DOES TAUNGYA FOSTER WOODY SPECIES DIVERSITY IN GHANA?
A case of the Afram Headwaters Forest Reserve

EMMANUEL AMOAH BOAKYE

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ABSTRACT

Taungya plantation is an Agroforestry land-use system in which woody species are interplanted with annual crops during the few years of plantation establishment until the canopy closes. Taungya plantation enhances the regeneration, establishment and succession of native woody species diversity by functioning as foster ecosystem. The ability of taungya plantation to foster natural regeneration of native woody species diversity was therefore, evaluated in comparison with adjacent natural forest in the Afram Headwaters Forest Reserve in Ghana. A total of 70 nested circular plots of horizontal radii 12.62 m, 8 m and 4 m were randomly established to assess the regeneration diversity of trees (height ≥ 3 m), saplings (height between 1 and 3 m) and seedlings (height ≤ 1 m) respectively. Species diversity was expressed in terms of Shannon-Weiner index, Species Richness, Shannon Evenness index and Density. Plantation stand characteristics namely, canopy cover percentage, age, perpendicular distances of sample plots to the boundary of the adjacent natural forest and stem density were also determined in each plot to establish their relationship with the Shannon-Weiner diversity index of the native woody species. Through snowball sampling method, taungya farmers were interviewed to solicit information about management practices having the potential to enhance the regeneration of native woody species diversity in the plantation. The amount of forest recovered through the taungya plantation was also quantified through post-classification comparison of ASTER images acquired in 2002 and 2008. The quantity of forest recovered through taungya plantation between 2002 and 2008 was 2,977 ha (26% expansion). The native woody species composition in the taungya plantation was less than the natural forest. Shannon-Weiner diversity index of seedlings did not show significant difference between the taungya plantation and the natural forest. Shannon-Weiner diversity index of saplings and trees were however, significantly lower in the taungya plantation compared to the natural forest. Generally, the overall Shannon-Weiner diversity index of the native woody species was significantly lower in the taungya plantation when compared with the natural forest. The diversity between the taungya plantation and natural forest followed a similar trend when Species Richness, Shannon Evenness index and Density were used. The study further showed that seedling and tree diversity were separately influenced positively by age and canopy cover percentage of the plantation. Sapling diversity was influenced negatively by distance to the natural forest and positively by age of plantation. In general, only the canopy cover percentage had positive influence on the overall native woody species diversity in the taungya plantation. The stem density, however, did not have any influence on the diversity of native woody species. The "slash" and "burn" process used in land preparation is the management practice leaving seed trees to enhance the diversity of native woody species regeneration in the taungya plantation. The taungya plantation seems to play a significant role in fostering regeneration of native woody species in the seedlings stage and reducing in diversity from saplings to trees. There is therefore, the need for silvicultural treatments to help maintain regenerated native woody species diversity in the taungya plantation.

Key words: taungya plantation, natural forest, diversity, stand characteristics, management practices

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LIST OF ACRONYMS

ASTER	Advanced Space-borne Thermal Emission and Reflection Radiometer
ALOS PALSAR	Advanced Land Observing Satellite Phased Array L-band SAR
CDB	Convention on Biological Diversity
DBH	Diameter at Breast Height
DEM	Digital Elevation Model
ERDAS	Earth Resource Data Analysis System
FORIG	Forest Research Institute of Ghana
GIS	Geographic Information System
GPS	Global Positioning System
Ha	Hectare
N. P. L. D.	Non-pioneer Light Demander
PROTA	Plant Resources of Tropical Africa
SPSS	Statistical Package for Social Science
U. S. G. S.	United States Geological Survey

1. INTRODUCTION

Native woody species diversity is important for forest ecosystem maintenance in the tropics. The presence of diverse species provides resources and habitats for all forest species (Barbier *et al.,* 2008). However, due to fire, logging and farming, woody species diversity in the forest is being altered (Rees and Juday, 2002; Tolera *et al.,* 2008; Brown and Boutin, 2009). Whereas moderate disturbance enhances forest maintenance, intensive disturbance causes destruction to vegetation, nutrient cycles and biodiversity in forest ecosystems (Rees and Juday, 2002; Brown and Boutin, 2009). Thus, many forest ecosystems have been degraded beyond their capacity to enhance and conserve native woody species diversity (Rees and Juday, 2002; Brown and Boutin, 2009).

In response to native woody species diversity destruction, several methods are being used to foster natural regeneration in degraded forests. Establishment of plantations through the "taungya" system is among these methods, with an additional advantage of providing livelihood for forest communities (Nair, 1991; Webb and Sah, 2003; Ehiagbonare, 2006). Generally, plantations enhance the regeneration, establishment and succession of native woody species diversity by functioning as foster ecosystems (Lamb *et al.,* 2005). Some studies have investigated the effectiveness of taungya plantations in fostering natural regeneration of native woody species diversity in certain countries. Native woody species diversity was found to be less in taungya plantation compared to adjacent vegetation in Terai of Nepal (Webb and Sah, 2003) and Edo State of Nigeria (Ehiagbonare, 2006). Nevertheless, with the wide adoption of taungya plantation, it is important that further studies are conducted to assess the extent to which this method can provide a viable option for native woody species diversity regeneration in degraded forests also in Ghana (Agyeman *et al.,* 2003).

Natural regeneration of native woody species diversity in taungya plantation may be influenced by a number of factors. Dominant tree attributes such as canopy cover percentage, leaf area index and stem density (Hardtle *et al.,* 2003; Lemenih *et al.,* 2004), site factors such as substrate quality, litter mass and depth (Harrington and Ewel, 1997; Dzwonko and Gawronski, 2002), altitude, solar radiation and air temperature (Lemenih *et al.,* 2004; Hall *et al.,* 2009). Other factors include plantation age (Brown and Boutin, 2009), landuse history (Ito *et al.,* 2004; Gachet *et al.,* 2007), management practices, degree of protection from disturbances (Estevan *et al.,* 2007; Brown and Boutin, 2009; Hall *et al.,* 2009) and distance to adjacent natural forest (Gunter *et al.,* 2007; Gonzales and Nakashizuka, 2010). Understanding these factors influencing native woody species diversity will be useful for improving plantation management to accelerate natural succession (Koonkhunthod *et al.,* 2007).

It has been demonstrated that Remote Sensing techniques could be useful for studying forest recovery through reforestation programmes such as plantation development (Rosenqvist *et al.,* 2003). Remote Sensing techniques enable the detection and classification of forest in order to derive information about its condition (Rosenqvist *et al.,* 2003). The application of the technique can provide up-to-date information about the impact of taungya plantation in enhancing forest recovery for planning and management purposes in the Afram Headwaters Forest Reserve in Ghana.

1.1. Plantation

Plantation is a forest stand established by planting or replanting tree species in areas previously forested or non-forested (Lamb *et al.,* 2005; Erskine *et al.,* 2006). Generally, plantation supplements and reduces pressure on woody resources derived from the natural forest (Lamb *et al.,* 2005). In spite of the recognised value as a source of woody products, plantation enhances natural regeneration of native tree species in degraded forests (Lamb *et al.,* 2005; Brockerhoff *et al.,* 2008; Wang *et al.,* 2009).

Plantation may be established using single species (monoculture) or mixed species. Comparatively, monoculture plantation enhances less native tree diversity than mixed species plantation (Lamb *et al.,* 2005; Erskine *et al.,* 2006; Piotto, 2008). The choice of tree species, either exotic or native used for plantation development also influences the diversity of regeneration. For instance, a plantation established with native species enhances conservation of biodiversity than exotic species (Erskine *et al.,* 2006; Piotto, 2008). This is because, native species plantation provide a broader range of ecological benefits for the total biodiversity in the forest (Piotto, 2008). Nevertheless, exotic species grow fast and are easy to establish and manage, hence their wide use in plantation development programmes (Lamb *et al.,* 2005).

1.2. Taungya plantation

Taungya plantation is an Agroforestry land-use system with origin in Myanmar (Burma) in which woody species are interplanted with annual crops during the few years of plantation establishment. After the plantation canopy closes, the crops are no longer maintained and the system is managed as plantation (Nair, 1991; Ehiagbonare, 2006). Generally, taungya plantation increases the total productivity of plants and animals in a sustainable manner under low levels of technical input in degraded lands (Nair, 1991; Ehiagbonare, 2006). The choice of tree species for taungya plantation depends on whether both productive and ecological advantages can be achieved in the same system (Nair, 1991).

Just like all other plantations, taungya plantation contribute to the conservation of biodiversity in deforested and fragmented landscapes by providing habitats and resources for plants and animal species, maintaining landscape connectivity and reducing the susceptibility of forest to fire (Schroth *et al.,* 2006;

Ashley *et al.,* 2006). Nevertheless, taungya plantations cannot provide the same value as natural forest but they offer an important tool for conservation of biodiversity (McNeely and Schroth, 2006; Jose, 2009).

1.3. Taungya plantation development in Ghana

The Government of Ghana initiated a plantation development programme under the taungya system in the 1930s. The main purpose of the taungya system was to establish plantations of fast growing timber species whilst addressing local people demand for farmlands. Under the system, farmers are given parcels of degraded forest reserve to produce annual food crops and to help establish and maintain timber trees. Nevertheless, the taungya system failed due to major lapses in ownership and benefit sharing system for farmers. Farmers neglected the tree crops and abused the system by killing planted trees, clearing land for plantation than are needed and also planted food crops that were not compatible with the tree crops (Agyeman *et al.,* 2003). The taungya system was therefore, suspended by Government in 1984.

After suspension, the taungya system was still viewed by farmers as one of the beneficial forest tenure systems and requested for its re-introduction with changes in the system. So in 2002, the taungya system was revised. In the new system, farmers are the owners of the plantation trees while the Forestry Commission, chiefs (landowners) and forest adjacent communities act as stakeholders. All stakeholders in the taungya system are eligible for a share of the benefits that accrue from the plantation. The benefit sharing system is determined by all stakeholders (Agyeman *et al.,* 2003). The farmers undertake most of the management activities such as pruning and tending. The Forestry Commission provides technical expertise and training to farmers to carry out their functions efficiently. The land owners contribute land whereas the forest adjacent communities provide protection from fire and encroachment (Agyeman *et al.,* 2003).

The taungya plantation development in Ghana has been through several programmes such as Community Resources Management Project (CRMP) (Community driven) and Government funded plantations. Generally, the total area of forest planted through all plantation development programmes in Ghana amounts to 135,576.40 ha (Forestry Commission, 2008). The timber species used in taungya plantation are determined by the Forestry Commission. They include the following; Teak (*Tectona grandis*), Cedrela (*Cedrela odorata*), Cassia (*Cassia siamea*), Wawa (*Triplochiton scleroxylon*), Oprono (*Mansonia altissima*), Ofram (*Terminalia superba*) and Emire (*Terminalia ivorensis*), Mahogany (*Milicia excelsa*), Ceiba (*Ceiba pentandra*), Nyankom (*Heritiera utilis*), Edinam (*Entandrophragma angolense*), Utille (*Entandrophragma utile*) and Otie (*Pycnanthus angolensis*) (Agyeman *et al.,* 2003; Forestry Commission, 2008).

1.4. Measuring biological diversity

"Biological diversity is defined as the variability among living organisms from all sources including *inter alia*, terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part. This includes diversity within species, between species, and of ecosystems" (CBD, 1992). In terms of forestry, "biodiversity is referred to as all forms of life found in forests, including trees, plants, animals, fungi and micro-organisms, and their roles in nature" (CBD, 2010). Biological diversity can be used as a synonym of species diversity or species richness (Groombridge, 1992).

Determination of species diversity in ecosystem is important for management and conservation purposes. The assessment of species diversity gives information to better understand the structure and functions of ecosystem (Beals *et al.,* 2000). In order to measure species diversity in the forest, diversity indices are used (Tolera *et al.,* 2008). One of the most commonly used diversity indices for ecological studies is the Shannon-Weiner index (Shannon, 1948). Shannon-Weiner index accounts for both abundance and evenness of species present and, increases with increasing number of species (Beals *et al.,* 2000). Shannon's equitability (evenness) (E_H) index is another measure derived from Shannon-Weiner index used to determine evenness of species distribution. The equitability assumes a value between 0 and 1 with 1 being complete evenness (Beals *et al.,* 2000).

1.5. Remote Sensing techniques and forest recovery

The development of high spatial resolution remote sensing instruments, both airborne and spaceborne, has provided opportunity to evaluate patterns of forest recovery. Optical and microwave remote sensing are among the approaches that can be used to assess forest recovery. Optical remote sensing data from ASTER and LANDSAT have been used extensively in assessing forest recovery (Rosenqvist *et al.,* 2003). However, their effectiveness is limited by atmospheric conditions. In recent years, microwave remote sensing has emerged to overcome these limitations. The Advanced Land Observing Satellite (ALOS) Phased Array L-band SAR (PALSAR) is an example of satellites using microwave sensor (Rosenqvist *et al.,* 2003; Kennedy *et al.,* 2009). PALSAR is unique in providing landcover information, particularly when integrated with other satellite data such as LANDSAT and ASTER images (Rosenqvist *et al.,* 2003).

Assessing forest recovery through Remote Sensing involves the use of two or more satellite images covering the same geographic location at different dates to discriminate changes associated with the landcover properties between the dates of imaging. Most documented change detection methods are based on per-pixel classifiers, such as post-classification comparison and pixel-based change information contained in the spectral domain of the images such as vegetation indices (Wang and Xu, 2010). Post-classification is one of the most widely used methods for assessing changes. It involves the overlay or differencing of two or more classified images. Changed areas are those which are not classified the same at different times (Kennedy *et al.,* 2009; Wang and Xu, 2010).

1.6. Problem analysis and Justification

Deforestation and degradation are responsible for reducing productivity and depleting the genetic diversity of forests in Ghana. The major drivers of the deforestation and degradation are fire, logging and farming intensification (FORIG, 2003; Blay *et al.,* 2008). For instance, it has been estimated that more than half of the total area of forest reserve representing 0.917 million hectares in the high forest zone of Ghana has been destroyed by fire since the 1980s (FORIG, 2003). Currently, the total forest area of Ghana is estimated at 1,600,000 ha (Aronsen *et al.,* 2010).

Afram Headwaters forest is one of the deforested and degraded reserves in Ghana (Wittenberg, 2004). Despite this, the forest reserve is unique in terms of its potential in conserving native timber species (Wittenberg, 2004). Taungya plantation has been adopted as a means for restoring the degraded forest since the 1980s. However, the taungya plantation failed (Hawthorne and Musah, 1993) and was re-introduced in 2002 (Agyeman *et al.,* 2003). In order to ensure effective forest restoration, it is important to assess the impact of the taungya plantation on the regeneration of native woody species diversity. This information would facilitate the development of appropriate management options for enhancing forest recovery and regeneration of native woody species diversity in the degraded forest.

Previous studies in the Afram Headwaters forest reserve focussed on comparing the impact of fire on the natural regeneration of tree species (Okyere, 2008). Another study compared natural tree regeneration in teak monoculture and mixed species plantation (Baatuuwie, 2009). Nevertheless, the impact of taungya plantation in fostering forest recovery and native woody species diversity in the Afram Headwaters Forest Reserve remains unknown. In addition to this, factors that have the potential to influence native wood species diversity require further research. Hence, the study contributes to addressing this knowledge gap.

1.7. General objective

The general objective is to evaluate the ability of taungya plantation in fostering forest recovery and natural regeneration of native woody species diversity in comparison with adjacent natural forest in the Afram Headwaters Forest Reserve in Ghana. Factors that have the potential to influence natural regeneration of native woody species diversity in taungya plantations are also assessed.

1.7.1. Specific objectives

- To quantify forest recovery between 2002 and 2008 using Remote Sensing techniques.
- To assess native woody species *composition, diversity, evenness of distribution, richness* and *density* in taungya plantation and the adjacent natural forest.
- To establish the relationship between stand characteristics *(canopy cover percentage, stem density of planted trees, age of plantation and distance to natural forest)* and native woody species diversity in taungya plantation.
- To describe the implication of management practices of taungya plantations on the regeneration of native woody species diversity.

1.7.2. Research questions

- How much forest has been recovered between 2002 and 2008?
- What is the *composition* of native woody species in taungya plantation and adjacent natural forest?
- Are there significant differences in native woody species *diversity, evenness of distribution, richness* and *density* in taungya plantation and adjacent natural forest?
- What is the relationship between stand characteristics *(canopy cover percentage, stem density of planted trees, age of plantation and distance to natural forest)* and native woody species diversity in taungya plantation?
- What management practices of taungya plantations have the potential to enhance natural regeneration of native woody species diversity?

1.7.3. Hypotheses

- There is significantly low native woody species *diversity, evenness of distribution, richness* and *density* in taungya plantation compared to the adjacent natural forest.
- There is a significant relationship between taungya plantation stand characteristics and native woody species diversity.

1.7.4. Research concept

The diagram (Figure 1) illustrates the research concept. It shows the drivers of deforestation and degradation (logging, farming and fire) and their influence on the dynamics of vegetation cover in the Afram Headwaters Forest Reserve. The relationship of taungya plantation at influencing forest recovery, managing the drivers of deforestation and degradation and the research needs are also depicted.

