2003; Oteng-Yeboah *et al.*, 2009). Thus the current work should be useful in enhancing conservation efforts of the GSBA as well as helpful in managing protected areas.

1.3 Main Objective

The general objective of the research is to determine the floristic patterns of the Tano Offin Forest Globally Significant Biodiversity Area (GSBA), assessing the floristic composition, structure, natural regeneration and canopy closure as well as the influence of elevation and invasive species on the aforementioned.

1.3.1 Specific Objectives

- To assess the floristic composition of the Tano Offin GSBA
- To determine the structure of the Tano Offin GSBA
- To determine the composition of natural regeneration and canopy closure of the Tano Offin GSBA
- To evaluate the influence of elevation and invasive species on the composition, structure and natural regeneration of the Tano Offin GSBA

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Diversity of Forest Plants

The different types of plant life forms or growth habits found in the tropical forest include trees, shrubs, climbers, epiphytes, herbs, grass and ferns. Precise definition of life form or habit for some plant species is difficult as observed by Hawthorne and Jongkind (2006) who attested to the fact that several species change their habit in accordance to growing conditions. As a result of genetics and environmental conditions, there is interplay among these life forms such that a tree, shrub, herb, grass or fern can be considered as an epiphyte when found growing epiphytically.

There are some epiphytes described as ‘mechanical parasites’ which include trees such as some fig trees. By using their adventitious or aerial roots to absorb nutrient in arboreal manner, some climbers are considered as epiphytes (Etisa, 2010). On the other hand, a description of a tree by Hawthorne and Jongkind (2006) as an erect woody plant with well-defined main trunk or bole makes it difficult to consider the tree-like fern such as the *Cyathea* of the Atewa forest (Hall & Swaine, 1981) as a fern or a tree. *Cyathea* does not expand its trunk like angiosperms where new woody tissues are produced (website 1).

Moffett (2000) describes epiphytes as plants sustained entirely by nutrients and water received non-parasitically from within the canopy in which it resides; it does not actively extract water or nutrients from the ground or from the live tissues of the host. The diversity and distribution of

epiphytes are determined by many factors which include the biophysical environment of phorophytes (a host plant used by an epiphyte for physical support) such as host size, bark texture and vertical stratification (Etisa, 2010). Moffett (2000) further classifies epiphytes as obligate if it exclusively sprouts and reproduces in the canopy, facultative if it can sprout and reproduce on non-plant substrates (in addition to its ability to sprout and reproduce in the canopy). Hemi-epiphytes are adapted to sprout as epiphytes but develop terrestrial roots later (Primary hemi-epiphytes) or as secondary hemi-epiphytes, they germinate on the ground and grow up like vines before losing connection with the soil once settled in the canopy (Etisa, 2010). There are also the accidental or occasional epiphytes which apply to ground plants that on rare occasions sprout in trees and manage to root to earth (Akinsoji, 1990). Reports on vascular epiphytes diversity sometimes do not identify the habit of those epiphytes, as to whether they are true epiphytes or other forms thus generating inaccurate information and comparisons.

Any smaller woody plants that does not have a single main stem and have got other stems branching right at ground level or even climbing, with other branches behaving as a small tree may be referred to as a shrub (Hawthorne & Jongkind, 2006). Any vine that grows upwards to a substantial distance from the ground, requiring the support of another object such as a host plant is considered as a climber and a vine with a woody stem is considered as liana (Moffett, 2000). Climbers grow upwards by methods which include scrambling (loosely ascend host object by leaning against it aided by hooks or thorns), tendril ascension, twining (the main stem circumnutates or spirals up the host) and by means of various surface-gripping adhesive organs (e.g. adventitious roots in root climbers) to hold the host without entwining it (Moffett, 2000).

2.2 The Forest Resources of Ghana

Generally, up-to-date information on the full coverage of the biological resources of Ghana is lacking and knowledge on genetic diversity of the various life forms is incomplete, diffuse and inaccurate (National Biodiversity Strategy for Ghana - NBSG, 2002; Oteng-Yeboah *et al.*, 2009). Nevertheless, about 3,600 vascular plants species (i.e. excluding mosses) have been recorded for Ghana and 2,200 are in the forest zone (McCullough *et al.*, 2005) with 1,360 species found in the unfarmed or primary forest (USAID, 2005). With 2974 indigenous plants and 253 introduced plant species (Appendix 1), floral diversity in Ghana is more distinct among the angiosperms and *Encephalartos barteri* is the only known gymnosperm indigenous to Ghana (NBSG, 2002). Endemic species identified in Ghana include 9 trees, 5 herbs, 3 shrubs, and 2 lianas while about 115 higher plants are threatened i.e. critically endangered, endangered or vulnerable (USAID, 2005).

The Wet Evergreen forest has the highest species richness and most endemic plants of Ghana e.g. *Hymenostegia gracilipes*, *Cola umbratilis*, *Alsodeiopsis chippii* and *Monocyclanthus vignei* (USAID, 2005; NBSG, 2002). A 2ha plot in the wet forest generates 150 trees of dbh > 10cm and a further 400 plant species per hectare if all plant forms (excluding mosses) are considered (USAID, 2005). The moist semi-deciduous forest has most of the country's valuable timber species (NBSG, 2002). On a 25 m x 25 m plot, the moist evergreen forest produces 170 plant species, the moist semi-deciduous type records 100 plant species whilst the dry semi-deciduous forest generates 40 – 100 plant species (USAID, 2005).

2.2.1 Causes of deforestation in Ghana

Agriculture is a dominant land use in Ghana and the size of agricultural lands increases every two years by 90 % (FOSA, 2002). The planting of cash crops such as cocoa and coffee has resulted in the removal of forests (Ekpe, 2002). Abbiw (2002) identifies slash and burn of the shifting cultivation traditional farming system as the major cause of deforestation in Ghana. As of 1987, the shifting cultivation agricultural system was noted to account for about 70 % of deforestation in Ghana (FOSA, 2002).

Mining presents severe threats to important forest areas of high conservational values. Mining of bauxite in the two Upland Evergreen forests, Tano Offin and Atewa Range forest reserves in the 1960s and 1970s was known to have caused some deforestation (Ekpe, 2002). Other areas which have been affected by mining include the wet evergreen forests of Cape Three Points and the Afao (Awaso) hills (NBSG, 2002). Neung North Forest Reserve, one of Ghana's exceptional botanical hotspots lost its northern half to large scale surface mining of gold (Ekpe, 2002). Illegal mining for gold in forests has particularly destroyed forests areas in Bosomtwe district of Ashanti region, notably, the Beposo community.

Wong (1989) identified fire and logging as two of the most important disturbance in Ghana's forest. In the 1980s, about one- third of the Moist Semi-deciduous forest zone were destroyed by fire (Ekpe, 2002). It is estimated that approximately 50 % of Ghana's vegetation cover was lost to bushfires orchestrated by severe droughts and strong harmattan winds in 1982 and 1983 (NBSG, 2002). With respect to logging, the forestry policy of 1994 introduced the "annual

allowable cut” system while the Timber Resource Management Act of 1998 advocated for logging permit which limits harvests of logs to one million cubic meters per year (USAID, 2005). These policies have not been enforced resulting in high volumes of illegal logs (USAID, 2005).

Other forest destructive activities include collection and gathering of fuel-wood, burning of charcoal, hydro-electric power generation, road and trail construction, housing, construction of factories and other infrastructures, industrial pollution, forest invasion by *Chromolaena odorata* weed (locally referred to as ‘Akyeampong’) and the exploitation of plant medicine from the wild for both local use and for export (Abbiw, 2002; NBSG, 2002). Underlying these causes of forest degradation in Ghana are reasons such as low forest taxes and fees regime, lack of stakeholder participation in forest management, weak institutional structures, poor institutional coordination, policy failures and population pressure (FOSA, 2002; USAID, 2005).

2.3 Effects of forest disturbance

Disturbance is defined by Pickett and White (1985) as a relatively discrete event in time that disrupts ecosystems, community or population structure and changes resources, substrate availability or the physical environment. Human disturbances in forests affect vegetation patterns, floristic composition and species richness of many forest types (Tchouto *et al.*, 2004). Deforestation disrupts the ecological processes of the forest which includes production, consumption, competition, ecosystem engineering, symbiotic associations, predation, and decomposition (Vermeulen & Koziell 2002). Man has practised shifting cultivation over large

forest areas for thousands of years (Vermeulen & Koziell 2002) spurring judgement on the level of human activity permissible in protected areas. Thus, a well managed disturbed forest is a good supplier of timber, Non-Timber Forest Products (NTFPs) and is able to deliver the same environmental services as primary forests, more so, fix atmospheric carbon faster than matured forests (FAO, 2002).

2.3.1 Effects of disturbance on forest floral composition

“Natural selection has taught New World mahoganies that the best way to survive is to become undesirable” (Hawthorne, 1993).

History of disturbance is known to be an important reason for the local variation of forest composition (Wong 1989). In between stands of forests recovering from disturbances is a high floristic heterogeneity but a stand of secondary forest especially at the early succession stages has lower species richness when compared to a primary forest (FAO, 2002). It is reported that many forests in Ghana are remarkably secondary in terms of species composition implying a history of heavy disturbances (Hawthorne, 1993). Wong (1989) found out that fire and logging disturbances strongly affect the composition of the forest in Ghana, especially the dry and moist semi-deciduous forest types. It's been observed that fast growing exotic species such as *Azadirachta indica* (neem tree) and *Leucaena leucocephala* have spread chiefly in the savannah zones of Ghana and have consequently displaced indigenous plants (NSBG, 2002).

Tchouto *et al.* (2004) found in the Cameroon forest that herbaceous species, pioneer species and climbers increase with increasing degree of disturbances. However, since epiphytes generally

depend on host plants such as trees, loss of trees as a result of deforestation leads to a destruction of the epiphytic community which implies a reduction of the total species richness. Although plant species numbers can increase after clear-cutting a forest, the new plants may constitute invasive species that hinder the regeneration of the endemic or local species (Vermeulen & Koziell 2002). Small numbers of secondary species which includes early pioneers grow also in natural gaps of primary forest, affecting the floristic composition (FAO, 2002).

It was reported that the invasive species *Broussonetia papyrifera* did not host any liana species in the Tinte Bepo forest implying a possible decrease of liana composition in the face of increasing invasion of *B. papyrifera* (Addo-Fordjour *et al.*, 2009a). Studies on invasive species in a humid forest of the Ashanti region in Ghana by Anning and Yeboah-Gyan (2007) showed higher invasive species richness in the degraded parts of the forest. Similarly, the species richness of an undisturbed portion of a semi-deciduous forest of Ghana was found to be higher than a disturbed and/or invaded portion, indicative of the harmful effect of disturbances on the floristic composition of a forest (Addo-Fordjour *et al.*, 2009b).

Disturbance and invasion of forest appear to favour the colonisation of certain liana species as found in the Tinte Bepo forest of Ghana although the forest in this disturbed-invasive state does not support much of liana density; 410 liana individuals *per* ha were found in the undisturbed forest as against 88 and 262 of the disturbed forest and disturbed-invaded forest respectively (Addo-Fordjour *et al.*, 2009a).

2.3.2 Effects of disturbance on forest structure

Forest structure refers to the distribution or the horizontal and vertical arrangement of woody and herbaceous vegetation across a given area (Pommerening, 2002). Forest structure influences the way a forest functions as well as the environmental services a forest can provide (Andreu *et al.*, 2009). When forest structure is conserved, its functioning and services are maintained as well (Vermeulen & Koziell 2002). It is understood that biodiversity determines the structure and function of ecosystems while the ecosystem determines the patterns of biodiversity so that changes to biodiversity patterns result in unproductive ecosystem services (Kim & Byrne, 2006).

Reflective of the detrimental effects of disturbances on forest structure is the findings of lesser plant species diversity, lower mean basal area, lower canopy cover and height of the disturbed and invaded part of Tinte Bepo forest when compared to its undisturbed portion (Addo-Fordjour *et al.*, 2009b). There were more trees in the understorey layer of the disturbed and invaded portions than was found in the undisturbed forest although the latter had the greatest tree density (Addo-Fordjour *et al.*, 2009b). Forests recovering from disturbances are seen with relatively few large trees and they generally do have an even lower canopy (FAO, 2002).

Forest degradation through timber extraction simplifies the structure of the forest and this disturbs habitat by removing ecological niches leading to a decrease in species diversity (NBSG, 2002). Selective logging tends to distort forest structure and creates lots of gaps which get occupied with tangles of climbers and dense stands of young trees (FAO, 2002). When forests change in structure, it alters the quantities and qualities of substrate available to epiphytes (Etisa,

2010). In the disturbed part of the Tinte Bepo forest of Ghana, liana basal area was greater when compared with undisturbed part of the forest, where large diameter lianas were missing (Addo-Fordjour *et al.*, 2009a). Likewise, Foli and Pinard (2009) found a relatively higher density of small lianas in intact forests than there were in disturbed or logged forest.

2.3.3 Effects of disturbance on forest cover and regeneration

Degradation of forests results in decrease in canopy density and cover although the canopy of secondary forests is generally more even than that of primary forests (FAO, 2002). As a result of disturbances, canopy openings can either stimulate or hinder plant growth, depending on the kind of species (Hall & Swaine, 1988). While it is thought that canopy gaps resulting from forest disturbances influences the proliferation of liana, it's been found that disturbances in the forest rather limit the number of support accessible for lianas which consequently decreases their abundance (Foli & Pinard, 2009).

As found in the Tinte Bepo forest of Ghana, not much of the trees in the disturbed and invaded forests could host lianas as does the undisturbed forest (Addo-Fordjour *et al.*, 2009a). High rate of deforestation has been noted to encourage the invasion of *Bronssonetia papyrifera* which hinders the regeneration of most native plant species (Bosu & Apetogbor, 2007; Addo-Fordjour *et al.*, 2009b). Seeds of *Bronssonetia papyrifera* hardly germinate in dense canopy forests but it does in large canopy gaps, neglected farm lands and along roads and its invasiveness is compounded by its ability to re-sprout from roots (Bosu & Apetogbor, 2007). Logging influences forest composition, affecting regeneration at the narrow skid trails and the larger

loading areas (Wong, 1989). Plant regeneration is poor at logging roads, loading bays and skid trails of logged forest.

Wong (1989) found fire as the biggest problem for the regeneration of Ghana's forests. Deforestation due to fire has such detrimental influence on forest regeneration such that it is considered as the biggest threat to forest survival and protection (Ekpe, 2002). Nevertheless, when it is well managed, disturbance such as fire and harvesting could be used as a tool to stimulate natural regeneration (Ward & Worthley, 2004). Desertification which results from deforestation (NBSG, 2002) is critical in altering forest regeneration and eventually wiping out whole forests. In re-growing forests, epiphytes would have to depend on dispersal from surrounding vegetation to regenerate (Akinsoji, 1990) since true epiphytes do not have seed bank in the soil (Etsia, 2010).

2.4 Forest Evaluation

Fundamental to resource management is tracking what is there through evaluation processes so that information that facilitates the effective management of the resources is generated (Vermeulen & Koziell, 2002). In disciplines such as conservation biology and urban ecology, there is increasing demand for information on the structure and composition of localised biodiversity (Kim & Byrne, 2006). Inventory, in the form of forest surveys, is necessary for understanding biodiversity and gaining information on the quality and quantity of forest resources.

Ecological knowledge can only grow to maturity on a good taxonomic foundation (Wong, 1989). However, there is inadequate taxonomic expertise to aid with the aspect of determining species (Kim & Byrne, 2006) and it is reported that many floral species, particularly in the tropics, remain poorly known, un-described and unnamed (Myers *et al.*, 2000). Forest evaluation offers opportunities for taxonomic discoveries and provides insights into the effects of human activities and/or disturbances on forest diversity patterns. Information on species distribution is critical for maximising the cost-effectiveness of surveys, enhancing conservation efforts, manage protected areas, provides pre-knowledge of where to do collections for research, and it facilitate the collection of genetic materials (Oteng-Yeboah *et al.*, 2009).

Plants diversity in the forest is overly complex to be evaluated thoroughly and thus measurements of obvious features and subset of characters are done to estimate the less discernible as well as to reflect the overall diversity (Vermeulen & Koziell, 2002; Lindenmayer *et al.*, 2000). In forest measurement, sampling techniques affect the quantity and quality of information generated as Tchouto *et al.* (2004) found a decrease in diversity and species richness when sampling resolution decreases.

2.4.1 Determination of floristic composition

The plant species that make up a forest defines the floral composition of that forest (Andreu *et al.*, 2009). Generation of species list out of inventory is essential for constant evaluation of conservation status, for effective management and control practices and to support environmental impact assessments among others (Oteng-Yeboah *et al.*, 2009). Information on species

composition is useful for defining priority areas for conservation (Newton *et al.*, 2003; Tchouto *et al.*, 2004). On a broader scale, Myers *et al.* (2000) report that plant family richness can often serve as a predictor of species richness for certain animal taxa such as mammals and reptiles.

To detect growth and changes of forest over time, and to know how a forest will respond to disturbances, information on the forest's plant species composition is needed (Andreu *et al.*, 2009). Knowledge of floral composition provides idea on subject such as mineral deposits, stage of ecological succession and the prevalent climate and soil type of an area (McCullough *et al.*, 2007). An understanding of the composition of the forest helps with the proper interpretation of forests' structure (Andreu *et al.*, 2009) as some species are naturally small, big, short or tall (Snyder, 2010).

Although field surveys have been conducted in Ghana to determine the growing stock of forest reserves, Wong (1989) advocated for a continuous update of this information considering the enigmatic nature of the dynamics of the natural forests. After all their extensive plant surveys, Hawthorne and Jongkind (2006) cautioned that it may never be absolute even in cases where they concluded on the presence or absence of certain species as, “botanical exploration is far from complete and new discoveries are being made annually”. Plant population increase or decrease over longer periods of time through adaptation to changing conditions (Vermeulen & Koziell, 2002). Plant species differ in growth rate, fecundity and mortality rate and these differences thus reflect in the transformation of the composition of young population into adult population (Hall & Swaine, 1988).

Although tree species often accounts for more than half of the floristic composition of a forest (Addo-Fordjour *et al.*, 2009b; Vordzogbe *et al.*, 2005; Pappoe *et al.*, 2010), its usefulness in biodiversity assessment is deficient in that other taxa such as herbs, shrubs, liana, herbaceous climbers and epiphytes are not or under-represented (Tchouto *et al.*, 2004). Thus forests assessment centred exclusively on trees might be insufficient for conservation purposes. This contrasts observations by Newton *et al.* (2003) that tree species diversity can be used as a substitute for the overall species diversity of forest ecosystems. Determinants of forest species composition is by all juvenile plants which have survived successive periods of regeneration from seeds despite mortality being high during early stages of most organisms (Hall & Swaine, 1988).

2.4.1.1 Biogeographical influence on species composition

Elevation among other abiotic factors such as rainfall and geology determine rate of recovering, recruitment and eventually the floristic composition of a forest (FAO, 2002). The following tree species were found to be predominant at Atewa Forest range, one of the upland evergreen forests of Ghana: *Cola boxiana*, and *Chidlowia sanguine* (at an elevation of 795 m), *Rinorea oblongifolia* and *Hymenostegia afzelii* (at an elevation of 690 m) and *Rinorea oblongifolia* (at an elevation of 769 m) (McCullough *et al.*, 2007). As a Hill Sanctuary, Ajenjua Bepo has its highest altitude point at about 500 m and commonly occurring species include *Celtis wightii*, *Celtis mildbraedii* and *Rinorea* species (Siaw & Dabo, 2009).

There are patterns of species distribution which are not necessarily ecological patterns, rather, they are biogeographic patterns thought to be related to historical changes in climate and vegetation and it often results in plant species being mountain endemic, endemic to rocky land, or being restricted to certain regions of same forest types (Hawthorne & Jongkind, 2006). High altitude forests have been found to be relatively more species rich than lowland forests in some forests of Cameroun (Tchouto *et al.*, 2004).

Creation of subdivisions as part of sampling processes results in communities with seemingly sharp borders nevertheless, since communities are never functionally independent and hardly ever possess fixed borders, transition zones are apparent (Hawthorne, 1993). While some forest (e.g. Upland Mt Nimba and *Talbotiella* forest of Ghana) are restricted to a particular region such that component plant species are restricted as well, other forests though widespread, do not have component plant species equally widespread. Such is the case of the wet evergreen forests of Ghana and Cote d'Ivoire where only the former has *Psychotria ankasensis* and *Combretum tarquense* (Hawthorne & Jongkind, 2006). It should be exceptional for closely related species to share mutually exclusive ranges though divergence of isolated populations within single species should be expected. It has been observed that some species change in appearance across the West African region (Hawthorne & Jongkind, 2006).

Soils have significant impact on forest composition. Summers (2006) for example, found the species composition of the Mt. Ambang Nature Reserve of Indonesia (measuring approximately 900 m) to be dominated by lowland species, an effect he attributed to the presence of rich

volcanic soils of the reserve. However, because of poor nutrient status of Mt. Tampotika forest soil, upland species were abundant on ridge top of an elevation of only 350 m (Summers, 2006). Ridge tops, swamps and areas with sandy soils usually have low soil fertility while valleys and lower slopes or benches on hillsides have high soil fertility (Ward & Worthley, 2004). At Buton forest in Indonesia, large numbers of big and tall trees were found apparently due to abundant supply of groundwater (Summers, 2006). The distribution of low-lying swampy land is an important source of local variation in the forest composition; swamp forest have been found to be ecologically quite different from the non-swamp forest and as an example, two species of *Mitragyna* are timber trees found only in swamps of Ghana (Wong, 1989).

2.4.2 Forest structure

Forest structure is a broad concept that covers the dimension of a forest stand, from the forest floor and the herb and shrub layers, into the understory, and through the canopy to the tree tops (Snyder, 2010). Forest structure refers to the horizontal and vertical arrangement or distribution of woody and herbaceous vegetation across a given area (Pommerening, 2002). Since there is no single measurement or index to express forest structure, various attributes of the forest vegetation such as tree height and diameter, number of trees *per* hectare, crown area, leaf area and basal area are measured to determine the structure of a forest (Pommerening, 2002; Andreu *et al.*, 2009; Snyder, 2010).

Quantification of forest structure enables the relation of forest structure to specific forest functions such as carbon storage and sequestration by trees, air pollution reduction and energy

conservation (Andreu *et al.*, 2009). Structurally complex forests are perceived to be more resilient and potentially even more productive (Snyder, 2010). Increasing variety of horizontal and vertical stand structure corresponds with higher species numbers and stands with greater ecological stability (Pommerening, 2002).

Wong (1989) observed that there is substantial local variation in the distribution of trees in a single forest of Ghana. Studies conducted in some Moist Semi-deciduous forests of Ghana revealed a decreasing number of trees with respect to increasing size of trees (Pappoe *et al.*, 2010; Addo-Fordjour *et al.*, 2009b). The abundance of seedlings was more than saplings and trees at the Kakum Park (Pappoe *et al.*, 2010). In an assessment of forests in Cameroun, the shrub layer was significantly more diverse than the tree layer and though the latter was appreciably more diverse than the herbaceous layer (Tchouto *et al.*, 2004). The shrub layer is usually made up of many life forms which include shrubs, small trees, immature large trees and liana, small herbaceous and woody climbers, tall herbs and hemi-epiphytes, which are not found in the upper tree layer (Tchouto *et al.*, 2004).

Taller trees with height up to 50 m were found in lowland forests of Cameroun than was found at higher grounds which had tree height of 25 – 35 m (Tchouto *et al.*, 2004). Trees in upland evergreen forest of Krokosua GSBA also rarely exceeds height of 45 m although those of the surrounding Moist Semi-deciduous forest often exceeds 50 – 60 m. (McCullough *et al.*, 2005). An assessment of the vertical structure of the Tinte Bepo forest reserve revealed more trees in the canopy layers than the emergent layer (Addo-Fordjour *et al.*, 2009b).

2.4.2.1 Factors influencing forest structure

Though forests types in West Africa are defined by structure and species composition, they are actually controlled on a greater part by precipitation and soil type (Hawthorne & Jongkind, 2006). Environmental variables such as altitude, rainfall and soil conditions account on a wider scale for the variation in forest composition and structure across forest types in Ghana and thus determine limits of species distribution (Hall & Swaine, 1981).

The distribution and abundance of plant species differ along environmental gradients as plant species vary in their requirement of and tolerance to environmental factors (Swaine, 1996). Rainfall and soil conditions co-vary (Swaine, 1996) as found in Ghana where low rainfall forests are less species-rich which grow in less leached soils of high pH and high soil fertility, tall in stature as well as possession of more deciduous plants than evergreen plants (Hall & Swaine, 1981). The reverse is true for the high rainfall forests.

According to Barrantes and Sandoval (2009), while species richness or composition of an area results from historical factors such as dispersion, past climatic and geological events, species abundance or density on the other hand is determined by reproductive potential and survival rates of each species as well as interactions within the population which include parasitism, predation and competition. Forests at higher elevations differ significantly in composition and structure when compared to that of lowlands forest which has higher canopy height, higher amount of timber species and higher quantity of deciduous canopy trees (Hall & Swaine, 1981).

2.4.2.2 Determining forest structure: Diversity indices

Species diversity is defined by richness and evenness which refers to the number of species found in a community and the relative abundance of each species respectively (Magurran, 1988). Thus a community is said to have high species diversity if many nearly equally abundant species are present (Magurran, 1988). However, Barrantes and Sandoval (2009) argue that diversity could either be species richness solely or a combination of species richness and their abundance or evenness. Species diversity is a useful indicator of a forest's vulnerability or resiliency to disturbances, with areas of high species diversity likely to be more resilient than low diversity areas (Andreu *et al.*, 2009).

Diversity indices give a quantitative view of diversity and thus provide information about rarity and commonness of species in a community which is essential for understanding community's numerical structure (Beals *et al.*, 1999). According to Vermeulen and Koziell (2002), indices and numerical measures have substantial advantages for comparing and prioritizing among sites. It is critiqued that diversity indices are sample size sensitive as almost all indices include number of species as one of their terms so that populations with different sample size tend to greatly affect the results (Barrantes & Sandoval, 2009).

Shannon-Wiener index is a distance independent algorithm that describes the mingling of species (Pommerening, 2002). The Shannon –Wiener index value is higher when there are more species and more so, are equally represented in terms of relative abundance (Pommerening, 2002). Simpson's index of diversity calculates the probability that two organisms sampled from a

community will belong to different species i.e. the more even the abundance of individual plant species, the higher the probability that the two individual plant species sampled will belong to different species. Simpson's Index of diversity values range from 0 to 1 so that the lower the value, the lower the diversity with 1 representing perfect evenness where all species present occur in equal numbers (Magurran, 1988). Simpson's index thus seems to place emphasis on evenness than species richness in describing diversity. The difference between Shannon-Wiener and Simpson's diversity indices is the relative weighting given to evenness and species richness (Magurran, 1988)

2.4.2.3 Determining forest structure: Importance Value Index

The Importance Value Index (IVI) is derived from a summation of the relative percentage values of dominance (basal area), frequency and density (Anning *et al.*, 2008; Pappoe *et al.*, 2010). Importance Value Index reveals the overall significance of species. The use of relative other than absolute values of frequency, dominance and density is essential for making valid comparisons between communities that were sampled at different intensities or that are of different sizes (Kuers, 2005). The maximum importance value for any one species is 300; it is 200 if there is data from only one plot so that frequency calculation is omitted and only relative dominance and relative density are used (Kuers, 2005).

Frequency defines how commonly a species occurs across the entire forest or how widely species is distributed among the same plots, density defines the total number of individuals of the species and dominance defines the total amount of forest area occupied by the species (Kuers, 2005).

Dominance has its bases from the total basal area *per* hectare (G) which is derived from the sum of tree basal area (g), that is the cross sectional area of a tree estimated at breast height (Philip, 1983). Basal area is a helpful measure for determining site potential and useful for comparing stocking of stands; its average value in a tropical forest is 35 m²/ha (Philip, 1983).

When species dominance exists for few species within an area, there is a high propensity for driving majority of the species rare in the face of disturbances while the dominance of the few is maintained. In their assessment of floristic composition of the Tinte Bepo forest of Ghana, 108 plant species of 8 different life forms were identified with *Celtis mildbraedii* and *Triplochiton sclerexylon* as the most dominant species (Addo-Fordjour *et al.*, 2009b). The dominance of these two species is consistent with the findings of Hall and Swaine (1981) who classified the moist semi-deciduous forest of Ghana based on their dominance.

2.4.3 Forest regeneration and canopy measurements

2.4.3.1 Regeneration

For a successful natural regeneration, the following is crucial: a seed source, an appropriate seed bed, a suitable microclimate, freedom from vegetation competition and browsing; light is often considered as the most limiting factor (Hale, 2004; Ward & Worthley, 2004). The structure of canopy in a forest determines the amount and quality of light distributed within the forest and thus influences growth and survival of plants which eventually determines vegetation type (Jennings *et al.*, 1999). The canopy of Upland Evergreen forests consists of both evergreen and deciduous species in varying proportions which controls the temporal and spatial distribution of

light significantly (McCullough *et al.*, 2005). Generally, light requirement for the growth of seedlings and development of trees varies with respect to species (Ward & Worthley, 2004).

Out of the 29 species belonging to the regeneration vegetation at Tinte Bepo forest reserve, 7 species were missing from the adult tree population and none of the adult tree species in the undisturbed part of the forest had seedlings (Addo-Fordjour *et al.*, 2009b). This is countered by Hall and Swaine (1988) who found out that the Ghanaian forest were generally well-represented by juveniles (especially *Antiaris toxicaria*, *Guarea cedrata* and *Strombosia pustulata*) although some species (e.g. *Celtis mildbraedii*, *Piptadeniastrum africanum*, *Lovoa trichilioides*) had low representation of individuals in smaller diameter classes. The fact that the upper canopy and lower canopy composition differ (coarse grained) or are similar (fine grained) could be explained by the stage of forest succession and the guilds making up the forest. In secondary forests especially, regeneration also constitute vegetative sprouting from tree stumps and root fragments (FAO, 2002).

2.4.3.2 Guild

Guilds are ecological groups resulting from efforts to categorize or make some order of the many ways forest plants respond to the most significant influences on forest composition (Hawthorne, 1993). According to Hawthorne (1996), guild is a flexible concept used to delineate groups of plant species with similar ecology and way of life. With respect to the fact that different types of tree respond differently to disturbance and they have certain requirements of exposure to sun before regeneration could occur, three of these ecological groups can be observed: Pioneer

species which regenerate abundantly in heavily disturbed forest, the Non-pioneer light demanders which does germinate in the shade of undisturbed forest but die in few years if the canopy remains undisrupted and finally, the Shade-bearers/Shade tolerant species which flourish in unlogged, un-burnt forest, found in the understorey (Wong, 1989).

There are cryptic pioneers which although regenerate in gaps under canopy tolerate shade later in life and have thus been misclassified with shade-bearers in practice (Hawthorne, 1993). Hawthorne (1993) observes a relentless rise in the general proportion of pioneers as forests gets drier. The presence of pioneer species in forests is directly dependent on past canopy gaps and sustained space of illumination for their crowns as they transit to adulthood and thus they decline in numbers with respect to increasing size (Hall & Swaine, 1988). Pioneer trees grow to about 90 cm in diameter and hardly exceed 20-30 m in height (FAO, 2002). Most plant species at the Kakum National Park were found to be Non-pioneer light demanding (Pappoe *et al.*, 2010).

2.4.3.3 Canopy cover and canopy closure

Conceptually, there are two fundamental ways of measuring the light regime in a forest: canopy cover (vertical canopy cover) and canopy closure (angular canopy cover) (Fiala *et al.*, 2006; Jennings *et al.*, 1999). Canopy cover describes the fraction of ground area covered by crowns while canopy closure describes the fraction of non-visible sky within a certain angle (Marchi & Paletto, 2010). Angular canopy cover will equal vertical canopy cover when the angle of view becomes zero such that measurement is made directly at the spot overhead (Fiala *et al.*, 2006). While canopy cover is independent of tree height, canopy closure is not: the taller the trees, the

narrower the angle of canopy openness as more of the sky hemisphere is concealed and canopy closure becomes greater (Jennings *et al.*, 1999). While canopy cover is essential for studies in under-storey vegetative productivity and for estimating functional variables such as leaf area index (LAI), canopy closure depicts relationship with species richness as well as with natural regeneration (Marchi & Paletto, 2010).

