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TISSUE CULTURE REGENERATION POTENTIAL OF AFRICAN ROSEWOOD IN GHANA: INSTITUTIONAL VARIABLES AND IMPLICATIONS FOR SUSTAINABILITY

BY

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DECLARATION

CANDIDATE'S DECLARATION

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for any degree other than that of my Master of Science in Kwame Nkrumah University of Science and Technology.

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DEDICATION

This thesis is dedicated to my Mum, my wife and my daughter.

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ABSTRACT

By examining the effect of trade and its concomitant effects of exploitation on the conservation and management of African Rosewood in Ghana, the cost of the shift to indigenous savannah species timber species such as African Rosewood is demonstrated in this thesis. Institutional determinants such as the "Chinese factor", a lopsided export market for Air dried lumber, abuses of the legal process, regulatory and administrative lapses amongst other factors continue to fuel the unbridled exploitation of the species.

Using results from this study conducted in the natural distribution range of the species in 6 regions of Ghana, the results indicate that there are significant disturbances within the population structure of African rosewood, at both the regional and national levels. The plot of the mean stem number per diameter class nationally does not present an inverse Jshaped curve as evidence of a balanced diameter structure of African Rosewood in Ghana. It further highlights the effect of the arbitrary interim 20cm dbh interim felling limit using the observed disturbances in the 20cm, 30cm, 40cm, 50cm and 60cm+ diameter classes. Utilising this data, questions on the sustainability of dynamic stock and the stock above the felling limit are raised. The study demonstrates the amenability of tissue culture to be successfully applied to *Pterocarpus erinaceus*, showing that the optimum combination of cytokinin treatment for the experimental set up is observed from the results to be 2.0mg/L BAP and 1.0mg/L Kinetin. In conclusion, the study recommends a tissue culture oriented conservation or management programme for African Rosewood.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to Study

Timber exports from Ghana have traditionally been based on extraction from natural forests in its High Forest Zone (HFZ) and in recent times from plantations. From 1948 to 1990, the area of the High Forest Zone decreased substantially from the original 8.2 million hectares (Mha) to about 21% of the original area, without a concomitant increase in the production capacity of the remaining forested areas (Tuffour, 1992). Thus, it was anticipated that attention will shift not only towards more sustainable sources of timber such as plantations, but also to species within the savannah zone that have export demand. Indigenous savannah species such as African Rosewood that previously had little export value currently demonstrate superlative qualities as timber and command a price premium, over teak and red star species such *Triplochiton scleroxyton* (Local Name: Wawa) as evidenced by export data for the past decade (TIDD, 1994-2013). They also possess the potential for use in forestry management programmes as plantation species. These superior qualities reflect on its price on the world market, with prices for Rosewood between US$1,000-US$3,000 per cubic metre. Prices within the Chinese local markets are reported to be even higher (Schumann *et al.*, 2009; ITTO, 2013; Yuhzu Wood Market, 2013; Global Wood Market, 2013). Data from the Timber Industry Development Division (TIDD) indicates that the year on year increases in exported volume and value of African Rosewood (TIDD, 2004-2013), does come at a cost:

Exploitation of the Resource Base.

The cost of exploitation of the resource base of African Rosewood is demonstrated in this thesis to be depletion of the resource base, the un-assessed consequent effects on biodiversity and genetic diversity and the loss of potential national foreign income earnings. These provide the push required for conservation and sustainable management of the species. The study examines the effect of trade and its attendant effects of exploitation on the conservation and management of African Rosewood in Ghana. It demonstrates the empirical reasons why tissue culture is required to propagate African Rosewood and proposes that even though there may be significant costs commitments for a tissue culture oriented conservation or management programme, it is an expedient means of augmenting the depleting resource base due to the low regeneration and survival rate of the species in the wild (Duvall, 2008; Zida *et al.*, 2008; Sawadogo, 2006; Kabore, 2004 and Bonkoungou *et al.*, 1998 and Appendix; photographs of 14 month old seedlings at less than 30cm high). The study concludes by reporting on the development of an in vitro method of propagation for the species using axillary buds as explants.