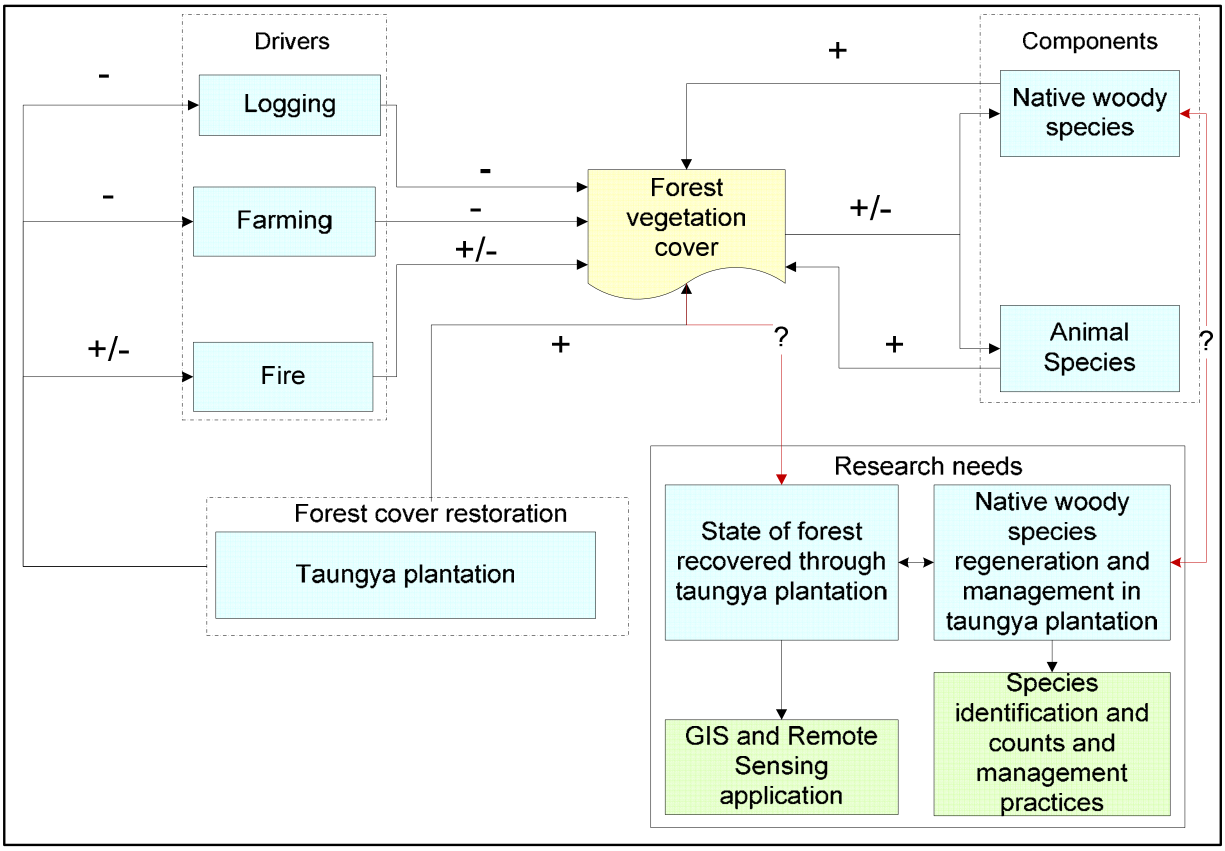


Figure 1: Conceptual diagram of research

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted in the Afram Headwaters Forest Reserve (1°32'W – 1°48'W and 6°45'N – 7°25'N) in the Offinso District of the Ashanti Region, located in the transitional zone of Ghana. The area is appropriate, both for scientific and practical purposes. Firstly, the forest has been degraded due to fire, logging and farming. Secondly, taungya plantation has been adopted as a method for enhancing the recovery of the forest. Thirdly, the forest is noted for its potential in conserving native timber species. Finally, ASTER images and ancillary information are available. Accessibility to the forest for the research is also good. Figure 2 shows the Afram Headwaters Forest Reserve. The red colour on the ASTER 2008 image represents forest areas whereas the white colour represents non-forest areas.

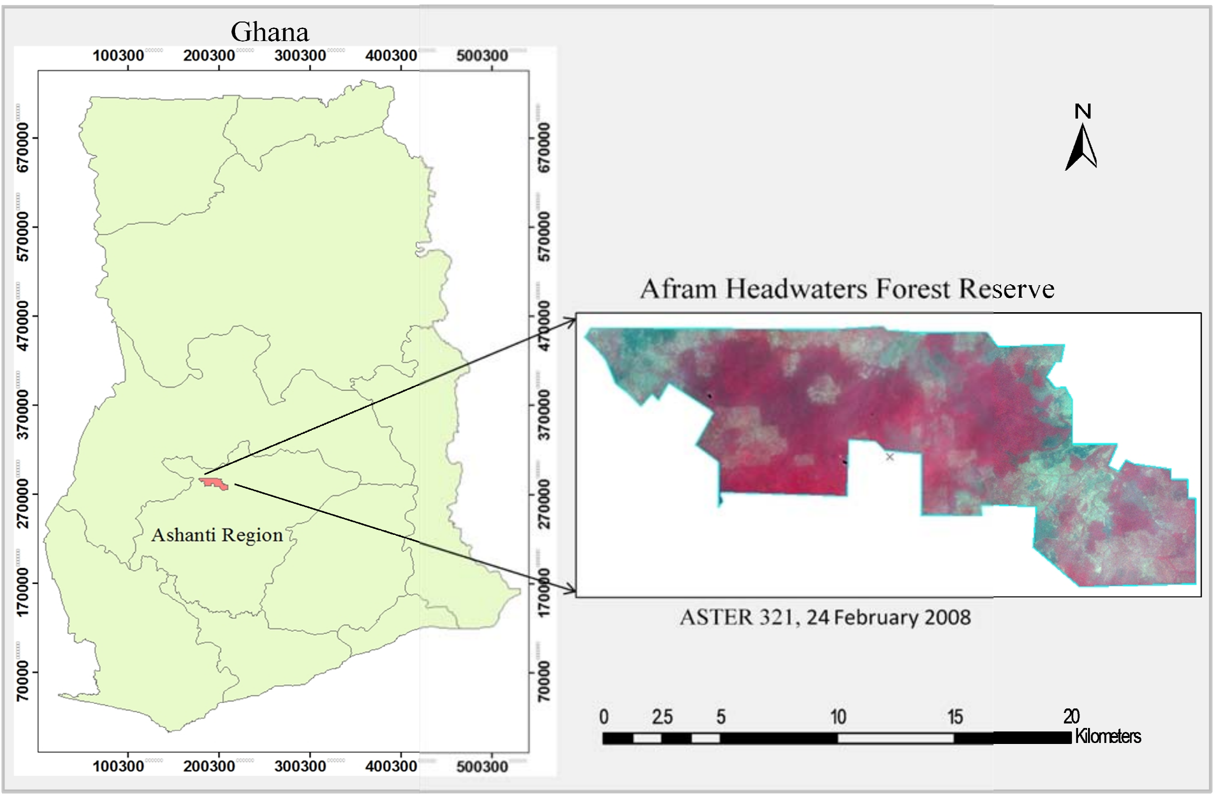


Figure 2: Location of Afram Headwaters Forest Reserve in the Ashanti Region of Ghana.

2.1.1. Vegetation

The vegetation has been categorised as a dry semi-deciduous forest fire sub-type. The severe and extensive wildfires in the 1980s has caused heavy deforestation and degradation. The degradation of the forest have also favoured the colonization of non-indigenous invasive species, *Broussonetia papyrifera*. The present vegetation comprises original remnant natural forest, plantation and legally admitted farmlands (Appendix 8.8) (Hawthorne and Musah, 1993; Dwomoh, 2009).

2.1.2. Climate

Afram Headwaters forest reserve located in the Offinso district experiences semi-equatorial conventional climate with two rainfall seasons. The major rain starts from April to July and the minor from September to Mid November. Annual rainfall ranges from 1500mm in the North to 1700mm in the South. Relative humidity is high during the major rainy season, reaching its peak of 90% between May and June. A maximum temperature of 30ºC is experienced between March and April. Monthly temperature is about 27ºC (Ghana Districts, 2010).

2.1.3. Topography

The topography is relatively flat or gently undulating. Altitude ranges from 300 to 410m above sea level. Limited areas of steep slopes occur in the eastern part of the reserve. The area is drained by two major streams, namely, Afram located in the Eastern and Brimu in the Western part. There are a number of other water bodies that are largely ephemerals in nature (Ghana Districts, 2010).

2.1.4. Soil characteristics

Soil characteristics in the reserve are generally uniform with most of the reserve consisting of reddish brown sandy loam and occasional patchy clay occurrence. The western part of the area overlies the upper and lower Birrimian series whiles other part overlies the upper Voltain sandstone. They are well drained and support the cultivation of food crops and trees (Ghana Districts, 2010).

2.1.5. Demography

The population of the district is 138,500 comprising 69,000 men and 69,500 females. The population density of the area is 63 persons per km^2. There are about 126 settlements in the District. Out of these settlements, five (5) can be described as urban. They are New Offinso (36, 190), Akomadan (14,018), Abofour (11,177), Nkenkaasu (10,014) and Afrancho (7,727) (Ghana Districts, 2010).

2.1.6. Socio-Economic situation

Agriculture is the main economic activity in the district. Over 70% of the active population are farmers, 25% of this number are youth. Total land area of about 24000 hectares is put under food crops production each year. The major crops that are cultivated in the district are cassava, maize, plantain, vegetables, oil palm, cocoa, cashew and rice. The animal production concentrates only on poultry farming (Ghana Districts, 2010).

2.2. Materials

2.2.1. Data used

The satellite data used for assessing forest recovery were ASTER images acquired on 24 February 2002 and 24 February 2008. ASTER images were selected because they have good spectral, temporal and spatial resolution. Additionally, ASTER images have been used widely in assessing forest recovery (Rosenqvist *et al.,* 2003; Kennedy *et al.,* 2009). ASTER image acquired in 2002 was selected due to the major reforestation programmes that started in the year 2002 in the study area. ASTER image acquired in 2008 was also selected for comparison owing to the fact that, ASTER 2009 and 2010 scenes in the study area were covered with clouds. LANDSAT 7 ETM+ scenes in the area for 2009 and 2010 also had line stripings (USGS, 2010). Nevertheless, the dates chosen could provide useful information about the recovery of the forest through the taungya plantation.

ALOS PALSAR image with HV (Horizontal-Vertical) and HH (Horizontal-Horizontal) polarizations acquired on 27 January, 2009 was used as an additional source of information for planning and collecting field data. Other data used in the research were secondary ground truth data of canopy cover measurements of different vegetation types collected in 2009 in the study area by Nguyen (2010), roads, rivers, villages, topographic and Afram Headwaters Forest Reserve boundary maps.

2.2.2. Instruments and software package

IPAQ and Global Positioning System (GPS)	Field navigation, identifying sample points and collecting ground truth data
Diameter tape	Measuring of diameter at breast height (dbh) of trees above 3m
Measuring tapes (50m)	Laying out nested circular plot.
Compass	Finding direction for laying out plot
Spherical densiometer	Measuring canopy cover percentage
Digital camera	Snap pictures of tree species difficult to identify on the field
ArcGIS 9.3, ERDAS Imagine 9.2	Processing and analysis of satellite data
SPSS, MS-Excel, MS-Word	Statistical analysis and thesis write-up

2.3. Methods

The research methods have been described using the flowchart indicated in Figure 3. It illustrates the field sampling and analysis of woody species diversity in the taungya plantation and the natural forest. It further illustrates the interview of taungya farmers and Forest Services Division staff in Offinso about the management practices in the taungya plantation. Ground truthing of vegetation cover for image classification and analysis for quantifying forest recovery has also been shown.

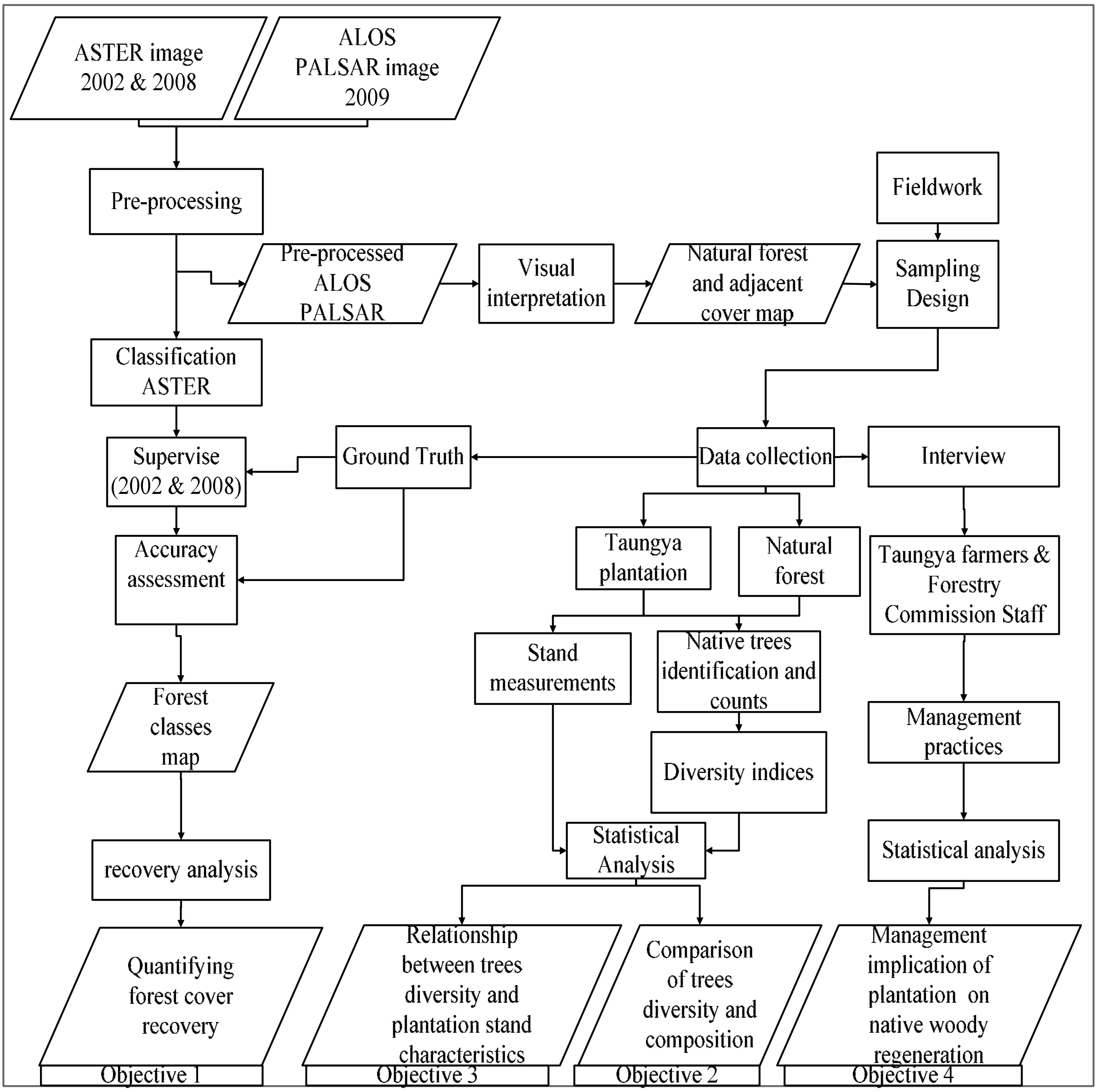


Figure 3: Flowchart of research methods in the study

2.3.1. Fieldwork preparation

The fieldwork preparation included pre-processing of satellite images by registering the images into one coordinate system (Transverse Mercator Projection in Legion datum) (Appendix 8.6). An unsupervised classification was performed on ASTER image of 2008 using Iterative Self-Organizing Data Analysis (ISODATA) classifier to produce a landcover map in order to have an initial impression about the study area and also to assist in deciding on the sampling method.

The study area was further stratified into forest and plantation areas on the ALOS PALSAR image acquired in 2009 (Figure 4) through visual interpretation to aid in the field sampling. During the visual interpretation, texture and tone were used as interpretation elements and a reference was made to landcover map produced for the study area by Nguyen (2010) using ALOS PALSAR image of 2009 fused with ASTER image of 2008 with a classification accuracy of 81.25%. In terms of texture, natural forest was medium and the plantation areas were coarse. In terms of tone also, the variation of change was uniform in the case of the natural forest whereas the plantation areas were varied.

2.3.2. Fieldwork duration and data types

The fieldwork was carried out from 28th September to 11th November, 2010. Three data types were collected namely; ground truth data, vegetation assessment in taungya plantation and natural forest and interview of taungya farmers and the Forest Services Division Managers in Offinso about management practices in the plantation.

- **Ground truthing**

Ground truth data were collected using IPAQ and GPS for the classification of ASTER images of 2002 and 2008. Due to the absence of secondary data of canopy cover measurements of 2002, ground truth for the ASTER 2002 image classification were collected using age of taungya plantation as an indicator for deciding "forest" and "non-forest" areas. The ages of the taungya plantations were solicited from the field staff of the Forest Services Division (Offinso) in charge of coordinating the taungya plantation development in the study area. Since the taungya plantations were established in the degraded forest areas, all the ground truth data from such locations were assumed to be "non-forest" for the ASTER 2002 image classification. Expert knowledge based on observation of forest cover condition was used to decide on areas of "forest" in 2002. Additionally, the remnants of the patches of the taungya plantation established in the 1980s were also classified as "forest". Nevertheless, these remnant plantations were being logged by the Forest Services Division in Offinso during the data collection. In the case of ASTER 2008 image, ground truth data for classification were collected based on canopy cover measurements during the fieldwork. Areas with tree canopy cover of 20% and greater were classified as forest and less than 20% as non-forest according to Hansen *et al.* (2003) cited in Potapov *et al.* (2009). In total, 87 primary ground truth data together with 81 secondary data of Nguyen (2010) were used in the image classification. The ground truth data was divided and used for the training and testing during the image classification.

The ground truth data collected was also classified into 3 major landcover types namely, natural forest, plantation and farmland. The farmland (Appendix 8.8) has been allowed legally for some community settlers to undertake farming in the forest reserve. The farmland was further verified using the Forest Compartment map (dated 21 January, 2008) of the study area (Appendix 8.8).

- **Vegetation assessment**

The taungya plantation could not be stratified according to ages. This was due to the small differences in the plantation ages (1 year) and therefore, making the separation of backscatter on the ALOS PALSAR image of 2009 and reflectance on the ASTER image of 2008 difficult. The compartment map (Appendix 8.8) provided by the Forest Services Division in Offinso also did not have information about the period of establishment of the taungya plantations. For this reason, during the vegetation assessment, random points were generated on the ALOS PALSA stratified map (Figure 4) using Hawth's tools in ArcGIS 9.3. A total of 70 sample points with 35 points each in taungya plantation and adjacent natural forest were surveyed during the fieldwork. IPAQ and GPS were used to locate the randomly sample points in the taungya plantation and the natural forest. Figure 4 shows the defined area where sample points were visited during the fieldwork.