In a spruce and pine stand, it was found that light transmittance through the canopy decreases as basal area increases although the relationship was a loose one (Hale, 2004). The structure of the forest and thus the structure of the canopy, irrespective of the amount of basal area determines to a large extent the amount of light transmitted to the forest floor: a high basal area stand with many small trees will have a very dense canopy, and will transmit less light than a stand with the same basal area but fewer, larger trees (Hale, 2004).

2.4.3.4 The densiometer

One of the most widely used instruments for canopy closure assessment is the spherical densiometer (Jennings *et al.*, 1999). It is reported by Fiala *et al.* (2006) of its intermediate angle of view, being a hybrid detector of both canopy cover and canopy closure, assessing both the cover of canopy and light penetration into forests. With 60° as angle of view, the spherical densiometer is considered suitable for measuring canopy closure and is usually obtained from an average of measurement made in the four cardinal points (Marchi & Paletto, 2010). For forest canopies' classification, when 10-39 % of the sky is obstructed by tree canopies, forest canopy is considered as open and moderately closed when 40-69 % of the sky is obstructed by tree

canopies or closed when 70-100 % of the sky is obstructed by tree canopies (PSU, 2010; O'Neil *et al.*, 2001). The quantitative estimation of both canopy cover and canopy closure is useful to estimate penetration of light to the understory (Marchi & Paletto, 2010).

Research work by Fiala *et al.* (2006) in five forest stands of Western Oregon Cascades (young unthinned forest, young lightly thinned forest, young heavily thinned forest, a matured forest (120–180 years), and an old-growth forest, > 250 years) revealed that the spherical densiometer gives the highest and lowest percent cover in the young unthinned forest and the heavily thinned forest respectively (Fiala *et al.*, 2006). This could be attributed to profuse vegetation with the young unthinned forest when compared with the heavy thinned forest. Fiala *et al.* (2006) reported that the abundance of trees with open, spreading crowns in contrast with trees with compact crowns could account for variability in measurements.

2.4.3.5 Relationship between canopy closure and forest regeneration

Canopy openings stimulate or hinder growth depending on the kind of species (Hall & Swaine, 1988). The amount of light transmitted through a canopy is determined by the amount of canopy cover, the size and distribution of canopy gaps (Hale, 2004). For the establishments and growth of new species, canopy gaps influence some parameters of microclimate such as air humidity, light intensity and air temperature (Ward & Worthley, 2004). While a certain percentage of light may be enough for natural regeneration, it can also encourage the growth of competing vegetation (Hale, 2004). It is particularly disturbing for light demanding species when the overstorey mother trees have not matured enough to produce seeds thereby encouraging

colonisation by competing species (Hale, 2004). A dense understory can develop when a large amount of sunlight is allowed to penetrate areas of the canopy while a heavy or dense canopy results in a small amount of available sunlight that reaches the forest floor, and subsequently a sparse understory (PSU, 2010; Marchi & Paletto, 2010).

Canopy closure affords a direct link to assess the growth and survival of seedlings and saplings at the point of measurement (Jennings *et al.*, 1999). In their study of two types of subalpine larch and spruce forests, Marchi and Paletto (2010) found out a negative linear correlation (Kendall's rank correlation coefficient) between canopy closure and natural regeneration. Light system beneath forest canopy varies with respect to time and space such that direct sunlight and sun flecks on sunny days tend to cause large differences in light levels at scales of less than one metre while on overcast days, light distribution is diffused and it varies more gradually from place to place across a stand (Hale, 2004)

2.5 Approach to Forest Conservation

Conservation is defined as “the management of human use of the biosphere in order for it to yield the greatest sustainable benefit to current generations while maintaining its potential to meet the needs and aspirations of future generations (website 2). Conservation thus includes preservation, maintenance, sustainable utilisation, restoration, and enhancement of the natural environment (website 2). The conservation value of a location can be measured according to several attributes which includes diversity, rarity or representativeness (Wong *et al.*, 2002). An area becomes important for conservation when rare and/or threatened species are known or

suspected to inhabit the area. Reasons for rareness of species include static populations, infrequent regeneration and declining or expanding populations due to changing conditions (Hawthorne, 1993). In ratings, weights are assigned to species in accordance to set-criteria such as how abundant it is globally or in accordance to risk of extinction (Vermeulen & Koziell, 2002).

2.5.1 The star rating system

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 assess 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 (Tchouto *et al.*, 2004; Hawthorne *et al.*, 1997). Plant species are ranked as green, blue, gold or black stars in increasing order of conservation importance (Pappoe *et al.*, 2010).

In addition, there is the reddish star system by Hawthorne which re-classifies green stars and that includes plant species which are not globally rare but are of local economic importance and under threat of over exploitation; there is the Scarlet star (common but under serious threat from heavy exploitation; restraint needs to be exercised if usage is to be sustained), Red star (Common but under pressure from exploitation; requires some protection) and Pink star (Common but moderately exploited plus non-abundant species of high potential value) (Hawthorne *et al.*, 1997). The star ratings however did not cover weedy species or savannah species found only at

margins of forests; the rating was also poor for epiphytes as there is scanty knowledge on its local distribution and ecology (Hawthorne, 1993).

2.5.2 Globally Significant Biodiversity Areas (GSBAs)

The Globally Significant Biodiversity Areas (GSBAs) are considered as innovations in biodiversity conservation in Ghana (NBSG, 2002). These are re-designated existing forest reserves established on the bases that these reserves contain higher level of biological resources of global conservation importance (NBSG, 2002; McCullough *et al.*, 2007). They were arrived at after a two-year extensive botanical survey across the high forest zone of Ghana, employing the Genetic Heat Index (GHI) – an index of the concentration of rare plants within forest community (McCullough *et al.*, 2007). There are 29 GSBAs in the country (covers 117,322 ha) though McCullough *et al.* (2005; 2007) report of 30 GSBAs; logging and other commercial extractive activities are prohibited in the GSBAs (NBSG, 2002). GSBAs are under permanent protection but fringe communities are allowed to harvest NTFPs for domestic purposes only (Afriyie, 2010).

Addressing the conflict between conservation initiatives and the needs of local community and other stakeholders is crucial to achieving conservation goals (Kim & Byrne, 2006; Tchouto *et al.*, 2004). Findings of forest destruction by people living around protected areas (McCullough *et al.*, 2005; 2007) lessen the hope that people of forest fringe communities could be stewards of forest biodiversity. Siaw and Dabo (2009) asserted that the main challenge in maintaining Ghana's forest diversity is the preservation of natural forest while reducing forest threats.

Findings by Afriyie (2010) indicate that increase in human populations around the Tano Offin GSBA has resulted in decrease in available farmlands and continual cultivation of these small farmlands have rendered them infertile, collectively justifying the GSBA as potential farmlands left.

In accordance with the collaborative management principles of GSBA, communities around GSBA profit from schemes such as financial grants for alternative livelihood ventures for which they are to reciprocate by protecting the GSBA from illegal activities, nevertheless the communities' share of the collaborative management is proving doubtful (Asamoah *et al.*, 2011). The decrease of forest constituents even within protected areas ostensibly renders in-situ conservation strategy ineffective, appraising ex-situ conservation as a better option (Rembold, 2011). It is thought that conservational goals will be achieved if dwellers around protected areas benefit from the preservation and sustainable utilization of forest biodiversity (McCullough *et al.*, 2005).

2.5.2.1 The Tano Offin GSBA

The Tano Offin GSBA is situated within the Tano Offin Forest Reserve which is one of the three upland evergreen forests of Ghana (Hall & Swaine, 1981). Although GSBA are under permanent protection, fringe communities are allowed to harvest NTFPs for domestic purposes only (Afriyie, 2010). In accordance with the collaborative management principles of GSBA, communities around GSBA profit from schemes such as financial grants for alternative livelihood ventures for which they are to reciprocate by protecting the GSBA from illegal

activities (Asamoah *et al.*, 2011). Nevertheless the communities' share of the collaborative management is proving doubtful (Afriyie, 2010; Asamoah *et al.*, 2011). Findings by Afriyie (2010) indicate that increase in human populations around the GSBA has resulted in decrease in available farmlands and continual cultivation of these small farmlands have rendered them infertile, collectively justifying the GSBA as potential farmlands left. Compared to Atewa Range Forest Reserve which is one of the upland evergreen forests of Ghana, Tano Offin Reserve is smaller and significantly more disturbed (McCullough *et al.*, 2007).

2.5.2.1.1 Geology

The Tano Offin GSBA is found on an elongated mountainous range with numerous steep slopes, particularly is the Nyinahin hills (Ntiama-Baidu *et al.*, 2001). Although the general relief of Ghana lies below 600 m (NBSG, 2002), elevation of Tano Offin reserve measures between 200 m and 740 m above sea level (FC, 2007; Hall & Swaine, 1981; Ntiama-Baidu *et al.*, 2001) with Aya Bepo as the highest point (740 m) which serves as tributaries for the Tano and Offin rivers (Birdlife International, 2011).

The GSBA is found to be located on a rocky base of the Cape Coast granite complex and the main soil type found is the forest ochrosol (FC, 2007). A survey of the reserve in 1998 revealed a high level of soil erosion of the southern terrain, resulting mainly from logging and occasional wildfires. The reserve has had bauxite concessions in the past (Afriyie, 2010).

2.5.2.1.2 Vegetation

Tano Offin Forest Reserve (of which the GSBA constitutes part), falls within the semi-deciduous forest zone of Ghana with 34,100 ha of the reserve occurring as an Upland Evergreen forest (Ntiama-Baidu *et al.*, 2001; Birdlife International, 2011). Reports by FC (2007) noted that the average maximum height of trees in the reserve is about 45 m and the dominant timber species include *Pterygota macrocarpa*, *Mansonia altissima* and *Terminalia superba*. The Tano Offin Forest Reserve recorded a GHI of 176.4 during the 2001/2002 botanical survey by the Forestry Commission of Ghana and a total of seventeen Gold Star species, three black star species, as well as the rare tree fern (*Cyathea manniana*) were discovered (FC, 2007). This underscores the conservational attention given to this reserve.

History has it that in the 1970s and 1980s, the reserve was partitioned into 16 timber concessions and the last official logging was undertaken in 1991 (Ntiama-Baidu *et al.*, 2001). Between the years of 1990 and 2000, 5 % or 26.76 ha of forest cover of Tano offin were lost, amounting to 2.76 % decline in basal area (Djablatey, 2005). By virtue of the protective status, the GSBA section of the Tano Offin Forest Reserve has not known any silvicultural treatment although past mineral exploration of the area resulted in the removal of some timber trees (FC, 2007). Since the establishment of the GSBA, there have been reports of illegal harvesting of timber (Djablatey, 2005; FC, 2007; Asamoah *et al.*, 2011) and prevalence of chainsaw lumbering (Plate 1). Illegal logging activities plus bushfires have resulted in a degradation of some parts of the forest which gives a patchy vegetation outlook to the forest reserve nevertheless a good forest is still prevalent (Ntiama-Baidu *et al.*, 2001). Annual forest loss of Tano Offin Reserve in general

is estimated as 0.3 % *per* year and as a result, basal area declined from 24.3 to 18.9 between the years of 1990 and 1996 and then it further declined from 18.9 to 16.9 between 1996 and 2001 (Djablatey, 2005).



Plate 1: Photos highlighting the prevalence of illegal chainsaw activities at the Tano Offin Forest GSBA - (a) Solid residue in the form of billets and sawdust (b) Rejected log (c) Stump (d) Lumber

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Site

The study was conducted in the Tano Offin GSBA (Globally Significant Biodiversity Area) which is part of the Tano Offin Forest Reserve of Ghana (Figure 1). The GSBA concept was instituted to promote preservation of forests in a state that mimics natural forest conditions so as protect unique flora, fauna and ecosystems (Asamoah *et al.*, 2011). A fraction of the Tano Offin Reserve was designated as a GSBA (Figure 1) in 1999 after a discovery of the area's outstanding biological diversity through an extensive national forest inventories (FC, 2007). The labelling as GSBA corresponds to IUCN's Category IV designation, i.e. a protected area designated mainly for conservation through management intervention (McCullough *et al.*, 2007).

The reserve is one of the three upland evergreen forests of Ghana (Hall & Swaine, 1981), situated within the Atwima-Mponua and Ahafo Ano District Assemblies. The Tano Offin Forest Reserve lies between longitudes 1°57" and 2°17" West and latitudes 6°54" and 6°35" North, covering an area of 413.92 km² of which the GSBA constitutes 44.5 % i.e. 178.34 km² (FC, 2007). As an Important Bird Area, nationally rare bird species have been identified in this reserve and these include *Cercococcyx olivinus*, *Columba uncinata* and *Tockus camurus* (Birdlife International, 2011). Inside the GSBA is the Kyekyewere village (6.27 km²/ 627 ha) whose inhabitants are permitted to live and farm within certain jurisdiction of the GSBA (Figure 1).

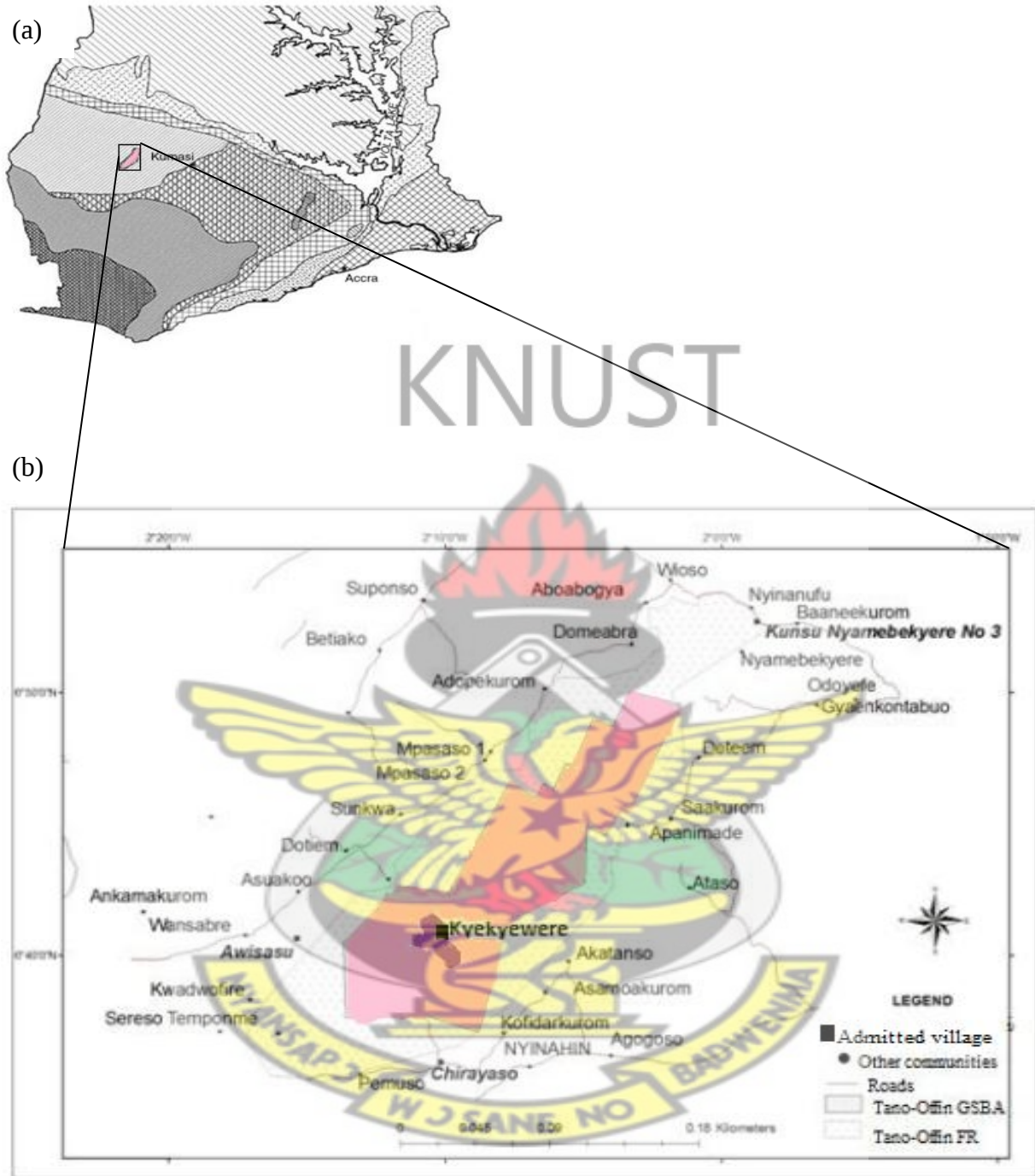


Figure 1: A map showing the GSB (in pink) and the surrounding communities of the Tano Offin forest reserve. Modified from (a) Pappoe *et al.*, 2010 (b) Derkyi, 2012

3.1.1 Climate

The GSBA is located on a mountainous range and is thus characterised by misty conditions, high relative humidity and rainfall as well as the formation of forest clouds (NBSG, 2002). The area experiences a bi-modal rainfall pattern where it peaks in May-June and September-October, and the mean annual rainfall is 1250 mm (FC, 2007). There is also a dry spell between mid-November and mid-March with January as the driest month, recording the minimum monthly average temperature of 19.6° C; the mean maximum temperature of the reserve is 33.04° C and the annual mean relative humidity is 80 % (FC, 2007).

3.2 Plot Establishment

With the help of a compass and a measuring tape, ten 50 m x 50 m permanent sample plots (termed tree layer in this study) were demarcated within the GSBA of the Tano Offin Forest Reserve, where reflective poles (Plate 2) were pegged at the corners and tagging (Plate 3) and painting (Plate 4) of all trees and other plant life forms with dbh (diameter at breast height) ≥ 10 cm were done. These individual plots varied in invasiveness and altitude, ranging from 264 m – 623 m: Lowland forests were ranked as plots with altitude < 300 m, Transition area as > 300 m but < 500 m in altitude; and 500 m – 700 m for Highland forests (Appendix 2). Each plot was subdivided into four 25 m x 25 m sub-plots for sampling. A 10 m x 10 m plot (termed shrub layer) was located within each of the 50 m x 50 m sample plot. In addition, a single 1 m x 1 m quadrat (termed herb layer) was laid at the corners of the 50 m x 50 m plots and its centre for the assessment of forest floor vegetation as well as canopy closure. A Garmin GPS 76 was used to determine the geo-reference positions and the elevation of sample plots.



Plate 2: Reflective pole pegged at the corner of a 50 m × 50 m plot



Plate 3: An example of tagged tree (*Pycanthus angolensis*) with tag number 4179



Plate 4: Cluster of painted trees (with dbh $\geq$ 10 cm) within a 50 m × 50 m plot

3.3 Data collection

The following processes were undertaken to gather data on the floristic composition of the forest, the height and diameter of trees as well as the natural regeneration and the level of light penetrating into the forest.

3.3.1 Plant identification

Employing the 25 m x 25 m subdivisions of the 50 m x 50 m, trees and other plant life forms with dbh $\geq$ 10 cm were identified; lianas/herbaceous climbers and epiphytes were also identified. The identification whilst in the forest was made possible by diagnostic factors (Plate 5) such as growth habit, a study of the crown shape and tree bole, the bark texture and its slash appearance, the smell, taste and a study of the nature of exudates from the slashed bark, the leaves, fruits, flowers and the root system. The aid of a catapult was employed to fetch tree leafs that were not easily within reach. The identity of plant species that could not be determined in the forest were identified with the aid of either Hawthorne or Jongkind (2006) and Hawthorne and Gyakari (2006), or at the herbarium of the Resource Management Support Centre of the Forestry Commission of Ghana.

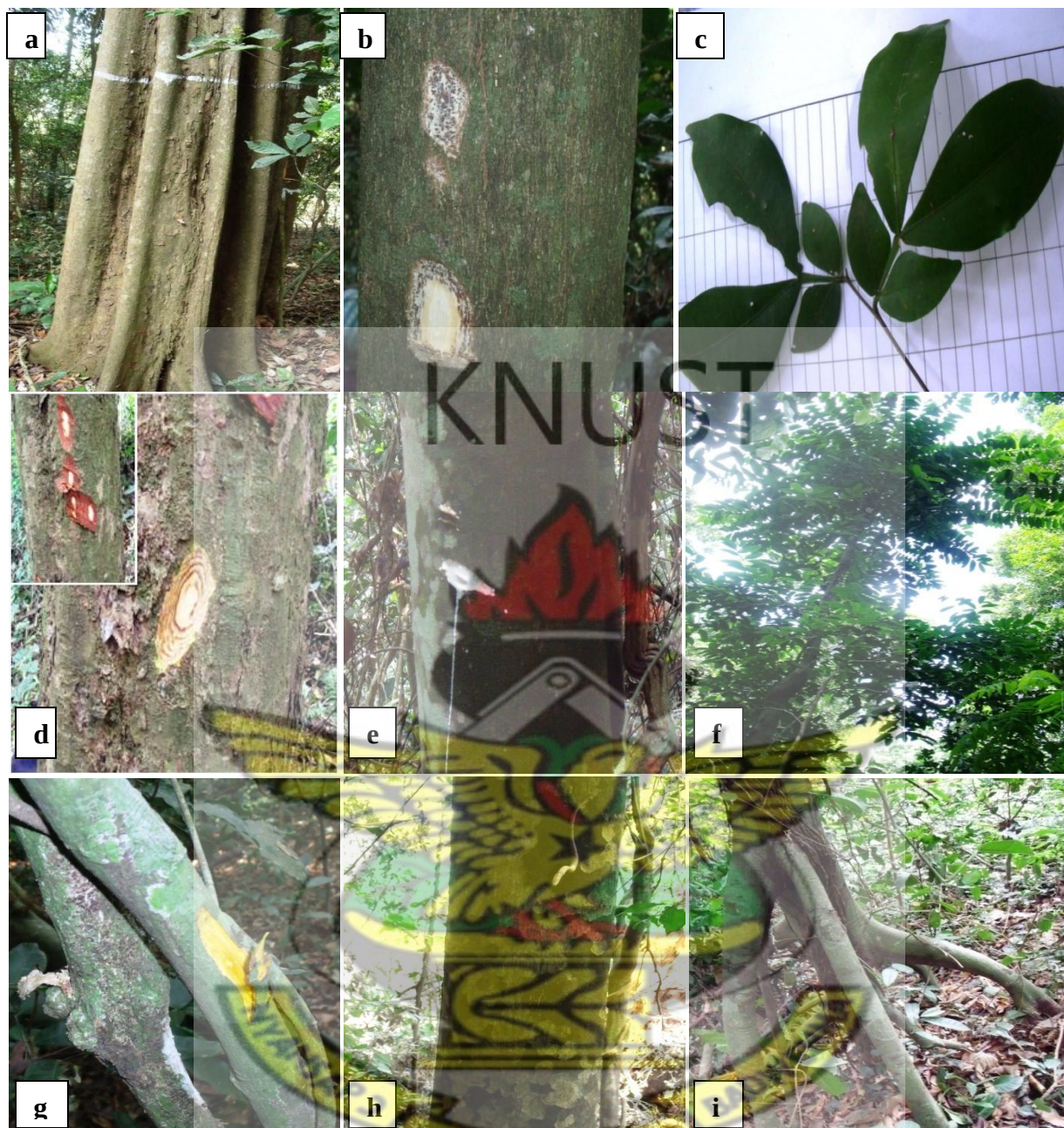


Plate 5: Photos of some diagnostic factors used in the identification of plants – (a) deeply fluted bole of *Hexalobus crispiflorus* (b) chocolate brown spots of slashed bark of *Celtis adolfi-friderici* (c) *Hymenostegia afzelii* - pinnate leaves with two leaflets pairs winged by a rachis (d) slashed bark - alternating brown and yellow layers (as with *Celtis mildbraedii*) which quickly turns brown as with *Celtis zenkeri* (inset) (e) profuse white latex of *Funtumia africana* which forms rubbery balls as with *Funtumia elastica* when rubbed between fingers (f) Horizontal branches forming the crown of *Allanblackia parviflora* (g) Bright golden yellow slashed bark of *Annickia polycarpa* (h) Scaly patchwork of the bark of *Strombosia pustulata* (i) Large spreading stilt roots of *Uapaca guineensis*

3.3.2 Tree height and diameter measurement

Within the 50 m x 50 m plots, the dbh of all trees and other plant life forms with dbh ≥ 10 cm were measured using a tree caliper. The dbh of trees with buttresses were measured with a relascope. Within the 50 m x 50 m, the height of all trees and shrubs with dbh ≥ 10 cm was determined with Vertex IV and Transponder III. Trees with broken tops were noted and dead trees were eliminated. The diameter of saplings (≤ 3 m high and dbh < 10 cm) and other plant life forms of dbh < 10 cm were measured in the 10 m x 10 m plot randomly located within the 50 m x 50 m plots.

3.3.3 Canopy measurement and regeneration assessment

The concave spherical densiometer (Model C) was used to assess the forest canopy closure. It consists of a spherical mirror which is concave shaped so as to reflect a large segment of the sky hemisphere. Engraved in the mirror is a grid made up of 24 squares and there is a bubble level that ensures that the instrument is horizontally hand-held when readings are taken. On the 1 m x 1 m quadrats at the corners and centre of the 50 m x 50 m sample plots, readings were taken by an assumption of 4 equally spaced dots in each square of the grid (Figure 2). A count was made of the number of dots that were not intercepted by the canopy reflection, in other words, the open spaces of the canopy.

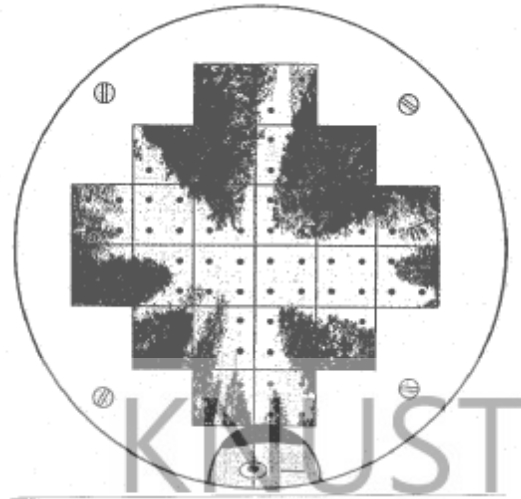


Figure 2: The spherical densiometer with a view of the 4 assumed dots per each square

Source: Werner (2009).

Based on recommendations from literature (Jennings *et al.*, 1999; Fiala *et al.*, 2006) readings were taken at each of the cardinal direction, resulting in four readings (sample size) for each point of measurement or quadrat. This was necessary to effectively increase the angle of view (Jennings *et al.*, 1999). The mean of the four readings for each quadrat was computed, producing five mean values for each plot. Seedlings (< 1.5 m high and $\text{dbh} \leq 1.5$ cm), grasses, herbs and other forest floor vegetation found within the 1 m x 1 m quadrats were identified and counted.

3.4 Analysis of data

3.4.1 Forest composition and structure assessment

Species richness for each plot was computed and the total number of genus, families and life forms were assessed. In order to describe the numerical structure of the forest, the diversity

quantification tools Simpson's (1-D) and Shannon- Wiener diversity ($H' = -\sum P_i \ln P_i$) indices were used, where $D = \sum (n / N)^2$ and P_i is the proportional individuals of species i . The basal area ($d^2 \times 0.00007854$; d = diameter in cm) *per* hectare for both plant species with dbh ≥ 10 cm (termed as tree layer) and those with dbh < 10 cm (termed as shrub layer) was determined. The structural significance of tree species was assessed by calculating the Importance Value Index (IVI) of each species which was attained by summing the Relative Frequency, Relative Density, and Relative Dominance for each species as shown below:

Procedures for calculating Importance Value Index

- (i) Density =
$$\frac{\text{Number of species A}}{\text{Area sampled}}$$
- (ii) Frequency =
$$\frac{\text{Number of plots in which species A occurs}}{\text{Total number of plots sampled}}$$
- (iii) Dominance =
$$\frac{\text{Total cover or basal area of species A}}{\text{Area sampled}}$$
- (iv) Relative density =
$$\frac{\text{Density of species A}}{\text{Total density of all species}} \times 100$$
- (v) Relative frequency =
$$\frac{\text{Frequency value for species A}}{\text{Total of all frequency values for all species}} \times 100$$
- (vi) Relative dominance =
$$\frac{\text{Dominance for species A}}{\text{Total Dominance of all species}} \times 100$$
- (vii) Importance Value Index = (relative density + relative dominance+ relative frequency)

The ecological guild (pioneer, non-pioneer light-demanding and shade-bearing) and star rating of the tree species were determined (Hawthorne, 1993; Hawthorne & Gyakari, 2006). The star rating consists of Black Star species (rare internationally and at least uncommon in Ghana); Gold Star (Fairly rare internationally and locally); Blue Star (widespread internationally but rare in Ghana or vice-versa); Scarlet Star (common, but under serious pressure from heavy exploitation); Red Star (common, but under pressure from exploitation); Pink Star (common and moderately exploited as well as being non-abundant and of high potential value); and Green Star species (common in Ghana and of no particular conservation concern).

Plants with dbh ≥ 10 cm were grouped into six diameter classes ($\geq 10 - 30$ cm; $> 30 - 50$ cm; $> 50 - 70$ cm; $> 70 - 90$ cm; $> 90 - 110$ cm; > 110 cm) whereas those with dbh < 10 cm were grouped into four diameter classes (> 0.1 cm – 2 cm; > 2 cm – 5 cm; > 5 cm – 8 cm; > 8 cm - 9.9 cm). In accordance to Antwi (1999), trees of dbh ≥ 10 cm were classified into four height classes (Emergent: > 35 m, Upper canopy: $> 25 - 35$ m, Lower canopy: > 15 m-25 m, Understorey: ≤ 15 m) to reflect the forest's vertical layer and the species composition of the various layers.

3.4.2 Determination of the effects of elevation and invasive species on floristic composition and structure

Differences in diversity, IVI, and basal area were assessed for the highland, lowland and the transition areas and similarly for the presence and absence of invasive species. Mean values of basal area, Simpson's and Shannon-Wiener diversity indices were compared using analysis of variance (ANOVA) so as to detect significant differences of the influence of elevation on

diversity and basal area. F-test, t-Test and Mann-Whitney U-Test were used to determine significant effects of invasive species on diversity and basal area. Proportions of the different guilds and star ratings of species composition of the different elevations were also determined on a 0.5 ha size bases. The choice of 0.5 ha for all three land belts as against 0.5 ha for lowland and 1 ha for the transition and highlands, was necessary to nullify the effect of increase in species richness with respect to increasing sample size (Magurran, 1988).

3.4.3 Canopy closure and regeneration assessment

The figures obtained from the canopy readings were deducted from 96 and the mean canopy readings *per* quadrat determined after which it was multiplied by 1.04 (Marchi & Paletto, 2010). The percentage canopy closure for each plot (i.e. 50 m x 50 m) was calculated. With respect to natural regeneration, the species that constituted seedlings (young tree plant with height < 1.5 m and dbh $\leq$ 1.5 cm) and saplings (young tree plant with height $\leq$ 3 m and dbh < 10 cm) and their abundance were determined. ANOVA was used to determine the significant difference of the influence of elevation on the diversity of the saplings and seedlings and F-test, t-Test and Mann-Whitney U-Test were used to find the significant effects of invasive species. Proportion of the different ecological guilds for the seedlings and saplings was also determined.

CHAPTER FOUR

4.0 RESULTS

4.1 Floristic composition

A total of 240 plant species were identified during the assessment of Tano Offin GSBA (Table 1). These comprised of 171 trees, 41 lianas, 11 shrubs, 7 herbs, 7 herbaceous climbers and a species of an epiphyte (Plate 6), grass (*Leptaspis cochleata*) and a fern (*Adiantum vogelii*). The star rating of 222 plant species were determined while 18 were not available – 1 Black star, 8 Gold stars, 17 Blue stars, 9 Scarlet stars, 7 Red stars, 21 Pink stars and 159 Green stars (Table 1). With the exception of 33 plant species, the guilds of 207 species were determined namely 42 pioneers, 68 non-pioneer light-demanding species, 93 shade-bearing, 2 swamp species and 2 invasive species (Table 1). There were 179 genera and 59 families with Fabaceae being the most contributing family with respect to species richness (15 %) – represented by 36 species (Figure 3). Forty-six families had less than 5 species (Figure 3).