Pterocarpus erinaceus, also known as African rosewood is a deciduous tree of up to 1525m tall, belonging the family Leguminosae; sub family Papilionaceae. The species is distributed through Senegal to Cameroon and the Central African Republic and is predominantly found in the Sudan, Guinean Savannahs and forest transition zones of Ghana. It is not found within the high forest zone. The wood is highly valued for the production of furniture, cabinet work, musical instruments, fuel wood and charcoal. (Duvall, 2008). The species also holds pharmacological promise, since the bark, roots, leaves, fruit and sap are all used in herbal medicine preparations. It produces a leafy fodder high in protein; an excellent animal feed crucial for the survival of livestock during the dry season, which livestock keepers rely heavily on. In 1990, over 78% of all fresh foliage, i.e. about 1,092 tons sold in Bamako, Mali as feed for small ruminants came from African rosewood (Duvall, 2008). African rosewood also shows great potential for use in agroforestry systems, because it may improve soil fertility as the roots nodules contain nitrogen fixing bacteria. This multipurpose tree species is currently undergoing very high rates of extraction from natural stands as a result of illegal logging. It faces severe threats from environmental degradation and climate change and is currently listed as Near Threatened on the IUCN Red list (IUCN, 3.1, 2012). The current levels of exploitation have resulted in the implementation of three (3) trade and export bans during the course of this research work. The latest ban been implemented on the 5th of August, 2014. During the course of the first ban, the Ghana News Agency (GNA) on the 10th of February, 2013 carried a news article with the headline: "*Mills calls for probe into missing 64 rosewood containers*: Mr Thomas O. Mills, a member of the Lands and Forestry Taskforce called on the Sector Minister to probe the disappearance of some 64 containers of rosewood. These containers containing rosewood are alleged to have been illegally exported to Asia and other destinations (GNA, 2013). Evidently, just placing a ban on export may be inadequate, especially when there is as well a huge local demand for the species as fuel wood, for charcoal burning and possibly in the near future for the local woodwork industry. It is anticipated that the high unsustainable rates of exploitation will threaten plant biodiversity and subsequently the livelihood security of rural communities within its distribution range.

Traditionally, extraction of African Rosewood had until recent times been driven by charcoal production, which generally fed into the domestic markets. Data available from Samar et al., 2012 indicated that African rosewood was the most preferred species for fuel wood and charcoal production in Ghana, with the predominance usage rate of about 72.2%. Given that, biomass fuels mainly firewood and charcoal still account for over 35% of energy supplies in developing countries (World Bank, 2010) including Ghana, this translates into a significantly high dependency rate on the species. Recent trends, such as the licensing of companies to export charcoal by the Energy Commission (Authors field notes, 2013; RMSC - FC, 2012) without the accompanying regulation for the sources of raw materials of production and the reported levels of legal and illegal logging driven by Chinese demand (Authors field notes, 2013; RMSC-FC, 2012) have resulted in a multileveled pressure on the resource base of the species. These levels of exploitation are regulated only on two fronts; as legal timber and exported charcoal. This level of regulation, especially in the case of charcoal does not extend to the production phase or to the domestic charcoal market.

In spite of these high rates of exploitation the species has a slow growth rate. Duvall (2008), reports that seedlings were only 15cm and 42cm tall after a period of one (1) and two (2) years respectively, as the species develops a long taproot. The superlative quality of the species, coupled with the slow rate of growth within its natural range accounts for the accelerated depletion of the species. It is therefore believed that tissue culture could help reverse the downward trend of the species, as it could be used to augment the low rates of regeneration and survival through the provision of quality planting material for use in woodlots and plantations establishment. Tissue culture has broadened the options for the propagation and production of viable plants from threatened and non-threatened plant species; as it has demonstrated great potential in the collection, multiplication and storage of plant germplasm. However, in Ghana its use in the propagation and conservation efforts of tree plant species has not been widespread; even though it offers the ability to produce “natural” products, provide genetic improvements of plants and germplasm storage, enable the production of disease free plants and allows rapid multiplication. This is due in part to factors such as lack of the technical know-how, inadequate infrastructure and the cost of in-vitro propagated plants as compared to “normally” propagated seedlings. Arya *et al.* (2002) report having produced 7,500 shoots from 10 explants originating from a single plant and hypothesized that within a period of six months, a minimum of 3,000 plants could be produced from a single explant. Through the provision of quality planting material, the rates of regeneration and survival could be augmented through in vitro propagation and the level of timber production from off reserve lands could subsequently be increased within the distribution range of the species.

There is also a dearth of information on the growth rate, regeneration success, natural mortality and the impact of fire, insects and disease on African rosewood. The absence of these, are seen as a reflection of weak or non-existent strategy required for management of emerging species such as African rosewood. The association between some management tools such as the felling limit, felling intensities and environmental degradation raises more questions than answers. These questions on sustainability are confirmed through an analysis of the 2012 stocking inventory for African rosewood (Dumenu & Bandoh, 2014). The study examines the need to revisit the management and conservation regime of the species.