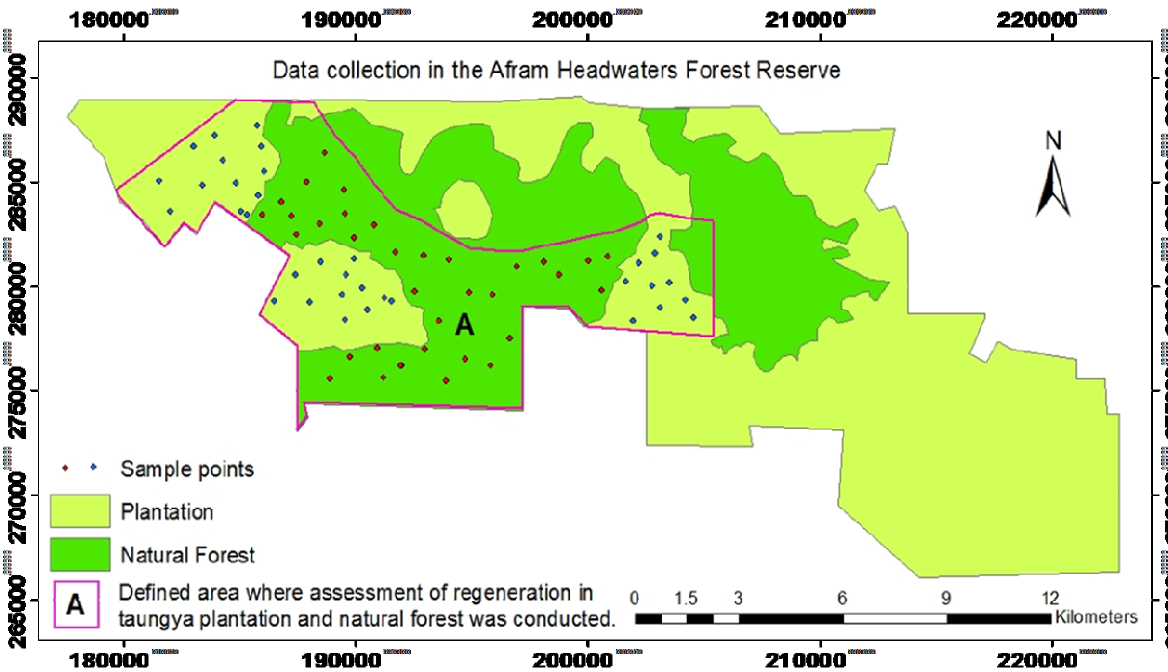


Figure 4: Visually interpreted map of study area using ALOS PALSAR image of 2009.

At each sample point in the taungya plantation and adjacent natural forest, a nested circular plot (bigger plot with sub-plots) was laid out (Figure 5). The sample points served as the centre of the nested circular plots. Nested circular plot was used due to its wide use in assessing vegetation composition (Moktan *et al.,* 2009; Rodeghiero *et al.,* 2010). Nested circular plot of horizontal radii 12.62 m (larger), 8 m (medium) and 4 m (small) were used for assessing trees (height ≥ 3 m), saplings (height between 1 and 3 m) and seedlings (height ≤ 1 m) respectively (Senbeta and Teketay, 2001). The heights were measured using a meter marked stick as used by Senbeta and Teketay (2001). Figure 5 shows the design of the nested plot.

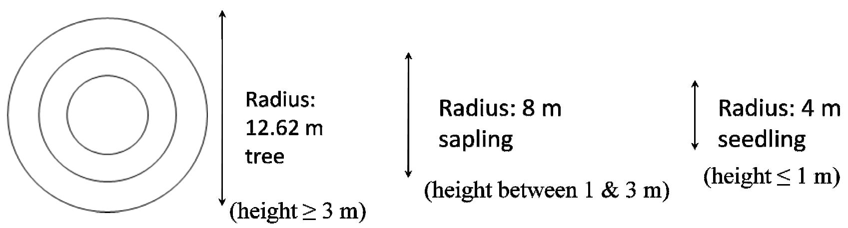


Figure 5: Design of nested circular plot for assessing native woody species

Reference was made to the Photoguide for Forest Trees in Ghana (Hawthorne and Gyakari, 2006) for the identification of native woody species. When identification proved difficult in the field, pictures of the bark, leaves and seedlings of trees were taken for identification at the office of the Forest Services Division in Offinso.

The following characteristics of the taungya plantations stand were determined in each plot.

- Diameter at breast height (dbh) (1.3 m) for overstorey planted trees ≥ 5 cm measured using diameter tape.
- Stems density, number of trees per unit area (Zeide, 2005) for overstorey planted trees ≥ 5cm (dbh).
- Age of the taungya plantation was solicited from the Forest Services Division Officer in charge of plantation in the study area. However, only plantations with ages above 3 years was used for this study. This was because between the ages of 1 and 3 years, the taungya farmers were still growing their crops alongside the planted trees. The ages of the taungya plantation could not be validated due to the absence of site specific growth and yield tables for the plantation species (*Cedrela odorata* and *Tectona grandis*). Nunifu and Murchison (1999) published a provisional yield model for *Tectona grandis* for the Northern part of Ghana which lies in the savannah zone (Appendix 8.7). This could not be used due to the differences in the ecological zones.
- Canopy cover percentage (taungya plantation and natural forest) was measured using spherical densiometer.
- Distance of sample plots in taungya plantation was measured perpendicular to the boundary of the adjacent natural forest in ArcGIS 9.3 on the ALOS PALSAR stratified map (Figure 4).

- **Interview of taungya farmers and Forest Services Division Staff**

Data on taungya plantation management practices were collected using two lines of evidence namely, direct field observation and personal interview of taungya farmers and the Forest Services Division Staff in the District. The interview was scheduled on sacred (taboo) days and weekends when taungya farmers were free to enable them allocate time for the interview.

Four communities (Abofour, Kwapanin, Asempanaye and Nkwakwa) were randomly selected from 8 communities (Asuboe, Akrofua, Abofour, Kwapanin, Asempanaye, Nkwakwa, Bemi and Bobra) (Hapsari, 2010) fringing the Afram Headwaters forest reserve. Due to the difficulty in profiling the taungya farmers in the sample communities, random sampling of the respondents could not be done. Therefore, the identification and selection of taungya farmers were done through Snowball sampling as used by Ni Dhubhain *et al.* (2009) in assessing stakeholders' perceptions of forestry in rural areas in Ireland. Snowball was similarly used by Kvarda (2004) to sample non-agricultural forest owners in Austria. During the application of the snowball sampling technique, the first taungya farmer respondent was identified with the help of the forest plantation officer in the community. After the interview, the respondent served as a guide to further contact the next respondent and so on.

The interview was conducted in the local dialect of farmers (Twi) using semi-structured questionnaire and responses were recorded. In total, 39 taungya farmers were interviewed from the 4 sample communities. The number of respondents from each community was as follows: Abofour (12 respondents), Kwapanin (9 respondents), Nkwakwa (6 respondents) and Asempanaye (12 respondents). The District Forest and Plantation Managers (staff) of the Forest Services Division were also interviewed to validate some of the information provided by the taungya farmers. The questionnaire used for the interview has been attached as Appendix 8.4.

2.4. Analysis of field data

2.4.1. Quantifying forest cover recovery between 2002 and 2008

Post-classification comparison of ASTER images, 2002 and 2008 was used to determine and quantify forest recovery. The ASTER images of 2002 and 2008 were classified using Supervised Classification technique with Maximum Likelihood Classifier (Lillesand *et al.,* 2004). Maximum likelihood Classification is a statistical means of assigning pixels to a class of the highest probability. The 2002 and 2008 images were classified into forest and non-forest areas. Areas with tree canopy cover of 20% and greater were classified as forest and canopy cover less than 20% as non-forest according to Hansen *et al.* (2003) cited in Potapov *et al.* (2009).

The classification accuracy of ASTER image of 2008 was assessed using primary ground truth data from the field and secondary data of Nguyen (2010) on canopy cover percentages. Accuracy of the 2002 image was also assessed with primary ground truth data using age as indicator of "forest" or "non-forest" area. The accuracy report was presented in the form of error matrix that indicates overall, producer and user accuracies. The classification results also included error of commission which related to the probability that a pixel was correctly classified and error of omission that related to the probability that a pixel denoted to a class. Another characteristic used to assess accuracy is the kappa (k) statistic that determined the extent at which classification result surpass random assignment of pixels (Lillesand *et al.,* 2004). In order to quantify the state of forest recovered, farmlands were masked. The area coverage of forest and non-forest were computed and differenced in order to determine the quantity of the forest recovered through taungya plantation between 2002 and 2008.

2.4.2. Measurement and comparison of native tree species diversity

Shannon-Weiner (Shannon, 1948) and Shannon Evenness indices (E_H) (Beals *et al.,* 2000) together with Species Richness (S) (Yirdaw, 2001) were used to measure species diversity in the taungya plantation and the adjacent natural forest. Shannon-Weiner and Shannon Evenness indices were computed using the formulae:

Shannon-Weiner Index (H)	Shannon's Evenness Index (E_H)
$H = -\sum_{j=1}^{S} p_i \ln p_i$	$E_H = H / \ln S$
Where S is the total number of different species present Pi is the proportion of total sample belonging to each species	Where H is the Shannon-Weiner Index S is the total number of different species present

Species Richness refers to the number of individual species present (Beals *et al.,* 2000; Yirdaw, 2001). The density of native woody species was also used for assessing regeneration. Density refers to the number of species per unit area (Zeide, 2005).

For further analysis, the native woody species were classified into the following guilds; pioneer species (those that are light demander species or at least exposure demanders), non-pioneer light demander (N.P.L.D) (those that require gaps to grow beyond the saplings stage) and shade-bearer trees (often seen as understorey trees) according to Hawthorne (1995).

The regenerated native woody species were also classified according to their conservation star ratings (Hawthorne, 1995; Hawthorne and Gyakari, 2006) as defined below:

- Pink star: species of commercial interest.
- Red star: species heavily exploited in Ghana.
- Scarlet star: species that are threatened in Ghana at least by over exploitation.
- Green star: species that are of little concern.

Student's t-test was used to test for the significance of the differences in native woody species diversity, evenness, richness and density between the taungya plantations and adjacent natural forest (McDonald, 2009). This is because the data meets the minimum number of samples required for students' t-test. A test of normality on the data also showed that the P value was greater than 0.05, meaning the data is normally distributed.

2.4.3. Relationship between native woody species diversity and taungya plantation stand characteristics

Linear regression and correlation were used to test the relationship between the Shannon-Weiner diversity index of the native woody species and taungya plantation stand characteristics *(canopy cover percentage and stems density of planted trees, age of plantation and distance to natural forest)*. Linear regression was used as it gave better significance of the variables (stand characteristics) than multiple regression results (Appendix 8.9). Linear regression has also been used in other studies to assess the effect of stand characteristics on species diversity (Yirdaw, 2001). Linear regression showed the cause-and-effect whereas correlation tested the direction and strength of the relationship between the stand characteristics and native woody species diversity in the taungya plantation (McDonald, 2009).

2.4.4. Interview on management practices of taungya plantations

Data from the interview of the taungya farmers and the Forest Services Division Managers (staff) on the management practices of the plantation was analyzed and presented using descriptive statistics (e.g. pie chart).

3. RESULTS

3.1. Forest recovery analysis between 2002 and 2008

3.1.1. Landcover mapping using ASTER image of 2008

The ASTER image of 2008 was classified into 3 classes using supervised classification with Maximum Likelihood Classification algorithm. The classes were farmland, plantation and natural forest (Figure 6).

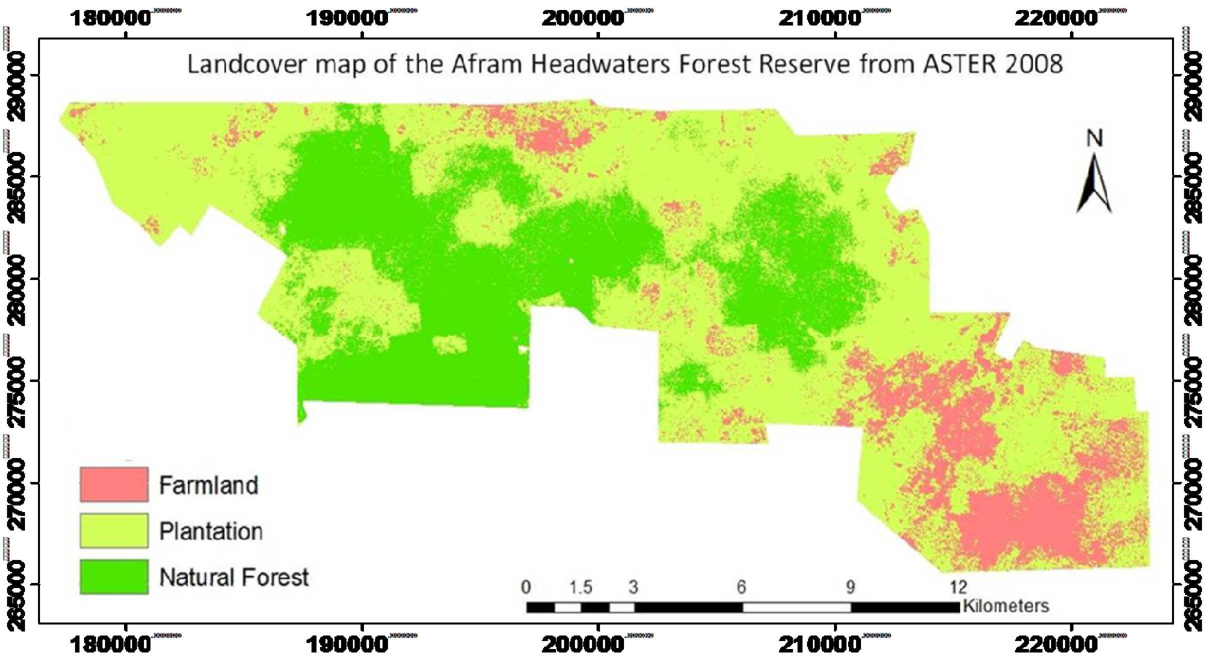


Figure 6: Landcover map of the Afram Headwaters Forest Reserve

3.1.2. Accuracy of Landcover map using ASTER image of 2008

Eighty ground truth data were used for assessing the accuracy of the landcover map of ASTER image of 2008. The result of the supervised classification confusion matrix errors and accuracy has been shown in Tables 1 and 2 respectively.

Table 1: Confusion matrix of errors for Landcover map using ASTER image of 2008

Classification	Farmland	Plantation	Natural Forest	Total	Error of commission %
Farmland	6	0	2	8	25
Plantation	3	29	4	36	19
Natural Forest	0	5	31	36	14
Total	9	34	37	80	
Error of omission, %	33	15	16		

Table 2: Classification accuracy of Landcover map using ASTER image of 2008

Landcover class	Reference totals	Classified totals	Number correct	Producer accuracy, %	User accuracy, %	Kappa
Farmland	9	8	6	67	75	0.72
Plantation	34	36	29	85	81	0.66
Natural Forest	37	36	31	84	86	0.74
Total	80	80	66			
Overall accuracy, %	82.50					
Overall Kappa	0.70					

The class "plantation" had the highest producer accuracy of 85%, followed by "natural forest" and "farmland". However, for user's accuracies, the class "natural forest" had the highest (86%) followed by the "plantation" and "farmland". The overall accuracy achieved was 82.50%, while the Kappa coefficient was 0.70. From the Kappa coefficient, it implied that 70% of the classification agrees with the reference data.

3.1.3. Description of the Landcover types

The predominant landcover type was plantation (*Tectona grandis* and *Cedrela odorata*) covering 11,391 ha (57.3%). This was followed by natural forest covering 5,854 ha (29.4%) and farmland (maize *(Zea mays)*, cassava *(Manihot esculenta)*, plantain and banana *(Musa species)* covering 2,648 ha (13.3%). Figure 7 shows the percentage of area coverage of the different cover types.

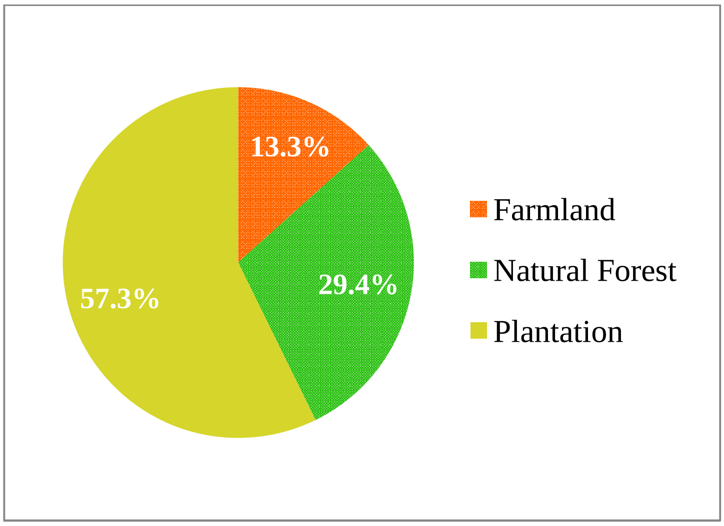


Figure 7: Coverage of Landcover types in the Afram Headwaters Forest Reserve

3.1.4. Classification of ASTER images of 2002 and 2008

The two ASTER images of 2002 and 2008 were classified into two classes namely, Forest and Non-forest. Figure 8 shows the classified images with areas of farmlands masked as they are recognised legally and therefore, assumed to remain unchanged between 2002 and 2008.