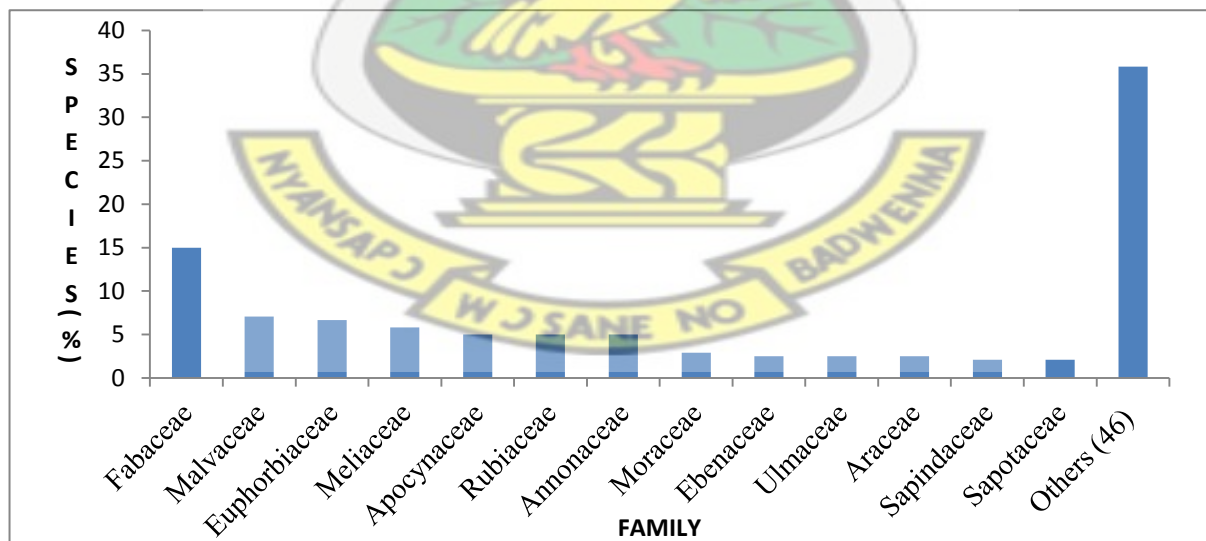


Figure 3: Percentage of plant species represented by families at Tano Offin GSBA

Table 1: Families, life forms, star ratings and guilds of the plant species identified at Tano Ofiin GSBA

Plant species	Family	Life form	Star	Guild
1. <i>Acacia kamerunesis</i> Gand.	Fabaceae	Liana	Green	Non-pioneer light-demanding
2. <i>Acacia pentagona</i> (Schumach. & Thonn.) Hook.f.	Fabaceae	Liana	Green	Non-pioneer light-demanding
3. <i>Acalypha ciliata</i> Forssk.	Euphorbiaceae	Shrub	Green	Pioneer
4. <i>Adenia rumicifolia</i> Engl. & Harms	Passifloraceae	Liana	Green	Pioneer
5. <i>Adiantum vogelii</i> Mett.	Adiantaceae	Fern	Green	N/a
6. <i>Afzelia bella</i> Harms	Fabaceae	Tree	Pink	Non-pioneer light-demanding
7. <i>Agelaea nitida</i> (Lam.) Baill.	Connaraceae	Liana	Green	Shade-bearing
8. <i>Agelaea paradoxa</i> Gilg	Connaraceae	Liana	Green	Non-pioneer light-demanding
9. <i>Agelaea pentagyna</i> (Lam.) Baill.	Connaraceae	Liana	Green	Shade-bearing
10. <i>Aidia genipiflora</i> (DC.) Dandy	Rubiaceae	Tree	Green	Shade-bearing
11. <i>Alafia barteri</i> Oliv.	Apocynaceae	Liana	Green	Non-pioneer light-demanding
12. <i>Albizia glaberrima</i> (Schumach. & Thonn.) Benth.	Fabaceae	Tree	Green	Non-pioneer light-demanding
13. <i>Albizia adianthifolia</i> (Schumach.) W. F. Wight	Fabaceae	Tree	Green	Non-pioneer light-demanding

Table 1: Continued

14. <i>Albizia zygia</i> (DC.) J. F. Macbr.	Fabaceae	Tree	Green	Non-pioneer light-demanding
15. <i>Allanblackia parviflora</i> A. Chev.	Guttiferae	Tree	Green	Shade-bearing
16. <i>Alstonia boonei</i> De. Wild.	Apocynaceae	Tree	Green	Pioneer
17. <i>Amphimas pterocarpoides</i> Harms	Fabaceae	Tree	Green	Non-pioneer light-demanding
18. <i>Anonidium mannii</i> (Oliv.) Engl. & Diels	Annonaceae	Tree	Blue	Shade-bearing
19. <i>Anopyxis klaineana</i> (Pierre) Engl.	Rhizophoraceae	Tree	Red	Non-pioneer light-demanding
20. <i>Anthonotha fragrans</i> (Baker. f) Excell & Hillcoat	Fabaceae	Tree	Green	Non-pioneer light-demanding
21. <i>Antiaris toxicaria</i> (Rumph. ex Pers.) Leschen.	Moraceae	Tree	Pink	Non-pioneer light-demanding
22. <i>Antrocaryon micraster</i> A. Chev. & Guillaum.	Anacardiaceae	Tree	Red	Non-pioneer light-demanding
23. <i>Aptandra zenkeri</i> Engl.	Olacaceae	Tree	Green	Shade-bearing
24. <i>Aubrevillea kerstingii</i> (Harms) Pellegr.	Fabaceae	Tree	Blue	Non-pioneer light-demanding
25. <i>Baissea baillonii</i> Hua	Apocynaceae	Liana	Green	N/a
26. <i>Baphia nitida</i> Lodd.	Fabaceae	Tree	Green	Shade-bearing
27. <i>Baphia pubescens</i> Hook. f.	Fabaceae	Tree	Green	Pioneer
28. <i>Berlinia tomentella</i> Keay	Fabaceae	Tree	Green	Shade-bearing

Table 1: Continued

29. <i>Blighia sapida</i> Konig	Sapindaceae	Tree	Green	Non-pioneer light-demanding
30. <i>Blighia welwitschii</i> (Hiern) Radlk.	Sapindaceae	Tree	Green	Non-pioneer light-demanding
31. <i>Bombax buonopozense</i> P. Beauv.	Malvaceae	Tree	Green	Pioneer
32. <i>Bridelia grandis</i> Pierre ex Hutch.	Euphorbiaceae	Tree	Green	Pioneer
33. <i>Broussonetia papyrifera</i> Vent.	Moraceae	Tree	Green	Invasive
34. <i>Bucholzia coriacea</i> Engl.	Capparaceae	Tree	Green	Shade-bearing
35. <i>Bussea occidentalis</i> Hutch.	Fabaceae	Tree	Green	Non-pioneer light-demanding
36. <i>Calpocalyx brevibracteatus</i> Harms	Fabaceae	Tree	Green	Shade-bearing
37. <i>Calycobolus africanus</i> (G. Don) Heine	Convolvulaceae	Liana	Green	N/a
38. <i>Canarium schweinfurthii</i> Engl.	Burseraceae	Tree	Pink	Pioneer
39. <i>Carapa procera</i> DC.	Meliaceae	Tree	Green	Shade-bearing
40. <i>Carpolobia lutea</i> G. Don	Polygalaceae	Shrub	Green	Shade-bearing
41. <i>Cassipourea lescotiana</i> J. G. Adam	Rhizophoraceae	Tree	Green	Shade-bearing
42. <i>Cedrela odorata</i> L.	Meliaceae	Tree	N/a	Non-forest
43. <i>Ceiba pentandra</i> (L.) Gaertn.	Malvaceae	Tree	Green	Pioneer

Table 1: Continued

44. <i>Celtis adolfi-friderici</i> Engl.	Ulmaceae	Tree	Green	Pioneer
45. <i>Celtis mildbraedii</i> Engl.	Ulmaceae	Tree	Green	Shade-bearing
46. <i>Celtis wightii</i> Blanco	Ulmaceae	Tree	Green	Shade-bearing
47. <i>Celtis zenkeri</i> Engl.	Ulmaceae	Tree	Green	Non-pioneer light-demanding
48. <i>Cercestis afzelii</i> Schott	Araceae	H. climber	Green	Shade-bearing
49. <i>Chidlowia sanguine</i> Hoyle	Fabaceae	Tree	Blue	Shade-bearing
50. <i>Chlamydocarya macrocarpa</i> A.Chev. ex Hutch. & Dalziel	Icacinaeae	Liana	Gold	Shade-bearing
51. <i>Chromolaena odorata</i> (L.) King & Robinson	Asteraceae	Shrub	N/a	Invasive
52. <i>Chrysophyllum albidum</i> G. Don	Sapotaceae	Tree	Pink	Shade-bearing
53. <i>Chrysophyllum perpulcrum</i> Mildbr. ex Hutch. & Dalziel	Sapotaceae	Tree	Green	Non-pioneer light-demanding
54. <i>Chrysophyllum subnudum</i> Baker	Sapotaceae	Tree	Green	Shade-bearing
55. <i>Chytranthus carneus</i> Radlk.	Sapindaceae	Tree	Green	Shade-bearing
56. <i>Cissus producta</i> Afzel.	Vitaceae	Liana	Green	N/a
57. <i>Cleidion gabonicum</i> Baill.	Euphorbiaceae	Tree	Green	Shade-bearing
58. <i>Cleistopholis patens</i> (Benith.) Engl. & Diels	Annonaceae	Tree	Green	Pioneer

Table 1: Continued

59.	<i>Clerodendrum capitatum</i> (Willd.) Schumach. & Thonn.	Verbenaceae	Tree	Green	Pioneer
60.	<i>Cnestis ferruginea</i> Vahl ex DC.	Connaraceae	Liana	Green	Pioneer
61.	<i>Coffea stenophylla</i> G. Don	Rubiaceae	Tree	N/a	N/a
62.	<i>Cola boxiana</i> Brenan & Keay	Malvaceae	Tree	Gold	Shade-bearing
63.	<i>Cola caricifolia</i> (G. Don) K. Schum.	Malvaceae	Tree	Green	Pioneer
64.	<i>Cola gigantea</i> A. Chev.	Malvaceae	Tree	Green	Non-pioneer light-demanding
65.	<i>Cola lateritia</i> K. Schum.	Malvaceae	Tree	Green	Shade-bearing
66.	<i>Cola millenii</i> K. Schum.	Malvaceae	Tree	Green	Non-pioneer light-demanding
67.	<i>Cola nitida</i> (Vent.) Schott. & Endl.	Malvaceae	Tree	Pink	Shade-bearing
68.	<i>Combretum paniculatum</i> Vent.	Combretaceae	Liana	Green	N/a
69.	<i>Combretum zenkeri</i> Engl. & Diels	Combretaceae	Liana	Blue	N/a
70.	<i>Cordia platythyrsa</i> Baker	Boraginaceae	Tree	Pink	Pioneer
71.	<i>Corynanthe pachyceras</i> K. Schum.	Rubiaceae	Tree	Green	Non-pioneer light-demanding
72.	<i>Craterispermum caudatum</i> Hutch.	Rubiaceae	Tree	Green	Shade-bearing
73.	<i>Craterispermum cerinanthum</i> Hiern	Rubiaceae	Tree	Green	Shade-bearing

Table 1: Continued

74. <i>Culcasia angolensis</i> Welw. ex Schott	Araceae	H. climber	Green	Non-pioneer light-demanding
75. <i>Culcasia parviflora</i> N. E. Br.	Araceae	H. climber	Green	Shade-bearing
76. <i>Culcasia scandens</i> P. Beauv.	Araceae	H. climber	Green	Shade-bearing
77. <i>Culcasia striolata</i> Engl.	Araceae	Herb	Green	Shade-bearing
78. <i>Dacryodes klaineana</i> (Pierre) H. J. Lam	Burseraceae	Tree	Green	Shade-bearing
79. <i>Dalbergia saxatilis</i> Hook. f.	Fabaceae	Liana	Green	N/a
80. <i>Daniellia ogea</i> (Harms) Holland	Fabaceae	Tree	Pink	Pioneer
81. <i>Dasylepis brevipedicellata</i> Chipp	Achariaceae	Tree	Green	Shade-bearing
82. <i>Desplatsia chrysochlamys</i> (Mild. & Burret) Mildb. & Burret	Malvaceae	Tree	Green	Shade-bearing
83. <i>Dialium aubrevillei</i> Pellegr.	Fabaceae	Tree	Green	Shade-bearing
84. <i>Dialium dinklagei</i> Harms	Fabaceae	Tree	Green	Non-pioneer light-demanding
85. <i>Dichapetalum angolense</i> Chodat	Dichapetalaceae	Shrub	Green	Non-pioneer light-demanding
86. <i>Dichapetalum madagascariense</i> Poir.	Dichapetalaceae	Tree	Green	Shade-bearing
87. <i>Dichapetalum toxicarium</i> (G. Don) Baill.	Dichapetalaceae	Shrub	Blue	Non-pioneer light-demanding
88. <i>Diospyros abyssinica</i> (Hiern) F. White	Ebenaceae	Tree	Green	Pioneer

Table 1: Continued

89. <i>Diospyros ferrea</i> (Willd.) Bakh.	Ebenaceae	Tree	Green	Shade-bearing
90. <i>Diospyros kamerunensis</i> Gürke	Ebenaceae	Tree	Green	Shade-bearing
91. <i>Diospyros monbuttenssis</i> Gürke	Ebenaceae	Tree	Green	Shade-bearing
92. <i>Diospyros soubreana</i> F. White	Ebenaceae	Tree	Green	Shade-bearing
93. <i>Diospyros viridicans</i> Hiern	Ebenaceae	Tree	Green	Shade-bearing
94. <i>Discoglyprena caloneura</i> (Pax) Prain	Euphorbiaceae	Tree	Green	Pioneer
95. <i>Distemonanthus benthamianus</i> Baill.	Fabaceae	Tree	Pink	Non-pioneer light-demanding
96. <i>Draceana mildbraedii</i> K. Krause	Dracaenaceae	Shrub	N/a	N/a
97. <i>Drypetes chevalieri</i> Beille	Euphorbiaceae	Tree	Green	Shade-bearing
98. <i>Drypetes aubrevillei</i> Léandri	Euphorbiaceae	Tree	Blue	Shade-bearing
99. <i>Drypetes aylmeri</i> Hutch. & Dalziel	Euphorbiaceae	Tree	Blue	Shade-bearing
100. <i>Drypetes gilgiana</i> (Pax) Pax & K. Hoffm.	Euphorbiaceae	Tree	Green	Shade-bearing
101. <i>Drypetes pellegrinii</i> Léandri	Euphorbiaceae	Tree	Gold	Shade-bearing
102. <i>Duboscia macrocarpa</i> Bocq.	Malvaceae	Tree	N/a	N/a
103. <i>Duguetia staudtii</i> (Engl. & Diels) Chatrou	Annonaceae	Tree	N/a	N/a

Table 1: Continued

104. <i>Elaeis guineensis</i> Jacq.	Arecaceae	Tree	Pink	Pioneer
105. <i>Enantia polycarpa</i> (A.DC.)Van Setten& Maas	Annonaceae	Tree	Green	Shade-bearing
106. <i>Entada pursuetha</i> Sprengel	Fabaceae	Liana	Green	N/a
107. <i>Entandrophragma angolense</i> (Welw.) DC.	Meliaceae	Tree	Red	Non-pioneer light-demanding
108. <i>Entandrophragma candollei</i> Harms	Meliaceae	Tree	Scarlet	Non-pioneer light-demanding
109. <i>Entandrophragma cylindricum</i> (Sprague) Sprague	Meliaceae	Tree	Scarlet	Non-pioneer light-demanding
110. <i>Entandrophragma utile</i> (Dawe & Sprague) Sprague	Meliaceae	Tree	Scarlet	Non-pioneer light-demanding
111. <i>Eremomastax speciosa</i> (Hochst.) Cufod.	Acanthaceae	Herb	N/a	N/a
112. <i>Erythrinia miildbraedii</i> Harms	Fabaceae	Tree	Green	Pioneer
113. <i>Erythroleum ivorensis</i> A. Chev.	Fabaceae	Tree	Pink	Non-pioneer light-demanding
114. <i>Erythroxylum mannii</i> Oliv.	Erythroxylaceae	Tree	Green	Pioneer
115. <i>Euclinia longiflora</i> Salisb.	Rubiaceae	Tree	Green	N/a
116. <i>Ficus bubu</i> Warb.	Moraceae	Tree	Blue	Swamp
117. <i>Funtumia africana</i> (Benth.) Stapf	Apocynaceae	Tree	N/a	N/a
118. <i>Funtumia elastic</i> (Preuss) Stapf	Apocynaceae	Tree	Pink	N/a

Table 1: Continued

119. <i>Garcinia kola</i> Heckel	Guttiferae	Tree	Scarlet	Shade-bearing
120. <i>Geophila obvallata</i> (Schumach.) F.Didr.	Rubiaceae	Herb	N/a	N/a
121. <i>Gongronema latifolium</i> Benth.	Asclepiadaceae	Liana	Green	Shade-bearing
122. <i>Greenwayodendron oliveri</i> (Engl.) Verdc.	Annonaceae	Tree	N/a	N/a
123. <i>Griffonia simplicifolia</i> (Vahl ex DC.) Baill.	Fabaceae	Liana	Green	Non-pioneer light-demanding
124. <i>Guarea cedrata</i> (A.Chev.) Pellegr.	Meliaceae	Tree	Pink	Shade-bearing
125. <i>Guarea thompsonii</i> Sprague & Hutch.	Meliaceae	Tree	Pink	Shade-bearing
126. <i>Guibourtia ehie</i> (A.Chev.) J.Léonard	Fabaceae	Tree	Red	Non-pioneer light-demanding
127. <i>Hannoa klaineana</i> Pierre & Engl.	Simaroubaceae	Tree	Green	Pioneer
128. <i>Hexalobus crispiflorus</i> A. Rich.	Annonaceae	Tree	Green	Shade-bearing
129. <i>Hippocratea Africana</i> (Willd.) Wilczek ex N.Hallé	Celastraceae	Liana	Green	Pioneer
130. <i>Hippocratea vignei</i> Hoyle	Celastraceae	Liana	Black	N/a
131. <i>Holoptelea grandis</i> (Hutch.) Mildbr.	Ulmaceae	Tree	Green	Pioneer
132. <i>Homalium sp</i>	Salicaceae	Tree	N/a	N/a
133. <i>Hunteria umbellata</i> (K.Schum.) Hallier f.	Apocynaceae	Tree	Green	Shade-bearing

Table 1: Continued

134. <i>Hymenocoleus rotundifolius</i> (A.Chev. ex Hepper) Robbr.	Rubiaceae	Herb	Blue	N/a
135. <i>Hymenostegia afzelii</i> (Oliv.) Harms	Fabaceae	Tree	Green	Shade-bearing
136. <i>Irvingia gabonensis</i> (Aubry-Lecomte) Baill.	Irvingiaceae	Tree	Green	Non-pioneer light-demanding
137. <i>Isolona deightonii</i> Keay	Annonaceae	Tree	Gold	Shade-bearing
138. <i>Justicia flava</i> (Forssk.) Vahl	Acanthaceae	Herb	Green	Pioneer
139. <i>Khaya anthotheca</i> (Welw.) C.DC.	Meliaceae	Tree	Scarlet	Non-pioneer light-demanding
140. <i>Khaya ivorensis</i> A.Chev.	Meliaceae	Tree	Scarlet	Non-pioneer light-demanding
141. <i>Landolphia owariensis</i> P.Beauv.	Apocynaceae	Liana	Green	N/a
142. <i>Landophia macrantha</i> (K.Schum.) Pichon	Apocynaceae	Liana	Blue	Non-pioneer light-demanding
143. <i>Lannea welwitschii</i> (Hiern) Engl.	Anacardiaceae	Tree	Green	Pioneer
144. <i>Lecaniodiscus cupaniodes</i> Planch. ex Benth.	Sapindaceae	Tree	Green	Shade-bearing
145. <i>Leptaspis cochleata</i> Thwaites	Poaceae	Grass	Green	Shade-bearing
146. <i>Leptaulus daphnoides</i> Benth.	Icacinaceae	Tree	Green	Shade-bearing
147. <i>Leptoderris brachyptera</i> (Benth.) Dunn	Fabaceae	Liana	Green	N/a
148. <i>Leptoderris micrantha</i> Dunn	Fabaceae	Liana	Gold	N/a

Table 1: Continued

149. <i>Lovoa trichiliodes</i> Harms	Meliaceae	Tree	Red	Non-pioneer light-demanding
150. <i>Macaranga barteri</i> Müll. Arg.	Euphorbiaceae	Tree	Green	Pioneer
151. <i>Maesobotrya barteri</i> (Baill.) Hutch.	Euphorbiaceae	Tree	Green	Shade-bearing
152. <i>Mallotus oppositifolius</i> (Geisel.) Müll. Arg.	Euphorbiaceae	Tree	Green	Shade-bearing
153. <i>Mammea Africana</i> Sabine	Guttiferae	Tree	Pink	Shade-bearing
154. <i>Manniophyton fulvum</i> Müll. Arg.	Euphorbiaceae	Liana	Green	Non-pioneer light-demanding
155. <i>Mansonia altissima</i> (A. Chev.) A. Chev.	Malvaceae	Tree	Pink	Non-pioneer light-demanding
156. <i>Maranthes grabla</i> (Oliv.) Prance	Chrysobalanaceae	Tree	Green	Shade-bearing
157. <i>Marantochloa mannii</i> (K. Schum.) Milne-Redh.	Marantaceae	Herb	Green	Pioneer
158. <i>Mareya micrantha</i> (Benth.) Müll. Arg.	Euphorbiaceae	Tree	Green	Shade-bearing
159. <i>Microdesmis keayana</i> J. Léonard	Pandaceae	Tree	N/a	N/a
160. <i>Microdesmis puberula</i> J. Léonard	Pandaceae	Tree	Green	Shade-bearing
161. <i>Microsorium punctatum</i> (L.) Copel.	Polypodiaceae	Epiphyte	Green	N/a
162. <i>Milicia excelsa</i> (Welw.) C. C. Berg	Moraceae	Tree	Scarlet	Pioneer
163. <i>Millettia chrysophylla</i> Dunn	Fabaceae	Liana	Green	Non-pioneer light-demanding

Table 1: Continued

164. <i>Millettia zechiana</i> Harms	Fabaceae	Tree	Green	Pioneer
165. <i>Momordica angusticepala</i> Harms	Cucurbitaceae	H. climber	N/a	Pioneer
166. <i>Monodora myristica</i> (Gaertn.) Dunal	Annonaceae	Tree	Green	Shade-bearing
167. <i>Monodora tenuifolia</i> Benth.	Annonaceae	Tree	Green	Pioneer
168. <i>Morus mesozygia</i> Stapf	Moraceae	Tree	Green	Pioneer
169. <i>Motandra guineensis</i> (Thonn.) A. DC.	Apocynaceae	H. climber	Green	Non-pioneer light-demanding
170. <i>Myrianthus arboreus</i> P.Beauv.	Cercropiaceae	Tree	Green	Shade-bearing
171. <i>Myrianthus libericus</i> Rendle	Cercropiaceae	Tree	Green	Shade-bearing
172. <i>Napoleonaea vogelii</i> Hook. & Planch.	Lecythidaceae	Tree	Green	Shade-bearing
173. <i>Nesogordonia papaverifera</i> (A.Chev.) R.Capuron	Malvaceae	Tree	Pink	Shade-bearing
174. <i>Neuropeltis prevosteoides</i> Mangenot	Convolvulaceae	Liana	Blue	Non-pioneer light-demanding
175. <i>Octoknema borealis</i> Hutch. & Dalziel	Olacaceae	Tree	Green	Shade-bearing
176. <i>Ongokea gore</i> (Hua) Pierre	Olacaceae	Tree	Green	Non-pioneer light-demanding
177. <i>Pancovia pedicellaris</i> Radlk. & Gilg	Sapindaceae	Shrub	Green	Shade-bearing
178. <i>Panda oleosa</i> Pierre	Pandanaceae	Tree	Green	Shade-bearing

Table 1: Continued

179. <i>Parinari excelsa</i> Sabine	Chrysobalanaceae	Tree	Green	Non-pioneer light-demanding
180. <i>Parkia bicolor</i> A.Chev.	Fabaceae	Tree	Green	Non-pioneer light-demanding
181. <i>Pentaclethra macrophylla</i> Benth.	Fabaceae	Tree	Green	Non-pioneer light-demanding
182. <i>Petersianthus macrocarpus</i> (P.Beauv.) Liben	Lecythidaceae	Tree	Green	Pioneer
183. <i>Phyllocosmus africanus</i> (Hook. f.) Klotzsch	Ixonanthaceae	Tree	Green	Non-pioneer light-demanding
184. <i>Picralima nitida</i> (Stapf) T. Durand & H.Durand	Apocynaceae	Tree	Blue	Shade-bearing
185. <i>Piper guineense</i> Schumach. & Thonn.	Piperaceae	Liana	Green	Shade-bearing
186. <i>Piptadeniastrum africanum</i> (Hook.f.) Brenan	Fabaceae	Tree	Pink	Non-pioneer light-demanding
187. <i>Pouteria altissima</i> (A.Chev.) Baehni	Sapotaceae	Tree	Red	Non-pioneer light-demanding
188. <i>Psychotria</i> sp	Rubiaceae	Tree	Gold	Shade-bearing
189. <i>Pterygota macrocarpa</i> K.Schum.	Malvaceae	Tree	Red	Non-pioneer light-demanding
190. <i>Pycnanthus angolensis</i> (Welw.) Warb.	Myristicaceae	Tree	Pink	Non-pioneer light-demanding
191. <i>Renealmia battenbergiana</i> Cummins ex Baker	Zingiberaceae	Herb	Gold	Shade-bearing
192. <i>Rhaphidophora africana</i> N.E.Br.	Araceae	H. climber	Green	Shade-bearing
193. <i>Rhaphiostylis cordifolia</i> Hutch. & Dalziel	Icacinaceae	Liana	Blue	Shade-bearing

Table 1: Continued

194. <i>Rhaphiolytis ferruginea</i> Engl.	Icacinaceae	Liana	Green	Shade-bearing
195. <i>Ricinodendron heudelotii</i> (Baill.) Pierre ex Pax	Euphorbiaceae	Tree	Green	Pioneer
196. <i>Rinorea ilicifolia</i> Kuntze	Violaceae	Shrub	Green	Shade-bearing
197. <i>Rinorea oblongifolia</i> (C.H.Wright) Marquand ex Chipp	Violaceae	Tree	Green	Shade-bearing
198. <i>Rinorea welwitschii</i> (Oliv.) O.Ktze.	Violaceae	Tree	Green	Shade-bearing
199. <i>Rinorea yaundensis</i> Engl.	Violaceae	Shrub	N/a	N/a
200. <i>Rothmannia hispida</i> (K. Schum.) Fagerlind	Rubiaceae	Tree	Green	Shade-bearing
201. <i>Rothmannia whitfieldii</i> (Lindl.) Dandy	Rubiaceae	Tree	Green	Shade-bearing
202. <i>Salacia owabiensis</i> (Sabine) Steud.	Celastraceae	Liana	Blue	N/a
203. <i>Salasia</i> sp	Celastraceae	Liana	N/a	N/a
204. <i>Scotellia klaineana</i> Pierre	Achariaceae	Tree	Pink	Shade-bearing
205. <i>Secamone afzelii</i> (Schult.) K.Schum.	Asclepiadaceae	Liana	Green	Shade-bearing
206. <i>Smilax kraussiana</i> Willd.	Smilacaceae	Liana	Green	Pioneer
207. <i>Sphenocentrum jollyanum</i> Pierre	Menispermaceae	Shrub	Green	Shade-bearing
208. <i>Stemonocoleus micranthus</i> Harms	Fabaceae	Tree	Blue	Non-pioneer light-demanding

Table 1: Continued

209. <i>Sterculia oblonga</i> Mast.	Malvaceae	Tree	Green	Non-pioneer light-demanding
210. <i>Sterculia rhinopetala</i> K. Schum.	Malvaceae	Tree	Pink	Non-pioneer light-demanding
211. <i>Sterculia tragacantha</i> Lindl.	Malvaceae	Tree	Green	Pioneer
212. <i>Strombosia pustulata</i> Oliv.	Olacaceae	Tree	Green	Shade-bearing
213. <i>Strychnos aculeata</i> Solered.	Loganiaceae	Liana	Green	Pioneer
214. <i>Strychnos campicola</i> Gilg ex Leeuwenberg	Loganiaceae	Liana	N/a	N/a
215. <i>Strychnos floribunda</i> Gilg	Loganiaceae	Liana	Green	Non-pioneer light-demanding
216. <i>Strychnos usambarensis</i> Gilg	Loganiaceae	Liana	Green	Non-pioneer light-demanding
217. <i>Symphonia glubulifera</i> L. f.	Guttiferae	Tree	Green	Swamp
218. <i>Tabernaemontana africana</i> A. DC.	Apocynaceae	Tree	Green	Shade-bearing
219. <i>Terminalia superba</i> Engl. & Diels	Combretaceae	Tree	Pink	Pioneer
220. <i>Tetrapleura tetraptera</i> (Schumach. & Thonn.) Taub.	Fabaceae	Tree	Green	Pioneer
221. <i>Tieghemella heckelii</i> Pierre ex A. Chev.	Sapotaceae	Tree	Scarlet	Non-pioneer light-demanding
222. <i>Tiliacora dielsiana</i> (Scott-Eliott) Diels	Menispermaceae	Liana	Green	Non-pioneer light-demanding
223. <i>Tiliacora leonensis</i> (Scott-Eliott) Diels	Menispermaceae	Liana	N/a	N/a

Table 1: Continued

224. <i>Treculia africana</i> Decne.	Moraceae	Tree	Green	Non-pioneer light-demanding
225. <i>Trema orientalis</i> (L.) Blume	Ulmaceae	Tree	Green	Pioneer
226. <i>Tricalysia pallens</i> Hiern	Rubiaceae	Tree	Green	Shade-bearing
227. <i>Trichilia monadelpha</i> (Thonn.) J. J. de Wilde	Meliaceae	Tree	Green	Non-pioneer light-demanding
228. <i>Trichilia prieuriana</i> A.Juss.	Meliaceae	Tree	Green	Non-pioneer light-demanding
229. <i>Trichilia tessmannii</i> Harms	Meliaceae	Tree	Green	Non-pioneer light-demanding
230. <i>Triclisia dictyophylla</i> Diels	Menispermaceae	Liana	Green	Pioneer
231. <i>Trilepisium madagascariense</i> DC.	Moraceae	Tree	Green	Non-pioneer light-demanding
232. <i>Triplochiton scleroxylon</i> K.Schum.	Malvaceae	Tree	Scarlet	Pioneer
233. <i>Uapaca guineensis</i> Müll. Arg.	Euphorbiaceae	Tree	Green	Non-pioneer light-demanding
234. <i>Uvariodendron occidentale</i> Le Thomas	Annonaceae	Tree	Gold	Shade-bearing
235. <i>Uvariostrum pierreanum</i> Engl.	Annonaceae	Tree	N/a	N/a
236. <i>Vitex micrantha</i> Gürke	Verbenaceae	Tree	Blue	Non-pioneer light-demanding
237. <i>Voacanga bracteata</i> Stapf	Apocynaceae	Tree	Green	Shade-bearing
238. <i>Warneckea membranifolia</i> (Hook. f.) Jacq.-Fél.	Melastomataceae	Shrub	Green	Shade-bearing
239. <i>Xylia evansii</i> Hutch.	Fabaceae	Tree	Blue	Non-pioneer light-demanding
240. <i>Xylopia villosa</i> Chipp	Annonaceae	Tree	Green	Shade-bearing

Out of the total 240 plant species, 97 occurred just once (i.e. among the ten main plots) while *Celtis mildbraedii*, *Culcasia angolensis*, and *Strombosia pustulata* occurred on all the ten main plots (Figure 4). Incidence of plants species decreased with increase in the number of plots such that fewer species were common on most plots (Figure 4).