1.2 Problem Analysis

Lack of information about factors contributing to exploitation of African Rosewood as timber may hinder a coherent comprehension of not only the problem, but in developing pathways for its sustainable utilisation. As timber, the species has gained market premium, due to increased demand for the species in the Middle East and Asia (TIDD, 2004-2013) and this is fuelling the unbridled exploitation. African rosewood possesses similar qualities as generic Rosewood from the *Dalbergia* spp. and is marketed as its replacement within the Asian and Chinese market due to CITIES restrictions on their trade (Global Witness and EIA, 2009; BBC News Report, 2010; Dumenu & Bandoh, 2014). This "new" use of the species in Ghana, is in direct conflict with its traditional use in charcoal production and could lead to significantly higher pressures on the resource base, even though it possesses the potential to generate much higher levels of foreign exchange. Whereas its use as timber is regulated on the legal front, the significant levels of illegal timber by chainsaw operators and production of charcoal from the species for both the local and export market is completely unregulated. There is currently no available data on the volumes of African rosewood utilised or traded within the local economy.

The continued survival of the species is undermined by its increasing importance as timber and fuel wood. It is also believed that this could be at variance with other uses such as it being a source of fodder, harnessing of its pharmacological properties and its ability for soil improvement in agroforestry. The low rate of regeneration of the species, as a result of the slow growth rate of wildlings, herbivory, fire, drought and other stressors (Zida *et al.*, 2008; Kabore, 2004; Sawadogo, 2005; Duvall, 2008), places local populations of the species under enormous pressure and may hamper any serious attempts at management and conservation. The sustainability of Ghana's African rosewood resource base over the next couple of decades may possibly be drawn into question as a result of the above factors. The resultant potential effects of these processes on levels of genetic diversity of the species and biodiversity could be severe.

1.3 Justification

In recent times, the growing importance of African rosewood as premium timber (possibly an alternative to generic Rosewood from *Dalbergia* spp.) and a high value wood for charcoal burning due to its high calorific value of 21,000kJ/kg (Duvall, 2008), has placed enormous pressure on the species within its natural distribution range. Natural regeneration of the species is gradually proving inadequate due to the high mortality rate of both seeds and seedlings (Kabore, 2004; Sokpon *et al.*, 2006) and due also in part to the combination of factors such as drought, fire and herbivory (Sawadogo, 2006). This is compounded by the levels of exploitation currently been witnessed (TIDD, 2004-2013) and the generally unsustainable nature of Ghana's timber harvest (Treue, 2001).

To address the continual degradation and overexploitation of the species, the study attempts to address the problem of overexploitation of the species by a twofold approach. Firstly, through facilitating an understanding of the institutional variables that surround the trade of the species in Ghana and how these impinge on the sustainability of the species in Ghana. Secondly, the study determines the regeneration potential of the species using tissue culture.

In vitro culture has enabled a variety of plant taxa to be micropropagated in the absence of viable conventional propagation methods and has played a significant role in plant biodiversity conservation as a technology for ex-situ conservation. It provides the ability to bypass dormancy factors and the slow rate of growth that affects the production of the species from seed, thereby reducing seedling growth time and increasing the seedling production rate. The technology further offers a system that is cost effective, allows the propagation of selected genotypes with subsequent high multiplication rates and provides planting stock that are sufficiently robust enough to ensure high survival rates.

Additionally, the provision of measures such as tissue culture will support the sustainable utilisation of the species, through the provision of quality seedlings. The growing economic, commodity and social needs of the communities dependent on African rosewood for their livelihoods can then be met. The strategy will focus on increasing populations of the highly preferred species.

Expected outputs in the medium to long term include the establishment of woodlots, plantations and fodder banks which may help reduce pressures on the remaining natural stands. This strategy can then be fed into national conservation and management plans. It may also guide managers of the timber resource in the allocation of yield and in other production constraints (Werger, 2011), whilst concurrently allowing a proper evaluation of the stumpage fees and local pricing of the species.

1.4 Objectives of the Study

The overall goal of the study is to:

- Determine the institutional variables of *Pterocarpus erinaceus* (Common Name: African Rosewood) trade in Ghana and its implication on sustainability of the species, and to assess the regeneration of the species through tissue culture.

1.4.1 Specific Objectives.

1. To determine the institutional variables of African Rosewood trade in Ghana and to assess its implication on species sustainability.
2. To assess the regeneration potential of the species using tissue culture.

1.5 Significance of Study

Envisaging the future sustainability of African Rosewood can assist in planning for a sustainability program. The knowledge gained provides the baseline information intended to inform policy and subsequently integration into the Systematic Planning framework of relevant bodies such as the Forestry Commission of Ghana, CSIR-Forestry Research Institute of Ghana, various plantation development bodies and the private sector.