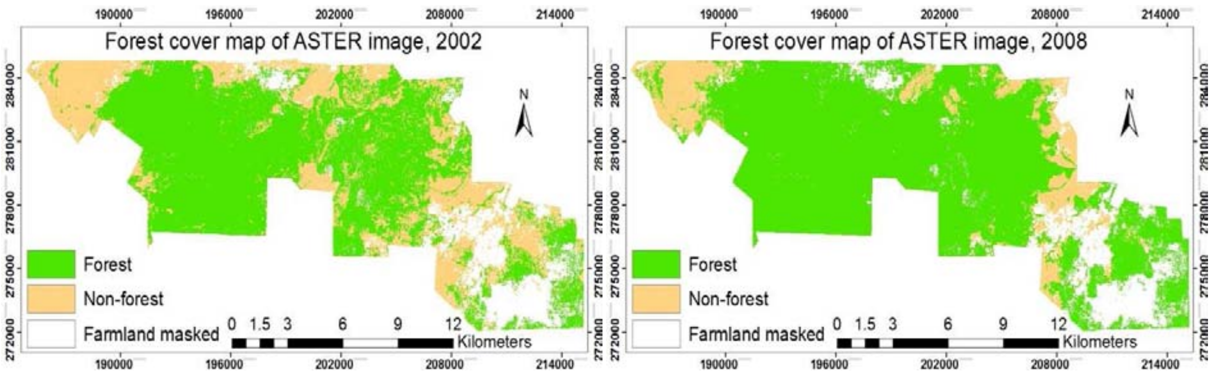


Figure 8: Forest cover maps of classified image of ASTER 2002 and 2008

3.1.5. Accuracy of forest cover map using ASTER image of 2002

Eighty ground truth data were used for assessing the accuracy of the forest cover map using ASTER image of 2002. The results of the supervised classification confusion matrix errors and accuracy have been shown in Tables 3 and 4 respectively.

Table 3: Confusion matrix of errors for forest cover map using ASTER image of 2002

Classification	Forest	Non-forest	Total	Error of commission, %
Forest	31	19	50	38
Non-forest	1	29	30	3
Total	32	48	80	
Error of omission, %	3	40		

Table 4: Classification accuracy of forest cover map using ASTER image of 2002

Forest cover class	Reference total	Classified total	Number correct	Producer accuracy, %	User Accuracy, %	Kappa
Forest	32	50	31	97	62	0.37
Non-forest	48	30	29	60	97	0.92
Total	80	80	60			
Overall accuracy, %	75					
Overall Kappa	0.52					

The class "Forest" had producer and user accuracies of 97% and 62% respectively. The class "Non-forest" also had producer and user accuracies of 60% and 97% respectively. The overall accuracy achieved was 75%, while the Kappa coefficient was 0.52. From the Kappa coefficient, it implies that 52% of the classification agrees with the reference data.

3.1.6. Accuracy of forest cover map using ASTER image of 2008

Eighty ground truth data were used for assessing the accuracy of the forest cover map using ASTER image of 2008. The results of the supervised classification confusion matrix errors and accuracy have been shown in Table 5 and 6 respectively.

Table 5: Confusion matrix of errors for forest cover map using ASTER image of 2008

Classification	Forest	Non-forest	Total	Error of commission, %
Forest	55	7	62	11
Non-forest	6	12	18	33
Total	61	19	80	
Error of omission	10	37		

Table 6: Classification accuracy of forest cover map using ASTER image of 2008

Forest cover class	Reference total	Classified total	Number correct	Producer accuracy, %	User Accuracy, %	Kappa
Forest	61	62	55	90	89	0.52
Non-forest	19	18	12	63	67	0.56
Total	80	80	67			
Overall accuracy, %	84					
Overall Kappa	0.54					

The class "Forest" had producer and user accuracies of 90% and 89% respectively. The class "Non-forest" on the other hand had producer and user accuracies of 63% and 67% respectively. The overall accuracy achieved was 84%, while the Kappa coefficient was 0.54. From the Kappa coefficient, it implies that 54% of the classification agrees with the reference data.

3.1.7. Quantification of forest recovery between 2002 and 2008.

Analysis of the forest cover map between 2002 and 2008 showed that there had been an increase in forest cover through the development of the taungya plantation. The area of forest cover increased from 11,638 ha to 14,615 ha. The amount of forest recovered was therefore, estimated to be 2,977 ha corresponding to an expansion of 26% with an average rate of 4% per year between 2002 and 2008. Nevertheless, there was deforestation in some parts of the reserve, especially in the North-Eastern part (552 ha). Figures 9 and 10 shows a map output and graphical representation of forest cover changes between 2002 and 2008 respectively.

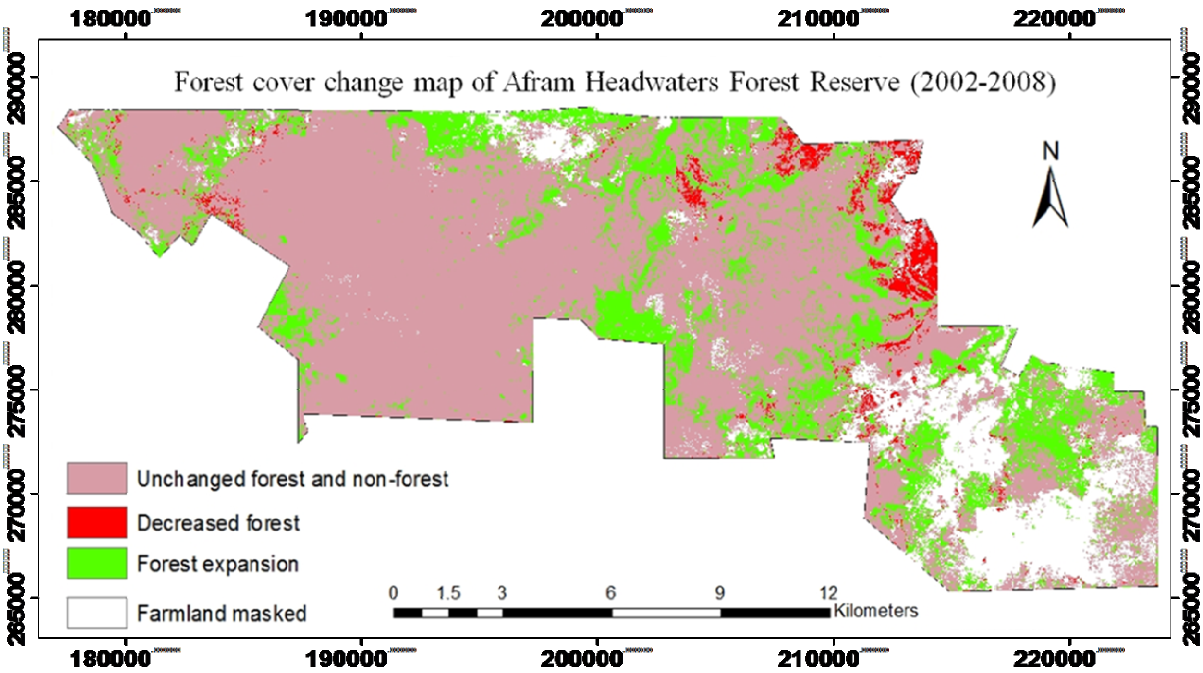


Figure 9: Forest cover change map of the Afram Headwaters Forest Reserve between 2002 and 2008

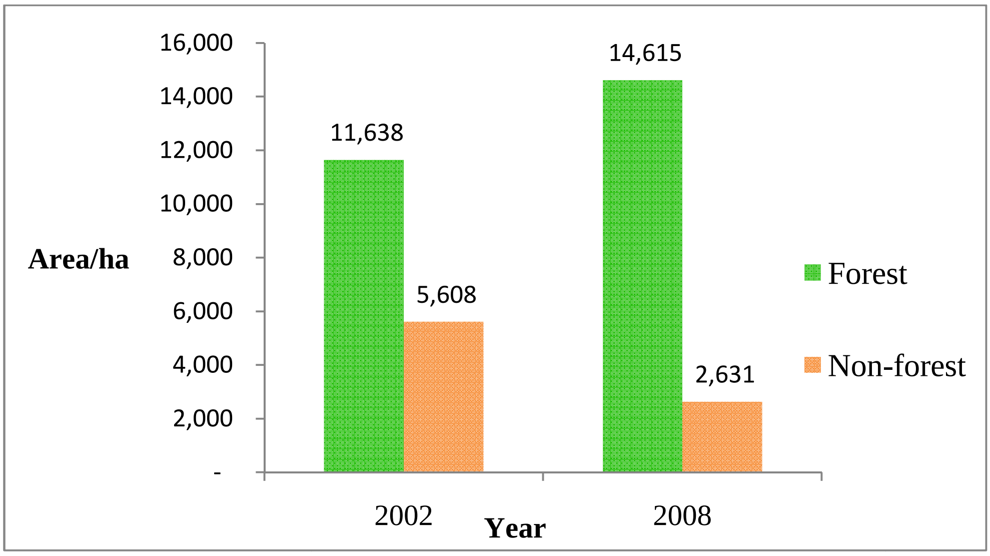


Figure 10: Forest cover analysis between 2002 and 2008

3.2. Stand characteristics of taungya plantation and natural forest

The overstorey of the taungya plantation consisted entirely of exotic plantation species, namely *Tectona grandis* and *Cedrela odorata,* while the understorey was dominated by naturally regenerated native woody species of trees, saplings and seedlings. *Tectona grandis* stand had a mean dbh and basal area of 12.8 cm and 2.6 m^2/ha respectively. *Cedrela odorata* had a mean dbh and basal area of 13 cm and 2.6 m^2/ha respectively. Generally, the stems density per hectare and canopy cover percentage of overstorey plantation species were 423 and 85.5% respectively. The mean distance of a sample plot in taungya plantation perpendicular to the boundary of the adjacent natural forest was 1039 m (Table 7). The adjacent natural forest on the other hand was highly heterogeneous with native woody species of trees, saplings and seedlings. The mean canopy cover percentage of the natural forest was 89.7% (Table 7). Generally, the mean canopy cover percentage of the taungya plantation was significantly lower than the natural forest (Table 8).

Table 7: Stand characteristics of taungya plantation and natural forest

Stand Characteristics	Taungya plantation		Natural forest	
	4-6 years old			
	Mean	SD	Mean	SD
Stem density (Stems/ha)	423	86.7	-	-
dbh (cm)			-	-
• *Tectonia grandis*	12.8	1.4		
• *Cedrela odorata*	13	1.8		
Basal area (m^2/ha)			-	-
• *Tectonia grandis*	2.6	0.28		
• *Cedrela odorata*	2.6	0.35		
Canopy cover percent (%)	85.5	5.1	89.7	2.8
Distance to natural forest (m)	1039	703.8	-	-

Table 8: Comparison of canopy cover percentage between taungya plantation and natural forest

Characteristic	Vegetation type	Mean	SD	N	t-value	d. f.	P-value
Canopy cover percentage	Taungya plantation	85.46	5.10	35	4.2884	68	<0.0001*
	Natural forest	89.66	2.75	35			

SD is Standard deviation, *Significant at P<0.05.

3.3. Native woody species composition in taungya plantation and the natural forest

The taungya plantation composed of 27 different native woody species that belong to 12 families (Appendix 8.1). The composition of species declined from seedlings (25) followed by saplings (20) to trees (17). Moraceae and Malvaceae were the most dominant families of woody species found in the taungya plantation (Appendix 8.1). Out of the 27 different species, *Antiaris toxicaria* was most dominant (Appendix 8.1) in the taungya plantation. In total, 856 native woody specimens, including 616 (72%) seedlings, 206 (24%) saplings and 34 (4%) trees were recorded (Figure 11) in the taungya plantation.

In the case of the natural forest, there were 47 different native woody species that belong to 19 families (Appendix 8.2). The composition of the species increased from seedlings (27), followed by saplings (33) to trees (44). Apocynaceae, Moraceae, Malvaceae, Sapindaceae, Sapotaceae, Ulmaceae and Meliaceae were the dominant families in the natural forest. Out of the 47 species, *Mansonia altissima, Nesogordonia papaverifera, Celtis mildbraedii, Sterculia rhinopetala, Funtumia elastic* and *Blighia sapida* were the dominant species (Appendix 8.2) in the forest. In total, 2028 native woody specimens, including 828 (41%) trees, 712 (35%) saplings and 488 (24%) seedlings were recorded (Figure 11) in the natural forest. Generally, the total number of native woody species and specimens recorded in the taungya plantation was lower than the natural forest.

In terms of conservation status (star ratings), the overall native woody species was composed of 9 pink species (201 total individuals), 7 red species (399 total individuals), 7 scarlet species (71 total individuals) and 4 green species (185 total individuals) in the taungya plantation. The natural forest on the other hand was composed of 12 pink species (1180 total individuals), 9 red species (220 total individuals), 11 scarlet species (283 total individuals) and 15 green species (345 total individuals). Appendix 8.1 and 8.2 list the species occurring in the taungya plantation and the natural forest, their families, guild, conservation star ratings and abundance.

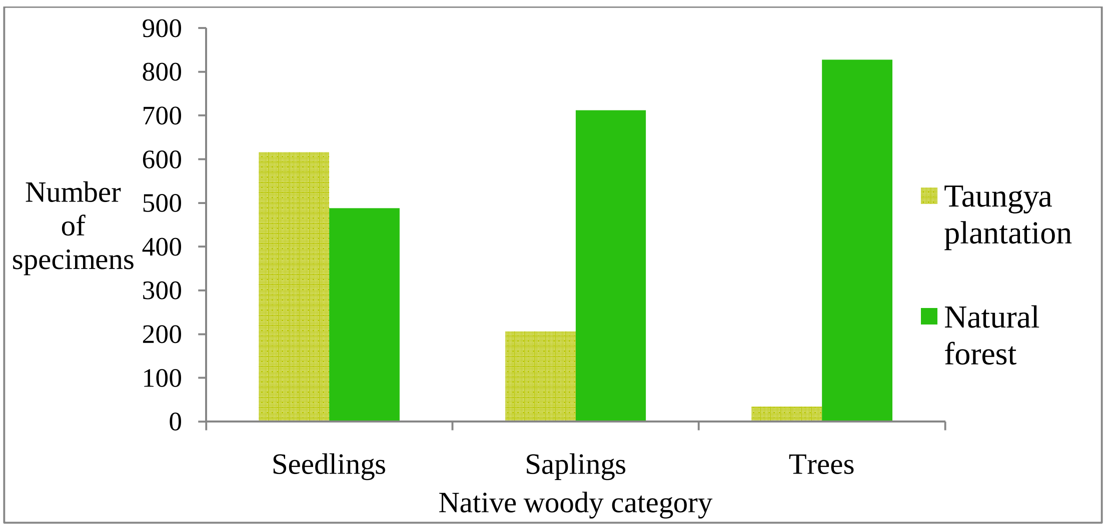


Figure 11: Native woody specimens' counts in taungya plantation and natural forest

3.3.1. Seedling composition

On the seedling species recorded, 20 (62%) were common to both taungya plantation and the natural forest. Additionally, 5 (16%) and 7 (22%) species were found only in taungya plantation and adjacent natural forest respectively (Figure 12).

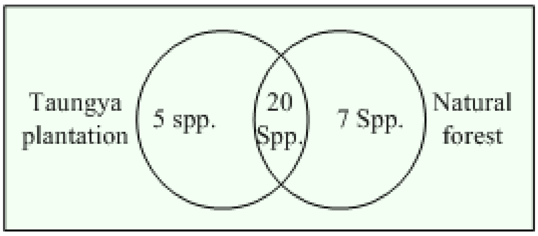


Figure 12: Native woody species (spp.) venn diagram for seedlings in taungya plantation and natural forest

In general, the seedlings in the taungya plantation were composed of 8 (32%) pioneer species, 15 (60%) non-pioneer light demanders and 2 (8%) shade-bearer species. The adjacent natural forest on the other hand was composed of 7 (26%) pioneer species, 16 (59%) non-pioneer light demanders and 4 (15%) shade-bearer species (Appendices 8.1 and 8.2).

3.3.2. Sapling composition

On the sapling species recorded, 19 (56%) were common to both taungya plantation and the natural forest. Additionally, 1 (3%) and 14 (41%) species were found only in the taungya plantation and the natural forest respectively (Figure 13).

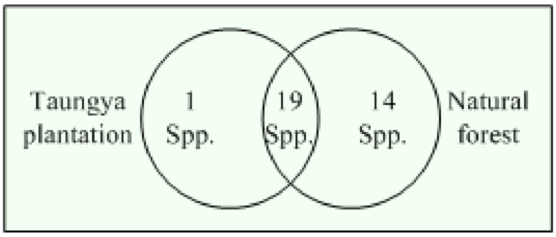


Figure 13: Native woody species (spp.) venn diagram for saplings in taungya plantation and natural forest

In general, the saplings in the taungya plantation were composed of 6 (30%) pioneer species, 12 (60%) non-pioneer light demanders and 2 (10%) shade-bearer species. The adjacent natural forest on the other hand was composed of 12 (36%) pioneer species, 17 (52%) non-pioneer light demanders and 4 (12%) shade-bearer species (Appendices 8.1 and 8.2).

3.3.3. Tree composition

On the tree species recorded, 16 (36%) were common to both taungya plantation and the natural forest. Additionally, 1 (2%) and 28 (62%) species were found only in taungya plantation and natural forest respectively (Figure 14).

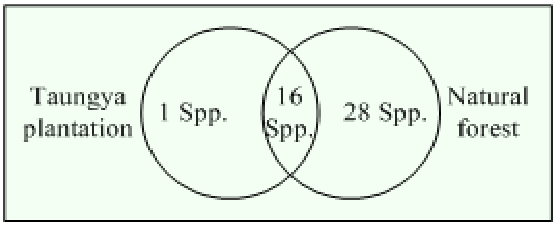


Figure 14: Native woody species (spp.) venn diagram for trees in taungya plantation and natural forest

In general, the trees in the taungya plantation were composed of 5 (29%) pioneer species, 10 (59%) non-pioneer light demanders and 2 (12%) shade-bearer species. The adjacent natural forest on the other hand was composed of 15 (34%) pioneer species, 23 (52%) non-pioneer light demanders and 6 (14%) shade-bearer species (Appendices 8.1 and 8.2).