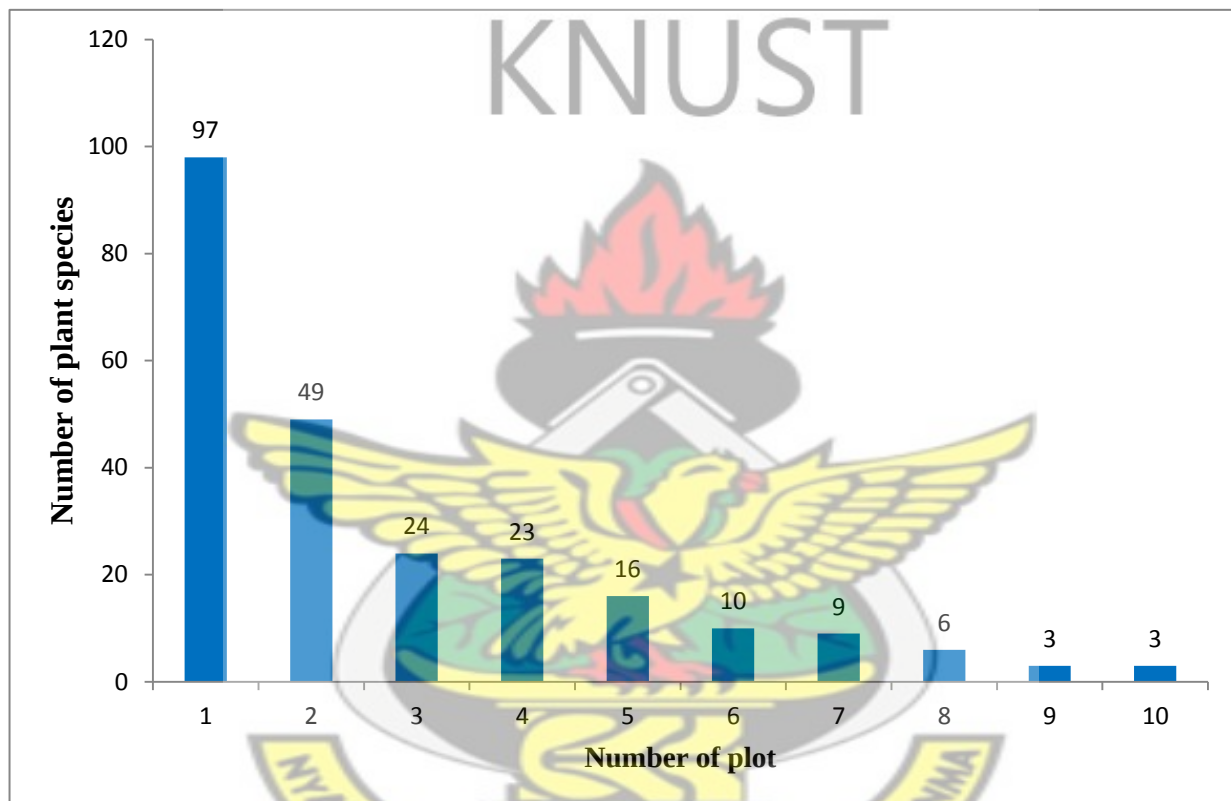


Figure 4: Frequency-index of plant species on the ten main plots



Plate 6: Epiphyte (*Microsorium punctatum*) found on *Berlinia tomentella* at the Tano Offin Forest GSBA



4.2 Influence of elevation on floristic composition

No varying pattern was observed for species richness in the various forest classes, thus species richness did not differ among the various elevation classes. On a 0.5 ha size bases, lowland forests, the forests of the transition portion and highland forests recorded species richness of 93, 102 and 98 (Table 2) respectively. Considering the ten main plots used for the sampling, both the least and highest record of species richness was obtained on plots of highland forests, the least being 55 and 94 the highest. With an exclusion of the least and highest, species richness ranged from 56 to 71 in all plots of the various forest types. Species that occurred more than once and exclusively on highlands include *Berlinia tomentella*, *Coffea stenophylla*, *Cola boxiana*, *Culcasia parviflora*, *Desplatsia chrysochlamys*, *Hexalobus crispiflorus*, *Momordica angusticepala*, *Picralima nitida*, and *Triclisia dictyophylla*; those of the transition zone include *Acacia kamerunensis*, *Duguetia staudtii* and *Leptoderris brachyptera* and that of the lowlands is *Strychnos campicola*.

The star rating of plant species were determined for a 0.5 ha area of each forest class (Table 2). Lowland forests had the only Black star species found in this study. The highlands had the most of the rare species, that is - 4 Gold stars and 8 Blue stars (12 in all) as against 1 Black star, 2 Gold stars and 4 Blue stars (7 in all) of the Lowlands and 4 Blue stars (4 in all) of the transition area. The lowlands had the most of the Scarlet stars while the highlands had the least of the Pink Stars. There were more Green and Red stars in the transition area than in the lowlands and highlands.

Similarly, the ecological guilds of plant species were determined for a 0.5 ha area of each forest class (Table 2). The transition area had the greatest constituents of pioneers; the lowlands had the greatest of non-pioneer light-demanding species while the highlands had the highest constituent of shade bearers. The 2 swampy species and 2 invasive species were found only in the transition area.

Table 2: Species richness, star and guild distribution of plant species on 0.5 ha of the three forest classes

	Lowland	Transition	Highland
Species richness	93	103	98
Star ratings			
Black	1	0	0
Gold	2	0	4
Blue	4	4	8
Scarlet	4	2	2
Red	3	4	3
Pink	11	12	7
Green	61	75	66
N/A	7	5	8
Ecological guild			
Pioneer	12	22	13
Non-pioneer light demanding	36	31	28
Shade bearers	34	35	46
Invasive	0	2	0
Swamp	0	2	0
N/A	11	10	11

4.3 Forest structure

4.3.1 Tree layer

The tree layer constituted trees and other plant forms with dbh ≥ 10 cm and height > 3 m which were sampled from the 50 m x 50 m main plots. A total of 977 individual plants were sampled and for the total size of 2.5 ha studied, there were 154 species and 120 genera (Table 5).

4.3.1.1 Species diversity

The Shannon-Wiener index (H') and the Simpson's index of diversity (1-D) calculated for the tree layer were $H' = 2.55$ and $1-D = 0.90$ respectively.

4.3.1.2 Diameter class distribution and basal area

There was a decrease in the number of individuals in the various diameter groups as size increased so that the highest number of plants with dbh ≥ 10 cm was found in the 10 – 30 cm diameter class (Figure 5). Although number of species followed the same pattern, difference in quantity closed with respect to the number of individual plants as diameter class increases, so that the number of species and the number of individual plants in the highest diameter class (> 110 cm) were almost the same (Figure 5). Species found in the $> 90 - 110$ cm class include *Antiaris toxicaria*, *Celtis mildbraedii*, *Parkia bicolor*, *Petersianthus macrocarpus* and *Sterculia oblonga*. Species of the highest diameter class include *Alstonia boonei*, *Hexalobus crispiflorus*, *Parkia bicolor*, *Sterculia oblonga* and *Triplochiton scleroxylon*. The basal area for this layer (dbh ≥ 10 cm) was 28.356 m²/ha.

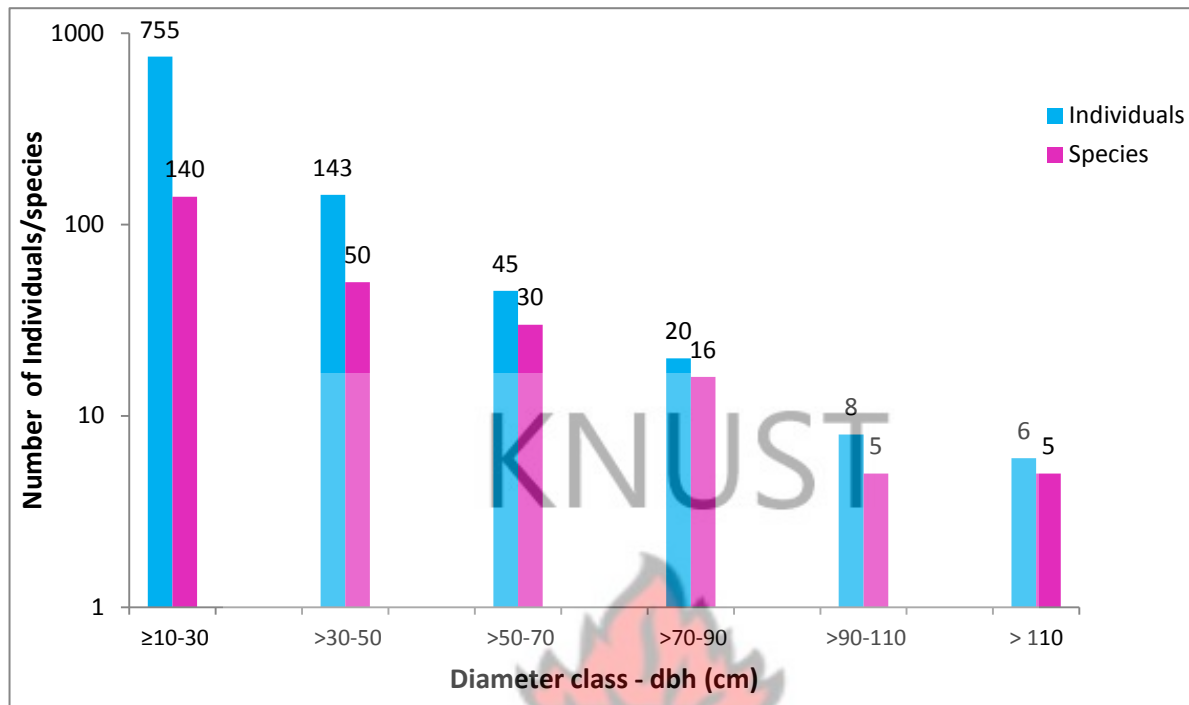


Figure 5: Diameter class distributions of individual plants (dbh $\geq$ 10 cm) and the respective number of species

4.3.1.3 Height

With respect to classifying trees of dbh $\geq$ 10 cm into height classes, four classes were obtained namely the understorey ($\leq$ 15 m) which had the highest individuals, followed by the lower canopy ($>$ 15 m – 25 m) and then the upper canopy ($>$ 25 – 35 m) and the emergent ($>$ 35 m) which was least in number of individuals (Figure 6). While number of individuals making up the classes of the vertical layer varied across a wider margin (73 – 443), the number of species varied at a narrower margin (34 – 113) as seen in Figure 6. Thus more species contributed in the makeup of the emergent layer relative to its number of individuals (lowest), than it was so in the understorey. Average tree height for the understorey, lower canopy, upper canopy and the

emergent were 11.22 m, 18.75 m, 29.20 m and 46.19 m respectively. Out of the 34 species that were emergents, 16 were non-pioneer light demanding, 10 were shade bearers and 6 were pioneers. Shade-bearers constituted a greater portion of the understorey layer (42.48 %), followed by the non-pioneer light demanders (28.32 %) whilst the pioneers constituted 19.47 % of the understorey.

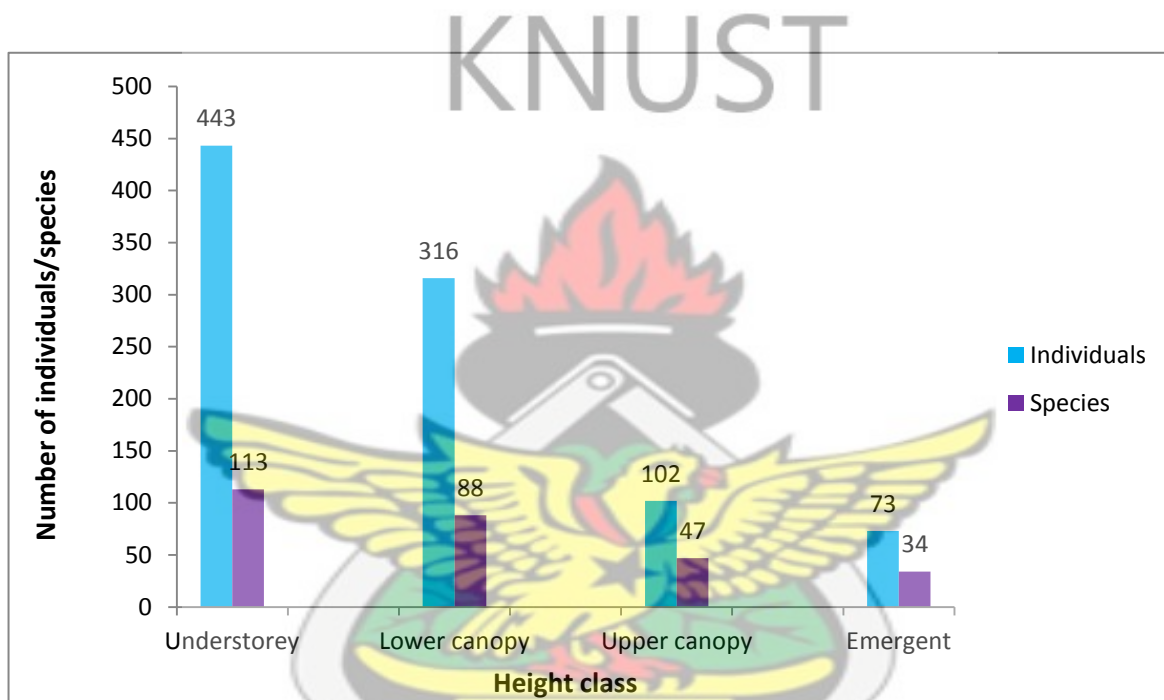


Figure 6: Number of species and individuals (dbh $\geq$ 10 cm) in the height classes

4.3.1.4 Structural significance of plant species

With the highest density, maximum percent score of frequency (most common) and the greatest dominance, *Celtis mildbraedii* was the most significant species for the tree layer of the Tano Offin GSBA, recording an IVI of 32.16 (Table 3). This was followed at a wider margin by

Strombosia pustulata and *Hymenostegia afzelii* which recorded an IVI of 12.01 and 11.31 respectively. Out of the total 154 species, 53 were available on just a single occasion (i.e. density =1; frequency = 2.5 %) so that the variation in IVI among these species resulted from differences in only their dominance. *Dalbergia saxatilis* and *Monodora myristica* were the least significant species occurring in the study area (Table 3).

Although *Chrysophyllum perpulcrum* had a greater density and was more frequent than *Pycnanthus angolensis*, the latter had a higher importance value than the former due to its greater dominance. The same pattern was observed for *Trichilia monadelpha*, *Antiaris toxicaria*, *Baphia pubescens*, *Blighia sapida*, *Nesogordonia papaverifera* and *Aidia genipiflora* as against *Alstonia boonei*; *Cola nitida*, *Octoknema borealis*, *Funtumia africana*, *Celtis zenkeri*, *Allanblackia parviflora*, *Trilepisium madagascariense*, *Calpocalyx brevibracteatus*, *Cola boxiana* and *Mansonia altissima* compared to *Parkia bicolor*.

On the other hand, although *Trichilia prieuriana* had little dominance compared to *Celtis adolfi-friderici*, *Chidlowia sanguinea*, *Alstonia boonei*, *Antiaris toxicaria*, *Blighia sapida*, *Sterculia oblonga* and *Parkia bicolor*, it was relatively more important than these due to its higher incidence and greater density. A total of 977 individual plant species were identified at this layer amounting to a density of 391.2/ha.

Table 3: Density, frequency, dominance and Importance Value Index of trees and other plant life forms with dbh $\geq$ 10 cm in the Tano Offin GSBA

No.	Species	D/2.25ha	Freq (%)	Dm	IVI
1.	<i>Celtis mildbraedii</i>	102	87.5	4.439	32.16
2.	<i>Strombosia pustulata</i>	54	60	0.732	12.01
3.	<i>Hymenostegia afzelii</i>	57	42.5	0.762	11.31
4.	<i>Scotellia klaineana</i>	45	45	0.695	9.999
5.	<i>Corynanthe pachyceras</i>	24	37.5	0.605	7.046
6.	<i>Dacryodes klaineana</i>	27	30	0.644	7.019
7.	<i>Hannoa klaineana</i>	22	32.5	0.706	6.891
8.	<i>Entandrophragma angolense</i>	24	35	0.598	6.864
9.	<i>Pycnanthus angolensis</i>	13	25	0.878	6.119
10.	<i>Bussea occidentalis</i>	14	20	0.843	5.773
11.	<i>Trichilia prieuriana</i>	21	37.5	0.336	5.761
12.	<i>Celtis adolfi-friderici</i>	12	27.5	0.677	5.445
13.	<i>Chidlowia sanguinea</i>	17	20	0.595	5.179
14.	<i>Alstonia boonei</i>	4	10	1.104	5.065
15.	<i>Chrysophyllum perpulcrum</i>	16	30	0.308	4.671
16.	<i>Trichilia monadelpha</i>	18	32.5	0.174	4.548
17.	<i>Antiaris toxicaria</i>	9	20	0.606	4.403
18.	<i>Baphia pubescens</i>	18	32.5	0.113	4.324
19.	<i>Blighia sapida</i>	12	20	0.487	4.275

Table 3: Continued

20.	<i>Sterculia oblonga</i>	6	15	0.726	4.211
21.	<i>Parkia bicolor</i>	2	5	0.989	4.121
22.	<i>Nesogordonia papaverifera</i>	12	27.5	0.302	4.082
23.	<i>Aidia genipiflora</i>	17	27.5	0.144	4.016
24.	<i>Triplochiton scleroxylon</i>	4	10	0.742	3.747
25.	<i>Drypetes pellegrinii</i>	13	20	0.31	3.734
26.	<i>Dasylepis brevipedicellata</i>	18	20	0.131	3.594
27.	<i>Cola nitida</i>	11	22.5	0.211	3.329
28.	<i>Allanblackia parviflora</i>	11	22.5	0.196	3.273
29.	<i>Octoknema borealis</i>	8	10	0.497	3.263
30.	<i>Funtumia africana</i>	13	17.5	0.204	3.186
31.	<i>Celtis zenkeri</i>	12	15	0.26	3.131
32.	<i>Trilepisium madagascariense</i>	10	20	0.195	3.008
33.	<i>Hexalobus crispiflorus</i>	5	10	0.473	2.87
34.	<i>Piptadeniastrum africanum</i>	6	15	0.333	2.782
35.	<i>Calpocalyx brevibracteatus</i>	13	15	0.131	2.763
36.	<i>Cola boxiana</i>	13	15	0.069	2.536
37.	<i>Mansonia altissima</i>	11	15	0.072	2.345
38.	<i>Cola lateritia</i>	5	10	0.278	2.162
39.	<i>Cola gigantea</i>	6	10	0.227	2.079
40.	<i>Chrysophyllum subnudum</i>	7	12.5	0.152	2.067
41.	<i>Panda oleosa</i>	6	12.5	0.176	2.051

Table 3: Continued

42.	<i>Petersianthus macrocarpus</i>	3	5	0.391	2.048
43.	<i>Myrianthus libericus</i>	7	12.5	0.147	2.047
44.	<i>Amphimas pterocarpoides</i>	7	15	0.086	1.987
45.	<i>Guarea cedrata</i>	5	15	0.124	1.919
46.	<i>Cola caricifolia</i>	7	15	0.041	1.822
47.	<i>Drypetes aylmeri</i>	6	15	0.061	1.794
48.	<i>Albizia zygia</i>	3	7.5	0.277	1.792
49.	<i>Chrysophyllum albidum</i>	6	15	0.048	1.746
50.	<i>Cleidion gabonicum</i>	9	10	0.044	1.718
51.	<i>Maesobotrya barteri</i>	6	15	0.037	1.704
52.	<i>Sterculia rhinopetala</i>	6	12.5	0.051	1.598
53.	<i>Celtis wightii</i>	5	12.5	0.078	1.591
54.	<i>Trichilia tessmannii</i>	6	10	0.078	1.534
55.	<i>Pterygota macrocarpa</i>	5	10	0.101	1.515
56.	<i>Berlinia tomentella</i>	4	7.5	0.17	1.506
57.	<i>Guibourtia ehie</i>	5	12.5	0.046	1.476
58.	<i>Diospyros viridicans</i>	4	10	0.114	1.461
59.	<i>Dialium dinklagei</i>	5	12.5	0.038	1.447
60.	<i>Baphia nitida</i>	6	7.5	0.074	1.359
61.	<i>Pouteria altissima</i>	5	10	0.039	1.29
62.	<i>Discoglyprena caloneura</i>	5	10	0.029	1.254
63.	<i>Anonidium mannii</i>	3	7.5	0.106	1.171

Table 3: Continued

64.	<i>Duguetia staudtii</i>	2	5	0.176	1.165
65.	<i>Sterculia tragacantha</i>	3	7.5	0.082	1.083
66.	<i>Pentaclethra macrophylla</i>	2	5	0.152	1.075
67.	<i>Broussonetia papyrifera</i>	4	7.5	0.042	1.039
68.	<i>Leptaulus daphnoides</i>	4	2.5	0.129	1.036
69.	<i>Albizia glaberrima</i>	1	2.5	0.201	0.993
70.	<i>Canarium schweinfurthii</i>	1	2.5	0.189	0.948
71.	<i>Khaya ivorensis</i>	3	7.5	0.045	0.947
72.	<i>Carapa procera</i>	3	7.5	0.044	0.946
73.	<i>Rinorea welwitschii</i>	4	7.5	0.015	0.943
74.	<i>Uapaca guineensis</i>	2	5	0.111	0.926
75.	<i>Ceiba pentandra</i>	2	5	0.11	0.922
76.	<i>Enantia polycarpa</i>	3	7.5	0.027	0.884
77.	<i>Ricinodendron heudelotii</i>	3	7.5	0.024	0.873
78.	<i>Xylia evansii</i>	3	7.5	0.023	0.868
79.	<i>Entandrophragma cylindricum</i>	3	7.5	0.021	0.862
80.	<i>Cola millenii</i>	3	7.5	0.015	0.838
81.	<i>Dichapetalum madagascariense</i>	3	5	0.047	0.798
82.	<i>Irvingia gabonensis</i>	3	5	0.036	0.757
83.	<i>Maranthes grabla</i>	2	2.5	0.105	0.745
84.	<i>Dialium aubrevillei</i>	3	5	0.032	0.74
85.	<i>Cleistopholis patens</i>	2	5	0.049	0.701

Table 3: Continued

86.	<i>Funtumia elastica</i>	2	5	0.046	0.692
87.	<i>Holoptelea grandis</i>	1	2.5	0.117	0.687
88.	<i>Treculia africana</i>	2	5	0.043	0.679
89.	<i>Desplatsia chrysochlamys</i>	2	5	0.042	0.677
90.	<i>Albizia adianthifolia</i>	1	2.5	0.111	0.665
91.	<i>Greenwayodendron oliveri</i>	3	5	0.009	0.658
92.	<i>Anopyxis klaineana</i>	2	5	0.036	0.655
93.	<i>Ongokea gore</i>	1	2.5	0.101	0.629
94.	<i>Entandrophragma utile</i>	1	2.5	0.096	0.611
95.	<i>Aptandra zenkeri</i>	2	5	0.022	0.602
96.	<i>Khaya anthotheca</i>	2	5	0.017	0.585
97.	<i>Distemonanthus benthamianus</i>	2	5	0.014	0.574
98.	<i>Tieghemella heckelii</i>	1	2.5	0.085	0.572
99.	<i>Picralima nitida</i>	2	5	0.012	0.566
100.	<i>Napoleonaea vogelii</i>	2	5	0.007	0.549
101.	<i>Morus mesozygia</i>	2	5	0.006	0.546
102.	<i>Parinari excelsa</i>	2	2.5	0.041	0.513
103.	<i>Entandrophragma candollei</i>	1	2.5	0.068	0.509
104.	<i>Elaeis guineensis</i>	1	2.5	0.065	0.499
105.	<i>Erythroleum Ivorensis</i>	1	2.5	0.049	0.441
106.	<i>Afzelia bella</i>	1	2.5	0.042	0.413
107.	<i>Vitex micrantha</i>	1	2.5	0.037	0.397

Table 3: Continued

108.	<i>Bridelia grandis</i>	1	2.5	0.028	0.365
109.	<i>Cordia platythyrsa</i>	1	2.5	0.026	0.357
110.	<i>Homalium sp</i>	1	2.5	0.025	0.353
111.	<i>Diospyros abyssinica</i>	1	2.5	0.023	0.346
112.	<i>Duboscia macrocarpa</i>	1	2.5	0.02	0.334
113.	<i>Cedrela odorata</i>	1	2.5	0.019	0.329
114.	<i>Bombax buonopozense</i>	1	2.5	0.018	0.329
115.	<i>Milicia excelsa</i>	1	2.5	0.017	0.324
116.	<i>Daniellia ogea</i>	1	2.5	0.017	0.322
117.	<i>Diospyros monbuttensis</i>	1	2.5	0.013	0.31
118.	<i>Antrocaryon micraster</i>	1	2.5	0.013	0.309
119.	<i>Phyllocosmus africanus</i>	1	2.5	0.013	0.308
120.	<i>Macaranga barteri</i>	1	2.5	0.012	0.307
121.	<i>Mammea africana</i>	1	2.5	0.011	0.3
122.	<i>Hunteria eburnea</i>	1	2.5	0.01	0.297
123.	<i>Guarea thompsonii</i>	1	2.5	0.009	0.296
124.	<i>Stemonocoleus micranthus</i>	1	2.5	0.009	0.295
125.	<i>Ficus bubu</i>	1	2.5	0.009	0.294
126.	<i>Blighia welwitschii</i>	1	2.5	0.009	0.293
127.	<i>Entada pursuetha</i>	1	2.5	0.008	0.291
128.	<i>Erythrinia miildbraedii</i>	1	2.5	0.008	0.291
129.	<i>Cassipourea lescotiana</i>	1	2.5	0.007	0.288

Table 3: Continued

130.	<i>Rothmannia hispida</i>	1	2.5	0.007	0.288
131.	<i>Terminalia superba</i>	1	2.5	0.007	0.287
132.	<i>Diospyros ferrea</i>	1	2.5	0.007	0.286
133.	<i>Lannea welwitschii</i>	1	2.5	0.007	0.285
134.	<i>Erythroxylum mannaii</i>	1	2.5	0.005	0.281
135.	<i>Trema orientalis</i>	1	2.5	0.005	0.281
136.	<i>Aubrevillea kerstingii</i>	1	2.5	0.005	0.28
137.	<i>Microdesmis puberrula</i>	1	2.5	0.005	0.28
138.	<i>Hunteria sp</i>	1	2.5	0.005	0.279
139.	<i>Myrianthus arboreus</i>	1	2.5	0.005	0.279
140.	<i>Isolona deightonii</i>	1	2.5	0.005	0.278
141.	<i>Calycobolus africanus</i>	1	2.5	0.004	0.278
142.	<i>Monodora tenuifolia</i>	1	2.5	0.004	0.278
143.	<i>Tetrapleura tetraptera</i>	1	2.5	0.004	0.278
144.	<i>Rinorea oblongifolia</i>	1	2.5	0.004	0.277
145.	<i>Bucholzia coriacea</i>	1	2.5	0.004	0.277
146.	<i>Drypetes aubrevillei</i>	1	2.5	0.004	0.277
147.	<i>Acacia pentagona</i>	1	2.5	0.004	0.276
148.	<i>Salacia sp</i>	1	2.5	0.004	0.275
149.	<i>Momordica angusticepala</i>	1	2.5	0.003	0.274
150.	<i>Voacanga bracteata</i>	1	2.5	0.003	0.274
151.	<i>Strychnos campicola</i>	1	2.5	0.003	0.273

Table 3: Continued

152.	<i>Symphonia globulifera</i>	1	2.5	0.003	0.273
153.	<i>Dalbergia saxatilis</i>	1	2.5	0.0005	0.264
154.	<i>Monodora myristica</i>	1	2.5	0.0004	0.263

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4.3.2 Shrub and Herb layers

The shrub layer constitutes plant life forms with dbh < 10 cm and height $\leq$ 3 m that were sampled from the 10 m x 10 m plots. The herb layer refers to the forest floor vegetation which had height of < 1 m and dbh of $\leq$ 1.5 cm, captured from the 1 m x 1 m quadrats. A total of 418 individuals were sampled at the shrub layer while 536 were found at the herb layer. On a total size 0.1 ha, 95 species of 69 genera were identified at the shrub layer whereas 102 species of 82 genera were identified on a 0.005 ha size at the herb layer (Table 5).

4.3.2.1 Species diversity

The mean values of Shannon-Wiener index (H') for the shrub and herb layers were $H' = 2.49$ and $H' = 2.54$ respectively. The mean value of Simpson's index of diversity (1-D) for the shrub and herb layers was 0.83 and 0.76 respectively.

4.3.2.2 Diameter class distribution and basal area

In a similar pattern to the tree layer, there was a decrease in the number of individuals in the various diameter groups as sizes increase so that the highest number of plants with dbh < 10 cm was found in the smallest diameter class (Figure 7). The seven species that formed the largest diameter class (> 8 - 9.9 cm) are *Blighia sapida*, *Celtis mildbraedii*, *Cola boxiana*, *Dacryodes klaineana*, *Napoleonaea vogelii*, *Rinorea oblongifolia* and *Rinorea welwitschii*. Basal area at the shrub layer was 3.822 m²/ha (Table 5).

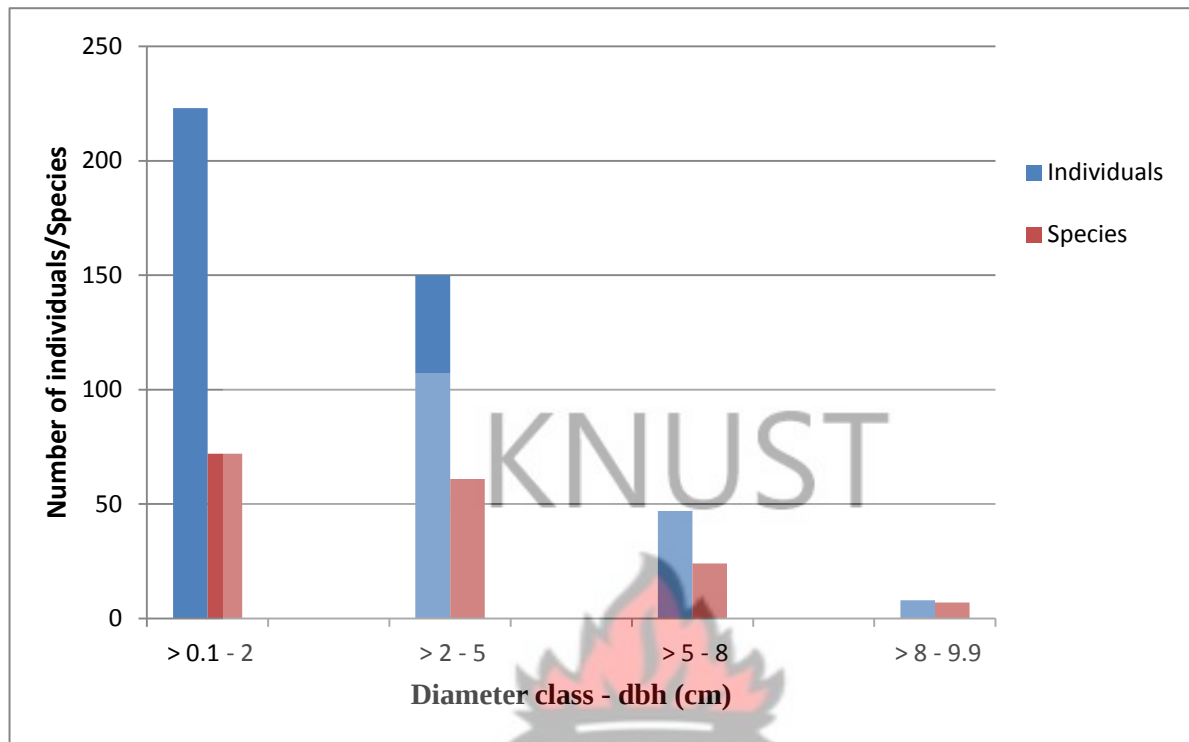


Figure 7: Diameter class distributions of individual plants (dbh < 10 cm) and the respective number of species

4.3.2.3 Structural significance of plant species

With an IVI of 33.94, *Rinorea welwitschii* was the most significant species for trees and other plant life forms with dbh < 10 cm in the GSBA, being the most dominant and most abundant; it was followed at a wider margin by *Drypetes chevalieri* (13.46), *Strombosia pustulata* (11.46) and *Greenwayodendron oliveri* (10.37). However, *Rinorea oblongifolia* with an IVI of 8.57 was the most frequent (70 %). With a density of 20 individuals per 0.1 ha and 10 % frequency level, *Cleidion gabonicum* appeared locally abundant unlike *Diospyros ferrea* which was relatively widespread (40 %) though of lower abundance (5/0.1 ha).