The study provides the empirical justification why the tissue culture approach should be considered; as means to augment the low rates of regeneration of African Rosewood (Kabore, 2004). These will allow for accelerated development of stock levels through the development of plantations, woodlots and fodder banks using high quality planting material established from tissue culture.

The combination of both laboratory work (primary quantitative data) and the analysis of other data sources poses unique challenges to any researcher. Firstly, the extensive nature of data collection, the time intensive nature of analysing both text and numeric data from various sources, require the researcher to be conversant with both quantitative and qualitative forms of research (Creswell, 2009). However, these challenges are offset by the ability to demonstrate the justification for a tissue culture oriented management and conservation approach to indigenous forestry species such as African rosewood: which possess significant potential as plantation, social or community forestry species or simply as species for climate change mitigation or restoration species.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Rosewood Timbers

Rosewood timber usually refer to a collection of hardwood timber from species that are loosely related and possess a rich brownish to black hue, with darker venation. The wood has a strong "rose like" sweet smell that persists over many years. About a dozen of the *Dalbergia* spp. known as the "True Rosewoods" are found native to Africa, Central America and Asia. Other species are *Pterocarpus indicus*, *Pterocarpus erinaceus* which is commonly referred to as African rosewood, *Machaerium scleroxylon* (Table 1). However, almost all timbers traded as rosewoods are poor in supply as a result of overexploitation and are listed on the IUCN Red list.

Table 1: A Selection of Species Commonly Called Rosewood

Species Name	Native Region	IUCN Status
Dalbergia retusa	Central America	IUCN Red List, Appendix 3
Dalbergia sissoo	Himalayan foothills in Northern India	IUCN Red List, Appendix 3
Dalbergia baronii	Eastern Madagascar	IUCN Red List, Appendix 3
Dalbergia chapelieri	Eastern Madagascar	IUCN Red List, Appendix 3
Dalbergia chlorocarpa	Western Madagascar	IUCN Red List, Appendix 3
Dalbergia greveana	Madagascar	IUCN Red List, Appendix 3
Dalbergia hildebrantii	Madagascar	IUCN Red List, Appendix 3
Dalbergia latifolia	Tropical Asia: From Nepal to Indonesia	IUCN Red List, Appendix 3

Table 1 *Cont'd.*

Species Name	**Native Region**	**IUCN Status**
Dalbergia nigra	**Brazil**	**IUCN Red List, Appendix 3**
Pterocarpus indicus	Southeast Asia	IUCN Red List
Machaerium scleroxylon	Tropical South America (Mainly Brazil and Bolivia)	IUCN Red List
Pterocarpus erinaceus	Through Senegal to Cameroon	IUCN Red List, Appendix 3
Dalbergia louvelii	Eastern Madagascar	IUCN Red List, Appendix 3
Dalbergia madagascariensis	Northern and Eastern Madagascar	IUCN Red List, Appendix 3
Dalbergia melanoxylon	From Senegal to Eritrea Ethiopia to Kenya, South to Namibia, Botswana, Northern South Africa and Swaziland	IUCN Red List, Appendix 3
Dalbergia mollis	Western and Central Madagascar	IUCN Red List, Appendix 3
Dalbergia monticola	Eastern Madagascar	IUCN Red List, Appendix 3
Dalbergia nitidula	DR Congo and Uganda, South to Angola, Zimbabwe, Mozambique, Northern South Africa.	IUCN Red List, Appendix 3
Dalbergia purpurascens	Madagascar	IUCN Red List, Appendix 3
Dalbergia trichorpa	Western Madagascar	IUCN Red List, Appendix 3

2.2 Species Description

Pterocarpus erinaceus is found in Africa and is commonly known as African Rosewood (Plate 1a & b). It belongs to the pantropical genus *Dalbergieae*, family Leguminosae; sub family, Papilionaceae.

It is a deciduous tree that grows to about 15-25m tall and has an open rounded crown. It has a straight bole up to 1m in diameter, this is cylindrical and branchless for up to 10m under good conditions, it may however present a twisted, fluted and low branched bole under poor conditions (Duvall, 2008). The bark presents a fissured and scaly surface, with a greyish brown to black and an inner yellowish brown bark. It exudes a reddish translucent gum upon slashing which hardens quickly. The stems are densely pubescent and become a glabrous grey (Duvall, 2008). The species presents leaves that alternate and imparipinnate with (5-)7-11(-15) leaflets of about 6-11cm long and 3-6cm across. These are ovate to elliptic in shape, usually notched at the apex and rounded at the base. Inflorescence, a lax panicle about 10-20cm long sets at the end of the branches. Its flowers are bisexual and papilionaceous with a golden yellow colour. The fruit is a flat samara about 4-7cm in diameter (Plate 2), with smooth red to dark brown kidney shaped seeds (Duvall, 2008).