3.3.4. Overall (Seedling, Sapling and Trees) woody species composition

On the overall native woody species, 26 (54%) species were common to both taungya plantation and the natural forest. Additionally, 1 (2%) and 21 (44%) species were found only in taungya plantation and natural forest respectively (Figure 15). Figure 16 shows the abundance of the top-ten of native woody species common to the taungya plantation and the natural forest (Appendices 8.1 and 8.2).

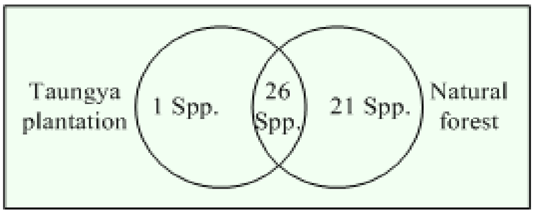
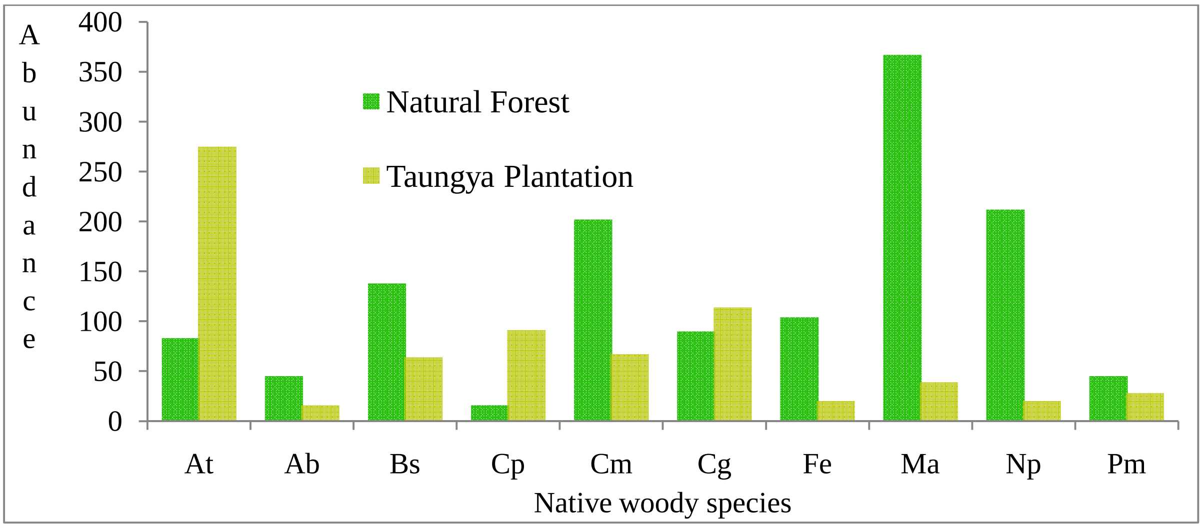


Figure 15: Overall native woody species (spp.) venn diagram in taungya plantation and natural forest

In general, the overall native woody species in the taungya plantation were composed of 7 (26%) pioneer species, 17 (63%) non-pioneer light demanders and 3 (11%) shade-bearer species. The adjacent natural forest on the other hand was composed of 16 (34%) pioneer species, 25 (53%) non-pioneer light demanders and 6 (13%) shade-bearer species.



Antiaris toxicaria	At	*Celtis mildbraedii*	Cm	*Mansonia altissima*	Ma
Alstonia boonei	Ab	*Cola gigantean*	Cg	*Nesogordonia papaverifera*	Np
Blighia sapida	Bs	*Funtumia elastic*	Fe	*Pterygota macrocarpa*	Pm
Ceiba pentandra	Cp				

Figure 16: Comparison of the abundance of top-ten native woody species common to natural forest and taungya plantation

3.4. Density, diversity, evenness of distribution and richness in taungya plantation and natural forest

3.4.1. Seedling

The taungya plantation had a mean seedling Density higher than the natural forest. The natural forest on the other hand, had a mean Shannon-Weiner diversity index, Shannon Evenness index and Species Richness higher than the taungya plantation. However, these observed differences in density, diversity, evenness and species richness in the taungya plantation and natural forest were not statistically significant (P>0.05) (Table 9).

Table 9: Comparison of seedling diversity in taungya plantation and natural forest

Index	Vegetation type	Mean	SD	N	t-value	d. f.	P-value
Shannon-Weiner	Taungya plantation	1.379	0.369	35	1.634	68	0.107
	Natural forest	1.531	0.406	35			
Shannon Evenness	Taungya plantation	0.787	0.153	35	1.355	68	0.180
	Natural forest	0.836	0.151	35			
Species Richness	Taungya plantation	6.00	1.86	35	1.497	68	0.139
	Natural forest	6.86	2.83	35			
Density	Taungya plantation	17.60	8.38	35	1.141	68	0.258
	Natural forest	15.17	9.40	35			

SD is Standard Deviation, N is number of samples, d.f. is degrees of freedom, *Significant at P<0.05.

3.4.2. Sapling

The taungya plantation had a mean sapling Density, Shannon-Weiner diversity index, Shannon Evenness index and Species Richness lower than the natural forest. Statistically, these observed differences were significant (P<0.05) (Table 10).

Table 10: Comparison of sapling diversity in taungya plantation and natural forest

Index	Vegetation type	Mean	SD	N	t-value	d. f.	P-value
Shannon-Weiner	Taungya plantation	0.809	0.602	35	7.823	68	<0.0001*
	Natural forest	1.764	0.399	35			
Shannon Evenness	Taungya plantation	0.662	0.387	35	2.452	68	0.0168*
	Natural forest	0.832	0.136	35			
Species Richness	Taungya plantation	3.110	2.22	35	9.962	68	<0.0001*
	Natural forest	8.740	2.5	35			
Density	Taungya plantation	5.890	5.16	35	8.348	68	<0.0001*
	Natural forest	19.43	8.09	35			

SD is Standard Deviation, N is number of samples, d.f. is degrees of freedom, *Significant at P<0.05.

3.4.3. Tree

The taungya plantation had a mean tree Density, Shannon-Weiner diversity index, Shannon Evenness index and Species richness lower than the natural forest. Statistically, these observed differences were significant (P<0.05) (Table 11).

Table 11: Comparison of tree diversity in taungya plantation and natural forest

Index	Vegetation type	Mean	SD	N	t-value	d. f.	P-value
Shannon-Weiner	Taungya plantation	0.233	0.468	35	18.428	68	<0.0001*
	Natural forest	2.169	0.409	35			
Shannon Evenness	Taungya plantation	0.224	0.418	35	9.164	68	<0.0001*
	Natural forest	0.886	0.089	35			
Species Richness	Taungya plantation	0.86	1.35	35	16.425	68	<0.0001*
	Natural forest	12.03	3.79	35			
Density	Taungya plantation	0.9700	1.460	35	17.943	68	<0.0001*
	Natural forest	23.340	7.230	35			

SD is Standard Deviation, N is number of samples, d.f. is degrees of freedom, *Significant at P<0.05.

3.4.4. Overall native woody species

The taungya plantation had lower overall mean Density, Shannon-Weiner diversity index, Shannon Evenness index and Species Richness less than the natural forest. Statistically, these observed differences were significant ($P<0.05$) (Table 12).

Table 12: Comparison of overall native woody species diversity in taungya plantation and natural forest

Index	Vegetation type	Mean	SD	N	t-value	d. f.	P-value
Shannon-Weiner	Taungya plantation	1.47	0.42	35	8.418	68	<0.0001*
	Natural forest	2.23	0.33	35			
Shannon Evenness	Taungya plantation	0.74	0.15	35	2.029	68	0.0464*
	Natural forest	0.80	0.09	35			
Species Richness	Taungya plantation	7.43	2.28	35	11.748	68	<0.0001*
	Natural forest	16.06	3.70	35			
Density	Taungya plantation	24.46	9.67	35	9.868	68	<0.0001*
	Natural forest	57.94	17.59	35			

SD is Standard Deviation, N is number of samples, d.f. is degrees of freedom, *Significant at $P<0.05$.

3.5. Relationship between Shannon-Weiner diversity index of overall native woody species and taungya plantation stand characteristics

Separately, Shannon-Weiner diversity index of native woody seedlings and trees in the taungya plantation showed weak significant positive relationships with the canopy cover percentage and age of the plantation stand ($P<0.05$). Nevertheless, Shannon-Weiner diversity index of seedlings and trees did not show significant relationships with the stem density of the overstorey plantation trees and distance to the natural forest ($P>0.05$) (Tables 13 and 14).

In the case of saplings, the age of plantation and distance to the natural forest showed weak significant relationships with Shannon-Weiner diversity index ($P<0.05$). Nevertheless, Shannon-Weiner diversity index of saplings did not show significant relationships with the stem density of overstorey plantation trees and canopy cover percentage ($P>0.05$) (Tables 13 and 14).

In general, the Shannon-Weiner diversity index of the overall native woody species showed a weak significant relationship with the canopy cover percentage of the taungya plantation stand ($P<0.05$). The age of taungya plantation, stem density of overstorey plantation trees and distance to natural forest did not show significant relationships with the Shannon-Weiner diversity index of the overall native woody species (Table 13 and 14).

Table 13: Correlation analysis between Shannon-Weiner diversity index and taungya plantation stand characteristics

Shannon-Weiner index	Canopy cover percent (%)		Distance to natural forest (m)		Stem density (Stems/m²)		Age (years)	
	R	P	R	P	R	P	R	P
Seedling	0.43	0.01*	-0.28	0.103	0.10	0.557	0.34	0.049*
Sapling	0.28	0.106	-0.37	0.028*	0.22	0.205	0.42	0.011*
Tree	0.35	0.042*	0.1	0.569	0.19	0.283	0.34	0.047*
Overall woody species	0.35	0.043*	-0.33	0.057	0.13	0.442	0.24	0.168

*Significant at P<0.05

Table 14: Linear regression analysis between Shannon-Weiner diversity index and taungya plantation stand characteristics

Shannon-Weiner index	Canopy cover percent (%)		Distance to natural forest (m)		Stem density (Stems/m²)		Age (years)	
	R^2	P	R^2	P	R^2	P	R^2	P
Seedling	0.18	0.01*	<0.0001	0.103	<0.0001	0.557	0.11	0.049*
Sapling	<0.0001	0.106	0.14	0.028*	<0.0001	0.205	0.18	0.011*
Tree	0.12	0.042*	<0.0001	0.569	<0.0001	0.283	0.11	0.047*
Overall woody species	0.12	0.043*	0.11	0.057	<0.0001	0.442	<0.0001	0.168

*Significant at P<0.05.

3.6. Management practices of taungya plantation

3.6.1. Land preparation

Slash and burn (100% of the responses) was the means by which the taungya farmers prepare the land for the cultivation of food crops and planting of trees. The trees (exotic) planted by the respondents in the taungya plantation were *Tectona grandis* and *Cedrela odorata.* The respondents also mentioned the following food crops which are cultivated alongside the trees: cassava *(Manihot esculenta)*, plantain *(Musa species)*, pepper *(Capsicum annuum)*, okro *(Abelmoschus esculentus)*, maize *(Zea mays)*, tomatoes *(Solanum lycopersicum)* and cabbage *(Brassica oleracea var capitata)*. During the slash and burn process, all the respondents (100%) mentioned that grass, herbs, seedlings, saplings and *Broussonetia papyrifera* (invasive tree species) are cleared in order to provide space for growing the plantation trees and food crops. Nevertheless, all the respondents (100%) mentioned that mature timber trees were not cleared during the slash and burn process. Observation in the field confirmed some timbers species preserved by the taungya farmers.

3.6.2. Silvicultural practices

Weed is controlled by taungya farmers through mannual weeding (56% responses), application of herbicide (weedicide) (18% responses) and a combination of manual weeding and application of herbicide (26% responses) (Figure 17). Field observation of herbicide containers (Appendix 8.5) littered in the taungya plantations was evidence that the herbicide could have been used extensively. Glyphosate (*N*(phosphonomethyl)glycine) was the active ingredient observed on the labels of the herbicide containers. With the timing of the application of herbicide, all the respondents (100% responses) mentioned that it was done before the planting of food crops and trees. However, field observation showed that the herbicides were still being used after crops and trees have been planted. During the interview with the Forest and Plantation Managers of the Forest Services Division, they confirmed the use of herbicide by some taungya farmers, but they did not know the type and source. In addition to weeding, 23% mentioned that they do pruning whereas 77% did not undertake pruning in their plantation.

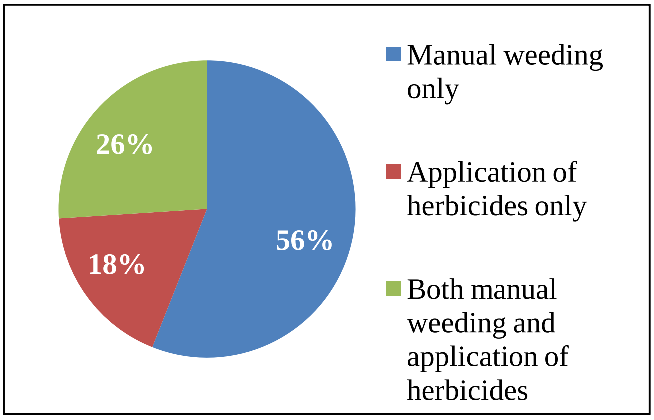


Figure 17: Method of weed control by farmers in taungya plantation

3.6.3. Fire threat to taungya plantation

The taungya farmers mentioned fire as as threat to the taungya plantation. This was also confirmed by the Forest and Plantation Managers during their interview. The observation of burnt scar under the canopy of the taungya plantation also confirmed fires that occurred in 2008. The fire scars observed in the taungya plantation were signs of burnt vegetation (Appendix 8.5), ashes and charcoal. Fire scars were also observable on the ASTER image of 2008. Figure 18 shows some of the observations of fire scars on false colour composite image of ASTER 2008. Dark color is an indication of burnt area.

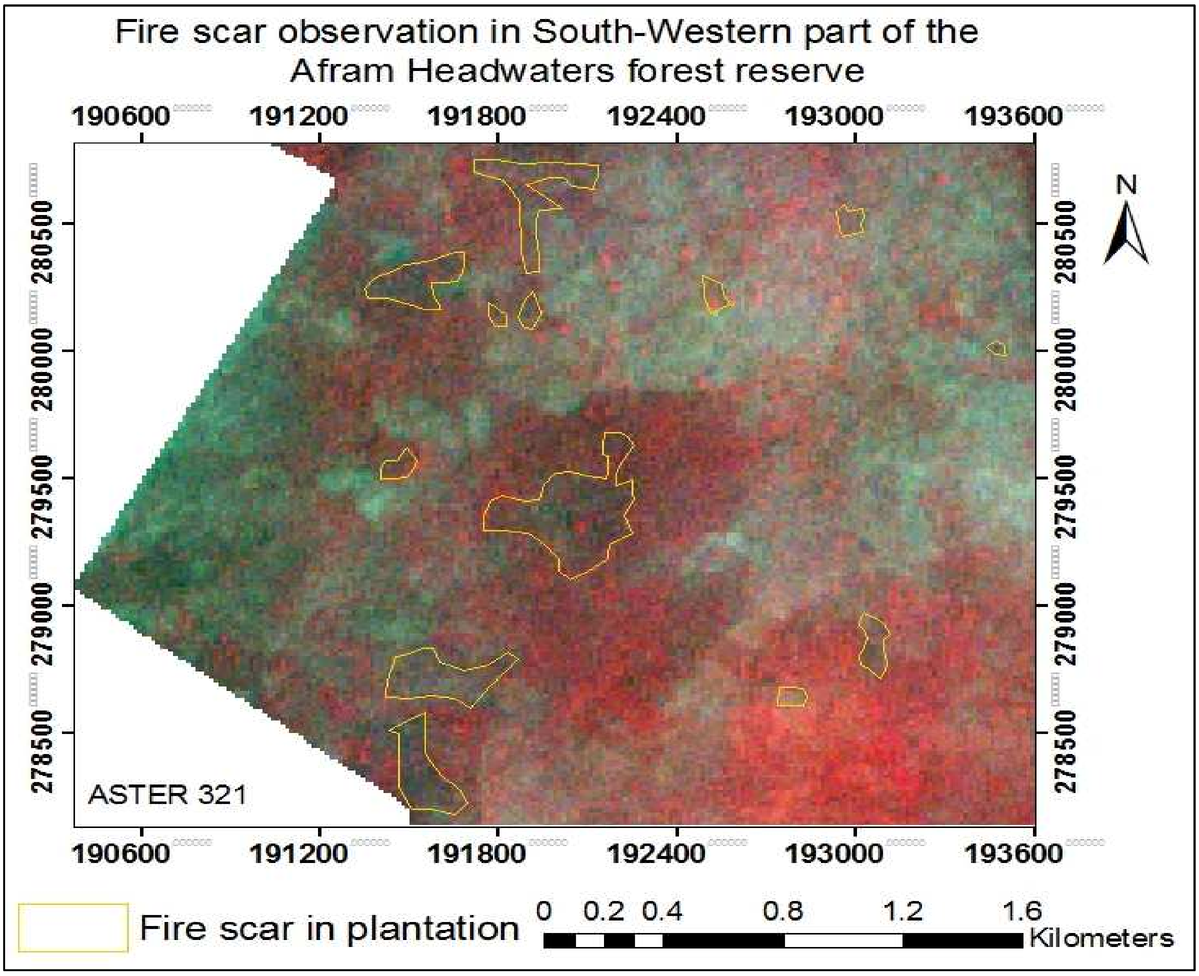


Figure 18: Some fire scars in the South-Western part of the Afram Headwaters forest reserve, ASTER 2008

4. DISCUSSION

4.1. Quantification of forest recovery between 2002 and 2008

The dominance of plantation (57.3% of the study area) compared to the adjacent natural forest (29.4% of the study area) (Section 3.1.3) was surprising considering that the area was gazetted as forest reserve in 1950 (Hawthorne and Musah, 1993; Dwomoh, 2009). The dominance of the plantation however, shows the effort made to restore the cover of the degraded forest. The result (section 3.1.7) on the forest recovery quantification showed that the Afram Headwaters forest cover expanded by 26% (2,977 ha) at an average rate of 4% per year between 2002 and 2008 through the taungya plantation. Nevertheless, the change map (Figure 9) showed that the North-Eastern part of the "forest" class reduced to "non-forest" from 2002 to 2008. Field observation of illegal chain saw lumber and fire scars are evidences that illegal logging and forest fires could have contributed to this decline as reported in literature (Hawthorne and Musah, 1993; Wittenberg, 2004; Okyere, 2008).