There was single incidence (10 %) for 48 species (from No. 48 to No. 95 in Table 4) and abundance at an appearance of just one individual for 35 species – density (1/0.1ha). Although *Treculia africana* occurred just once, it was far more significant than 75 other species. *Pterygota macrocarpa*, *Rothmannia whitfieldii*, *Coffea stenophylla* and *Trilepisium madagascariense* had the lowest IVI stemming from their small dominances (Table 4). Total number of individual plant species measured for this area (shrub layer) was 418, resulting in an overall density of 4180/ ha.



Table 4: Density, frequency, dominance and Importance Value Index of trees and other plant life forms dbh < 10 cm in the Tano Offin GSBA

No.	Species	D(0.1ha)	Freq (%)	Dm	IVI
1.	<i>Rinorea welwitschii</i>	51	50	0.734	33.94
2.	<i>Drypetes chevalieri</i>	30	60	0.114	13.46
3.	<i>Strombosia pustulata</i>	14	60	0.186	11.46
4.	<i>Greenwayodendron oliveri</i>	15	50	0.155	10.37
5.	<i>Hymenostegia afzelii</i>	20	30	0.132	9.852
6.	<i>Microdesmis puberula</i>	14	60	0.103	9.327
7.	<i>Baphia nitida</i>	12	50	0.137	9.17
8.	<i>Celtis mildbraedii</i>	14	50	0.096	8.591
9.	<i>Rinorea oblongifolia</i>	10	70	0.089	8.567
10.	<i>Craterispermum cerinanthum</i>	15	60	0.063	8.543
11.	<i>Cleidion gabonicum</i>	20	10	0.113	8.273
12.	<i>Rinorea yaundensis</i>	15	30	0.1	7.845
13.	<i>Napoleonaea vogelii</i>	7	30	0.141	6.966
14.	<i>Tabernaemontana africana</i>	6	40	0.086	5.864
15.	<i>Microdesmis keayana</i>	5	20	0.132	5.71
16.	<i>Mansonia altissima</i>	8	20	0.1	5.599
17.	<i>Chrysophyllum perpulcrum</i>	7	30	0.078	5.336
18.	<i>Diospyros ferrea</i>	5	40	0.018	3.87
19.	<i>Chrysophyllum albidum</i>	3	20	0.076	3.795

Table 4: Continued

20.	<i>Treculia africana</i>	2	10	0.113	3.711
21.	<i>Trichilia prieuriana</i>	5	30	0.031	3.665
22.	<i>Blighia sapida</i>	3	20	0.07	3.632
23.	<i>Dacryodes klaineana</i>	2	20	0.076	3.546
24.	<i>Scotellia klaineana</i>	4	20	0.056	3.497
25.	<i>Cola boxiana</i>	2	10	0.094	3.458
26.	<i>Guarea cedrata</i>	4	20	0.047	3.273
27.	<i>Strychnos floribunda</i>	3	10	0.071	3.104
28.	<i>Calpocalyx brevibracteatus</i>	3	20	0.044	2.963
29.	<i>Diospyros kamerunensis</i>	3	30	0.017	2.807
30.	<i>Dichapetalum toxicarium</i>	3	30	0.014	2.731
31.	<i>Hannoa klaineana</i>	2	20	0.042	2.669
32.	<i>Dasylepis brevipedicellata</i>	4	10	0.042	2.585
33.	<i>Guibourtia ehie</i>	3	30	0.006	2.526
34.	<i>Monodora myristica</i>	3	30	0.004	2.478
35.	<i>Strychnos campicola</i>	4	20	0.012	2.386
36.	<i>Sterculia rhinopetala</i>	4	20	0.011	2.35
37.	<i>Drypetes aubrevillei</i>	2	20	0.029	2.345
38.	<i>Dichapetalum madagascariense</i>	3	20	0.011	2.101
39.	<i>Nesogordonia papaverifera</i>	2	20	0.018	2.053
40.	<i>Drypetes gilgiana</i>	4	10	0.017	1.95
41.	<i>Voacanga bracteata</i>	2	20	0.014	1.942

Table 4: Continued

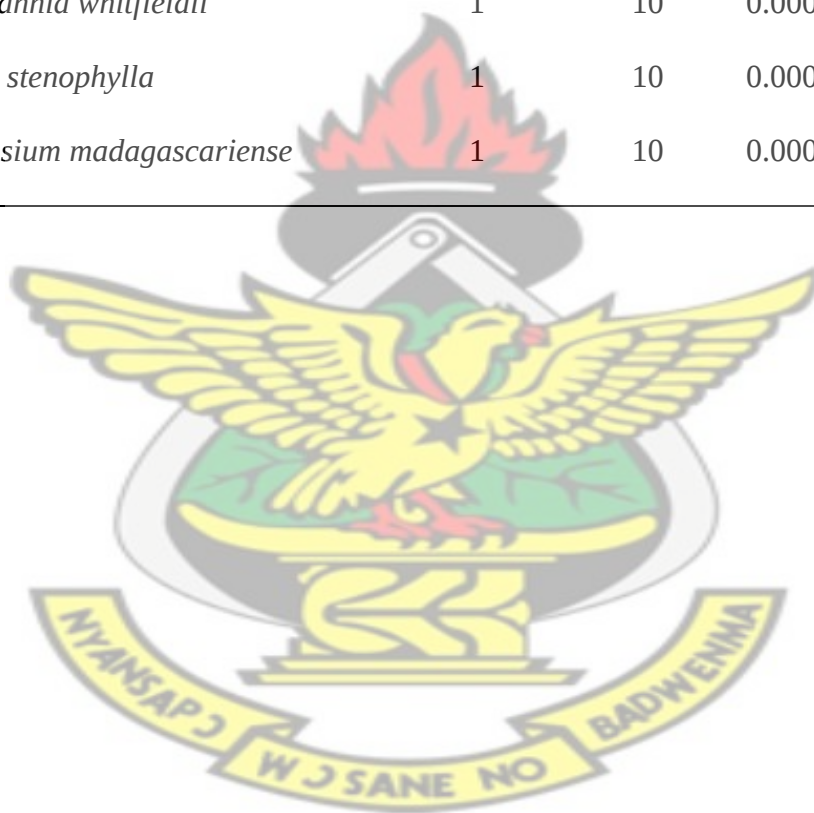
42.	<i>Aidia genipiflora</i>	3	10	0.025	1.917
43.	<i>Tricalysia pallens</i>	2	20	0.007	1.773
44.	<i>Rothmannia hispida</i>	2	20	0.007	1.764
45.	<i>Pycnanthus angolensis</i>	2	20	0.006	1.737
46.	<i>Enantia polycarpa</i>	2	20	0.005	1.724
47.	<i>Hunteria eburnea</i>	2	20	0.004	1.688
48.	<i>Pancovia pedicellaris</i>	4	10	0.006	1.668
49.	<i>Monodora tenuifolia</i>	3	10	0.015	1.666
50.	<i>Ceiba pentandra</i>	1	10	0.028	1.522
51.	<i>Cissus producta</i>	2	10	0.018	1.508
52.	<i>Trichilia monadelpha</i>	2	10	0.018	1.507
53.	<i>Celtis zenkeri</i>	3	10	0.008	1.483
54.	<i>Funtumia africana</i>	1	10	0.025	1.428
55.	<i>Pouteria altissima</i>	3	10	0.004	1.385
56.	<i>Griffonia simplicifolia</i>	1	10	0.02	1.299
57.	<i>Hunteria umbellata</i>	2	10	0.008	1.244
58.	<i>Garcinia kola</i>	1	10	0.017	1.24
59.	<i>Calycobolus africanus</i>	1	10	0.017	1.221
60.	<i>Baphia pubescens</i>	2	10	0.007	1.221
61.	<i>Diospyros soubreana</i>	2	10	0.007	1.2
62.	<i>Carapa procera</i>	1	10	0.015	1.167
63.	<i>uvariostrum pierreanum</i>	2	10	0.005	1.156

Table 4: Continued

64.	<i>Rinorea ilicifolia</i>	2	10	0.004	1.143
65.	<i>Euclinia longiflora</i>	1	10	0.013	1.117
66.	<i>Celtis wightii</i>	2	10	0.003	1.097
67.	<i>Xylopiia villosa</i>	2	10	0.002	1.082
68.	<i>Strychnos usambarensis</i>	2	10	0.001	1.065
69.	<i>Antiaris toxicaria</i>	1	10	0.01	1.041
70.	<i>Millettia chrysophylla</i>	1	10	0.01	1.041
71.	<i>Craterispermum caudatum</i>	1	10	0.009	1.013
72.	<i>Funtumia elastica</i>	1	10	0.008	0.987
73.	<i>Sterculia tragacantha</i>	1	10	0.007	0.975
74.	<i>Bussea occidentalis</i>	1	10	0.006	0.94
75.	<i>Entandrophragma cylindricum</i>	1	10	0.005	0.919
76.	<i>Entandrophragma angolense</i>	1	10	0.004	0.9
77.	<i>Mammea africana</i>	1	10	0.003	0.882
78.	<i>Carpolobia lutea</i>	1	10	0.003	0.873
79.	<i>Cola gigantea</i>	1	10	0.003	0.865
80.	<i>Chytranthus carneus</i>	1	10	0.003	0.858
81.	<i>Mareya micarantha</i>	1	10	0.003	0.858
82.	<i>Pentaclethra macrophylla</i>	1	10	0.002	0.844
83.	<i>Blighia welwitschii</i>	1	10	0.002	0.838
84.	<i>Octoknema borealis</i>	1	10	0.002	0.838
85.	<i>Dialium dinklagei</i>	1	10	0.002	0.832

Table 4: Continued

86.	<i>Sterculia oblonga</i>	1	10	0.002	0.832
87.	<i>Anthonotha fragrans</i>	1	10	0.001	0.827
88.	<i>Maesobotrya barteri</i>	1	10	0.001	0.827
89.	<i>Amphimas pterocarpoides</i>	1	10	0.001	0.821
90.	<i>Rhaphiotylis ferruginea</i>	1	10	0.001	0.821
91.	<i>Warneckea membrnifolium</i>	1	10	0.001	0.821
92.	<i>Pterygota macrocarpa</i>	1	10	0.0006	0.809
93.	<i>Rothmannia whitfieldii</i>	1	10	0.0006	0.809
94.	<i>Coffea stenophylla</i>	1	10	0.0004	0.802
95.	<i>Trilepisium madagascariense</i>	1	10	0.0003	0.8



4.4 Influence of elevation and invasive species on forest structure

4.4.1 Tree layer

4.4.1.1 Species diversity

The Shannon-Wiener index value was similar for all forest types: lowland forests ($H' = 2.57$); highland forests ($H' = 2.54$) and the transition zone ($H' = 2.54$). Likewise, the mean value for Simpson's index of diversity was similar for highland forests ($1-D = 0.89$), lowland forests ($1-D = 0.91$) and the transition zone ($1-D = 0.90$). A test using ANOVA did not show any significant difference of the influence of varying elevation positions on diversity ($P > 0.05$), i.e. for both Shannon-Wiener index and Simpson's index of diversity. On invasiveness, a one-tailed t-Test for both Shannon-Wiener and Simpson's index of diversity showed no strong evidence for the influence of invasive species on species diversity.

4.4.1.2 Diameter class distribution and basal area

Lowland forest had the greatest number of individuals in the biggest diameter class (> 110 cm) though it had no representative in the diameter class boundary > 70 to 90 cm class (Figure 8). The highest girth encountered was a *Parkia bicolor* tree with a dbh of 146 cm found in a lowland forest. The highlands dominated in the three classes ranging from > 30 to 90 cm but the same in number with lowlands in the > 90 to 110 cm class (Figure 8). The transition belt had the greatest representation in the smallest diameter class (≥ 10 to 30 cm) but the least in the > 90 to 110 cm class (Figure 8).

Basal area for trees and other plant life forms with dbh ≥ 10 cm generally increased with increasing elevation (Table 5). The mean basal area of trees and other plant life forms dbh ≥ 10 cm for the highland forests was highest ($G = 31.04 \text{ m}^2/\text{ha}$) followed by the transition zone ($G = 28.30 \text{ m}^2/\text{ha}$) and then the lowest recorded for the lowlands forests ($G = 23.10 \text{ m}^2/\text{ha}$). Analysis of variance performed showed that altitude was insignificant ($P > 0.05$) on the basal area of trees and other plant life forms with dbh ≥ 10 cm. Analysis by Mann Whitney U-Test showed that basal area was insignificantly lower in forests with invasive species ($24.63 \text{ m}^2/\text{ha}$) than forests without invasive species ($29.27 \text{ m}^2/\text{ha}$).

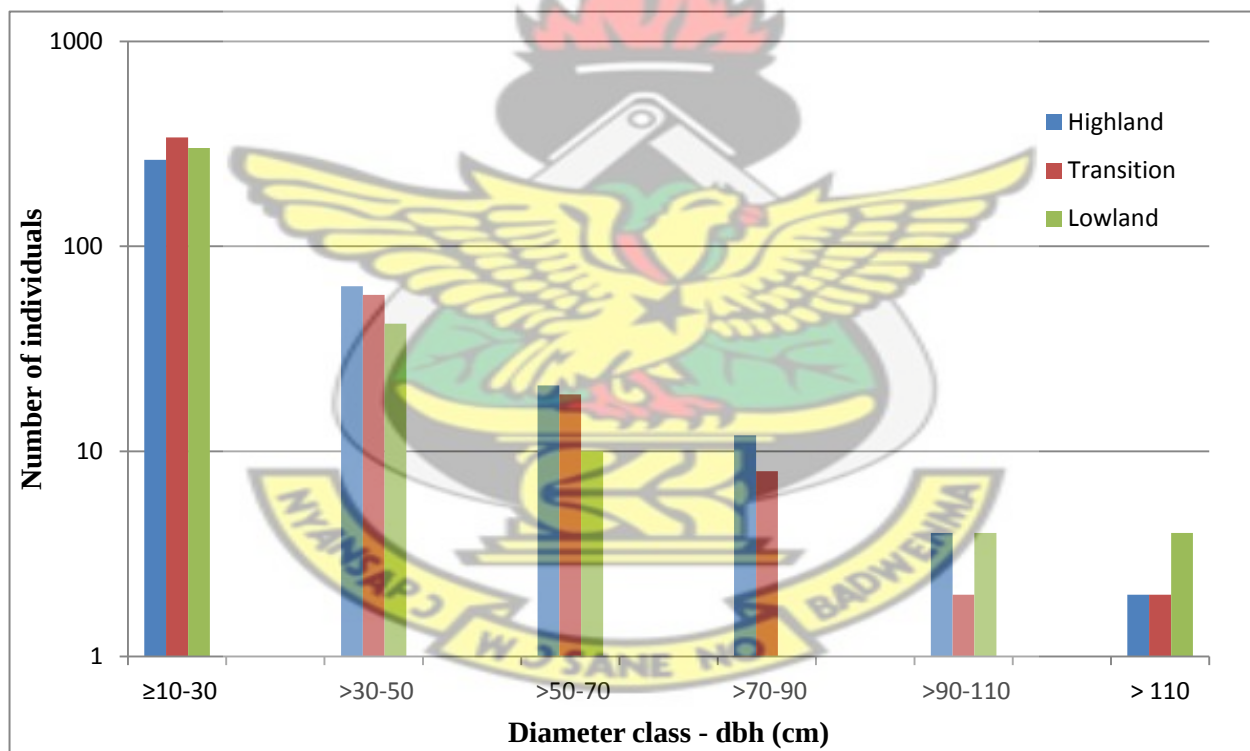


Figure 8: Number of individual plants (dbh ≥ 10 cm) in the diameter classes of the three forest types

4.4.1.3 Height

Highland forests had more individuals in the emergent and upper canopy layers while the transition area had more in the lower canopy and understorey layers (Figure 9). The highest tree was *Canarium schweinfurthii*, a pioneer species which recorded a height of 83.8 m and was found in a highland forest.

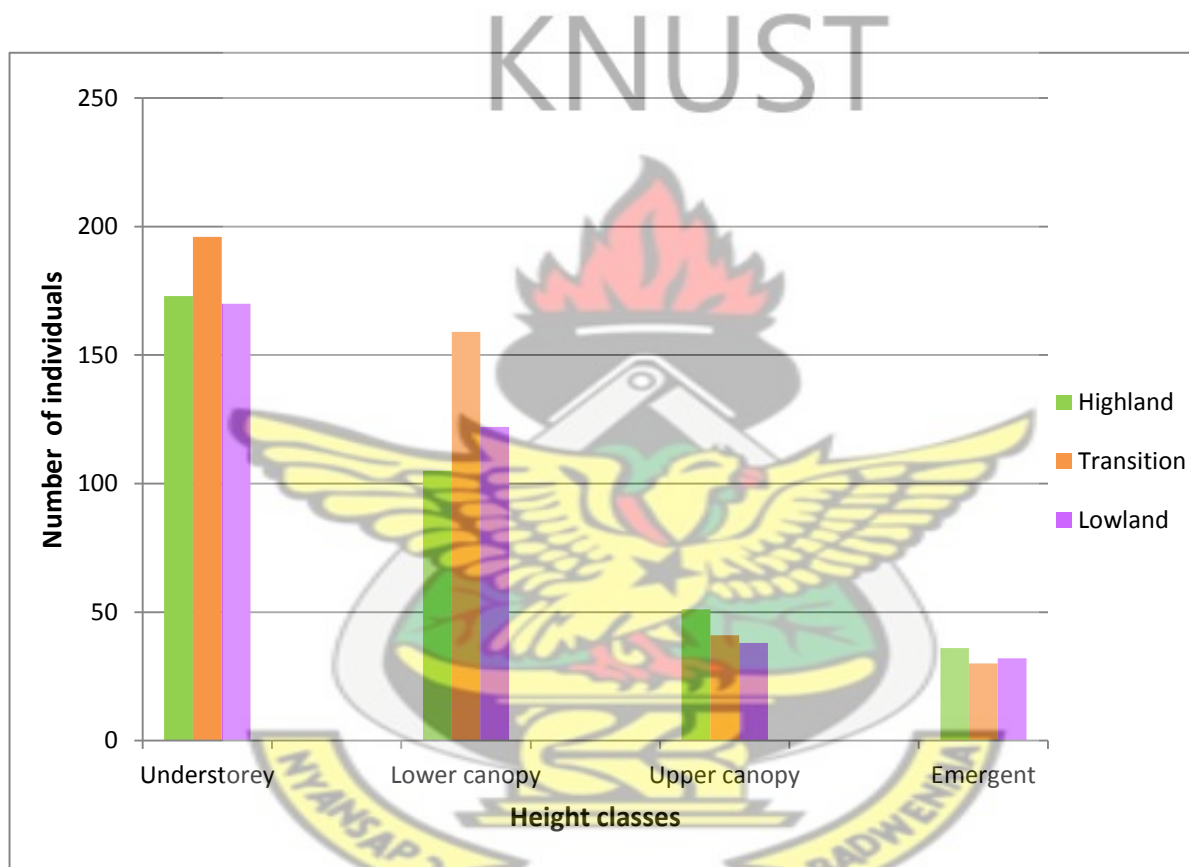


Figure 9: Number of individual trees ($\text{dbh} \geq 10 \text{ cm}$) in the height classes of the three forest types

4.4.1.4 Structural significance of plant species

For the tree layer, *Celtis mildbraedii* again was the most significant species for all forest classes, recording Importance Value Index (IVI) of 23.26 for highland forests, 35.73 for lowland forests and 39.62 for the transition zone (Table 6). Other species which recorded IVI greater than ten include *Sterculia oblonga*, *Parkia bicolor*, *Allanblackia parviflora*, *Scotellia klaineana*, *Strombosia pustulata*, *Dacryodes klaineana* and *Corynanthe pachyceras* for the lowlands, *Hymenostegia afzelii*, *Strombosia pustulata*, *Hannoa klaineana* and *Dacryodes klaineana* for the transition zone and *Hymenostegia afzelii*, *Strombosia pustulata* and *Trichilia prieuriana* for the highlands (Table 6).

The least significant species include *Microdesmis puberrula*, *Acacia pentagona* and *Strychnos campicola* for the lowlands, *Monodora myristica*, *Morus mesozygia* and *Cola millenii* for the transition zone and *Rinorea welwitschii*, *Momordica angusticepala* and *Voacanga bracteata* for the highlands (Table 6).

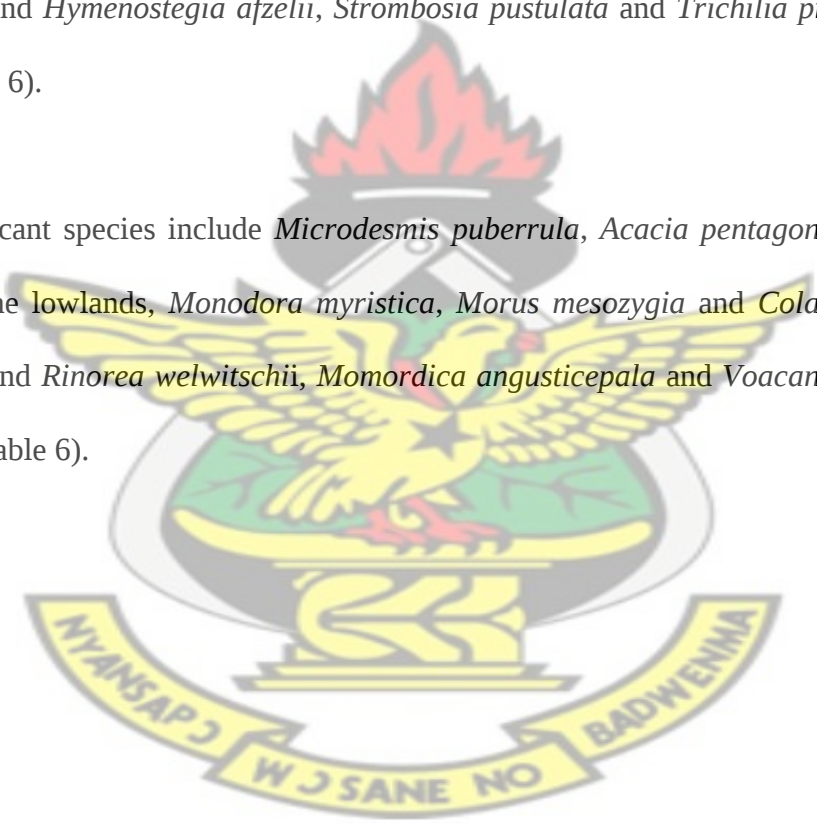


Table 5: Summary of number of individuals, number of species, number of genera, Shannon-Wiener index (H'), Simpson's index of diversity (1-D) Basal area (m²/ha), canopy closure and the influence of elevation and invasiveness on the afore-mentioned

	Tree layer			Shrub layer			Herb layer		
Number of Individuals	977 (~391/ha)			418 (4180/ha)			536 (107200/ha)		
Number of species	154/2.5ha			95/0.1 ha			102/0.005ha		
Number of genera	120/2.5ha			69/0.1/ha			82/0.005ha		
Shannon-Wiener index (H')	2.55			2.49			2.54		
Simpson's index of diverisity (1-D)	0.9			0.83			0.76		
Basal area (m ² /ha)	28.356			3.822			-		
	Lowland	Transition	Highland	Lowland	Transition	Highland	Lowland	Transition	Highland
Shannon-Wiener index (H')	2.57	2.54	2.54	2.56	2.47	2.45	2.52	2.54	2.54
Simpson's index of diverisity (1-D)	0.91	0.9	0.89	0.86	0.87	0.75	0.87	0.89	0.51
Basal area (m ² /ha)	23.1	28.3	31.04	4.34	3.59	3.8	-	-	-
Canopy closure (%)	84.9	87.84	89.06	84.9	87.84	89.06	84.9	87.84	89.06
	Invasive	Non invasive		Invasive	Non invasive		Invasive	Non invasive	
Shannon-Wiener index (H')	2.57	2.54		2.43	2.52		2.48	2.55	
Simpson's index of diverisity (1-D)	0.9	0.91		0.86	0.81		0.88	0.88	
Basal area (m ² /ha)	24.69	29.27		3.42	3.92		-	-	
Canopy closure (%)	87.39	87.85		87.39	87.85		87.39	87.85	

Table 6: Density, frequency, dominance and Importance Value Index of trees and other plant life forms with dbh $\geq$ 10 cm in the lowland, transition and highland forests of the Tano Offin GSBA

Species	Lowland				Transition				Highland			
	D/ha	Freq(%)	Dm	IVI	D/ha	Freq(%)	Dm	IVI	D/ha	Freq(%)	Dm	IVI
1. <i>Acacia pentagona</i>	2	12.5	0.019	1.44	-	-	-	-	-	-	-	-
2. <i>Afzelia bella</i>	-	-	-	-	-	-	-	-	1	6.25	0.104	1.005
3. <i>Aidia genipiiflora</i>	12	37.5	0.338	7.164	9	37.5	0.165	5.122	2	12.5	0.025	1.42
4. <i>Albizia adianthifolia</i>	-	-	-	-	-	-	-	-	1	6.25	0.277	1.562
5. <i>Albizia glaberrima</i>	-	-	-	-	-	-	-	-	1	6.25	0.503	2.289
6. <i>Albizia zygia</i>	2	12.5	0.229	2.349	-	-	-	-	2	12.5	0.577	3.198
7. <i>Allanblackia parviflora</i>	16	75	0.775	12.58	3	18.75	0.103	2.287	-	-	-	-
8. <i>Alstonia boonei</i>	-	-	-	-	2	12.5	1.179	5.775	2	12.5	1.582	6.435

Table 6: Continued

9. <i>Amphimas pterocarpoides</i>	4	25	0.119	3.23	4	18.75	0.144	2.68	1	6.25	0.012	0.707
10. <i>Anonidium mannaii</i>	4	25	0.348	4.222	-	-	-	-	1	6.25	0.091	0.962
11. <i>Anopyxis klaineana</i>	-	-	-	-	2	12.5	0.091	1.61	-	-	-	-
12. <i>Antiaris toxicaria</i>	8	37.5	0.746	7.843	3	18.75	0.392	3.394	2	12.5	0.751	3.76
13. <i>Antrocaryon micraster</i>	-	-	-	-	1	6.25	0.033	0.757	-	-	-	-
14. <i>Aptandra zenkeri</i>	-	-	-	-	-	-	-	-	2	12.5	0.054	1.512
15. <i>Aubrevillea kerstingii</i>	-	-	-	-	-	-	-	-	1	6.25	0.012	0.709
16. <i>Baphia nitida</i>	2	12.5	0.081	1.707	-	-	-	-	5	12.5	0.143	2.622
17. <i>Baphia pubescens</i>	6	37.5	0.226	5.048	6	25	0.032	3.116	9	37.5	0.137	5.277
18. <i>Berlinia tomentella</i>	-	-	-	-	-	-	-	-	4	18.75	0.425	3.651
19. <i>Blighia sapida</i>	4	12.5	0.183	2.692	9	37.5	0.566	6.653	1	6.25	0.561	2.476
20. <i>Blighia welwitschii</i>	2	12.5	0.043	1.544	-	-	-	-	-	-	-	-

Table 6: Continued

21. <i>Bombax buonopozense</i>	-	-	-	-	-	-	-	-	1	6.25	0.046	0.817
22. <i>Bridelia grandis</i>	2	12.5	0.141	1.969	-	-	-	-	-	-	-	-
23. <i>Broussonetia papyrifera</i>	-	-	-	-	4	18.75	0.104	2.526	-	-	-	-
24. <i>Bucholzia coriacea</i>	-	-	-	-	-	-	-	-	1	6.25	0.011	0.703
25. <i>Bussea occidentalis</i>	-	-	-	-	5	18.75	0.523	4.361	9	31.25	1.584	9.546
26. <i>Calpocalyx brevibracteatus</i>	18	37.5	0.397	9.048	4	18.75	0.13	2.624	-	-	-	-
27. <i>Calycobolus africanus</i>	-	-	-	-	1	6.25	0.011	0.673	-	-	-	-
28. <i>Canarium schweinfurthii</i>	-	-	-	-	-	-	-	-	1	6.25	0.472	2.189
29. <i>Carapa procera</i>	-	-	-	-	2	12.5	0.07	1.53	1	6.25	0.04	0.8
30. <i>Cassipourea lescotiana</i>	-	-	-	-	-	-	-	-	1	6.25	0.018	0.728

Table 6: Continued

31. <i>Cedrela odorata</i>	-	-	-	-	1	6.25	0.046	0.809	-	-	-	-
32. <i>Ceiba pentandra</i>	-	-	-	-	1	6.25	0.246	1.574	1	6.25	0.027	0.758
33. <i>Celtis adolfi-friderici</i>	2	12.5	0.041	1.533	5	25	0.45	4.482	6	37.5	1.223	7.954
34. <i>Celtis mildbraedii</i>	50	100	3.611	35.73	54	93.75	5.5	39.62	23	75	3.792	23.26
35. <i>Celtis wightii</i>	-	-	-	-	3	18.75	0.147	2.459	2	12.5	0.047	1.489
36. <i>Celtis zenkeri</i>	-	-	-	-	7	18.75	0.201	3.596	5	18.75	0.45	4.005
37. <i>Chidlowia sanguinea</i>	-	-	-	-	14	31.25	1.223	9.937	3	18.75	0.264	2.86
38. <i>Chrysophyllum albidum</i>	6	37.5	0.073	4.386	3	18.75	0.084	2.216	-	-	-	-
39. <i>Chrysophyllum perpulcrum</i>	8	50	0.544	7.779	10	37.5	0.459	6.479	2	12.5	0.039	1.465
40. <i>Chrysophyllum subnudum</i>	-	-	-	-	4	12.5	0.105	2.132	3	18.75	0.275	2.895
41. <i>Cleidion gabonicum</i>	-	-	-	-	9	25	0.11	4.111	-	-	-	-

Table 6: Continued

42. <i>Cleistopholis patens</i>	-	-	-	-	1	6.25	0.035	0.764	1	6.25	0.088	0.952
43. <i>Cola boxiana</i>	-	-	-	-	-	-	-	-	13	37.5	0.172	6.486
44. <i>Cola caricifolia</i>	4	12.5	0.071	2.206	3	18.75	0.021	1.974	2	12.5	0.046	1.488
45. <i>Cola gigantea</i>	2	12.5	0.04	1.531	3	12.5	0.14	2.031	2	6.25	0.409	2.26
46. <i>Cola lateritia</i>	-	-	-	-	2	12.5	0.563	3.417	3	12.5	0.133	2.041
47. <i>Cola millenii</i>	2	12.5	0.039	1.524	1	6.25	0.001	0.635	1	6.25	0.016	0.721
48. <i>Cola nitida</i>	10	50	0.696	8.981	5	25	0.164	3.387	1	6.25	0.017	0.723
49. <i>Cordia platythyrsa</i>	-	-	-	-	-	-	-	-	1	6.25	0.065	0.879
50. <i>Corynanthe pachyceras</i>	16	50	0.608	10.23	7	25	0.287	4.325	9	43.75	0.92	8.198
51. <i>Dacryodes klaineana</i>	16	37.5	0.911	10.73	16	50	1.075	11.03	3	6.25	0.081	1.477
52. <i>Dalbergia saxatilis</i>	-	-	-	-	1	6.25	0.001	0.636	-	-	-	-
53. <i>Daniellia ogea</i>	-	-	-	-	-	-	-	-	1	6.25	0.042	0.803
54. <i>Dasylepis brevipedicellata</i>	-	-	-	-	10	25	0.215	4.747	8	25	0.113	4.137