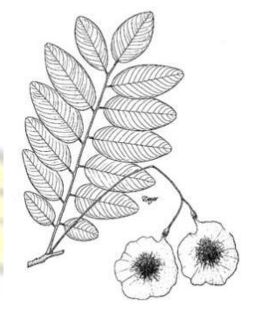


Plate 1a: Leaves and Fruits drawing of African Rosewood

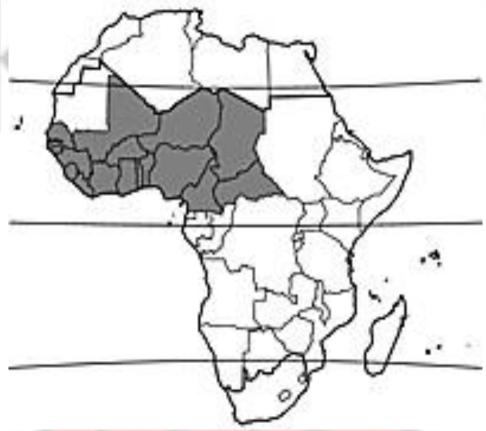
Plate 1b: Photographs of Leaves and Bark of African Rosewood (Source: Brunken *et al.*, 2008)

Plate 2: Samara of African Rosewood (Picture taken in CSIR-FORIG, 2013)

2.3 Origin and Geographic Distribution

The species is distributed through Senegal to Cameroon and the Central African Republic

(Figure 1). In Ghana, it is predominantly found in the Sudano-Guinean and Guinean Savannahs.



Key:

Non-Shaded areas indicate areas outside natural distribution range of Pterocarpus species

Shaded area indicates natural distribution range of Pterocarpus species

Figure 1: Geographic Distribution of African Rosewood

2.4 Anatomy and Properties

The wood has an energy value of about 21,000kJ/kg and is not permeable to preservatives (CIRAD, 2012). It is resistant to freshwater organisms, termites, dry wood borers and fungi. The heartwood is yellowish to reddish brown with purplish streaks, this presents a distinct demarcation from the sapwood which is 2-8cm thick and is pale cream to yellowish in colour. The fresh wood has an unpleasant smell. The species presents the following IAWA hardwood codes as given below (Wheeler *et al.,* 1989). (For full list of species IAWA codes, please refer to the Appendix)

2: indistinct or absent growth ring boundaries.

5: a diffuse-porous wood.

22: intervessel pits alternate.

26: intervessel pits medium (7-10µm).

58: gums and other deposits in heartwood vessels.

136, 142: mineral inclusions. Prismatic crystals present in chambered axial.

2.5 Ecology

2.5.1 Distribution Range

In Ghana, *Pterocarpus erinaceus* occurs in the Sudan, Guinean Savannahs and Forest Transition zones which are characterised as semi-arid to sub-humid. It can be found on all soil types, though it prefers free draining, light to medium, acid to neutral soils.

The Sudan Savannah zone which covers an estimated area of 1,900 $km^2$is characterized by a uni-modal rainfall regime lasting 5-6 months and a long dry period of 6-7 months in a year. Average annual rainfall, temperature, relative humidity, wind speed, sunshine hours and solar radiation are 885mm, 28.6^oC, 54%, 81km/day, 7.9 hours and 20.4MJ/m2/day respectively(EPA, 2002).The potential evaporation is 1,652mm per annum and the annual aridity index is 0.60.

The Guinean savannah covers almost the northern two-thirds of the Ghana with an area of 147,900km^2, it experiences similar rainfall pattern to the Sudan Savannah zone (EPA, 2002). Average annual rainfall, temperature, relative humidity, wind speed, sunshine hours and solar radiation are 1033mm, 28.1^oC, 61%, 138km/day, 7.3 hours and 19.6MJ/m^2/day respectively. The potential evaporation is 1,720mm per annum and the annual aridity index is 0.60. The Forest-Savanna Transitional Zone (Derived Savannah) covers about 8,300km^2 and most of the trees species present in the zone are similar to those in the forest zone and occur in association with tall to medium tall grasses (EPA, 2002).

The tree flowers when leafless (Plate 3 & 4), between December and April; and is visited by bees most likely responsible for pollination. Natural regeneration may be abundant, if the species is protected from grazing. The root nodules contain nitrogen fixing bacteria and the tree may demonstrate some potential in agroforestry systems, however *Pterocarpus erinaceus* has low nitrogen fixing potential in comparison to other leguminous trees (Kramer &Kozlowski, 1979).