The observed classification accuracy (82.5%) of the landcover map using ASTER 2008 image (Figure 6) falls within the range of overall accuracy (80-85%) considered as good (Treitz and Rogan, 2004). Nevertheless, with the exception of farmlands that had low accuracy, the producer and user accuracies of plantation and natural forest were sufficiently good. The value of the Kappa statistic (70%) obtained from the landcover classification of the ASTER 2008 image is substantial according to Viera and Garrett (2005). The observed cover classification accuracies of ASTER 2002 (75%) and 2008 (84%) images may be attributed to the heterogeneity of the canopy cover caused by fire, illegal logging and farming (Hawthorne and Musah, 1993; Wittenberg, 2004; Okyere, 2008). The different classification accuracies (75% for ASTER 2002 and 84% for ASTER 2008) and the moderate Kappa (52% for ASTER 2002 and 54% for ASTER 2008) of the images are likely to make the change detection between 2002 and 2008 less representative of the true forest cover expansion (Viera and Garrett, 2005). The result is in line with Omo-Irabor and Oduyemi (2007) in mapping landcover change in Niger Delta, Nigeria using LANDSAT TM and ETM+ of 1987 and 2002 with overall classification accuracies of 83.03% and 76.16% respectively. In order to enhance the classification of forest cover, further research should consider Artificial Neural-Network (Fauzi *et al.*, 2005) or Object Oriented analysis (Darvishi *et al.,* 2006) as they have also been used in forest and landcover mapping.

The classified map of ASTER image of 2002 (Figure 8) showed that the South-Western part of the Forest Reserve, occupied by taungya plantation currently had substantial forest cover in 2002, which was contrary to the report of the Forest and Plantation Managers of the Forest Services Division (Offinso) that all the areas where taungya plantations have been established were degraded. This observation is an indication that some of the areas with forest cover were deliberately cleared to pave way for the development of plantation.

4.2. Composition of species in taungya plantations and the adjacent natural forest.

The 27 native woody species recorded in the understorey of the plantation testifies to the importance of the fostering function of taungya for the regeneration of native woody species diversity. The result on the decline in the diversity of species composition from seedlings over saplings to trees (Section 3.3) in the taungya plantation could be attributed to fire disturbance. During fire disturbance, only species adaptable to such conditions are able to survive (Lee *et al.,* 2005; Goldammer, 2006; Peterson and Reich, 2008) and therefore, this could explain why there was a decline in the diversity of the species composition. The similarity in the native woody species composition between the natural forest and post-taungya plantation (Section 3.3) suggests that the natural forest contributed as seed source for the taungya plantation as the regeneration of plantation is influenced by the presence of natural forest within its vicinity at a distance of about 1-2 km (Senbeta and Teketay, 2001; Farwig *et al*., 2009; Gonzales and Nakashizuka, 2010).

The decline in number of native woody specimens from seedlings over saplings to trees (Figure 11) in the taungya plantation could be attributed to competition among them for sunlight and nutrients in an attempt to outgrow each other as reported in other studies (Koonkhunthod *et al.,* 2007*;* Farwig *et al.,* 2009). The silvicultural practices such as weeding during the first three years when farmers were growing their food crops alongside the planted trees could also have limited the chances of seedlings growing into saplings and trees in the taungya plantation. In the case of the natural forest, the lower counts of seedlings (Section 3.3) could be attributed to the tree canopy cover that shades light from entering the forest floor to enhance the establishment and growth of seedlings (Brockerhoff *et al.,* 2003). This might also explain why the count of saplings under the canopy was less than the trees in the natural forest.

The high abundance of *Antiaris toxicaria* (Figure 16) in the taungya plantation could be explained by the fact that the species has high germination rate with fresh seeds rate reaching up to 95% in 2.5-13 weeks (PROTA, 2010). The fewer occurrences of threatened species (scarlet star) such as *Milicia excelsa* and *Entandrophragma angolense* (Appendix 8.1) is an indication of few mother trees of such species preserved by the taungya farmers in the plantation. Scarlet star species are under threat of over exploitation in Ghana (Hawthorne and Gyakari, 2006) and therefore, they require immediate attention for protection and conservation in the taungya plantation.

The dominance of pioneer and non-pioneer light demander species (Appendix 8.1) means that the taungya plantation is in an early successional state in which stand canopies are open to allow sunlight to reach the lower strata (Brockerhoff *et al.,* 2003; Lee *et al.,* 2005). However, as the plantations age, changes in light availability shade out the light demanders and facilitate the establishment of shade-bearer trees as reported by Brockerhoff *et al.* (2003). This could explain why few shade-bearer species (*Celtis mildbraedii* and *Chrysophyllum gigiant*) were observed (Appendix 8.1) in the lower strata of the young post-taungya plantation.

4.3. Native woody Species diversity in taungya plantation and natural forest

The finding on diversity (Table 9) is consistent with a similar study reporting no significant difference in seedlings diversity between plantation and the natural forest (Farwig *et al.,* 2009). The finding in this study however, does not agree with Webb and Sah (2003) reporting low tree seedlings diversity in plantation in comparison with the natural forest. In Webb and Sah (2003) study, there was no dispersal from the natural forest, whereas in this study there are inflows of seeds through the dispersal from the adjacent natural forest and mother seed trees preserved by the taungya farmers in the plantation.

In the case of saplings and trees, the findings (Table 10 and 11) on the low diversity is consistent with Lee (2005) reporting less naturally regenerated native woody species in exotic tree plantations (age ranging between 15 to 50 years) when compared with secondary natural forest (age ranging between 25 to 50 years) in Hong Kong, China. In general, there was low native woody species diversity in the taungya plantation in comparison with the adjacent natural forest (Table 12) as hypothesized in the study.

4.4. Relationship between native woody species diversity and stand characteristics of taungya plantation

4.4.1. Taungya plantation stand canopy cover percentage and native woody species diversity

The result (Table 13) on the correlation analysis is in agreement with Cusack and Montagnini (2004) reporting significant positive relationship of canopy cover percentage with woody species diversity in plantations of ages between 9 and 10 years. The result (Table 14) on the regression analysis is also in agreement with Lemenih *et al.* (2004) reporting an influence of the canopy cover percentage on the colonization of native woody species in plantations of ages ranging from 28 to 31 years in Southern Ethiopia. The findings in this study was expected in the young post-taungya plantation as canopies are still open to allow light under the canopy to encourage the germination and establishment of woody species. Even though the canopy cover percentage did not have influence on saplings, the effect was highest on the regeneration of seedlings than trees and the overall native woody species. Canopy cover percentage did not have effect on saplings perhaps because of fire disturbance in some plots in the taungya plantation.

4.4.2. Taungya plantation stand age and native woody species diversity

The result on the significant positive correlation of age with native woody species diversity (Table 13) is in agreement with Senbeta and Teketay (2001) reporting increasing regeneration diversity of plantations with age (ranging between 14 and 42 years) in Central Ethiopia. The result in this study is contrary to the finding of Nagaike (2002) reporting a decrease in regeneration diversity from young plantation (12-16 years) to old plantation (57-78 years). The finding in this study could be attributed to the modification of the soil and light conditions beneath the canopy of the young post-taungya plantation that allow arriving seeds of species to germinate with time. Young plantations have low litter accumulation (Senbeta and Teketay, 2001) which encourages the establishment of species and therefore, this could also explain why the age had positive effect on the diversity of regeneration of wood species in the young post-taungya plantation.

4.4.3. Taungya plantation stand distance to the natural forest and native woody species diversity

The result on the siginificant negative relationship (Table 13) and effect (Table 14) of distance to the natural forest on sapling diversity is contrary to the finding of Gonzales and Nakashizuka (2010) reporting no significant effect on broad-leaf saplings diversity. The result (Table 13 and 14) further showed that the distance to the natural forest did not show significant relationship with seedlings, trees and overall woody species diversity in the taungya plantation as reported in other studies (Farwig *et al.,* 2009; Gonzales and Nakashizuka, 2010). The finding in this study may be attributed to the mother seed trees preserved in the taungya plantation which also provided seeds to contribute to enhance the regeneration in the plantation, hence reducing the significance of distance from the natural forest on the regeneration of native woody species diversity.

4.4.4. Taungya plantation stems density and native woody species diversity

The result (Table 13 and 14) on the effect of the overstorey planted density on native woody species diversity is consistent with a previous study by Yirdaw (2001), who observed no significant relationship between the understory species diversity and the density of the overstorey trees in forest plantation in Ethiopian highlands. Similar results observed in Congo by Luometo and Huttel (1997) showed that plantation density resulted in few changes in the understorey floristic composition, in spite of the increase in the stand density by a factor of 3.7 to 5.7. The finding in this study could be explained by the fact that the native woody species are adaptable to the stand conditions such as water and soil nutrients in the taungya plantation. The uniform planting density in the taungya plantation could also have contributed to the finding in this study.

4.5. Management practices and native woody species regeneration in taungya plantation

4.5.1. Slash and burn process in taungya plantation land preparation

The similarity in the seedling diversity, richness and density between the taungya plantation and the adjacent natural forest suggests that the slash and burn process supported regeneration of native woody species in the taungya plantation (Table 9). A study by Raharimalala *et al.* (2010) on the impact of slash and burn process on soil-vegetation patterns in Central Menabe, Madagascar showed that an increase in duration (20 years) after abandonment of a vegetation subjected to slash and burn process enhanced woody species richness. This happened due to an increase in nutrients such as carbon and nitrogen content of the soil. Field observation of native timber species preserved selectively by the taungya farmers (Appendix 8.5) during the slash and burn process could also have served as seed sources to enhance the regeneration in the taungya plantation (Senbeta and Teketay, 2001).

4.5.2. Weeds control and pruning in taungya plantation

The use of herbicides and manual weeding (Figure 17) appears not to have inhibited the regeneration of tree seedlings diversity (Table 9) in the taungya plantation. This finding is contrary to the report of others (Schreffler and Sharpe, 2003; Jones *et al.*, 2009) reporting less woody species regeneration diversity in forest plantations with herbicide application. The finding in this study may be attributed to the fact that the active ingredient (glyphosate) in the herbicides degrade quickly after application thereby, not destroying the inflows of seeds from the adjacent natural forest and matured timber trees preserved during the slash and burn process. It has been found in this study that the seedlings have little chance of growing into saplings and trees and this could be attributed to the effect of weeding during the first three years when taungya farmers were maintaining their crops. The few (about 23%) taungya farmers undertaking pruning as a management activity (Section 3.6.2) suggest that the lightning conditions under the canopy could have been enhanced partly to encourage the regeneration of native woody species diversity as reported by Aubin *et al.* (2008).

4.6. Fire threat to taungya plantation development

The burnt scars (Appendix 8.5) observed under the canopy and on the ASTER 2008 image (Figure 18) in the taungya plantation suggest that the native woody species diversity could have been influenced by fire. In the presence of frequent fire disturbance, only species adapted to such environment survive to maturity (Lee *et al.,* 2005; Peterson and Reich, 2008). Okyere (2008) observed that natural regeneration in repeatedly burnt plantation areas was lower than old burnt areas in the Afram Headwaters Forest Reserve. Thus given time in the absence of fire disturbance, more species get established in an area due to the gradual change in site conditions such as nutrient accumulation (Goldammer, 2006).

5. CONCLUSION

The study has demonstrated the use of temporal and spatial remote sensing data and Geographic Information System (GIS) tools in quantifying forest recovery. The study showed that taungya plantation contributed to the expansion of forest cover by 26% (2,977 ha) between 2002 and 2008. Nevertheless, the observed different classification accuracies and the moderate Kappa of the ASTER 2002 and 2008 image is likely to make the forest recovery estimate less representative of the true forest cover expansion.

Post-taungya plantation can be useful to foster natural regeneration of native woody species diversity, particularly if there is a natural seed source such as mother seed trees and natural forest in the vicinity at a distance of about 1-2 km. Even though tree sapling and mature tree richness, diversity, evenness and density were lower in the young post-taungya plantation (4-6 years) compared to the adjacent natural forest, the similarity in tree seedlings suggest that the taungya plantation has the potential to develop with medium diversity of native trees in the next 40 years.

The study has shown that some of the taungya plantation stand characteristics had influence on the regeneration of the native woody species diversity. Specifically, the seedling and tree diversity were separately influenced positively by age and canopy cover percentage of the plantation. Sapling diversity was influenced negatively by distance to the natural forest and positively by age of plantation. In general, only the canopy cover percentage had positive influence on the overall native woody species diversity in the taungya plantation. The stem density, however, did not have any influence on the diversity of native woody species. The selective "slash" and "burn" process used in land preparation is the management practice leaving mother trees to serve as seed source to enhance native woody species diversity regeneration in the taungya plantation.

Limitation

The non-availability of current (2010) cloud free ASTER image limited the estimation of the forest cover expansion through taungya plantation to reflect real change on the ground.

6. RECOMMENDATIONS

The study recommends the following:

- The Forestry Commission of Ghana should consider applying Remote Sensing and GIS to monitor the development of taungya plantation.
- Due to the low overall classification accuracy and Kappa statistic of the 2002 and 2008 ASTER image, further studies should explore Artificial Neural Network or Objected Oriented analysis to enhance classification of the forest in the study area.
- The restoration of degraded forest in Ghana should take advantage of the potential of taungya plantation to ensure the recovery of some of the native tree species diversity in the original forest.
- There is a need for silvicultural treatments to enhance and maintain regenerated native woody seedlings due to their high density and diversity in the taungya plantation.
- The high regeneration density of *Antiaris toxicaria* indicates greater survivorship and adaptability of the species in the taungya plantation. For this reason, *Antiaris toxicaria* could be considered when promoting the use of native tree species for reforestation programmes.
- The Forest Services Division in Offinso should pay attention to the management and conservation of Scarlet star (threaten) woody species owing to their low density in the taungya plantation.
- There is a need to have taungya plantation established at a distance of about 1-2 km from a natural forest to serve as seed source to facilitate the regeneration of native woody species. It is also important that mother seed trees are preserved in plantation areas to provide seed sources for regeneration.

7. LIST OF REFERENCES

Agyeman, V. K., Marfo, K. A., Kasanga, K. R., Danso, E., Asare, A. B., Yeboah, O. M., & Agyeman, F. (2003). Revising the taungya plantation system: new revenue-sharing proposals from Ghana. *Unasylva (FAO), 54*, 40-43.

Aronsen, I., Lindhjem, H., & Braten, K. G. (2010). Experiences with forest benefit sharing and issues for REDD-Plus in Ghana. Final Technical Report. International Union for Conservation of Nature (IUCN), Gland, Switzerland.

Ashley, R., Russell, D., & Swallow, B. (2006). The Policy Terrain in Protected Area Landscapes: Challenges for Agroforestry in Integrated Landscape Conservation. *Biodiversity and Conservation, 15*(2), 663-689.

Aubin, I., Messier, C., & Bouchard, A. (2008). Can plantations develop understory biological and physical attributes of naturally regenerated forests? *Biological Conservation, 141*(10), 2461-2476.

Baatuuwie, B. N. (2009). *Forest plantations and the resotration of degraded forests in Ghana : a case study in the Offinso forest district.* ITC MSc Thesis, Enschede.

Barbier, S., Gosselin, F., & Balandier, P. (2008). Influence of tree species on understory vegetation diversity and mechanisms involved - A critical review for temperate and boreal forests. *Forest Ecology and Management, 254*(1), 1-15.

Beals, M., Gross, L., & Harrell, S. (2000). Diversity Indices: Shannon's H and E. Retrieved 20 August 2010, from http://www.tiem.utk.edu/~mbeals/shannonDI.html

Blay, D., Appiah, M., Damnyag, L., Dwomoh, F., Luukkanen, O., & Pappinen, A. (2008). Involving local farmers in rehabilitation of degraded tropical forests: some lessons from Ghana. *Environment, Development and Sustainability, 10*(4), 503-518.

Brockerhoff, E., Jactel, H., Parrotta, J., Quine, C., & Sayer, J. (2008). Plantation forests and biodiversity: oxymoron or opportunity? *Biodiversity and Conservation, 17*(5), 925-951.

Brockerhoff, E. G., Ecroyd, C. E., Leckie, A. C., & Kimberley, M. O. (2003). Diversity and succession of adventive and indigenous vascular understorey plants in Pinus radiata plantation forests in New Zealand. *Forest Ecology and Management, 185*(3), 307-326.

Brown, C. D., & Boutin, C. (2009). Linking past land use, recent disturbance, and dispersal mechanism to forest composition. *Biological Conservation, 142*(8), 1647-1656.

Convention on Biological Diversity (CBD). (2010). Forest Biodiversity. Retrieved 20 August 2010, from http://www.cbd.int/iyb/doc/prints/factsheets/iyb-cbd-factsheet-forest-en.pdf

Convention on Biological Diversity (CBD). (1992). Article 2. Use of Terms Retrieved 20 August 2010, from http://www.cbd.int/convention/articles.shtml?a=cbd-02.

Cusack, D., & Montagnini, F. (2004). The role of native species plantations in recovery of understory woody diversity in degraded pasturelands of Costa Rica. *Forest Ecology and Management, 188*(1-3), 1-15.

Darvishi B. A., Erasmi, S., & Kappas, M. (2006). *Urban Land Cover Mapping using Object/Pixel-Based Data Fusion and IKONOS Images.* Paper presented at the ISPRS Commission VII Mid-term Symposium, "Remote Sensing: From Pixels to Processes". Enschede, the Netherlands.

Dwomoh, F. K. (2009). *Forest fire and carbon emission from burnt tropical forest: the case of the Afram Headwaters Forest Reserve, Ghana* . ITC MSc Thesis, Enschede.