Table 6: Continued

55. <i>Desplatsia chrysochlamys</i>	-	-	-	-	-	-	-	-	2	12.5	0.105	1.678
56. <i>Dialium aubrevillei</i>	-	-	-	-	1	6.25	0.026	0.731	2	6.25	0.053	1.113
57. <i>Dialium dinklagei</i>	-	-	-	-	1	6.25	0.029	0.743	4	25	0.066	2.888
58. <i>Dichapetalum madagascariense</i>	-	-	-	-	1	6.25	0.039	0.781	2	6.25	0.08	1.199
59. <i>Diospyros abyssinica</i>	-	-	-	-	-	-	-	-	1	6.25	0.058	0.856
60. <i>Diospyros ferrea</i>	-	-	-	-	-	-	-	-	1	6.25	0.017	0.722
61. <i>Diospyros monbuttensis</i>	-	-	-	-	-	-	-	-	1	6.25	0.033	0.777
62. <i>Diospyros viridicans</i>	-	-	-	-	2	12.5	0.157	1.865	2	12.5	0.128	1.749
63. <i>Discoglyprema caloneura</i>	4	25	0.117	3.221	3	12.5	0.013	1.547	-	-	-	-
64. <i>Distemonanthus benthamianus</i>	4	25	0.07	3.014	-	-	-	-	-	-	-	-

Table 6: Continued

65.	<i>Drypetes aubrevillei</i>	-	-	-	-	-	-	-	-	1	6.25	0.01	0.703
66.	<i>Drypetes aylmeri</i>	-	-	-	-	4	25	0.062	2.763	2	12.5	0.092	1.634
67.	<i>Drypetes pellegrinii</i>	-	-	-	-	1	6.25	0.023	0.718	12	43.75	0.753	8.481
68.	<i>Duboscia macrocarpa</i>	-	-	-	-	-	-	-	-	1	6.25	0.049	0.829
69.	<i>Duguetia staudtii</i>	-	-	-	-	2	12.5	0.441	2.95	-	-	-	-
70.	<i>Elaeis guineensis</i>	2	12.5	0.325	2.766	-	-	-	-	-	-	-	-
71.	<i>Enantia polycarpa</i>	-	-	-	-	1	6.25	0.009	0.665	2	12.5	0.059	1.528
72.	<i>Entada pursuetha</i>	-	-	-	-	1	6.25	0.02	0.709	-	-	-	-
73.	<i>Entandrophragma angolense</i>	6	25	0.13	3.821	10	37.5	0.35	6.062	11	37.5	1.081	8.868
74.	<i>Entandrophragma candollei</i>	2	12.5	0.339	2.826	-	-	-	-	-	-	-	-

Table 6: Continued

75. <i>Entandrophragma cylindricum</i>	4	25	0.051	2.933	-	-	-	-	1	6.25	0.027	0.758
76. <i>Entandrophragma utile</i>	-	-	-	-	-	-	-	-	1	6.25	0.24	1.443
77. <i>Erythrinia miildbraedii</i>	-	-	-	-	-	-	-	-	1	6.25	0.02	0.734
78. <i>Erythroleum ivorensis</i>	2	12.5	0.246	2.421	-	-	-	-	-	-	-	-
79. <i>Erythroxylum mannaii</i>	-	-	-	-	1	6.25	0.013	0.682	-	-	-	-
80. <i>Ficus bubu</i>	-	-	-	-	1	6.25	0.022	0.715	-	-	-	-
81. <i>Funtumia africana</i>	6	25	0.103	3.703	6	12.5	0.293	3.318	4	18.75	0.164	2.81
82. <i>Funtumia elastica</i>	-	-	-	-	1	6.25	0.011	0.673	1	6.25	0.105	1.006
83. <i>Greenwayodendron oliveri</i>	6	25	0.044	3.446	-	-	-	-	-	-	-	-
84. <i>Guarea cedrata</i>	4	25	0.081	3.063	2	12.5	0.203	2.041	1	12.5	0.066	1.278
85. <i>Guarea thompsonii</i>	-	-	-	-	-	-	-	-	1	6.25	0.024	0.745

Table 6: Continued

86. <i>Guibourtia ehie</i>	2	12.5	0.025	1.463	1	6.25	0.035	0.764	3	18.75	0.068	2.228
87. <i>Hannoa klaineana</i>	4	25	0.034	2.86	13	43.75	1.402	11.18	7	25	0.346	4.614
88. <i>Hexalobus crispiflorus</i>	-	-	-	-	-	-	-	-	5	25	1.182	6.761
89. <i>Holoptelea grandis</i>	-	-	-	-	-	-	-	-	1	6.25	0.292	1.611
90. <i>Homalium sp</i>	-	-	-	-	1	6.25	0.062	0.871	-	-	-	-
91. <i>Hunteria eburnea</i>	-	-	-	-	-	-	-	-	1	6.25	0.024	0.748
92. <i>Hunteria sp</i>	-	-	-	-	-	-	-	-	1	6.25	0.012	0.708
93. <i>Hymenostegia afzelii</i>	-	-	-	-	27	50	0.5	11.4	30	56.25	1.405	16.3
94. <i>Irvingia gabonensis</i>	-	-	-	-	1	6.25	0.026	0.733	2	6.25	0.064	1.149
95. <i>Isolona deightonii</i>	-	-	-	-	-	-	-	-	1	6.25	0.011	0.706

Table 6: Continued

96. <i>Khaya anthotheca</i>	-	-	-	-	1	6.25	0.033	0.757	1	6.25	0.01	0.7
97. <i>Khaya ivorensis</i>	2	12.5	0.061	1.62	1	6.25	0.065	0.881	1	6.25	0.016	0.72
98. <i>Lannea welwitschii</i>	-	-	-	-	1	6.25	0.016	0.694	-	-	-	-
99. <i>Leptaulus daphnoides</i>	-	-	-	-	4	6.25	0.321	2.561	-	-	-	-
100. <i>Macaranga barteri</i>	2	12.5	0.062	1.626	-	-	-	-	-	-	-	-
101. <i>Maesobotrya barteri</i>	-	-	-	-	4	25	0.041	2.683	2	12.5	0.051	1.503
102. <i>Mammea africana</i>	-	-	-	-	1	6.25	0.026	0.732	-	-	-	-
103. <i>Mansonia altissima</i>	-	-	-	-	10	31.25	0.167	4.961	1	6.25	0.014	0.715
104. <i>Maranthes grabla</i>	-	-	-	-	-	-	-	-	2	6.25	0.262	1.786
105. <i>Microdesmis puberrula</i>	2	12.5	0.025	1.463	-	-	-	-	-	-	-	-

Table 6: Continued

106. <i>Milicia excelsa</i>	-	-	-	-	-	-	-	-	1	6.25	0.043	0.808
107. <i>Momordica angusticepala</i>	-	-	-	-	-	-	-	-	1	6.25	0.009	0.697
108. <i>Monodora myristica</i>	-	-	-	-	1	6.25	0.001	0.635	-	-	-	-
109. <i>Monodora tenuifolia</i>	-	-	-	-	1	6.25	0.011	0.673	-	-	-	-
110. <i>Morus mesozygia</i>	-	-	-	-	1	6.25	0.001	0.635	1	6.25	0.015	0.716
111. <i>Myrianthus arboreus</i>	-	-	-	-	1	6.25	0.012	0.676	-	-	-	-
112. <i>Myrianthus libericus</i>	2	12.5	0.094	1.765	3	12.5	0.143	2.045	3	12.5	0.176	2.179
113. <i>Napoleonaea vogelii</i>	-	-	-	-	2	12.5	0.017	1.329	-	-	-	-
114. <i>Nesogordonia papaverifera</i>	4	25	0.254	3.813	3	18.75	0.232	2.784	7	37.5	0.397	5.567
115. <i>Octoknema borealis</i>	-	-	-	-	-	-	-	-	8	25	1.241	7.772
116. <i>Ongokea gore</i>	-	-	-	-	1	6.25	0.252	1.598	-	-	-	-

Table 6: Continued

117. <i>Panda oleosa</i>	4	12.5	0.185	2.702	2	12.5	0.181	1.958	2	12.5	0.166	1.872
118. <i>Parinari excelsa</i>	-	-	-	-	2	6.25	0.102	1.255	-	-	-	-
119. <i>Parkia bicolor</i>	2	12.5	3.348	15.85	1	6.25	0.798	3.686	-	-	-	-
120. <i>Pentaclethra macrophylla</i>	2	12.5	0.032	1.496	1	6.25	0.363	2.022	-	-	-	-
121. <i>Petersianthus macrocarpus</i>	4	12.5	0.374	3.52	-	-	-	-	1	6.25	0.79	3.215
122. <i>Phyllocosmus africanus</i>	2	12.5	0.064	1.634	-	-	-	-	-	-	-	-
123. <i>Picalima nitida</i>	-	-	-	-	-	-	-	-	2	12.5	0.029	1.433
124. <i>Piptadeniastrum africanum</i>	2	12.5	0.048	1.565	3	18.75	0.619	4.264	2	12.5	0.189	1.948
125. <i>Pouteria altissima</i>	-	-	-	-	4	18.75	0.084	2.449	1	6.25	0.012	0.709
126. <i>Pterygota macrocarpa</i>	2	12.5	0.101	1.792	4	18.75	0.201	2.898	-	-	-	-

Table 6: Continued

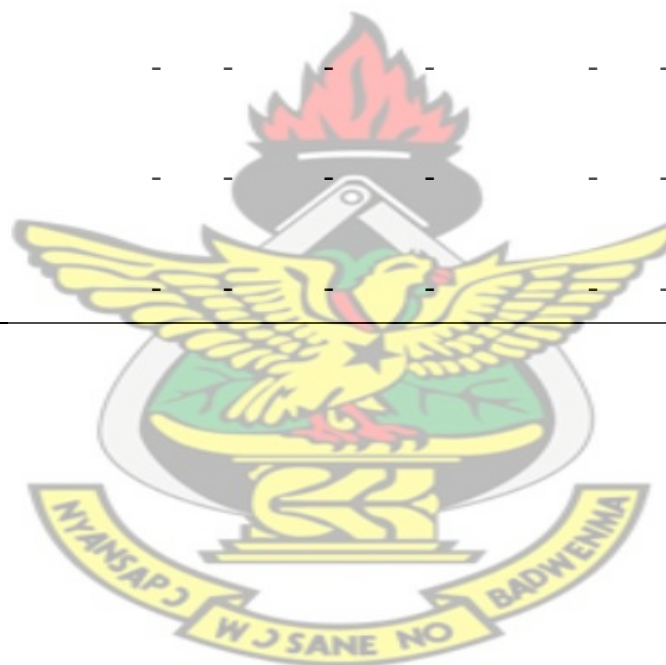
127. <i>Pycnanthus angolensis</i>	8	37.5	0.875	8.401	3	12.5	0.433	3.154	6	31.25	1.325	7.888
128. <i>Ricinodendron heudelotii</i>	4	25	0.074	3.032	-	-	-	-	1	6.25	0.024	0.746
129. <i>Rinorea oblongifolia</i>	-	-	-	-	-	-	-	-	1	6.25	0.011	0.704
130. <i>Rinorea welwitschii</i>	6	25	0.058	3.507	-	-	-	-	1	6.25	0.009	0.698
131. <i>Rothmannia hispida</i>	-	-	-	-	1	6.25	0.018	0.702	-	-	-	-
132. <i>Salacia sp</i>	-	-	-	-	1	6.25	0.009	0.667	-	-	-	-
133. <i>Scotellia klaineana</i>	20	50	0.892	12.55	23	43.75	0.482	9.997	12	43.75	0.808	8.658
134. <i>Stemonocoleus micranthus</i>	-	-	-	-	1	6.25	0.023	0.719	-	-	-	-
135. <i>Sterculia oblonga</i>	6	37.5	3.568	19.52	3	18.75	0.03	2.01	-	-	-	-
136. <i>Sterculia rhinopetala</i>	-	-	-	-	4	18.75	0.09	2.471	2	12.5	0.039	1.464
137. <i>Sterculia tragacantha</i>	-	-	-	-	1	6.25	0.077	0.926	2	12.5	0.128	1.749

Table 6: Continued

138. <i>Strombosia pustulata</i>	18	87.5	0.313	11.94	22	50	0.757	11.21	23	56.25	0.917	12.81
139. <i>Strychnos campicola</i>	2	12.5	0.016	1.424	-	-	-	-	-	-	-	-
140. <i>Symphonia glubulifera</i>	-	-	-	-	1	6.25	0.008	0.662	-	-	-	-
141. <i>Terminalia superba</i>	-	-	-	-	1	6.25	0.017	0.697	-	-	-	-
142. <i>Tetrapleura tetraptera</i>	-	-	-	-	-	-	-	-	1	6.25	0.011	0.704
143. <i>Tieghemella heckelii</i>	-	-	-	-	1	6.25	0.213	1.448	-	-	-	-
144. <i>Treculia africana</i>	2	12.5	0.06	1.615	-	-	-	-	2	12.5	0.107	1.683
145. <i>Trema orientalis</i>	-	-	-	-	1	6.25	0.013	0.682	-	-	-	-
146. <i>Trichilia monadelpha</i>	12	50	0.36	8.071	4	25	0.099	2.905	8	31.25	0.157	4.672
147. <i>Trichilia prieuriana</i>	12	37.5	0.268	6.861	1	6.25	0.032	0.754	14	68.75	0.673	10.35
148. <i>Trichilia tessmannii</i>	-	-	-	-	5	18.75	0.128	2.851	1	6.25	0.067	0.884

Table 6: Continued

149.	<i>Trilepisium madagascariense</i>	-	-	-	-	6	25	0.191	3.724	4	25	0.296	3.632
150.	<i>Triplochiton scleroxylon</i>	2	12.5	0.026	1.468	1	6.25	1.233	5.352	2	12.5	0.609	3.301
151.	<i>Uapaca guineensis</i>	2	12.5	0.095	1.768	1	6.25	0.229	1.508	-	-	-	-
152.	<i>Vitex micrantha</i>	-	-	-	-	-	-	-	-	1	6.25	0.093	0.969
153.	<i>Voacanga bracteata</i>	-	-	-	-	-	-	-	-	1	6.25	0.008	0.697
154.	<i>Xylia evansii</i>	-	-	-	-	-	-	-	-	3	18.75	0.057	2.192



4.4.2 Shrub and herb layers

4.4.2.1 Species diversity

Shannon-Wiener diversity index of the shrub layer of the lowland, transition area and highland forests were $H' = 2.56$, $H' = 2.47$ and $H' = 2.45$ respectively. The Shannon-Wiener index diversity of the herb layer of the lowland, transition area and highland forests were $H' = 2.52$, $H' = 2.54$ and $H' = 2.54$ respectively. At the presence of invasive species, the shrub layer records a Shannon-Wiener index value of $H' = 2.43$ and $H' = 2.52$ in its absence. Similarly, the herb layer records a Shannon-Wiener index value of $H' = 2.48$ in the presence of invasive species and $H' = 2.55$ in the absence of invasive species.

Simpson's index of diversity (1-D) of the shrub layer in the lowland, transition area and highland forests were 0.86, 0.87 and 0.75, respectively. Simpson's index of diversity (1-D) of the herb layer in the lowland, transition area and highland forests were 0.87, 0.89 and 0.51, respectively. At the presence of invasive species, the shrub layer records a Simpson's index value (1-D) of 0.86 and 0.81 in its absence. Similarly, the herb layer records a Simpson's index value (1-D) of 0.88 both in the presence and absence of invasive species.

ANOVA shows no significant differences ($P > 0.05$) in the influence of elevation on species diversity of both the shrub and herb layers of the three forest classes. A one-tailed t-Test on both Shannon-Wiener index of diversity and Simpson's index of diversity (1-D) also showed no strong evidence for the influence of invasive species on species diversity of shrub and herb layers of the three forest classes.

4.4.2.2 Diameter class distribution and basal area

Number of individuals decreased with increasing diameter classes of all three forest types. Forest of the transition area had the greatest number of individuals (110) in the smallest diameter class ($> 0.1 - 2$ cm) in the shrub layer (Figure 10) although it had only 38 species. However, highland forests had 75 individuals in the $> 0.1 - 2$ cm-diameter class but there were 39 species. Lowland forests had the highest number of representatives in the largest diameter class ($> 8 - 9.9$ cm) (Figure 10).

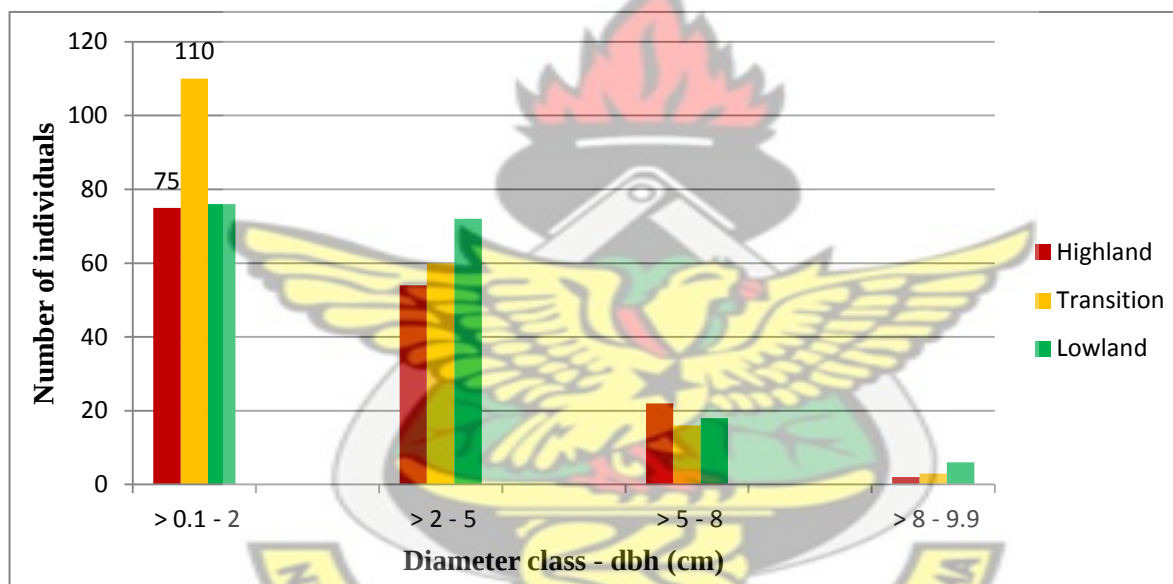


Figure 10: Number of individual plants (dbh < 10 cm) in the diameter classes of the three forest types

Elevation did not significantly affect basal area of trees and other plant life forms with dbh < 10 cm ($P > 0.05$) although lowlands forests had the biggest mean basal area value ($G = 4.34 \text{ m}^2/\text{ha}$) when compared to the transition zone ($G = 3.59 \text{ m}^2/\text{ha}$) and highland forests ($G = 3.80 \text{ m}^2/\text{ha}$).

On the other hand, no significance ($P > 0.05$) was found to support the influence of invasive species on basal area of trees and other plant life forms with dbh < 10 cm by the application of t-Test, nevertheless, a lower mean basal area value ($G = 3.42 \text{ m}^2/\text{ha}$) was recorded for forest with invasive species (Table 5) when compared with forests without invasive species ($G = 3.92 \text{ m}^2/\text{ha}$).

4.4.2.3 Ecological guild

In all the forest types, a greater percentage of constituents of the shrub and herb layers were shade-tolerant/bearers, followed by non-pioneer light demanders which were also in greater proportion than the pioneers (Table 7). Pioneers were completely absent in the lowland shrub layer whilst invasive species were found only at the herb layer of the transition area (Table 7).

At the herb layer, highlands had the least representation of pioneers while the transition had the highest. Lowlands was the highest with non-pioneer light demanding and highlands was the highest with shade-bearers. The transition area had the least representation of non-pioneer light demanders as well as the shade-bearers (Table 7).

At the shrub layer, there were more shade-bearers at the lowlands than the transition area which was also higher in representation than the highlands. The guilds of about 17% plant species at the herb layer for all three forest classes could not be determined (unknown) while an average value of about 13% were equally 'unknown' at the shrub layer (Table 7).

Table 7: Guild proportion (%) of the three forest classes at the shrub and herb layers

	Herb layer			Shrub layer		
	Lowland	Transition	Highland	Lowland	Transition	Highland
Pioneer	10	17.86	7.02	0.00	5.45	5.36
Non-pioneer light demand	33.33	25	31.58	15.15	29.09	32.14
Shade-bearers	40	35.71	43.86	66.67	56.36	51.79
Invasive	0.00	3.57	0.00	0.00	0.00	0.00
Unknown	16.67	17.86	17.54	18.18	9.09	10.71

4.4.2.4 Structural significance of plant species

For trees and other plant life forms with dbh < 10 cm, *Rinorea welwitschii* was the most significant species for the lowlands and the highlands forests, recording an IVI of 58.58 and 56.09 respectively (Table 8). *Hymenostegia afzelii* with an IVI of 21.72 was the most significant species for the transition zone while *Rinorea welwitschii* was absent from this zone. *Monodora myristica* and *Microdesmis puberula* were among the least significant in the lowland forests, *Rothmannia hispida*, *Pterygota macrocarpa*, and *Rothmannia whitfieldii* for the transition zone while *Enantia polycarpa*, *Coffea stenophylla* and *Trilepisium madagascariense* were among the least significant for the highland forests (Table 8).

Table 8: Density, frequency, dominance and Importance Value Index of trees and other plant life forms with dbh < 10 cm in the lowland, transition and highland forests of the Tano Offin GSBA

Species	Lowland				Transition				Highland			
	D/ha	Freq(%)	Dm	IVI	D/ha	Freq(%)	Dm	IVI	D/ha	Freq(%)	Dm	IVI
1. <i>Aidia genipiflora</i>	150	50	0.125	8.934	-	-	-	-	-	-	-	-
2. <i>Amphimas pterocarpoides</i>	-	-	-	-	25	25	0.003	2.054	-	-	-	-
3. <i>Anthonotha fragrans</i>	-	-	-	-	25	25	0.003	2.067	-	-	-	-
4. <i>Antiaris toxicaria</i>	50	50	0.048	4.836	-	-	-	-	-	-	-	-
5. <i>Baphia nitida</i>	-	-	-	-	225	100	0.128	14.21	75	25	0.214	8.853
6. <i>Baphia pubescens</i>	-	-	-	-	50	25	0.018	3.031	-	-	-	-
7. <i>Blighia sapida</i>	-	-	-	-	50	25	0.027	3.261	25	25	0.149	5.847
8. <i>Blighia welwitschii</i>	-	-	-	-	-	-	-	-	25	25	0.004	2.177

Table 8: Continued

9. <i>Bussea occidentalis</i>	-	-	-	-	-	-	-	-	25	25	0.014	2.429
10. <i>Calpocalyx brevibracteatus</i>	100	50	0.011	5.152	25	25	0.105	4.889	-	-	-	-
11. <i>Calycobolus africanus</i>	-	-	-	-	-	-	-	-	25	25	0.042	3.122
12. <i>Carapa procera</i>	-	-	-	-	25	25	0.036	2.986	-	-	-	-
13. <i>Carpolobia lutea</i>	-	-	-	-	-	-	-	-	25	25	0.008	2.264
14. <i>Ceiba pentandra</i>	-	-	-	-	-	-	-	-	25	25	0.071	3.864
15. <i>Celtis mildbraedii</i>	150	100	0.052	9.81	75	50	0.195	9.913	200	25	0.019	7.278
16. <i>Celtis wightii</i>	-	-	-	-	50	25	0.006	2.696	-	-	-	-
17. <i>Celtis zenkeri</i>	-	-	-	-	75	25	0.02	3.637	-	-	-	-
18. <i>Chrysophyllum albidum</i>	50	50	0.073	5.401	50	25	0.155	6.826	-	-	-	-

Table 8: Continued

19.	<i>Chrysophyllum perpulcrum</i>	-	-	-	-	125	25	0.076	6.271	50	50	0.118	7.132
20.	<i>Chytranthus carneus</i>	-	-	-	-	25	25	0.006	2.152	-	-	-	-
21.	<i>Cissus producta</i>	-	-	-	-	50	25	0.046	3.806	-	-	-	-
22.	<i>Cleidion gabonicum</i>	-	-	-	-	500	25	0.283	20.25	-	-	-	-
23.	<i>Coffea stenophylla</i>	-	-	-	-	-	-	-	-	-	25	0.001	2.089
24.	<i>Cola boxiana</i>	-	-	-	-	-	-	-	-	-	25	0.235	8.723
25.	<i>Cola gigantea</i>	-	-	-	-	-	-	-	-	-	25	0.007	2.245
26.	<i>Craterispermum caudatum</i>	50	50	0.043	4.713	-	-	-	-	-	-	-	-
27.	<i>Craterispermum cerinanthum</i>	300	100	0.195	16.61	175	50	0.056	8.25	50	50	0.004	4.23
28.	<i>Dacryodes klaineana</i>	50	50	0.076	5.48	25	25	0.152	6.209	-	-	-	-

Table 8: Continued

29. <i>Dasylepis brevipedicellata</i>	-	-	-	-	-	-	-	-	100	25	0.104	6.739
30. <i>Dialium dinklagei</i>	50	50	0.008	3.904	-	-	-	-	-	-	-	-
31. <i>Dichapetalum madagascariense</i>	-	-	-	-	75	50	0.027	5.242	-	-	-	-
32. <i>Dichapetalum toxicarium</i>	50	50	0.035	4.542	25	25	0.003	2.067	25	25	0.013	2.402
33. <i>Diospyros ferrea</i>	150	100	0.074	10.31	25	25	0.003	2.054	25	25	0.005	2.192
34. <i>Diospyros kamerunensis</i>	-	-	-	-	25	25	0.01	2.264	50	50	0.031	4.926
35. <i>Diospyros soubreana</i>	100	50	0.033	5.64	-	-	-	-	-	-	-	-
36. <i>Drypetes aubrevillei</i>	-	-	-	-	25	25	0.014	2.374	25	25	0.059	3.576
37. <i>Drypetes chevalieri</i>	150	50	0.016	6.433	450	50	0.123	16.11	225	75	0.155	14.19
38. <i>Drypetes gilgiana</i>	-	-	-	-	-	-	-	-	100	25	0.043	5.173

Table 8: Continued

39. <i>Enantia polycarpa</i>	-	-	-	-	25	25	0.012	2.317	25	25	0.001	2.097
40. <i>Entandrophragma angolense</i>	-	-	-	-	-	-	-	-	25	25	0.01	2.329
41. <i>Entandrophragma cylindricum</i>	-	-	-	-	-	-	-	-	25	25	0.012	2.377
42. <i>Euclinia longiflora</i>	-	-	-	-	25	25	0.031	2.85	-	-	-	-
43. <i>Funtumia africana</i>	50	50	0.123	6.567	-	-	-	-	-	-	-	-
44. <i>Funtumia elastica</i>	-	-	-	-	-	-	-	-	25	25	0.019	2.545
45. <i>Garcinia kola</i>	-	-	-	-	25	25	0.043	3.183	-	-	-	-
46. <i>Greenwayodendron oliveri</i>	300	100	0.179	16.23	100	25	0.158	8.015	125	50	0.141	9.741
47. <i>Griffonia simplicifolia</i>	-	-	-	-	25	25	0.049	3.342	-	-	-	-
48. <i>Guarea cedrata</i>	150	50	0.102	8.408	25	25	0.066	3.814	-	-	-	-

Table 8: Continued

49. <i>Guibourtia ehie</i>	-	-	-	-	50	50	0.012	4.285	25	25	0.002	2.125
50. <i>Hannoa klaineana</i>	-	-	-	-	25	25	0.003	2.067	25	25	0.102	4.655
51. <i>Hunteria eburnea</i>	-	-	-	-	-	-	-	-	50	50	0.01	4.385
52. <i>Hunteria umbellata</i>	-	-	-	-	50	25	0.02	3.092	-	-	-	-
53. <i>Hymenostegia afzelii</i>	-	-	-	-	450	50	0.324	21.72	50	25	0.005	2.87
54. <i>Maesobotrya barteri</i>	-	-	-	-	-	-	-	-	25	25	0.003	2.149
55. <i>Mammea africana</i>	-	-	-	-	-	-	-	-	25	25	0.009	2.285
56. <i>Mansonia altissima</i>	-	-	-	-	100	25	0.119	6.92	100	25	0.131	7.421
57. <i>Mareya micarantha</i>	-	-	-	-	-	-	-	-	25	25	0.006	2.226
58. <i>Microdesmis keayana</i>	100	50	0.119	7.632	75	25	0.271	10.6	-	-	-	-

Table 8: Continued

59. <i>Microdesmis puberula</i>	50	50	0.003	3.8	300	100	0.253	19.31	25	25	0.003	2.137
60. <i>Millettia chrysophylla</i>	-	-	-	-	25	25	0.024	2.645	-	-	-	-
51. <i>Monodora myristica</i>	50	50	0.006	3.857	-	-	-	-	50	50	0.007	4.307
62. <i>Monodora tenuifolia</i>	-	-	-	-	-	-	-	-	75	25	0.038	4.388
63. <i>Napoleonaea vogelii</i>	150	50	0.337	13.83	100	50	0.183	10.14	-	-	-	-
64. <i>Nesogordonia papaverifera</i>	50	50	0.087	5.727	-	-	-	-	25	25	0.002	2.115
65. <i>Octoknema borealis</i>	50	50	0.009	3.931	-	-	-	-	-	-	-	-
66. <i>Pancovia pedicellaris</i>	-	-	-	-	100	25	0.015	4.035	-	-	-	-
67. <i>Pentaclethra macrophylla</i>	50	50	0.01	3.959	-	-	-	-	-	-	-	-
68. <i>Pouteria altissima</i>	-	-	-	-	75	25	0.011	3.373	-	-	-	-

Table 8: Continued

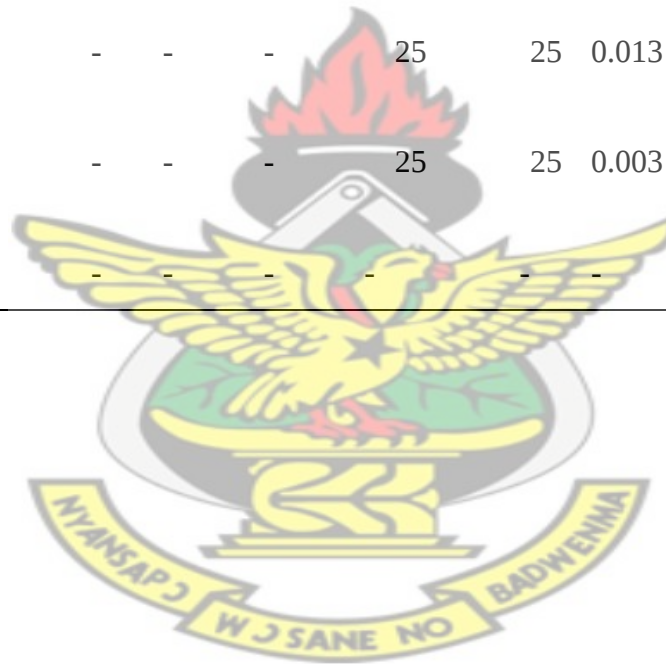
69. <i>Pterygota macrocarpa</i>	-	-	-	-	25	25	0.002	2.019	-	-	-	-
70. <i>Pycnanthus angolensis</i>	-	-	-	-	25	25	0.004	2.098	25	25	0.01	2.329
71. <i>Rhaphiolytis ferruginea</i>	-	-	-	-	-	-	-	-	25	25	0.003	2.137
72. <i>Rinorea ilicifolia</i>	-	-	-	-	-	-	-	-	50	25	0.011	3.013
73. <i>Rinorea oblongifolia</i>	200	100	0.396	18.92	75	50	0.015	4.917	75	75	0.01	6.441
74. <i>Rinorea welwitschii</i>	950	100	1.365	58.71	-	-	-	-	800	75	1.153	55.12
75. <i>Rinorea yaundensis</i>	50	50	0.035	4.542	275	25	0.097	10.13	75	25	0.137	6.894
76. <i>Rothmannia hispida</i>	50	50	0.031	4.437	25	25	0.002	2.03	-	-	-	-
77. <i>Rothmannia whitfieldii</i>	-	-	-	-	25	25	0.002	2.019	-	-	-	-
78. <i>Scotellia klaineana</i>	100	50	0.044	5.909	50	25	0.117	5.772	-	-	-	-
79. <i>Sterculia oblonga</i>	-	-	-	-	25	25	0.004	2.082	-	-	-	-

Table 8: Continued

80. <i>Sterculia rhinopetala</i>	-	-	-	-	50	25	0.017	2.984	50	25	0.011	3.023
81. <i>Sterculia tragacantha</i>	-	-	-	-	25	25	0.018	2.467	-	-	-	-
82. <i>Strombosia pustulata</i>	150	50	0.237	11.51	75	50	0.188	9.742	200	75	0.158	13.58
83. <i>Strychnos campicola</i>	200	100	0.062	11.22	-	-	-	-	-	-	-	-
84. <i>Strychnos usambarensis</i>	-	-	-	-	50	25	0.003	2.61	-	-	-	-
85. <i>Strychnos floribunda</i>	-	-	-	-	-	-	-	-	75	25	0.178	7.934
86. <i>Tabernaemontana africana</i>	100	50	0.255	10.76	-	-	-	-	100	75	0.087	9.09
87. <i>Treculia africana</i>	-	-	-	-	-	-	-	-	50	25	0.283	9.927
88. <i>Tricalysia pallens</i>	-	-	-	-	25	25	0.015	2.404	25	25	0.003	2.137
89. <i>Trichilia monadelpha</i>	-	-	-	-	-	-	-	-	50	25	0.046	3.912

Table 8: Continued

90. <i>Trichilia prieuriana</i>	100	50	0.147	8.28	-	-	-	-	75	50	0.005	4.927
91. <i>Trilepisium madagascariense</i>	-	-	-	-	-	-	-	-	25	25	0.001	2.083
92. <i>uvariostrum pierreanum</i>	-	-	-	-	-	-	-	-	50	25	0.012	3.045
93. <i>Voacanga bracteata</i>	-	-	-	-	25	25	0.013	2.345	25	25	0.021	2.609
94. <i>Warneckea membrnifolium</i>	-	-	-	-	25	25	0.003	2.054	-	-	-	-
95. <i>Xylopi villosa</i>	-	-	-	-	-	-	-	-	50	25	0.005	2.862



4.5 Natural regeneration

A total of 75 plant species were found regenerating as saplings and seedlings. Species richness of saplings was 61 (Table 9) while 45 species were seedlings (Table 10). Other constituents of the regeneration flora were plant species that were encountered only as sapling (*Anthonothea fragrans*, *Drypetes gilgiana*, *Garcinia kola*, *uvariostrum pierreanum* and *Xylopia villosa*) or seedling (*Lecaniodiscus cupaniodes*, *Lovoa trichiliodes* and *Mallotus oppositifolius*) and were thus absent from the adult community. The Shannon-Wiener index value for the saplings and the seedlings were $H' = 1.98$ and $H' = 1.84$ respectively.