Plate 2: Flowering African rosewood
(Source: Brunken *et al.*, 2008)

Plate 3: Bole of African Rosewood
(Picture taken in Atebubu Forest District)

The germinated rate of untreated seeds is about 50%, however treatment by either soaking in water, with sulphuric acid and mechanical scarification can yield germination rate of over 70%. The optimal germination temperature is 25-35^{o}C. The seedlings have a slow growth rate (Zida *et al.*, 2008) and Duvall, (2008)reports that in Mali seedlings were only 15cm and 42cm tall after a period of one (1) and two (2) years respectively, as the species develops a long taproot. Coppiced trees, however it is believed may grow more than 1m per year. The species however survives bushfires, with minimal impact, though it is recommended in plantations, saplings below five years require protection from wildfire (Bonkoungou *et al.*, 1998). The species does not appear to be susceptible to genetic erosion as it is widespread and occurs abundantly in many parts of its range.

2.6 Contribution to Rural Livelihoods and Poverty reduction

African rosewood is a true multipurpose tree, as it produces valuable products such as wood, fodder, fuel, medicine and shows potential for use in agroforestry systems. The species provides important contributions in addressing the issues of poverty and livelihoods, through the areas of income generation, energy provision, subsistence and vulnerability and agriculture and rural development (FAO, 1991). These are crucial to farmers, herders and communities in its distribution range.

Unlike timber from *Dalbergia* species, which is actively traded on the international market; African rosewood has been mainly used by local artisans and small scale timber merchants. There is an abundance of literature that indicates its importance in local markets; however the international trade of the species appears to be on the ascendancy. It is highly valued for furniture, cabinetry and can also be used for heavy construction; it is commonly used for house posts in the Upper East region. It is also used for musical instruments, novelties, interior trim, and precision equipment. However, Duvall, (2008) reports that locally, over-browsing for livestock and overexploitation for timber seem to be on an unsustainable basis. This has led to a ban been placed on the harvesting of timber in countries such as Mali and even Ghana.

African rosewood provides high-quality leaf fodder with an average nutritive value in dry matter of 5.3 MJ kg^{-1} as net energy, 16–19% of crude protein and 0.15% phosphorus. Pastoralists traditionally lopped wild trees in silvopastoral systems to feed their livestock during the dry season (Bonkoungou *et al.*, 1998). Increasingly, this fodder is brought to urban and semi-urban markets for sale. In 1990, over 1,092tons of African rosewood were sold in Bamako, Mali as fodder, this formed approximately 78% of all feed sold for small ruminants in the market. This is an important commodity for local communities, both as an income earner and feed for their livestock (Duvall, 2008). It was estimated that vendors generated revenue between US$6-7/day from this activity (Duvall, 2008). Given the fact that half the Malian population lives below the international poverty line of US$1.25, this was a significant income generating activity. In Ghana, livestock keepers rely heavily on the leafy branches to feed their livestock. The high livestock densities of the three northern regions; the Upper West, Upper East and Northern Regions which hold 74.4%, 36.4% and 43.4% of the national cattle, sheep and goat stocks respectively with densities of about 77 to 103 per km in the Bawku and Lawra districts respectively (EPA, 2002), highlight the enormous pressure on the species.

The consumption of fuelwood and charcoal is particularly important in the provision of the energy needs of both rural and urban households in Ghana. It is estimated that about 84% of Ghanaians in both urban and rural areas depend on charcoal and fuelwood for their energy needs (Energy Commission of Ghana, 2014). This need has buoyed the growth of a vibrant sector of the informal economy: the charcoal burning industry, whose exact contribution to GDP and the labour pools is unknown. Kristensen *et al.* (2003) in a local knowledge informant-based valuation concerning the use of 20 woody species showed that *Pterocarpus erinaceus* was of high importance as a species for fuelwood and charcoal. They indicated the clear preference the respondents had for the species and the prime value they placed on it in comparison to other species. African rosewood is rapidly gaining prominence as a premium species for charcoal burning, due to its high calorific value. Samar *et al.* (2012) reported that in Ghana, African rosewood was the most preferred species for charcoal burning, with a usage rate of about 72.2%. This rate is clearly unsustainable and in the absence of a management plan for the species, the availability of the species in the natural forest and savannah will be significantly reduced.