Dzwonko, Z., & Gawronski, S. (2002). Effect of litter removal on species richness and acidification of a mixed oak-pine woodland. *Biological Conservation, 106*(3), 389-398.

Ehiagbonare, J. E. (2006). Effect of Taungya on regeneration of endemic forest tree species in Nigeria: Edo State Nigeria as a case study. *African Journal of Biotechnology, 6(1)*, 1608 - 1611.

Erskine, P. D., Lamb, D., & Bristow, M. (2006). Tree species diversity and ecosystem function: Can tropical multi-species plantations generate greater productivity? *Forest Ecology and Management, 233*(2-3), 205-210.

Estevan, H., Lloret, F., Vayreda, J., & Terradas, J. (2007). Determinants of woody species richness in Scot pine and beech forests: climate, forest patch size and forest structure. *Acta Oecologica, 31*(3), 325-331.

Farwig, N., Sajita, N., & Böhning-Gaese, K. (2009). High seedling recruitment of indigenous tree species in forest plantations in Kakamega Forest, western Kenya. *Forest Ecology and Management, 257*(1), 143-150.

Forest Research Institute of Ghana (FORIG). (2003). Forest Fire Management in Ghana. Final Technical Report. Forest Research Institute of Ghana, Kumasi.

Forestry Commission of Ghana. (2008). National Forest Plantation Development Annual Report. Retrieved 20 August 2010, from http://www.fcghana.com/publications/forestry_issues/plantation/nfpdp_annual%20report_2008.pdf

Fauzi, A., Hussin, Y. A. & Weir, M. J. C. (2005). A comparison of neural networks and maximum likelihood remotely sensed data classifiers to detect logged - over tropical rain forest in Indonesia. *International Journal of Geoinformatics*, 1 (2), 47-56.

Gachet, S., Leduc, A., Bergeron, Y., Nguyen-Xuan, T., & Tremblay, F. (2007). Understory vegetation of boreal tree plantations: Differences in relation to previous land use and natural forests. *Forest Ecology and Management, 242*(1), 49-57.

Ghana Districts. (2010). Offinso Municipal. Retrieved 20 August 2010, from http://www.ghanadistricts.com/districts/?news&r=2&_=24

Goldammer, J. (2006). *Fire Ecology of the Recent Anthropocene.* In: Ehlers, E., Krafft, T., (Ed.), Earth System Science in the Anthropocene. Springer-Verlag Berlin Heidelberg, New York.

Gonzales, R. S., & Nakashizuka, T. (2010). Broad-leaf species composition in Cryptomeria japonica plantations with respect to distance from natural forest. *Forest Ecology and Management,* 259(10), 2133–2140.

Groombridge, B. (Ed.). (1992). *Global biodiversity : status of the earth's living resources : compiled by the World Conservation Monitoring Centre* London ; New York Chapman & Hall.

Günter, S., Weber, M., Erreis, R., & Aguirre, N. (2007). Influence of distance to forest edges on natural regeneration of abandoned pastures: a case study in the tropical mountain rain forest of Southern Ecuador. *European Journal of Forest Research, 126*(1), 67-75.

Hall, J., Burgess, N. D., Lovett, J., Mbilinyi, B., & Gereau, R. E. (2009). Conservation implications of deforestation across an elevational gradient in the Eastern Arc Mountains, Tanzania. *Biological Conservation, 142*(11), 2510-2521.

Hapsari, A. (2010). *Assessing and mapping ecosystem services in Offinso district, Ghana.* ITC MSc Thesis, Enschede.

Hardtle, W., von Oheimb, G., & Westphal, C. (2003). The effects of light and soil conditions on the species richness of the ground vegetation of deciduous forests in northern Germany (Schleswig-Holstein). *Forest Ecology and Management, 182*(1-3), 327-338.

Harrington, R. A., & Ewel, J. J. (1997). Invasibility of tree plantations by native and non-indigenous plant species in Hawaii. *Forest Ecology and Management, 99*, 153-162.

Hawthorne, W., & Gyakari, N. (2006). *Photoguide for the Forest Trees of Ghana. A tree-spotter's field guide for identifying the largest trees*. Department of Plant Science, Oxford Forestry Institute.

Hawthorne, W. D. (1995). *Ecological Profiles of Ghanaian Forest Trees.* Tropical Forestry Papers, No. 29. Department of Plant Science, Oxford Forestry Institute.

Hawthorne, W. D. & Musah, A. (1993). Forest protection in Ghana, Forest Inventory and Management Project, Planning Branch, Forestry Department, Kumasi, Ghana.

Ito, S., Nakayama, R., & Buckley, G. P. (2004). Effects of previous land-use on plant species diversity in semi-natural and plantation forests in a warm-temperate region in southeastern Kyushu, Japan. *Forest Ecology and Management, 196*(2-3), 213-225.

Jones, P. D., Edwards, S. L., Demarais, S., & Ezell, A. W. (2009). Vegetation community responses to different establishment regimes in loblolly pine (Pinus taeda) plantations in southern MS, USA. *Forest Ecology and Management, 257*(2), 553-560.

Jose, S. (2009). Agroforestry for ecosystem services and environmental benefits: an overview. *Agroforestry Systems, 76*(1), 1-10.

Kennedy, R. E., Townsend, P. A., Gross, J. E., Cohen, W. B., Bolstad, P., Wang, Y. Q., & Adams, P. (2009). Remote sensing change detection tools for natural resource managers: Understanding concepts and tradeoffs in the design of landscape monitoring projects. *Remote Sensing of Environment, 113*(7), 1382-1396.

Kvarda, M. E. (2004). Non-agricultural forest owners' in Austria - a new type of forest ownership. *Forest Policy and Economics, 6*(5), 459-467.

Koonkhunthod, N., Sakurai, K., & Tanaka, S. (2007). Composition and diversity of woody regeneration in a 37-year-old teak (Tectona grandis L.) plantation in Northern Thailand. *Forest Ecology and Management, 247*(1-3), 246-254.

Lamb, D., Erskine, P. D., & Parrotta, J. A. (2005). Restoration of Degraded Tropical Forest Landscapes. *Science, 310*(5754), 1628-1632.

Lemenih, M., Gidyelew, T., & Teketay, D. (2004). Effects of canopy cover and understory environment of tree plantations on richness, density and size of colonizing woody species in southern Ethiopia. *Forest Ecology and Management, 194*(1-3), 1-10.

Lee, E. W. S., Hau, B. C. H., & Corlett, R. T. (2005). Natural regeneration in exotic tree plantations in Hong Kong, China. *Forest Ecology and Management, 212*(1-3), 358-366.

Lillesand, T. M., Kiefer, R. W., & Chipman, J. W. (2004). *Remote Sensing and Image Interpretation.* (4 ed.). New York: Wiley and Sons.

Luometo, J. J. & Huttel, C. (1997). Understory vegetation in fast-growing tree plantations on savanna soils in Congo. *Forest Ecology and Management,* 99: 65–81.

McDonald, J. H. (Ed.). (2009). *Handbook of Biological Statistics* (2 Ed.). Baltimore, Maryland: Sparky House Publishing.

McNeely, J., & Schroth, G. (2006). Agroforestry and Biodiversity Conservation – Traditional Practices, Present Dynamics, and Lessons for the Future. *Biodiversity and Conservation, 15*(2), 549-554.

Moktan, M. R., Gratzer, G., Richards, W. H., Rai, T. B., Dukpa, D., & Tenzin, K. (2009). Regeneration of mixed conifer forests under group tree selection harvest management in western Bhutan Himalayas. *Forest Ecology and Management, 257*(10), 2121-2132.

Nagaike, T. (2002). Differences in plant species diversity between conifer (Larix kaempferi) plantations and broad-leaved (Quercus crispula) secondary forests in central Japan. *Forest Ecology and Management, 168*(1-3), 111-123.

Nair, P. K. R. (1991). State-of-the-art of agroforestry systems. *Forest Ecology and Management, 45*(1-4), 5-29.

Nguyen, N. T. (2010). *Estimation and mapping of above ground biomass for the assessment and mapping of carbon stocks in tropical forest using SAR data : a case study in Afram headwaters forest, Ghana.* ITC MSc Thesis, Enschede.

Ni Dhubhain, A., Flechard, M. C., Moloney, R., & O'Connor, D. (2009). Stakeholders' perceptions of forestry in rural areas-Two case studies in Ireland. *Land Use Policy, 26*(3), 695-703.

Nunifu, T. K., & Murchison, H. G. (1999). Provisional yield models of Teak (*Tectona grandis* Linn F.) plantations in northern Ghana. *Forest Ecology and Management, 120*(1-3), 171-178.

Okyere, T. (2008). *Post - forest fire rehabilitation assessment using remote sensing and GIS techniques : implications for fire management.* ITC MSc Thesis, Enschede.

Omo-Irabor, O. O., & Oduyemi, K. (2007). *A hybrid image classification approach for the systematic analysis of Land Cover (LC) Changes in the Niger Delta Region.* Paper presented at the 5th International Symposium on Spatial Data Quality. International Institute for Geo-Information Science and Earth Observation, Enschede, Netherlands.

Peterson, D., & Reich, P. (2008). Fire frequency and tree canopy structure influence plant species diversity in a forest-grassland ecotone. *Plant Ecology, 194*(1), 5-16.

Piotto, D. (2008). A meta-analysis comparing tree growth in monocultures and mixed plantations. *Forest Ecology and Management, 255*(3-4), 781-786.

Plant Resources of Tropical Africa (PROTA). (2010). Protabase record display. Retrieved 10 January, 2011 from http://database.prota.org/PROTAhtml/Antiaris%20toxicaria_En.htm

Potapov, P., Laestadius, L., Yaroshenko, A., & Turubanova, S. (2009). Measuring and assessing forest degradation. Global mapping and monitoring the extent of forest alteration: The intact forest landscapes method: Food and Agriculture Organization of the United Nations (FAO), Forest Resource Working Paper 166.

Raharimalala, O., Buttler, A., Dirac Ramohavelo, C., Razanaka, S., Sorg, J. P., & Gobat, J. M. (2010). Soil-vegetation patterns in secondary slash and burn successions in Central Menabe, Madagascar. *Agriculture, Ecosystems & Environment, 139*(1-2), 150-158.

Rees, D. C., & Juday, G. P. (2002). Plant species diversity on logged versus burned sites in central Alaska. *Forest Ecology and Management, 155*(1-3), 291-302.

Rodeghiero, M., Tonolli, S., Vescovo, L., Gianelle, D., Cescatti, A., & Sottocornola, M. (2010). INFOCARB: A regional scale forest carbon inventory (Provincia Autonoma di Trento, Southern Italian Alps). *Forest Ecology and Management,* (259), 1093-1101.

Rosenqvist, Å., Milne, A., Lucas, R., Imhoff, M., & Dobson, C. (2003). A review of remote sensing technology in support of the Kyoto Protocol. *Environmental Science & Policy, 6*(5), 441-455.

Schroth, G., da Fonseca, G. A. B., Harvey, C. A., Gascon, C., Vasconcelos, H. L., & Izac, A. N. (2006). *Agroforestry and Biodiversity Conservation in Tropical Landscapes: Washington DC, Island Press.*

Schreffler, A. M., & Sharpe, W. E. (2003). Effects of lime, fertilizer, and herbicide on forest soil and soil solution chemistry, hardwood regeneration, and hardwood growth following shelterwood harvest. *Forest Ecology and Management, 177*(1-3), 471-484.

Senbeta, F., & Teketay, D. (2001). Regeneration of indigenous woody species under the canopies of tree plantations in central Ethiopia. *Tropical Ecology,* (42), 175–185.

Shannon, C. E. (1948). A mathematical theory of communication, Part 1. *Bell System Technical Journal* (27), 379–423.

Tolera, M., Asfaw, Z., Lemenih, M., & Karltun, E. (2008). Woody species diversity in a changing landscape in the south-central highlands of Ethiopia. *Agriculture, Ecosystems & Environment, 128*(1-2), 52-58.

Treitz, P., & Rogan, J. (2004). Remote sensing for mapping and monitoring land-cover and land-use change--an introduction. *Progress in Planning, 61*(4), 269-279.

United States Geological Survey (USGS). (2010). Earth Resources Observation and Science Center. Retrieved 20 August 2010, from http://glovis.usgs.gov/

Viera, A. J. & Garrett, J. M. (2005). Understanding interobserver agreement: the kappa statistic. *Research Series*, 37(35), 360-363.

Wang, F., & Xu, Y. (2010). Comparison of remote sensing change detection techniques for assessing hurricane damage to forests. *Environmental Monitoring and Assessment, 162*(1), 311-326.

Wang, J., Ren, H., Yang, L., Li, D., & Guo, Q. (2009). Soil seed banks in four 22-year-old plantations in South China: Implications for restoration. *Forest Ecology and Management, 258*(9), 2000-2006.

Webb, E. L., & Sah, R. N. (2003). Structure and diversity of natural and managed sal (Shorea robusta Gaertn.f.) forest in the Terai of Nepal. *Forest Ecology and Management, 176*(1-3), 337-353.

Wittenberg, R. (2004). Instruments and tools for assessing the impact of invasive plant species in Africa. Report submitted under the PDF-B phase of the UNEP/GEF Project: Removing Barriers to Invasive Plant Management in Africa. CABI Africa Regional Centre, Nairobi, Kenya.

Yirdaw, E. (2001). Diversity of naturally-regenerated native woody species in forest plantations in the Ethiopian highlands. *New Forests, 22*(3), 159-177.

Zeide, B. (2005). How to measure stand density. *Trees-Structure and Function,* 19(1), 1-14.

8. APPENDICES

8.1. List of native woody species recorded in taungya plantation

No	Scientific name	Family	Star	Guild	Seedling	Sapling	Tree	Total
1	*Afzelia africana*	Leguminosae	Pink	N.P.L.D.	1	2	2	5
2	*Alstonia boonei*	Apocynaceae	Red	Pioneer	4	12		16
3	*Antiaris toxicaria*	Moraceae	Red	N.P.L.D.	216	51	8	275
4	*Amphimas pterocarpoides*	Leguminosae	Red	N.P.L.D.	3	3	1	7
5	*Albizia ferruginea*	Leguminosae	Scarlet	N.P.L.D.	3			3
6	*Bombax buonopozense*	Bombacaceae	Pink	Pioneer	7		1	8
7	*Blighia sapida*	Sapindaceae	Green	N.P.L.D.	45	17	2	64
8	*Celtis mildbraedii*	Ulmaceae	Pink	Shade-bearer	50	17		67
9	*Chrysophyllum gigiant*	Sapotaceae	Red	Shade-bearer			1	1
10	*Cola gigantea*	Malvaceae	Green	N.P.L.D.	67	41	6	114
11	*Ceiba pentandra*	Bombacaceae	Red	Pioneer	66	23	2	91
12	*Entandrophragma angolense*	Meliaceae	Scarlet	N.P.L.D.	4			4
13	*Funtumia elastica*	Apocynaceae	Pink	N.P.L.D.	9	10	1	20
14	*Khaya grandisfoliola*	Meliaceae	Scarlet	N.P.L.D.	7		2	9
15	*Mansonia altissima*	Malvaceae	Pink	N.P.L.D.	31	7	1	39
16	*Morus mesozygia*	Moraceae	Pink	Pioneer	28	6	1	35
17	*Milicia excelsa*	Moraceae	Scarlet	Pioneer	1	4		5
18	*Nesogordonia papaverifera*	Malvaceae	Pink	Shade-bearer	15	3	2	20
19	*Pouteria altissima*	Sapotaceae	Scarlet	N.P.L.D.	13	1	1	15
20	*Pterygota macrocarpa*	Malvaceae	Scarlet	N.P.L.D.	24	3	1	28
21	*Pycnanthus angolensis*	Myristicaceae	Red	N.P.L.D.		1		1
22	*Recinodendron heudelotii*	Euphorbiaceae	Pink	Pioneer	1		1	2
23	*Sterculia rhinopetala*	Malvaceae	Pink	N.P.L.D.	4	1		5
24	*Triplochiton*	Malvaceae	Scarlet	Pioneer	5	1	1	7

	scleroxylon							
25	*Terminalia superba*	Combretaceae	Red	Pioneer	6	2		8
26	*Trilepisium madagascariense*	Moraceae	Green	N.P.L.D.	5	1		6
27	*Trichilia monadelpha*	Meliaceae	Green	N.P.L.D.	1			1
					616	206	34	856