4.6 Influence of elevation and invasive on natural regeneration

Shannon-Wiener index of the saplings of the lowland, transition area and highland forests were $H' = 2.01$, $H' = 1.92$ and $H' = 2.03$ respectively. Shannon-Wiener index of the seedlings of the lowland, transition area and highland forests were $H' = 2.00$, $H' = 1.56$ and $H' = 2.04$ respectively. Anova showed significant difference ($P < 0.5$) in species diversity of seedlings at the three forest classes of varying elevations but not with the saplings.

At the presence of invasive species, sapling diversity was $H' = 2.11$ as against $H' = 1.95$ in its absence. On the other hand, species diversity was lesser for seedlings at the presence of invasive species ($H' = 1.27$) than in its absence ($H' = 1.98$). Mann-Whitney U-Test analysis showed significant difference ($P < 0.05$ one tailed) in species diversity of seedlings at forest classes of varying invasiveness.

For the lowland areas, 50.94 % of the adult trees were regenerating while 46.74 % and 42.86 % of the adults were regenerating at the transition area and the highlands respectively. Lowland forests had 27 regenerating tree species, 47 for the transition area and 46 for the highlands (Table 9, 10).

Celtis mildbraedii, *Drypetes chevalieri* and *Strombosia pustulata* were regenerating as saplings in all three forest classes (Table 9) while *Baphia nitida*, *Celtis mildbraedii*, *Guibourtia ehie* and *Trichilia monadelpha* were regenerating as seedlings in all three forest classes (Table 10).



Table 9: Recruitment of saplings at the lowland, transitional and highland forests

Saplings	Lowland	Transition	Highland
1. <i>Amphimas pterocarpoides</i>	-	1	-
2. <i>Anthonotha fragrans</i>	-	1	-
3. <i>Antiaris toxicaria</i>	1	-	-
4. <i>Baphia nitida</i>	-	9	3
5. <i>Baphia pubescens</i>	-	2	
6. <i>Blighia sapida</i>	-	2	1
7. <i>Blighia welwitschii</i>	-	-	1
8. <i>Bussea occidentalis</i>	-	-	1
9. <i>Calpocalyx brevibracteatus</i>	2	1	-
10. <i>Carapa procera</i>	-	1	-
11. <i>Ceiba pentandra</i>	-	-	1
12. <i>Celtis mildbraedii</i>	3	3	8
13. <i>Celtis wightii</i>	-	2	-
14. <i>Celtis zenkeri</i>	-	3	-
15. <i>Chrysophyllum albidum</i>	1	2	-
16. <i>Chrysophyllum perpulcrum</i>	-	4	2
17. <i>Cleidion gabonicum</i>	-	20	-
18. <i>Cola boxiana</i>	-	-	2
19. <i>Cola gigantea</i>	-	-	1
20. <i>Dacryodes klaineana</i>	1	1	-

Table 9: Continued

21. <i>Dasylepis brevipedicellata</i>	-	-	4
22. <i>Dialium dinklagei</i>	1	-	-
23. <i>Drypetes aubrevillei</i>	-	1	1
24. <i>Drypetes chevalieri</i>	3	18	9
25. <i>Drypetes gilgiana</i>	-	-	4
26. <i>Enantia polycarpa</i>	-	1	1
27. <i>Entandrophragma angolense</i>	-	-	1
28. <i>Entandrophragma cylindricum</i>	-	-	1
29. <i>Funtumia africana</i>	1	-	-
30. <i>Funtumia elastica</i>	-	-	1
31. <i>Garcinia kola</i>	-	1	-
32. <i>Guarea cedrata</i>	3	1	-
33. <i>Guibourtia ehie</i>	-	2	1
34. <i>Hannoa klaineana</i>	-	1	1
35. <i>Hunteria umbellata</i>	-	2	2
36. <i>Hymenostegia afzelii</i>	-	18	2
37. <i>Mammea africana</i>	-	-	1
38. <i>Mansonia altissima</i>	-	4	4
39. <i>Monodora myristica</i>	1	-	2
40. <i>Monodora tenuifolia</i>	-	-	3
41. <i>Napoleonaea vogelii</i>	3	4	
42. <i>Nesogordonia papaverifera</i>	1	-	1

Table 9: Continued

43.	<i>Octoknema borealis</i>	1	-	-
44.	<i>Pentaclethra macrophylla</i>	1	-	-
45.	<i>Pouteria altissima</i>	-	3	-
46.	<i>Pterygota macrocarpa</i>	-	1	-
47.	<i>Pycnanthus angolensis</i>	-	1	1
48.	<i>Rinorea oblongifolia</i>	1	3	3
49.	<i>Rinorea welwitschii</i>	19	-	32
50.	<i>Scotellia klaineana</i>	2	2	-
51.	<i>Sterculia oblonga</i>	-	1	-
52.	<i>Sterculia rhinopetala</i>	-	2	2
53.	<i>Sterculia tragacantha</i>	-	1	-
54.	<i>Strombosia pustulata</i>	3	3	8
55.	<i>Tabernaemontana africana</i>	2	-	4
56.	<i>Treculia africana</i>	-	-	1
57.	<i>Trichilia monadelpha</i>	-	-	2
58.	<i>Trichilia prieuriana</i>	2	-	3
59.	<i>Trilepisium madagascariense</i>	-	-	1
60.	<i>Uvariostrum pierreanum</i>	-	-	2
61.	<i>Xylopiella villosa</i>	-	-	2

Table 10: Recruitment of seedlings at the lowland, transitional and highland forests

#	Seedlings	Lowland	Transition	Highland
1.	<i>Albizia zygia</i>	-	-	3
2.	<i>Alstonia boonei</i>		1	
3.	<i>Amphimas pterocarpoides</i>	-	-	1
4.	<i>Antiaris toxicaria</i>	-	1	-
5.	<i>Baphia nitida</i>	-	2	4
6.	<i>Baphia pubescens</i>	6	3	5
7.	<i>Blighia sapida</i>	2	-	-
8.	<i>Broussonetia papyrifera</i>	-	4	-
9.	<i>Bussea occidentalis</i>	-	-	2
10.	<i>Calpocalyx brevibracteatus</i>	1	1	-
11.	<i>Celtis mildbraedii</i>	5	1	4
12.	<i>Celtis wightii</i>	-	-	1
13.	<i>Celtis zenkeri</i>	-	-	1
14.	<i>Chrysophyllum perpulcrum</i>	-	-	1
15.	<i>Cleidion gabonicum</i>	-	1	-
16.	<i>Cola boxiana</i>	-	-	7
17.	<i>Cola gigantea</i>	-	-	1
18.	<i>Discoglypremna caloneura</i>	-	-	1
19.	<i>Drypetes chevalieri</i>	-	2	1
20.	<i>Entandrophragma angolense</i>	-	-	4

Table 10: Continued

21. <i>Entandrophragma cylindricum</i>	-	-	1
22. <i>Funtumia africana</i>		2	
23. <i>Funtumia elastica</i>	-	-	1
24. <i>Guarea cedrata</i>	2	-	-
25. <i>Guibourtia ehie</i>	4	1	9
26. <i>Hymenostegia afzelii</i>	-	-	6
27. <i>Lecaniodiscus cupanioides</i>	-	1	-
28. <i>Leptaulus daphnoides</i>	-	3	-
29. <i>Lovoa trichiliodes</i>	-	-	1
30. <i>Mallotus oppositifolious</i>	-	1	-
31. <i>Millettia zechiana</i>		1	
32. <i>Nesogordonia papaverifera</i>	-	2	-
33. <i>Panda oleosa</i>	-	1	-
34. <i>Petersianthus macrocarpus</i>	1	-	-
35. <i>Phyllocosmus africanus</i>	-	1	-
36. <i>Piptadeniastrum africanum</i>	1	-	-
37. <i>Pouteria altissima</i>	-	-	1
38. <i>Ricinodendron heudelotii</i>		1	
39. <i>Rinorea oblongifolia</i>	-	3	1
40. <i>Rinorea welwitschii</i>	4	-	16
41. <i>Sterculia oblonga</i>	1	-	-
42. <i>Strombosia pustulata</i>	1	-	6

Table 10: Continued

43.	<i>Tabernaemontana africana</i>	-	-	1
44.	<i>Trichilia monadelpha</i>	1	2	2
45.	<i>Trichilia prieuriana</i>	1	-	-

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4.6.1 Ecological guild

While pioneers constituted the least abundant among seedlings and saplings in all three forest classes, pioneer saplings were absent from lowland forests and invasive species was present only at the transition area (Table 11). Shade-bearers constituted the majority among seedlings and saplings in all forests classes except seedlings of highland forests where non-pioneer light demanders were the highest in proportion; there was also equal number of shade-bearers and non-pioneer light demanders among seedlings of lowland forests (Table 11).

The transition area had the highest representation of pioneers both among the seedlings and saplings while the highlands had the highest representation of non-pioneer light demanders (Table 11). However, the highlands had the least representation of shade bearers both among the seedlings and saplings. The transition area had the highest representation of shade bearers among the seedlings while the lowlands had the highest representation of shade bearers among the saplings.

The specific ecological guild of about 5% saplings at the lowlands and highlands could not be determined (unknown) while 5% of the transition area seedlings were equally 'unknown' (Table 7).

Table 11: Guild proportion (%) of seedlings and saplings of the three forest classes

	Seedling			Sapling		
	Lowland	Transition	Highland	Lowland	Transition	Highland
Pioneer	14.29	20.00	8.00	0.00	8.82	7.89
Non-pioneer light demanding	42.86	20.00	48.00	20.00	32.35	39.47
Shade-bearers	42.86	50.00	40.00	75.00	58.82	47.37
Invasive	0.00	5.00	0.00	0.00	0.00	0.00
Unknown	0.00	5.00	0.00	5.00	0.00	5.26

4.7 Canopy closure

There was a decline in canopy closure with respect to decreasing altitude: the mean canopy closure for highland forests was 89.06 %, 87.84 % for the transition portion and 84.9 % for lowland forests (Table 5).

CHAPTER FIVE

5.0 DISCUSSION

5.1 Floristic composition

Trees were the highest in number among the various life forms (or growth habit) and this is consistent with other forest studies at different regions of Ghana (Hall & Swaine, 1981; Vordzogbe *et al.*, 2005; Anning *et al.*, 2008; Addo-Fordjour *et al.*, 2009b; Pappoe *et al.*, 2010). The presence of just a single species of epiphyte among the species list could be attributed to the hardly accessible habitat of some epiphyte coupled with logistic limitations that is associated with studying epiphytes. These constraints have also been discussed by Etisa (2010). More so, reports on vascular epiphytes sometimes do not specify the habit of those epiphytes, as to whether they are true epiphytes, hemi-epiphytes, accidental epiphytes, occasional epiphytes or other forms which results in inaccuracies for comparisons.

In addition, the fact that some species change their habit in accordance to growing conditions could have affected the numbers of all life forms; thus the precise life form definition for some plant species becomes difficult in this condition as observed by Hawthorne and Jongkind (2006). *Uvaria* or *Combretum* species, for instance, behave and flower as shrubs when growing in open vegetation but become lianas when they live long enough and forests develop around them (Hawthorne & Jongkind, 2006). In this study, there was identification challenge for some species such as *Dichapetalum angolense* which was found growing sometimes as liana and sometimes as shrub or tree.

The dominance of Fabaceae family is similar to findings of Addo-Fordjour *et al.* (2009b) in another Semi-deciduous forest of Ghana. The reason for Fabaceae being the most predominant family (in terms of species richness) could be due to its origination from aggregation of the now three sub-families namely, Mimosaceae, Caesalpiniaceae and Papilionaceae. Otherwise, Euphorbiaceae would have been the predominant family in this study because Malvaceae, the family after Fabaceae is also an aggregation of the now three sub-families: Bombacaceae, Tiliaceae and Sterculiaceae.

The incidence of less number of plant species with respect to increase in plot number (Figure 4) is consistent with observation of Magurran (1988) who attested that majority of plant species are rare within a normal ecological community while a moderate number are common with only few being very common. When species dominance exists for few species within an area, there is a high propensity for driving majority of the species to be rare while maintaining dominance of the few in the face of disturbances.

However, considering the star rating system which assigns rarity with respect to global distribution, there were few rare plants: 1 black star (rare internationally and at least uncommon in Ghana), 8 gold stars (Fairly rare internationally and locally) and 17 blue stars (widespread internationally but rare in Ghana or vice-versa) while green stars (common in Ghana and of no particular conservation concern) were 159 in number. The presence of 7 red stars and 9 scarlet stars could be an indication of serious exploitation activities in the GSBA. Pink stars which are moderately exploited were slightly higher in number (21) than the scarlet (9) and red stars (7).

Their higher presence than red and scarlet stars could also be that the value of some pink stars are yet to be ascertained (Hawthorne *et al.*, 1997) otherwise they would have dwindled under pressure due to poaching.

5.1.1 Influence of elevation on floristic composition

Elevation does determine the floristic composition of a forest (McCullough *et al.*, 2007; Hawthorne & Jongkind, 2006; FAO, 2002). High altitude forests have been found to be relatively more species rich than lowland forests in some forests of Cameroun (Tchouto *et al.*, 2004). However, no pattern of species richness was observed in the different forest types of varying elevation in this study. This lack of species richness pattern could be an indication of indiscriminate harvesting of forest products in all parts of the GSBA. Human disturbances in forests affect vegetation patterns, floristic composition and species richness of many forest types (Tchouto *et al.*, 2004). Although logging and other commercial extractive activities are prohibited in the GSBA, findings by Afriyie (2010) indicate increase in human populations around the Tano Offin GSBA. This has resulted in decrease in available farmlands and continual cultivation of these small farmlands have rendered them infertile, collectively justifying the GSBA as potential farmlands left. Effect of the encroachment on the GSBA is also revealed in the low representation of the ‘common but under exploited stars’ (i.e. Scarlet, Red and Pink) in all three forest classes. History of disturbance is an important reason for the local variation of forest composition (Wong, 1989).

The exclusive presence of *Cola boxiana* at highland forests more than once confirms findings by Hawthorne and Jongkind (2006) who noted the prevalence of this species at Upland forests. At an elevation of 795 m in Atewa forest (one of the Upland forests of Ghana), *Cola boxiana* was also present (McCullough *et al.*, 2007). Nevertheless, the exclusive representation of some species at some forests classes in this study may not have been restricted by elevation *per se*, but other factors have contributed. For example, *Berlinia tomentella* recorded to occur strictly in highland forests in this study is also reported to be limited to swamps, riverbanks or in lower parts of landscape in moist forests (Hawthorne & Jongkind, 2006). On the other hand, two swampy species (*Symphonia globulifera* and *Ficus bubu*) recorded in this study were both found in the transition area.

5.2 Forest structure

On *per* hectare basis, the herb layer contained the highest individual plant species, followed by the shrub layer which was also higher in number than the tree layer. Similarly, there were more individuals at the shrub layer than they were in the tree layer at the Campo-Ma'an rain forest of Cameroon (Tchouto *et al.*, 2004). The greater number of individuals in the shrub layer as compared to the tree layer must be due to the many life forms which make up the shrub layer namely shrubs, shrublets, small trees (pigmy trees and treelets), immature large trees, liana, and hemi-epiphytes, which are not usually found in the tree layer.

5.2.1 Species diversity

There was no significant difference in species diversity of the tree layer, shrub and herb layers as shown by the Shannon-Wiener diversity index. Typical values reported for Shannon-Wiener index range from 1.5 to 3.5 (Kerkhoff, 2010; Magurran, 1988) and so all three layers named above could be said to have recorded moderate diversity as their diversity values ranged from 2.48 to 2.55. However, since the Shannon-Wiener index incorporates both evenness and richness and because most species had single incidence (Figure 4), there is a presupposition that an imbalance of evenness might have smothered species richness in the Shannon index calculation thus reflecting a moderate diversity state for all three layers. According to Kerkhoff (2010), the fact that Shannon-Wiener index integrates both components of biodiversity is a weakness when comparing sites with great differences in species richness.

5.2.2 Diameter class distribution

Results of other studies conducted in some Moist Semi-deciduous forests of Ghana (Pappoe *et al.*, 2010; Addo-Fordjour *et al.*, 2009b) agree with findings in the Tano Offin GSBA where there was a similar decrease in the number of individuals in the various diameter groups as tree and liana sizes increased so that the highest number of trees and lianas with dbh ≥ 10 cm were found in the 10 – 30 cm diameter class. However, tree diameters could suggest tree age (Andreu *et al.*, 2009) and so the preponderance of trees and other plant forms with dbh ≥ 10 cm in the 10 – 30 cm diameter class imply abundance of young trees and thus a possible harvesting of older bigger trees in the GSBA.

Since the establishment of the GSBA, there have been reports of illegal harvesting of timber and prevalence of chainsaw lumbering (The Chronicle, 2011; FC, 2007; Asamoah *et al.*, 2011). History also shows that in the 1970s and 1980s, the reserve in general was partitioned into 16 timber concessions and the last official logging was undertaken in 1991 (Ntiama-Baidu *et al.*, 2001). This must have also contributed to fewer trees of higher diameter class in the GSBA.

5.2.3 Basal area

With reference to average value for basal area of tropical forest found to be 35 m²/ha (Philip, 1983), the basal area of the GSBA recorded in this study as 28.36 m²/ha is below average. Over the years, there has been decline in basal area as a result of logging of the Tano Offin Forest Reserve even before the GSBA was demarcated: between the years of 1990 and 2000, 5 % or 26.76 ha of forest cover of Tano Offin were lost, amounting to 2.76 % reduction in basal area (Djablatey, 2005).

Annual forest loss of Tano Offin Reserve in general is pegged at 0.3 % and as a result, basal area declined from 24.3 m²/ha to 18.9 m²/ha between the years of 1990 and 1996 and then it further declined from 18.9 m²/ha to 16.9 m²/ha between 1996 and 2001 (Djablatey, 2005). Establishment of the GSBA with logging prohibition then must have appreciated the basal area though it is not completely adhered to (The Chronicle, 2011; Asamoah *et al.*, 2011; Afriyie, 2010).

5.2.4 Height

Average tree height of the emergent layer was 46.19 m, similar to the report by FC (2007) where the average maximum height of trees in the reserve was found to be about 45 m. The findings of decreasing number of trees with respect to increasing height classes of the tree layer, in relation to decreasing number of trees with respect to increasing tree size, adds credence to the possible exploitation of older trees as tree size tends to correlates with tree height (Addo-Fordjour *et al.*, 2009b). More so, greater constituents of the emergents were non-pioneer light demanders which are known to include most of the timber species (Wong, 1989).

Pioneers were least represented in the emergent layer (> 35 m) as they hardly exceed the height of 20 - 30 m (FAO, 2002) and they decline in numbers with respect to increasing size (Hall and Swaine, 1988). Most constituents of the understorey were shade-bearers which flourish beneath upper and lower canopies. What could have also compounded the great number of shade bearers at the understorey might be the presence of cryptic pioneers which are often misclassified as shade-bearers; unlike pioneers, they tolerate shade later in life (Hawthorne, 1993).

5.2.5 Structural significance

Celtis mildbraedii representing as the most significant species is consistent with the reported feature of the Moist Semi-deciduous forests of Ghana (Hall & Swaine, 1981) which constitute parts of the Tano Offin GSBA. *Celtis mildbraedii* together with *Triplochiton sclerexylon* are known as the most common species of the Semi-deciduous forests of Ghana (Hall & Swaine, 1981). Although *Pterygota macrocarpa*, *Mansonia altissima* and *Terminalia superba* are

reported to be the dominant timber species of the GSBA, FC (2007), the less favourability of *C. mildbraedii* as timber species (Dabo pers comm.) compared to *P. macrocarpa*, *M. altissima* and *T. superba* as well as *T. sclerexylon* perhaps must have led to their exploitation, resulting in their low significance in this study and the high significance of *C. mildbraedii*. In conformity to exploitation pressure, *M. altissima*, *T. superba*, *P. macrocarpa* and *T. sclerexylon* have all been classified under the reddish star system (Hawthorne, 1993).

The exploitation must have necessitated the creation of *P. macrocarpa*, *M. altissima* and *T. superba* plantations in a Taungya system at the reserve (Birdlife International, 2011). The significance of *Celtis mildbraedii* was followed at a wider margin by *Strombosia pustulata* and then *Hymenostegia afzelii*. When present, *Strombosia pustulata* is reported to have high incidence (Hawthorne & Jongkind, 2006) and thus it was not surprising that *S. pustulata* recorded the highest frequency value after *Celtis mildbraedii*. Likewise, *Hymenostegia afzelii* when present is reported to occur in abundance (Hawthorne & Jongkind, 2006) and is also therefore not surprising that it recorded the highest value for density after *Celtis mildbraedii*. *Dalbergia saxatilis* and *Monodora myristica* were the least significant species because they were the least dominant species.

Rinorea welwitschii was the most significant species for trees and other plant life forms with dbh < 10 cm in the GSBA as members of the *Rinorea* family are noted to be locally dominant and widespread understorey species (Hawthorne & Jongkind, 2006). This assertion is further confirmed in this study by the highest frequency score attained by *Rinorea oblongifolia*. The

local abundance of *Cleidion gabonicum* (all 20 individuals were found on a single plot) at the shrub layer concurs with the view of Hawthorne and Jongkind, (2006) who found that *Cleidion gabonicum* is a gregarious understorey tree.

5.3 Influence of elevation and invasive species on the structure

5.3.1 Species diversity

Diversity indices give a quantitative view of diversity and thus provide information essential for understanding community's numerical structure (Beals *et al.*, 1999) and useful for comparing and prioritizing among sites (Vermeulen & Koziell, 2002). Although Shannon-Wiener and Simpson's diversity indices assess different facets of diversity through relative weighting assigned to evenness and species richness (Magurran, 1988), these diversity indices indicated that floristic diversity does not differ significantly in all three forest types of the tree layer. In addition, diversity of the shrub and herb layers of the highland, transitional and lowland forests also did not differ considerably (Table 5).

If forests at higher elevations have been found to differ significantly in diversity when compared to that of lowlands forest (Tchouto *et al.*, 2004; Hall & Swaine, 1981), then the insignificant differences of the indices in the various forest types could either be a further support for the point that the GSBA is indiscriminately exploited and so actual diversity patterns may have been tampered with; or that diversity indices are sample size sensitive so that populations with different sample size tend to greatly affect the results (Peet, 1975). Peet (1975) showed that with just a change in one species to another in a sample of 1000 individuals through sampling error,

there were major decreases or increases of actual results of 14 indices that he was experimenting with; so that if indices are to be meaningful, they should be relatively insensitive to small changes as these.

In addition, species richness and evenness are unrelated aspects of diversity. While species richness results mainly from historical factors such as dispersal events, and extinction due to past climatic and geological events, abundance or evenness on the other hand relates to the combination of each species' life history traits (such as reproductive rate) and population regulatory interactions such as predation, parasitism and competition (Barrantes & Sandoval, 2009). Thus, species lose their identity and most vital information is lost by the time all the species are aggregated into a single digit index which makes it quite impossible for inferences to be made such as species' biogeographical patterns (Barrantes & Sandoval, 2009).

Invasive species are known to affect the species composition and the numerical structure of a forest (Anning & Yeboah-Gyan, 2007; Luwum, 2002). While it is argued that invasion adversely affects the development of indigenous plants and even leads to their extinction sometimes, it is also reported that Central European flora has undergone diversity enrichment as a result of plant invasions (Di Castri, 1989). Apparently, invasive species did not have significant influence on plant species diversity of the tree, shrub and herb layers of all three forest classes in this study. This is in sync with Bosu *et al.* (2013) who found no differences in species composition of an invaded forest ecosystem of Ghana (Afram Headwaters Forest Reserve) when compared to its un-invaded parts.

A further study of the characteristics of the shrub and herb layers was done in view of prevalence of invasive species at these layers at the time of data collection. It was informative that invasive species were present only at the transition area which had the lowest percentage of shade bearers and non-pioneer light demanders but the highest with pioneers. If non-pioneer light demanders and shade bearers grow in undisturbed forest and pioneers flourishes in disturbed forests (Wong, 1989), then it implies that the opening of the canopy supported the growth of ‘disturbed-area-loving-species’ which included the pioneers and invasive species. According to Hale (2004), while a certain percentage of light may be enough for natural regeneration, it can also encourage the growth of competing vegetation.

5.3.2 Diameter class distribution and basal area

For the tree layer, highland forest had the highest basal area while the lowland forests had the least (most contribution to basal area in all three forest classes came from trees, as lianas in this category were few). While the highland forests fall within the Upland Evergreen forest zone, the transition area and lowlands fall within the Moist Semi-deciduous zone, known to contain much of the country’s important timber species (NBSG, 2002; Hall and Swaine, 1981). Lowland forests are likely to generating large numbers of big trees due to generally abundant supply of groundwater (Summers, 2006). In this study, the highest girth encountered was a *Parkia bicolor* tree with a dbh of 146 cm found in a lowland forest.

Thus, the possession of more timber species at lowland forests might have attracted timber-exploiters who by harvesting timbers (which are of bigger girth) have contributed to reducing the

basal area. Moreover, the timber species found on the highland forest may have been spared through past protection where logging was forbidden in Hill Sanctuaries - forested hills of which the Tano Offin Forest Reserve was included (Ntiamoa-Baidu *et al.*, 2001).

For the shrub layer, lowlands forests had the biggest mean basal area value ($G = 4.34 \text{ m}^2/\text{ha}$) when compared to the transition zone ($G = 3.59 \text{ m}^2/\text{ha}$) and highland forests ($G = 3.80 \text{ m}^2/\text{ha}$). The influence of varying environmental factors such as temperature, soil/geology, and rainfall should be a contributing factor to this result. Nevertheless, disturbances cannot be ruled out. Disturbed forests are often seen with few large and disturbance in the form of logging creates lots of gaps which get occupied with dense stands of young trees (FAO, 2002). The lowland forests in this study seemed much disturbed and the many young trees and lianas must have contributed to the higher mean basal area at this level.

Unlike the highland forests which had 75 individual plants and 39 species in the $> 0.1 - 2 \text{ cm}$ -diameter class, forest of the transition area had a greater number of individual plants (110) in this diameter class ($> 0.1 - 2 \text{ cm}$) of the shrub layer although it had only 38 species. This suggests the prevalence of gregarious species in the transition area, such as *Cleidion gabonicum* as found in this study.

Forests with invasive species recorded lower mean basal area at both the tree and shrub layers. Addo-Fordjour *et al.* (2009b) also reported a lower mean basal area for disturbed and invaded part of Tinte Bepo forest when compared to its undisturbed part. This must be due to competition

for resources for growth by invasive species (Ward & Worthley, 2004) which can hinder the growth of native plant species.

5.3.3 Height

There was a general increase in the number of taller trees with increase in elevation as highland forests had more individuals in the emergent and upper canopy layers while the transition area had more individuals in the lower canopy and understorey layers. The record of more tall trees at highlands contrasts with the report of McCullough *et al.* (2005) who found out that most trees in upland evergreen forest of Krokosua GSBA rarely exceeds height of 45 m though those of the surrounding lowland forest often exceeds 50 – 60 m. Similarly, taller trees with height up to 50 m were found in lowland forests than were found at higher grounds of Cameroun which had tree height of 25 – 35 m (Tchouto *et al.*, 2004).

Rainfall and soil conditions co-vary (Swaine, 1996) and so high grounds which receive high rainfall are more prone to leaching and are poor in nutrients (Ward & Worthley, 2004) which lead to forests short in stature (Hall & Swaine, 1981). Therefore, the possession of more tall trees in highland forests could be a reflection of more timber exploitation at the lowlands leaving more tall trees at the highlands. In the same way, a disturbed portion of the Tinte Bepo forest was found with lower mean heights and there were more trees in the understorey layer when compared with its undisturbed portion (Addo-Fordjour *et al.*, 2009b).

5.3.4 Structural significance

Celtis mildbraedii was the most significant species for trees and lianas with dbh ≥ 10 cm due to the fact that it was the most dominant, most frequent and of the highest density in all forest classes except the highlands where *Hymenostegia afzelii* had the greatest density. At an elevation of 690 m, *Hymenostegia afzelii* was also predominant at Atewa Forest range, one of the upland evergreen forests of Ghana (McCullough *et al.*, 2007; Hawthorne & Jongkind, 2006). Although *Celtis mildbraedii* was the most significant species in all three forest classes, its IVI value was highest in the highland class compared to lowlands and transition belt. At highlands, the forest transit from being semi-deciduous to an upland evergreen type (Hall & Swaine, 1981) and thus trait of the semi-deciduous type (such as dominance and commonness of *Celtis mildbraedii*) diminishes.

For trees and other plant forms with dbh < 10 cm, *Rinorea welwitschii* was the most significant species for the lowlands and the highlands forests while *Hymenostegia afzelii* was the most significant species for the transition zone. *R. welwitschii* was completely missing from the transition zone and this could be an indication of its narrower ecological adaption and need for specialized environment. *Rinorea* species were common at Ajenjua Bepo - a Hill Sanctuary with highest altitude point at about 500 m (Siaw & Dabo, 2009) but specifically, *Rinorea welwitschii* is reported to be widespread in African lowland forests, montane areas or rocky hills (Hawthorne & Jongkind, 2006).

The high significance of *R. welwitschii* resulted from its dominance and greatest density in both the lowlands and the highlands. The small significance of *R. welwitschii* in the highlands at the tree layer (though most significant at the shrub layer) could be due to its natural small size and height of about 15 m (Hawthorne & Jongkind, 2006).