The World Bank (2000) report states that 75% to 90% of people in developing countries depend solely on natural products as a source of medicine. In Ghana, the species contributes to reducing the vulnerability of rural communities who do not have access to healthcare, as it has considerable pharmacological properties. The bark, leaf and roots of African rosewood are used in traditional medicine and play a pivotal role in improving the quality of life of communities within its distribution range. Decoctions and infusions of the root or bark are used in treating wounds, dysmenorrhoea, bronchial infections, toothache, dysentery and other bacterial infections. Root preparations are administered as an enema to treat sexually transmitted diseases such as gonorrhea. The bark exudates (kino) contain between 30-80% kinotannic acid, a strong astringent, antioxidants and phenolic compounds. In in-vitro tests against several human pathogens, the bark extract showed in-vitro antibacterial and antifungal activities. It also demonstrated moderate invitro antimalarial activity against strains of *Plasmodium falciparum* (Duvall, 2008).

The species has a lower nitrogen fixing potential in comparison with other leguminous trees. Notwithstanding this, its presence in the Sudan and Guinean savannah is of prime importance to soil fertility and degradation mitigation within the area. The Environmental Protection Agency (EPA) ranks the regions which cover about 50% of Ghana as liable to desertification, lightly to severely degraded, with low soil organic content and a nutrient depletion rate of 35 kg N, 4kg P and 20 kg K ha-1 (EPA, 2002). The species could play an important role in the restoration of nitrogen depleted soils and may also be used as a priority pioneer species for the rehabilitation of degraded and overexploited forests, it is therefore important that the potential for use within agroforestry systems in the region is explored and vigorously implemented. In agroforestry systems; it can therefore improve soil fertility, serve as an agroforestry fodder bank. It could be vital on farmlands to sustaining agricultural productivity and improving marginal soils, since with the exception of nitrogen from biological nitrogen fixation, the plant nutrient resource of farmers is essentially fixed if chemical inputs are not supplied (Bonkoungou *et al.*, 1998). It could also provide a source of fuelwood, for the needs of rural communities. A 1ha plot of African rosewood with trees at 70cm dbh can provide fodder for about 24 heads of cattle of 250kg, 1,851.3m^3 of timber and 2,286.9$m^3$of firewood (Bonkoungou *et al.*, 1998). Due to the absence of conclusive studies in the literature search, it may be possible that the nitrogen fixation potential may vary in different management systems.

2.7 Threats to African rosewood

Even though environmental processes such as climate change and desertification are profoundly altering the natural range of African rosewood, the main threats to the species have been of an anthropogenic nature. Activities such as illegal mining, popularly called "galamsey" are destroying the land with its natural range. Over-browsing and overexploitation by livestock and fodder collection, coupled with the unregulated and unsustainable exploitation of the species for timber both locally and increasingly for export is also placing the species under severe pressure (Plate 5 and 6). Harvesting for timber or fodder is now illegal in several countries, including Mali. The increasing preference for the species in charcoal production is also a worrying trend giving the unsustainable usage and preference rates.

Other threats in Ghana have been of a regulatory nature; these have included the absence of national and local management strategies in the utilisation of African rosewood within the savannah ecosystem has left a gap which is being abused to the detriment of all the relevant stakeholders.

These threats are compounded by the slow growth of the species, which is reported to have a yearly height increment of 11-15cm during the first year and 25cm-42cm in the second year (Bonkoungou *et al.*,1998; Duvall, 2008), even though survival is high. This slow rate of regeneration poses a complex that places the future of this multipurpose tree in jeopardy, as it is envisaged that demand for species may far outstrip its availability. It is believed that tissue culture could be used to augment the low rate of regeneration through the provision of quality planting material for use in woodlots and plantations.

Plate 4: A felled tree of African Rosewood in the Atebubu Forest District

Plate 5: Lumber obtained from African rosewood (Picture credits: Author, 11/12/2012)

2.8 Status of Species

The species is listed on the IUCN red list, version 3.1, (2012) as Near Threatened. This has largely been due to the synergistic effects of three factors; over exploitation due to its increasing importance as timber and fuelwood, environmental degradation and climate change (IUCN, 3.1, 2012). However, in Ghana, the species has not been classified according to the Degree of Utilisation or "Reddish list" and is considered as a Lesser Used Species (LUS) in Schedule 3 of LI 1649. No studies have been conducted on sustainability estimates of the species in Ghana, but exploitation trends over the past decade are cause for concern.