*N.P.L.D. is Non-pioneer Light Demander

8.2. List of native woody species recorded in natural forest

No	Scientific name	Family	Star	Guild	Seedling	Sapling	Tree	Total
1	*Alstonia boonei*	Apocynaceae	Red	Pioneer	3	19	23	45
2	*Antiaris toxicaria*	Moraceae	Red	N.P.L.D.	40	25	18	83
3	*Amphimas pterocarpoides*	Leguminosae	Red	N.P.L.D.		1	12	13
4	*Antrocaryon micraster*	Anacardiaceae	Pink	N.P.L.D.			3	3
5	*Albizia ferruginea*	Leguminosae	Scarlet	N.P.L.D.	2	7	9	18
6	*Bombax buonopozense*	Bombacaceae	Pink	Pioneer		1	4	5
7	*Blighia sapida*	Sapindaceae	Green	N.P.L.D.	48	42	48	138
8	*Chrysophyllum albidum*	Sapotaceae	Pink	Shade-bearer	3	7	12	22
9	*Chrysophyllum perpulchrum*	Sapotaceae	Pink	N.P.L.D.	22	16	17	55
10	*Canarium schweinfurthii*	Burgeraceae	Red	N.P.L.D.			2	2
11	*Celtis mildbraedii*	Ulmaceae	Pink	Shade-bearer	32	76	94	202
12	*Chrysophyllum gigiant*	Sapotaceae	Red	Shade-bearer			2	2
13	*Cleistopholis patens*	Annonaceae	Green	Pioneer			1	1
14	*Cola gigantea*	Malvaceae	Green	N.P.L.D.	31	27	32	90
15	*Ceiba pentandra*	Bombacaceae	Red	Pioneer	7	4	5	16
16	*Entandrophragma utile*	Meliaceae	Scarlet	N.P.L.D.			1	1
17	*Entandrophragma angolense*	Meliaceae	Scarlet	N.P.L.D.	6	6	17	29
18	*Entandrophragma cylindricum*	Meliaceae	Scarlet	N.P.L.D.			1	1
19	*Funtumia elastica*	Apocynaceae	Pink	N.P.L.D.	9	40	55	104
20	*Ficus exasperata*	Moraceae	Green	Pioneer			1	1
21	*Hexalobus*	Annonaceae	Green	Shade-			1	1

	crispiflorus			bearer				
22	*Khaya grandisfoliola*	Meliaceae	Scarlet	N.P.L.D.	7	6	4	17
23	*Lonchocarpus sericeus*	Leguminosae	Green	N.P.L.D.	1			1
24	*Mansonia altissima*	Malvaceae	Pink	N.P.L.D.	101	126	140	367
25	*Musanga cecropioides*	Cecropiaceae	Green	Pioneer			1	1
26	*Morus mesozygia*	Moraceae	Pink	Pioneer		5	7	12
27	*Monodora myristica*	Annonaceae	Green	Shade-bearer	3	5	4	12
28	*Milicia excelsa*	Moraceae	Scarlet	Pioneer		6	10	16
29	*Nauclea dederrichii*	Rubiaceae	Scarlet	Pioneer	5	5	5	15
30	*Nesogordonia papaverifera*	Malvaceae	Pink	Shade-bearer	54	96	62	212
31	*Newbouldia laevis*	Bignoniaceae	Green	Pioneer			1	1
32	*Pouteria altissima*	Sapotaceae	Scarlet	N.P.L.D.	31	36	29	96
33	*Piptadeniastrum africanum*	Leguminosae	Red	N.P.L.D.			13	13
34	*Pericopsis elata*	Leguminosae	Scarlet	N.P.L.D.			1	1
35	*Pterygota macrocarpa*	Malvaceae	Scarlet	N.P.L.D.	18	12	15	45
36	*Pycnanthus angolensis*	Myristicaceae	Red	N.P.L.D.	6	18	12	36
37	*Recinodendron heudelotii*	Euphorbiaceae	Pink	Pioneer	1	1	2	4
38	*Spathodea campanulata*	Bignoniaceae	Green	Pioneer		1		1
39	*Sterculia rhinopetala*	Malvaceae	Pink	N.P.L.D.	35	80	78	193
40	*Sterculia oblonga*	Malvaceae	Pink	N.P.L.D.		1		1
41	*Treculia africana*	Moraceae	Green	N.P.L.D.			2	2
42	*Triplochiton scleroxylon*	Malvaceae	Scarlet	Pioneer	6	11	27	44
43	*Terminalia superba*	Combretaceae	Red	Pioneer	2	3	5	10
44	*Trilepisium madagascariense*	Moraceae	Green	N.P.L.D.	5	7	13	25
45	*Trichilia monadelpha*	Meliaceae	Green	N.P.L.D.	9	17	25	51
46	*Tetrapleura*	Leguminosae	Green	Pioneer		4	12	16

	tetraptera							
47	*Zanthoxylum leprieurii*	Rutaceae	Green	Pioneer	1	1	2	4
					488	**712**	**828**	**2028**

*N.P.L.D. is Non-pioneer Light Demander

8.3. Data sheet for assessing regeneration

Data sheet for assessing native woody species regeneration				Date:
Plot ID.	GPS Reading	X		Name of recorder:
		Y		
Landcover type:	A) Taungya plantation		b) Natural forest	

Densiometer reading	1st		2nd		3rd		4th		Average	
Stem density										
Distance to forest										

No.	Species name	Local name	Count	Height (m)	dbh(cm)	Regeneration, R / Planted, P
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						

8.4. Sample questionnaire

A. Taungya farmers

1.0 Background information of respondents

1.1 Name …………………………………………………………………………...…………………...

1.2 Location

1.2.1 Community ……………………… Coordinate x....…………….…. y………….…………

1.2.2 Plantation ……………………… Coordinate x………..………. y……………...…….

2.0 Taungya plantation development

2.1 What year did you get involved in the taungya programme?

a) 2001 b) 2002 c) 2003 d) 2004 e) 2005 f) 2006 g) 2007 h) 2008 i) 2009

2.2 Why are you participating in the taungya programme?

a) food stuff b) money from trees c) access to fertile land d) protecting the environment

e) Other…………………………..…………………………………………

2.3 What is the size of your land?

a) 0-1ha b) 1-2ha c) 2-3ha d) 3-4ha e) 4-5ha f) 6-7ha g) 8-9ha h) 9-10ha i) Others…..ha

2.4 How much area of the land have you planted with tree since inception?

a) 0-5 b) 5-10ha c) 10-15ha d) 15-20ha e) 20-25ha f) 25-30ha g) 35-40ha h) Others…..ha

2.5 What has limited the size of area planted?

a) Land b) Time c) Money d) Labour e) Others………..…………………………………....

2.6 What crops have you integrated alongside trees?

a) Cassava b) Cocoyam c) Maize d) plantain e) Others……..……………………………….....

2.7 What trees have you planted?

a) Cedrela b) Teak c) Ceiba d) Terminalia (Ofram) e) Milicia (Mahogany) f) Triplochiton (Wawa)

g) Others ……………………..……………………………………………………………

3.0 Taungya plantation Management

3.1 What is/are the sources of labour on your farm?

a) Family/household b) Hiring labour per day c) Nnoboa/cooperative d) Others…………..……

3.2 What are your responsibilities in the taungya plantation?

a) Weeding b) Pruning c) Protection from fire d)Thinning e) Planting f) logging g) Raising seedling

3.3 How do you prepare/maintain land for crop cultivation?

a) Slash & burn b) Set fire in the bush c) Zero burning d) Minimum tillage e) fertilizer application

f) Others ………………………………………………………………………………………………..

3.4 What do you consider as weed in your farm?

a) grass b) seedlings c) saplings e) Others …………………………………………………………

3.5 What is the mode of weed control in your farm?

a) Manually b) Use of weedicides c) burning d) others …………………………………..

3.6 What local tree species can you identify growing in the taungya plantation?

a) Edinam (*Entandrophragma spp.)* b) Otie (*Pycnanthus spp*.) c) Ceiba d) Terminalia (Ofram) e) Milicia (Mahogany) f) Triplochiton (Wawa) f) Cola gigantean g) Others …...…………………

3.7 What helps you to identify the native tree species in the taungya plantation?

a) leaves b) bark c) stem d) branches e) flower f) fruit g) Others………………………………

3.8 What problems do you have with the taungya programme?

a) fire c) distance to plantation d) benefit sharing e) tree seedling quality f) tree pest

e) Others…………………………………………………………………………………………..

3.9 How do you manage the problem?

a) fire belt b) have transport c) seed tree quality check d) pesticide spraying

d) Others…………………………………………………………………………………………

3.10 What extension support do you receive from Forestry Commission or non-governmental organizations?

a) fire control b) planting c) tree identification d) Pruning e) thinning f) Others……………...

B. Forestry Commission

1.0 Background information

1.1 Name of respondent ……………………………...……………………..…………………………
1.2 Job title ………………………………………………………………………………………..
1.3 Location district.…………………… Coordinate x……........………... y………………...……

2. Plantation development

2.1 What was the condition of forest before being used for taungya plantation?

a) Very degraded b) Moderately degraded c) Slightly degraded d) Not degraded at all

2.1 What activities led to the degradation of the forest?

a) Logging b) Farming c) Fire d) Other …………………………………………………………

2.2 Who were the causes of forest degradation?

a) Local people b) Illegal chainsaw operators c) Staff deployed for forest protection d) Natural means

d) Other ………………………………………………………………………………………

2.1 Management and regeneration

2.1 How would you rank the interest of Forestry Commission in using taungya plantation to enhance regeneration of native tree species?

a) High b) Medium c) Low

2.2 What extension support do you provide to communities?

a) fire control b) planting c) tree identification d) pruning e) thinning f) others………………….

2.3) What are the key successes of the taungya programme?

a) Increasing in forest cover b) Increasing natural regeneration c) Frequency of forest fire reduced

e) Others …………………………………...……………………………..………………….

2.4 What is the condition of the total forest at present compared to 2001?

a) More degraded than past b) Still degraded in the same rate as past c) Less degraded than past

d) Not degraded at all at present

2.5) What are the key constraints of the taungya programme in conserving native tree species?

a) Lack of farmers interest b) Lack of farmers knowledge c) Inadequate monitoring resources of FC

f) Others ………………………………………………...……………………………..…..

2.6 Can you enumerate strategies adopted by the Forestry Commission to ensure that farmers protect the regeneration of local tree species in taungya plantation?

a) Training b) Regular plantation monitoring c) fire management skills

d) Others…………………………………………………………………………….………………..

2.7 Please, is there any information you will like to let me know about the role of the taungya plantation in Ghana in protecting local native tree species diversity.

……………………………………………………………………………………………………..

8.5. Pictures of fieldwork

Herbicide use in taungya plantation

Burnt *Cola gigantean* from herbicide spraying

Cola gigantean (seed tree) in taungya plantation

Field assistant (tree spotter) preparing to lay plot

Slash and burn and timber preservation in taungya

Burnt scar in taungya plantation of 2008 fire

8.6. Image projection system

Projection: Transverse_Mercator

False_Easting: 274319.510000

False_Northing: 0.000000

Central_Meridian: -1.000000

Scale_Factor: 0.999750

Latitude_Of_Origin: 4.666667

Linear Unit: Meter (1.000000)

Geographic Coordinate System: GCS_Leigon

Angular Unit: Degree (0.017453292519943299)

Prime Meridian: Greenwich (0.000000000000000000)

Datum: D_Leigon

Spheroid: Clarke_1880_RGS

Semimajor Axis: 6378249.144999999600000000

Semiminor Axis: 6356514.869549775500000000

Inverse Flattening: 293.464999999999970000

8.7. Yield table of *Tectonia grandis*

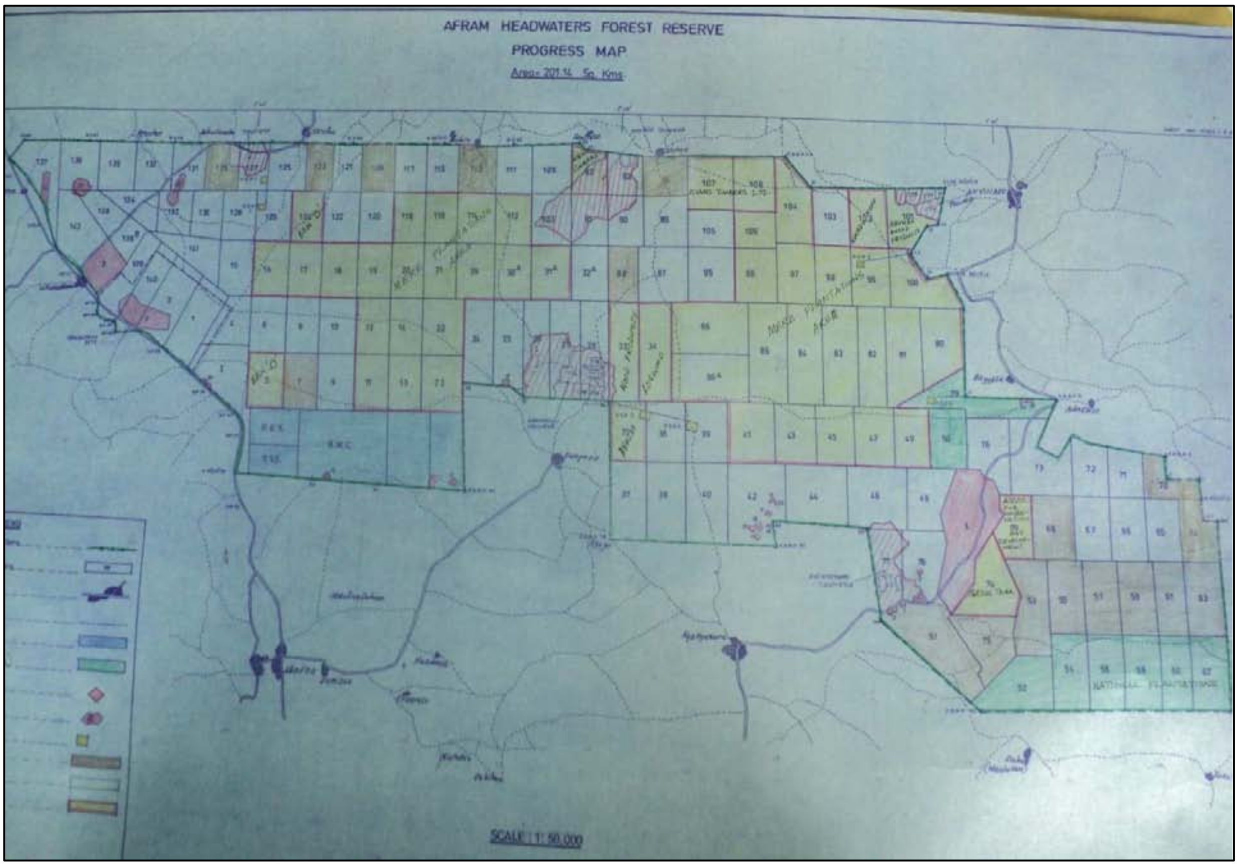
Provisional yield tables for teak plantations in northern Ghana

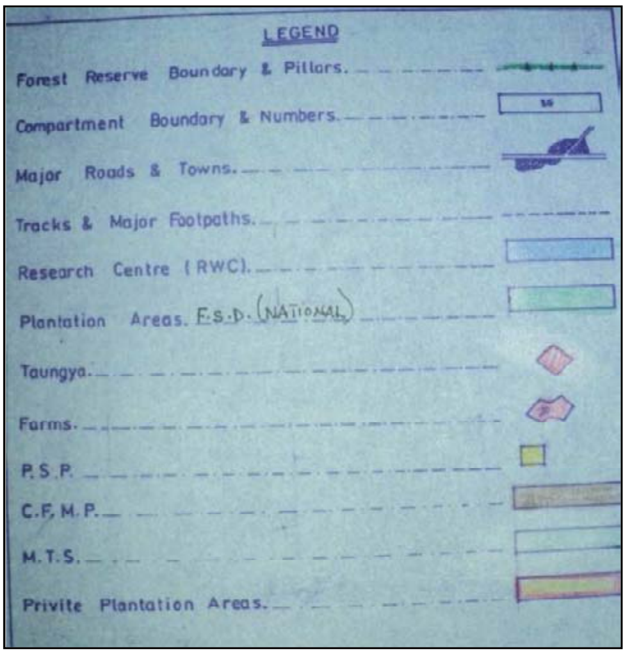
Age	dbh (cm)	Height (m)		BA (m^2/ha)	Volume (m^3)		
	Mean	Top	Mean		Gross	CAI	MAI
Site class I							
4	5.81	6.72	4.55	4.48	12.62	8.78	3.15
8	11.88	11.54	8.55	17.24	64.39	15.84	8.05
12	16.30	14.66	11.31	31.32	132.56	17.75	11.05
16	19.69	16.90	13.36	44.70	203.87	17.73	12.74
20	22.39	18.63	14.97	56.99	273.49	17.02	13.67
24	24.63	20.02	16.28	68.17	339.71	16.08	14.15
28	26.52	21.17	17.38	78.36	402.07	15.10	14.36
32	28.14	22.15	18.32	87.68	460.57	14.16	14.39
36	29.57	22.99	19.13	96.22	515.43	13.28	14.32
40	30.83	23.73	19.85	104.1	566.91	12.47	14.17
Site class II							
4	3.29	4.98	3.03	1.44	5.50	4.24	1.38
8	7.36	8.55	6.28	6.93	33.47	9.12	4.18
12	10.51	10.86	8.68	13.91	74.49	11.05	6.21
16	13.00	12.52	10.52	21.06	120.00	11.56	7.50
20	15.03	13.80	12.00	27.96	166.16	11.45	8.31
24	16.73	14.83	13.23	34.46	211.27	11.08	8.80
28	18.19	15.68	14.26	40.54	254.64	10.60	9.09
32	19.45	16.41	15.16	46.21	296.00	10.08	9.25
36	20.56	17.03	15.94	51.50	335.29	9.57	9.31
40	21.55	17.58	16.64	56.45	372.58	9.08	9.31
Site class III							
4	1.62	3.69	1.72	0.40	1.15	1.02	0.29
8	4.01	6.33	3.71	2.22	9.10	2.84	1.14
12	5.99	8.04	5.21	4.75	22.74	3.86	1.89
16	7.61	9.28	6.38	7.48	39.25	4.33	2.45
20	8.97	10.23	7.32	10.20	56.98	4.50	2.85
24	10.12	10.99	8.10	12.83	75.02	4.50	3.13
28	11.12	11.62	8.77	15.32	92.90	4.43	3.32
32	11.99	12.15	9.35	17.69	110.38	4.30	3.45
36	12.76	12.62	9.86	19.92	127.32	4.16	3.54
40	13.46	13.02	10.31	22.02	143.66	4.01	3.59

dbh – diameter at breast height; BA – basal area; CAI – current annual increment; MAI – mean annual volume increment.

Source: Nunifu and Murchison (1999).

8.8. Section of Afram Headwaters Forest Reserve compartment map





8.9. Results of Multiple Regression of Shannon-Weiner index of native woody species and plantation stand characteristics

Seedlings

Multiple R^2 = 0.183	P-value
Canopy cover percentage	0.01*
Distance to natural forest	0.28
Stem density	0.77
Age	0.24

Saplings

Multiple R^2 = 0.275	P-value
Canopy cover percentage	0.69
Distance to natural forest	0.049*
Stem density	0.82
Age	0.02*

Trees

Multiple R^2 = 0.119	P-value
Canopy cover percentage	0.04*
Distance to natural forest	0.23
Stem density	0.67
Age	0.17

Overall native woody species

Multiple R^2 = 0.119	P-value
Canopy cover percentage	0.04*
Distance to natural forest	0.14
Stem density	0.92
Age	0.48

* Significant at $P<0.05$.