The underlying reason for the varying importance or significance (dominance, density and frequency) of the various species along the three elevation gradient could be due to environmental variables such as rainfall and soil which are known to account for the variation in forest composition and structure across forest types in Ghana and thus limits species distribution (Hall & Swaine, 1981). The distribution and abundance of plant species differ along environmental gradients as plant species vary in their requirement of and tolerance to environmental factors (Swaine, 1996). Though forests types in West Africa are defined by structure and species composition, they are actually controlled on a greater part by precipitation and soil type (Hawthorne & Jongkind, 2006). The varying significance could also be a reason of soil catena development where different soils are formed due to varying soil forming factors from hill tops to valleys so that plant growth differ along slope gradient with growth being profuse at the foot or the flatter portions of the slope (Hewitt, 2012).

In relation, upland plant species at Mt. Tampotika were abundant on ridge top of an elevation of only 350 m because of poor soil nutrient and exposure of the ridge top (Summers, 2006). According to Hawthorne and Jongkind (2006), there are patterns of species distribution which are not necessarily ecological rather, are biogeographic patterns thought to be related to historical

changes in climate and vegetation and it often results in plant species being mountain endemic, endemic to rocky land, or being restricted to certain regions of same forest types.

5.4 Natural Regeneration

Less than 50 % of the adult population were regenerating as saplings and seedlings in this study and this is in variance to the findings of Hall and Swaine (1988) who found 68 % of the adults in their study regenerating and concluded that the Ghanaian forests were generally well-represented by juveniles. The lower representation of adult tree populations regenerating as seedlings and saplings could have been due to limiting factors which include seed source, an appropriate seed bed and light, a suitable microclimate, freedom from vegetation competition and browsing (Hale, 2004). According to Hall and Swaine (1988), the canopy of a forest is composed of trees which probably started life over a hundred years earlier, and beneath it are the survivors of successive periods of regeneration from seed. Plant species differ in growth rate, fecundity and mortality rate and these differences thus reflect in the transformation of the composition of young population into adult population (Hall & Swaine, 1988).

Saplings had higher species richness than seedlings and this was further supported by a higher value of species diversity index of the saplings as compared to the seedlings. The emergence of seedlings might have been challenged by the absence of seeds which could be due to factors such as removal of parent trees and lack of effective dispersal mechanisms. Since most forest trees have recalcitrant seeds and are very unlikely to be found in seed banks, illegal logging activities (as reported earlier) acting in concert with unfavourable growing conditions might have led to a

lower representation of species as seedlings. For a successful natural regeneration, a seed source, an appropriate seed bed, a suitable microclimate, freedom from vegetation competition and browsing and light are very crucial (Hale, 2004; Ward & Worthley, 2004).

Other constituents of the regeneration flora which occurred exclusively as saplings (*Anthonotha fragrans*, *Drypetes gilgiana*, *Garcinia kola*, *uvariostrum pierreanum* and *Xylopia villosa*) and seedlings (*Lecaniodiscus cupaniodes*, *Lovoa trichiliodes* and *Mallotus oppositifolius*) were comparable to findings of Addo-Fordjour *et al.* (2009b) where 7 species of the regeneration vegetation were missing from the adult tree population at Tinte Bepo forest reserve. Seedlings of *Lovoa trichilioides* if present are often found within the vicinity of parent trees (Hawthorne & Jongkind, 2006). The Red Star status of the species (Hawthorne, 1993) suggests exploitation pressure on adult trees which might have led to their absence among the adult trees in this study. *Lecaniodiscus cupaniodes* and *Mallotus oppositifolius* may have been new to the population as colonisers. Though both are shade tolerant species, they are reported to be very common in secondary forests and *Mallotus oppositifolius* is reported to exhibit weedy behaviour (Hawthorne & Jongkind, 2006). Furthermore, *Lecaniodiscus cupaniodes* is purported to be a cryptic pioneer and that adds credence to the fact that it is a coloniser and now making appearance into the community; cryptic pioneers regenerate in gaps under canopy but tolerate shade later in life and have thus been misclassified with shade-bearers in practice (Hawthorne, 1993).

5.4.1 The influence of elevation and invasive species on natural regeneration

The exclusive presence of invasive species at the transition area may have affected its sapling and seedling diversities as it had the lowest score of diversity in both cases. The effect of invasive species was significant among seedlings than it was with the saplings but generally, invasive species in a competitive and alleleopathic manner stifle the regeneration of indigenous plants (Luwum, 2002; Bosu & Apetorgbor, 2007).

The presence of invasive species at the transition area seemed to have affected the quantity of regeneration as mean regeneration count was 39 at the transition area compared to 50 and 43 for the highland and the lowland respectively. *Broussonetia papyrifera* and *Chromolaena odorata*, the two invasive species recorded in this study were also found to hinder regeneration of native plants at a disturbed part of the Tinte Bepo forest (Addo-Fordjour *et al.*, 2009b). As a result of disturbances, canopy openings can either stimulate or hinder plant growth, depending on the kind of species (Hall & Swaine, 1988). It is particularly alarming for light demanding species when the overstorey mother trees have not matured enough to produce seeds thereby encouraging colonisation by competing species (Hale, 2004).

A good representation of saplings of *Strombosia pustulata* in all three forest classes agrees with Hawthorne and Jongkind (2006) who reported the abundance of saplings of this species, especially in the shade. Hall & Swaine (1988) also found saplings of *S. pustulata* very common in their assessments of some forests reserves in Ghana. Similar to the findings in this study,

seedlings of *Guibourtia ehie* was noted to be very abundant around mother trees (Hawthorne & Jongkind, 2006) irrespective of elevation.

5.5 Canopy closure

There was a decline in canopy closure with respect to decreasing altitude: the mean canopy closure for highland forests was 89.06 %, 87.84 % for the transition portion and 84.9 % for lowland forests. For forest canopies' classification, when 10-39 % of the sky is obstructed by tree canopies, forest canopy is considered as open and moderately closed when 40-69 % of the sky is obstructed by tree canopies or closed when 70-100 % of the sky is obstructed by tree canopies (PSU, 2010; O'Neil *et al.*, 2001). The forest canopy of the Tano offin forest GSBA could thus be described as closed canopy.

Mean canopy closure was highest in the highlands; in relation to more taller trees found in the highland forests (highland forests had more individuals in the emergent and upper canopy layers) this finding agrees with that of Jennings *et al.* (1999) who reported that taller trees in a forest resulted in greater canopy closure. Ideally, forests under exploitation should have more of an open canopy than closed. Although the study indicated exploitation of the GSBA, the generally closed forest of Tano Offin GSBA as found in this study must have been due to the structure of the forest and structure of the canopy.

The structure of the forest irrespective of the amount of basal area, determines to a large extent the amount of light transmitted to the forest floor. The basal area of a stand with many small

trees will have a very dense canopy, and will transmit less light (greater canopy closure) than a stand with the same basal area but fewer, larger trees (Hale, 2004). Thus the fewer larger trees in this regard supported the view of exploitation of the GSBA. Fiala *et al.* (2006) also reported that the abundance of trees with open, spreading crowns in contrast with trees with compact crowns could account for variability in measurements of canopy closure. Moreover, light system beneath forest canopy varies with respect to time and space such that direct sunlight and sun flecks on sunny days tend to cause large differences in light levels at scales of less than one metre; on overcast days, light distribution is diffused and it varies more gradually from place to place across a stand (Hale, 2004).

5.5.1 Relation of canopy closure to natural regeneration

Canopy closure affords a direct link to assess the growth and survival of seedlings and saplings at the point of measurement (Jennings *et al.*, 1999). Highlands had the least percentage of adult tree species regenerating. As Marchi and Paletto (2010) found a negative linear correlation between canopy closure and natural regeneration, so highland (with the most closed canopy), had the least proportion of regeneration of its adult. Light is the most limiting factor for regeneration and canopy gaps therefore influence some parameters of microclimate (such as air humidity, light intensity and air temperature) in the establishments of new species (Ward & Worthley, 2004).

The closed canopies of all forest classes favoured the shade-bearers and non-pioneer light demanding species that composed a greater portion of the natural regeneration flora in each

forest class. Shade-bearers and non-pioneer light demanding species germinate in the shade of undisturbed forest (Hawthorne, 1993). The absence of pioneer saplings from lowland forests can be a sign of recent heavy disturbances. The presence of pioneer species in forests is directly dependent on past canopy gaps and sustained space of illumination for their crowns as they transit to adulthood (Hall & Swaine, 1988). Tchouto *et al.* (2004) found out that pioneer species increase with increasing degree of disturbances. The ecological guilds of plant species that were unknown may require further research in the form of physiological experiments as most of the known ones were determined based on observed local distribution patterns (Hawthorne, 1993).



CHAPTER SIX

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The present work sought to determine the floristic patterns of the Tano Offin GSBA, assessing the floristic composition, structure, natural regeneration and canopy closure as well as the influence of elevation and invasive species on the aforementioned.

There were 240 plant species that were identified during the assessment and these comprised of 170 trees, 41 lianas, 12 shrubs, 7 herbs, 7 herbaceous climbers, 1 epiphyte, 1 grass and 1 fern. Fabaceae was the predominant family in terms of species richness. Incidence of plants species decreased with increase in the number of plots so that 97 out of the total 240 plants occurred just once while only 3 plant species occurred on all plots. In view of the star rating system which assigns rarity with respect to global distribution, there were few rare plants: 1 Black star, 8 Gold stars and 17 blue stars while Green stars were 159 in number. The presence of 7 Red stars and 9 Scarlet stars indicates serious exploitation activities in the GSBA.

On a 0.5 ha area of each forest class, highlands had the most of the rare species, that is - 4 Gold stars and 8 Blue stars (12 in all) as against 1 Black star, 2 Gold stars and 4 Blue stars (7 in all) of the Lowlands, and 4 Blue stars (4 in all) of the transition area. The lowlands had the most of the Scarlet stars while the highlands had the least of the Pink Stars. Thus the star rating system should be updated, especially the reddish star system, to reflect current exploitation pressure on species so as to accord the necessary conservation attention.

Species that occurred more than once and exclusively on highlands include *Berlinia tomentella*, *Coffea stenophylla*, *Cola boxiana*, *Culcasia parviflora*, *Desplatsia chrysochlamys*, *Hexalobus crispiflorus*, *Momordica angusticepala*, *Picralima nitida*, and *Triclisia dictyophylla*; those of the transition zone include *Acacia kamerunesis*, *Duguetia staudtii* and *Leptoderris brachyptera* and that of the lowlands is *Strychnos campicola*. In addition, *B. tomentella* has been noted to occur in swampy areas. This is indicative of the specialized growing environment required by some species as well as the adaptive strategies adopted by others.

There was no significant differences in species diversity of the tree layer, shrub and herb layers and with typical values reported for Shannon-Wiener index ranging from 1.5 to 3.5, diversity of all three layers named above were determined to be moderate as their diversity values ranged from 2.48 to 2.55. If serious attention is not given to maintain and upgrade the floral diversity of the GSBA, its conservation value will decrease.

There was a decrease in the number of individuals in the diameter groups as trees, shrubs and liana sizes increases so that the highest percentage of trees, shrubs and lianas with dbh ≥ 10 cm were found in the 10 – 30 cm diameter class. In addition, the basal area of the GSBA was found to be 28.36 m²/ha which was below the 35 m²/ha conventional value for basal area of tropical forests. This is evident of timber exploitation in the GSBA. The implication is that there are abundance of young trees to rejuvenate the forest if exploitation is curbed and care is taken to nurture the GSBA unto a functionally matured forest in the years to come.

With respect to classifying trees with dbh ≥ 10 cm into height classes, four classes were obtained namely the understorey which constituted the highest individuals (443), the lower canopy which comprised of 316 individuals, the upper canopy which contained 102 trees and the emergent which constituted 73 individuals. Average tree height of the emergent layer was 46.19 m consistent with report by FC (2007) where the average maximum height of trees in the reserve was found to be about 45 m.

Celtis mildbraedii was the most significant species among trees, shrubs and lianas with dbh ≥ 10 cm (tree layer) and in all the three forest classes. *Rinorea welwitschii* was the most significant species at the shrub layer in general as well as the shrub layers of the lowlands and the highlands but completely missing from the transition area. *Rinorea oblongifolia* was the most frequent species at the shrub layer. In sync with conservation strategies where precedence is given to plant populations that are limited to a narrower area, *Rinorea* species must be accorded greater conservation concern. In totality, the significance or importance of many of the species encountered in the study was low, resulting from interplay of dwindling abundance, dominance (in terms of size) and commonness.

It was revealing that invasive species were present only at the transition area which had the lowest percentage of shade bearers and non-pioneer light demanders but the highest with pioneers. Environmental conditions at the transition area appear to favour the establishments of invasive species, notably, the creation of gaps as a result of logging. Commencing the control of

invasive species at the transition area is tactical in restraining its spread unto the other forest classes. In all the forest classes, a greater percentage of constituents of the shrub and herb layers were shade bearers, followed by non-pioneer light demanders which were also in greater proportion than the pioneers. Pioneers were completely absent in the lowland shrub layer.

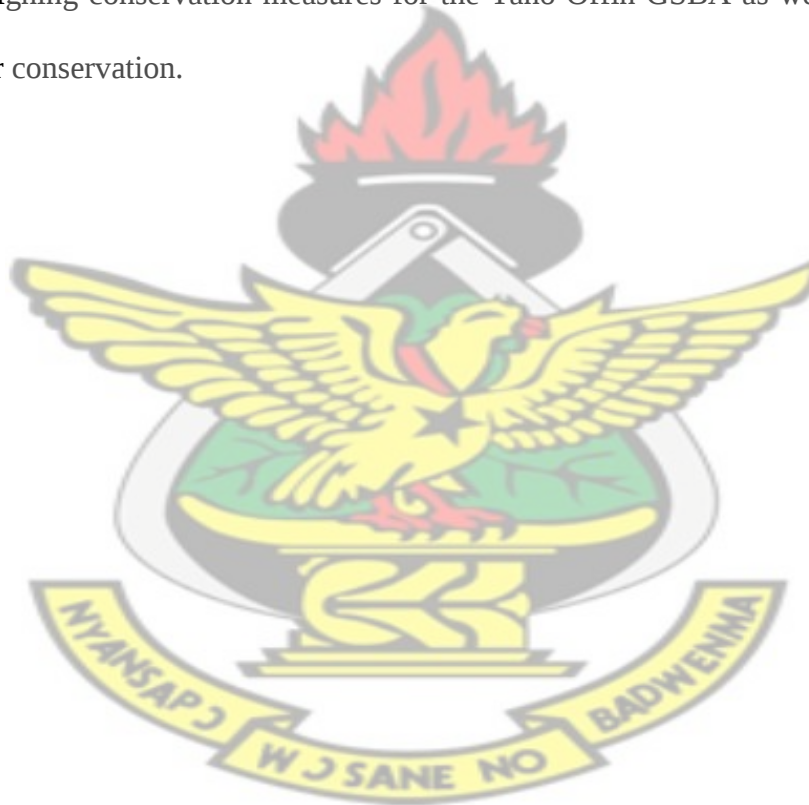
Basal area for trees and other plant life forms with $dbh \geq 10$ cm generally increased with increasing elevation. Elevation did not significantly affect basal area of trees other plant life forms $dbh < 10$ cm although lowlands forests had the biggest mean value for basal area at this layer. There was a general increase in the number of taller trees with increase in elevation. It is apparent that the structure of the forest with respect to elevation has been distorted. Forests with invasive species recorded lower mean basal area at both the tree and shrub layers.

A total of 74 species were found regenerating as saplings and seedlings. Species richness of saplings was 61 while seedlings constituted of 44 species. Eight species as constituents of the regeneration flora were absent from the adult community.

Invasiveness had significant influence on the species diversity of seedlings at the three forest classes. This is suggestive of early phase of attack and it will be commensurate to deal with it now. For the lowland forests, 50.94 % of the adult tree population were regenerating while 46.74 % were regenerating in the transition area and 42.86 % at the highlands. Pioneer saplings were absent from lowland forests. Shade-bearers and non-pioneer light demanding species composed a greater portion of the natural regeneration flora in each forest class. There was a decline in

canopy closure with respect to decreasing altitude but the forest canopy of the Tano offin forest GSBA in general was found to be closed.

The effect of varying environmental conditions in shaping the diversity, structure and natural regeneration of the GSBA forest is factual; nevertheless, effect of exploitation cannot be ruled. It is shown that the GSBA is under exploitation especially in lowland forests and multiple conservation strategies at different spatial levels are required. The information generated should be useful in designing conservation measures for the Tano Offin GSBA as well as for defining priority areas for conservation.



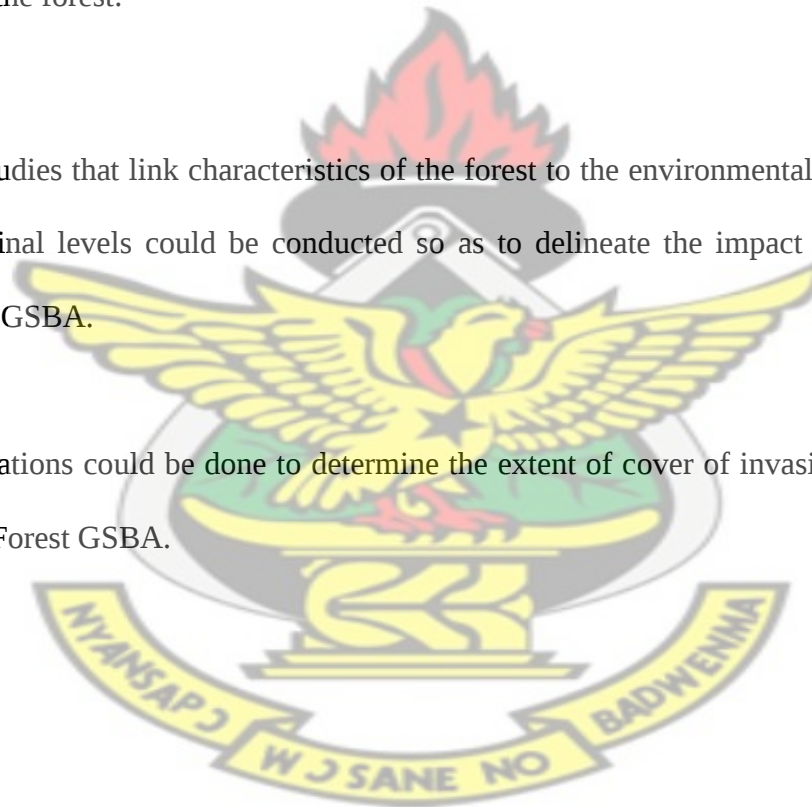
6.2 Recommendations for further studies

With the establishments of permanent sampling plots within the GSBA, a follow up investigations can be done to determine the productivity of the forest and also to ascertain the trend of disturbances within the GSBA.

Due to the mountainous and hilly nature of the Tano Offin Forest Reserve, an assessment could be done to determine the influence of slope and soil on the floristic composition, structure and regeneration of the forest.

Experimental studies that link characteristics of the forest to the environmental conditions of the different altitudinal levels could be conducted so as to delineate the impact of environmental elements on the GSBA.

Further investigations could be done to determine the extent of cover of invasive species within the Tano Offin Forest GSBA.



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APPENDICES

Appendix 1: Census of vascular plants in Ghana

(a) Indigenous			
Group	Families	Genera	Species
Pteridophytes	15	43	124
Gymnosperms	1	1	1
Angiosperms:			
Monocotyledons	30	227	780
Dicotyledons	127	806	2069
	173	1077	2974
(b) Introduced (Naturalised)			
Group	Families	Genera	Species
Monocotyledons	15	42	53
Dicotyledons	63	149	200
	78	191	253

Source: (NBSG, 2002)

Appendix 2: Grouping of plots into elevation and invasive classes.

<300 m (L)		> 300 m but < 500 m (T)	500 m – 700 m (H)	Invasiveness
Lowland		Transition	Highland	
Elevation				
Plot 1	569 m	H		Non-invasive
Plot 2	291 m	L		Non-invasive
Plot 3	264 m	L		Non-invasive
Plot 4	394 m	T		Invasive
Plot 5	482 m	T		Non-invasive
Plot 6	569 m	H		Non-invasive
Plot 7	623 m	H		Non-invasive
Plot 8	501 m	H		Non-invasive
Plot 9	328 m	T		Non-invasive
Plot 10	438 m	T		Invasive

Appendix 3: Statistical testing for differences: elevation and invasiveness

Unless specified, $P = 0.05$.

(a) Anova: influence of elevation on the Shannon-Wiener diversity at the tree layer

SUMMARY

Groups	Count	Sum	Average	Variance
Lowland	8	20.55685	2.569606	0.10029452
Transition	16	40.63872	2.53992	0.05841
Highland	16	40.61663	2.53854	0.20520293

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00592055	2	0.00296	0.02352323	0.976766	3.251924
Within Groups	4.656255572	37	0.125845			
Total	4.662176122	39				

(b) Anova: influence of elevation on the Shannon-Wiener diversity at the shrub layer

SUMMARY

Groups	Count	Sum	Average	Variance
Lowland	2	5.114198	2.557098999	0.232381
Transition	4	9.897813	2.474453275	0.151658218
Highland	4	9.785077	2.446269138	0.704672539

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.0165	2	0.00828	0.020692117	0.97958	4.737414
Within Groups	2.8013	7	0.40019			
Total	2.8179	9				

(c) Anova: influence of elevation on the Shannon-Wiener diversity at the herb layer

SUMMARY

Groups	Count	Sum	Average	Variance
Lowland	2	5.032516	2.516258066	0.072621479
Transition	4	10.17655	2.544136948	0.013907266
Highland	4	10.15225	2.538063378	0.044592636

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.00106	2	0.00053	0.01497	0.98517	4.7374
Within Groups	0.24812	7	0.03544			
Total	0.24918	9				

(d) Anova: influence of elevation on the Simpson's index of diversity at the tree layer

SUMMARY

Groups	Count	Sum	Average	Variance
Lowland	8	0.73263	0.091579	0.000988
Transition	16	1.588954	0.09931	0.000728
Highland	16	1.72375	0.107734	0.004409

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.001481	2	0.00074	0.326234	0.723691	3.251924
Within Groups	0.083968	37	0.002269			
Total	0.085449	39				

(e) Anova: influence of elevation on the Simpson's index of diversity at the shrub layer

SUMMARY

Groups	Count	Sum	Average	Variance
Lowland	2	0.272733	0.136367	0.012665
Transition	4	0.53026	0.132565	0.004015
Highland	4	1.008581	0.252145	0.048269

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.033615	2	0.016807	0.694028	0.530919	4.737414
Within Groups	0.169519	7	0.024217			
Total	0.203133	9				

(f) Anova: influence of elevation on the Simpson's index of diversity at the herb layer

SUMMARY

Groups	Count	Sum	Average	Variance
Lowland	2	0.257952	0.128976	0.005318
Transition	4	0.446118	0.111529	0.00011
Highland	4	0.492982	0.123245	0.001153

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.000489	2	0.000245	0.188135	0.832558	4.737414
Within Groups	0.009105	7	0.001301			
Total	0.009594	9				

(g) Anova: influence of elevation on basal area at the tree layer

SUMMARY

Groups	Count	Sum	Average	Variance
Lowland	8	184.7888	23.0986	270.7774
Transition	16	452.8547	28.30342	206.6225
Highland	16	496.5975	31.03734	158.2926

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	336.1998	2	168.0999	0.844016	0.438091	3.251924
Within Groups	7369.169	37	199.1667			
Total	7705.369	39				

(h) Anova: influence of elevation on basal area at the tree layer (p = 0.5)

SUMMARY

Groups	Count	Sum	Average	Variance
Lowland	8	184.7888	23.0986	270.7774
Transition	16	452.8547	28.30342	206.6225
Highland	16	496.5975	31.03734	158.2926

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	336.1998	2	168.0999	0.844016	0.438091	0.706296
Within Groups	7369.169	37	199.1667			
Total	7705.369	39				

(i) Anova: influence of elevation on basal area at the shrub layer

SUMMARY

Groups	Count	Sum	Average	Variance
Lowland	2	8.67254388	4.33627194	0.007487
Transition	4	14.3637879	3.590946975	0.26863
Highland	4	15.18578754	3.796446885	2.607431

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.745105	2	0.37255	0.301988	0.7485	4.7374
Within Groups	8.635671	7	1.23367			
Total	9.380776	9				

(j) F-Test and t-Test: influence of invasive species on species diversity (Shannon-Wiener index) at the tree layer

F-Test Two-Sample for Variances

t-Test: Two-Sample Assuming Unequal Variances

	non-invasive	Invasive		non-invasive	Invasive
Mean	2.538747541	2.571535	Mean	2.538748	2.571535
Variance	0.131477877	0.082783	Variance	0.131478	0.082783
Observations	32	8	Observations	32	8
df	31	7	Hypothesized Mean Difference	0	
F	1.588220607		df	13	
P(F<=f) one-tail	0.272332871		t Stat	-0.27269	
F Critical one-tail	3.371282212		P(T<=t) one-tail	0.394687	
			t Critical one-tail	1.770933	
			P(T<=t) two-tail	0.789374	
			t Critical two-tail	2.160369	

(k) F-Test and t-Test: influence of invasive species on species diversity (Shannon-Wiener index) at the shrub layer

F-Test Two-Sample for Variances			t-Test: Two-Sample Assuming Unequal Variances		
	Invasive	Non-invasive		Invasive	Non-invasive
Mean	2.4262	2.5175	Mean	2.4262	2.5175
Variance	0.401027	0.365	Variance	0.401027	0.365
Observations	2	8	Observations	2	8
df	1	7	Hypothesized Mean Difference	0	
F	1.098835		df	1	
P(F<=f) one-tail	0.329361		t Stat	-0.18396	
F Critical one-tail	5.591448		P(T<=t) one-tail	0.442092	
			t Critical one-tail	6.313752	
			P(T<=t) two-tail	0.884183	
			t Critical two-tail	12.7062	

(l) F-Test and t-Test: influence of invasive species on species diversity (Shannon-Wiener index) at the herb layer

F-Test Two-Sample for Variances			t-Test: Two-Sample Assuming Unequal Variances		
	Non-invasive	Invasive		Non-invasive	Invasive
Mean	2.550511	2.4786	Mean	2.550511	2.4786
Variance	0.032801	0.0113	Variance	0.032801	0.0113
Observations	8	2	Observations	8	2
df	7	1	Hypothesized Mean Difference	0	
F	2.900763		df	3	
P(F<=f) one-tail	0.424452		t Stat	0.727961	
F Critical one-tail	236.7684		P(T<=t) one-tail	0.259655	
			t Critical one-tail	2.353363	
			P(T<=t) two-tail	0.51931	
			t Critical two-tail	3.182446	

(m) F-Test and t-Test: influence of invasive species on species diversity (Simpson's index of diversity) at the tree layer

F-Test Two-Sample for Variances

	Non-invasive	Invasive
Mean	0.10198	0.0978
Variance	0.00251	0.0011
Observations	32	8
df	31	7
F	2.32989	
P(F<=f) one-tail	0.12363	
F Critical one-tail	3.37128	

t-Test: Two-Sample Assuming Unequal Variances

	Non-invasive	Invasive
Mean	0.10198	0.0978
Variance	0.00251	0.0011
Observations	32	8
Hypothesized Mean Difference	0	
df	16	
t Stat	0.28973	
P(T<=t) one-tail	0.38787	
t Critical one-tail	1.74588	
P(T<=t) two-tail	0.77574	
t Critical two-tail	2.11991	

(n) F-Test and t-Test: influence of invasive species on species diversity (Simpson's index of diversity) at the shrub layer

F-Test Two-Sample for Variances

	Non-invasive	Invasive
Mean	0.192	0.13778
Variance	0.0268	0.01088
Observations	8	2
df	7	1
F	2.4621	
P(F<=f) one-tail	0.4558	
F Critical one-tail	236.77	

t-Test: Two-Sample Assuming Unequal Variances

	Non-invasive	Invasive
Mean	0.192	0.138
Variance	0.02679	0.011
Observations	8	2
Hypothesized Mean Difference	0	
df	2	
t Stat	0.57839	
P(T<=t) one-tail	0.31073	
t Critical one-tail	2.91999	
P(T<=t) two-tail	0.62145	
t Critical two-tail	4.30265	

(o) F-Test and t-Test: influence of invasive species on species diversity (Simpson's index of diversity) at the herb layer

F-Test Two-Sample for Variances			t-Test: Two-Sample Assuming Unequal Variances		
	Non-invasive	Invasive		Non-invasive	Invasive
Mean	0.1252	0.11773	Mean	0.12516	0.1177
Variance	0.0018	0.00016	Variance	0.00176	0.0002
Observations	6	2	Observations	6	2
df	5	1	Hypothesized Mean Difference	0	
F	11.086		df	6	
P(F<=f) one-tail	0.224		t Stat	0.38396	
F Critical one-tail	230.16		P(T<=t) one-tail	0.35712	
			t Critical one-tail	1.94318	
			P(T<=t) two-tail	0.71424	
			t Critical two-tail	2.44691	

(p) F-Test and Mann-Whitney U-Test: influence of invasive species on basal area at the tree layer

F-Test Two-Sample for Variances			Mann-Whitney U-Test	
	Non-invasive	Invasive		
Mean	29.2714	24.695	N1	8
Variance	233.52	47.455	N2	32
Observations	32	8	R1	141
df	31	7	R2	679
F	4.92083		U1	105
P(F<=f) one-tail	0.01769		U2	151
F Critical one-tail	3.37128		U	105
			z	-0.77
			since the obtained z (-0.77) is less than 1.96, Ho is accepted, implying no difference.	

(q) F-Test and t-Test: influence of invasive species on basal area at the shrub layer

F-Test Two-Sample for Variances			t-Test: Two-Sample Assuming Unequal Variances		
	Non-invasive	Invasive		Non-invasive	Invasive
Mean	3.9222	3.4225	Mean	3.9222	3.4225
Variance	1.2716	0.0803	Variance	1.2716	0.0803
Observations	8	2	Observations	8	2
df	7	1	Hypothesized Mean Difference	0	
F	15.838		df	8	
P(F<=f) one-tail	0.1912		t Stat	1.1199	
F Critical one-tail	236.77		P(T<=t) one-tail	0.1476	
			t Critical one-tail	1.8595	
			P(T<=t) two-tail	0.2952	
			t Critical two-tail	2.306	

(r) Anova: influence of elevation on saplings diversity

SUMMARY

Groups	Count	Sum	Average	Variance
Lowland	2	4.0154	2.0077	0.40097
Transition	4	7.6718	1.9179	0.18337
Highland	4	8.1173	2.0293	1.04966

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.0267	2	0.01333	0.02276	0.9776	4.7374
Within Groups	4.1001	7	0.58572			
Total	4.1267	9				

(s) Anova: influence of elevation on seedlings diversity (p = 0.5)

SUMMARY

Groups	Count	Sum	Average	Variance
Lowland	2	3.9950	1.9975	0.0073
Transition	4	6.2497	1.5624	0.2310
Highland	4	8.1738	2.0435	0.0761

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.5234	2	0.261682	1.9730	0.2092	0.7666
Within Groups	0.9284	7	0.132633			
Total	1.4518	9				

(t) F-Test and t-Test: influence of invasive species on species diversity of saplings

F-Test Two-Sample for Variances

	Non-Invasive	Invasive
Mean	1.9473	2.1131
Variance	0.5522	0.2171
Observations	8	2
df	7	1
F	2.54375	
P(F<=f) one-tail	0.449442	
F Critical one-tail	236.7684	

t-Test: Two-Sample Assuming Unequal Variances

	Invasive	Non-Invasive
Mean	2.1131	1.9473
Variance	0.2171	0.5522
Observations	2	8
Hypothesized Mean Difference	0	
df	3	
t Stat	0.393421	
P(T<=t) one-tail	0.360151	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.720302	
t Critical two-tail	3.182446	

(u) F-Test and Mann-Whitney U-Test: influence of invasive species on species diversity of seedlings

F-Test Two-Sample for Variances

	Invasive	Non-Invasive
Mean	1.272276	1.984242
Variance	0.327584	0.044739
Observations	2	8
df	1	7
F	7.322098	
P(F<=f) one-tail	0.030377	
F Critical one-tail	5.591448	

Mann-Whitney U-Test

N1	2
N2	8
R1	3
R2	33
U1	0
U2	-3
U (min)	-3

U critical for $n=8/2$ at $p = 0.05$ one tailed is 1. Since -3 is smaller than 1, H_0 is rejected, implying significant difference