2.9 Tissue Culture

Tissue culture technology is of great interest for the collection, multiplication and storage of plant germplasm (Engelmann, 1991), as it has broadened the options for the propagation and production of viable plants from threatened and non-threatened plant species. However, in Ghana its use in the propagation and conservation efforts of tree plant species has not been widespread; even though it offers the ability to produce “natural” products, provide genetic improvements of plants and germplasm storage, enable the production of disease free plants and allows rapid multiplication. This is due in part to factors such as lack of the technical know-how, inadequate infrastructure and the cost of in-vitro propagated plants as compared to “normally” propagated seedlings. The perception that tissue culture is of practical use to only difficult to propagate species continues to contribute to the limited applicability of the technology nationwide, but it is important to recognise that it may offer economic advantages for some species which are considered relatively easy to propagate (Konkumadi *et al.*, 2009; Lineberger, 1980). Arya et al.(2002) report having produced 7,500 shoots from 10 explants originating from a single plant and hypothesized that within a period of six months, a minimum of 3,000 plants could be produced from a single explant. The tissue culture system allows the propagation of selected genotypes with high multiplication rates in an aseptic, temperature-controlled environment. Tissue culture has created new opportunities in global trading, benefited growers, farmers, nursery owners, and has improved rural employment. This it is believed could be exploited in management systems of African rosewood for the gain of communities within its range and the nation at large (Bunn *et al.*, 2007).

Integrating tissue culture into forestry conservation and management programmes (Palo &Gerardo, 1996) of African rosewood will allow the production of high quality and uniform planting material. Such material can be multiplied on a year-round basis under disease-free conditions anywhere irrespective of the season or weather for subsequent transfer to the field: this is the main advantage ofTissue culture. The method could also be a useful way of circumventing or eliminating disease which can accrue in stock plants. Tissue culture plantlets may also have increased branching and flowering, greater vigour and higher yield, mainly due to the possibility of elimination of diseases. In vitro propagation has several purposes:

- Rescue of threatened germplasm (Paunescu, 2009).
- Production of material for conservation biology research.
- Bulking up germplasm for storage in various forms of ex situ facility (Ramsay *et al.*, 2000).
- Supplying material for various purposes to remove or reduce pressure from wild collecting.
- Growing those species with recalcitrant seeds that cannot be maintained in a seed store (Ruiz *et al.*, 2008).
- Make available material for conservation education and display.
- Producing material for reintroduction, reinforcement, habitat restoration and management (Sudhersan *et al.*, 2003; Botanic Gardens Conservation International, 2001).

2.10 In-Vitro Propagation of Woody Plants

Tissue culture technology is based on the theory of totipotency i.e., the ability of a single cell to develop into whole organism. Virtually any growing part of the plant can in theory be used for tissue culture. In practice though; the lateral meristems, shoot apices and excised plant parts such as leaves are commonly used (Dirr & Heuser, 1987). The fundamental types of vegetative regeneration in tissue culture have been: Shoot apex culture, axillary shoot proliferation, adventitious shoot initiation, organogenesis and embryogenesis. The major components of the technology include choice of explant (excised part of plant), growing of explant on a defined medium in glass vessel (in vitro), elimination and or prevention of diseases, providing appropriate cultural environment and transfer of hardening of plantlets from culture vessel in the nursery. These constitute protocol for tissue culture, which varies from species to species and variety to variety within the same species.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Institutional Determinants of African Rosewood trade

3.1.1 Description of Study Areas

Table 2 provides a breakdown of both the forest and political districts that constitute the study areas. African Rosewood is known to occur in six (6) regions; namely the Ashanti, Brong Ahafo, Northern, Upper East, Upper West and Volta regions. Using the National Stocking inventory for African Rosewood (RMSC - FC, 2012), a minimum of four (4) political districts were selected on the basis of species abundance. The study involved a total of twenty (20) visits to all forest districts within the study area. These visits were used in the administration of semi- and unstructured questionnaires used for interviews with the staff of Forestry Services Division (FSD). The visits also provided the opportunity for direct field observation, and were as well used in the collection of field reports and species inventory data.

Table 2: Forest Districts and Political Districts within which Rosewood occurs

Region	Forest District	Political Districts
Upper East	Bolgatanga	Bongo
		Tongo
		Chiana Paga
	Navrongo	Sandema
Upper West	Tumu	Sisala East
		Sisala East
	Lawra	Wa east
		Wa east

Table 2 *Cont'd.*

Region	Forest District	Political Districts
Volta	Jasikan	Biakoye
	Nkwanta	Krachi East
		Nkwanta South
		Nkwanta North
Ashanti	Kumawu	Sekyere
		Sekyere Afram Plains
Brong Ahafo	Atebubu	Sene East
		Sene West
		Pru
		Prang
	Dormaa	Jaman North
		Jaman South
	Kintampo	Kintampo Municipal
		Nkoransa North
	Sunyani	Nkoransa South
		Tain
Northern	Bole	Bole Bamboi

		Sawla Tuna Kuba
	Buipe	Central Gonja
		West Gonja
	Yendi	Saboba
		Yendi
		Zabzugu

3.1.2 Map of Study Area

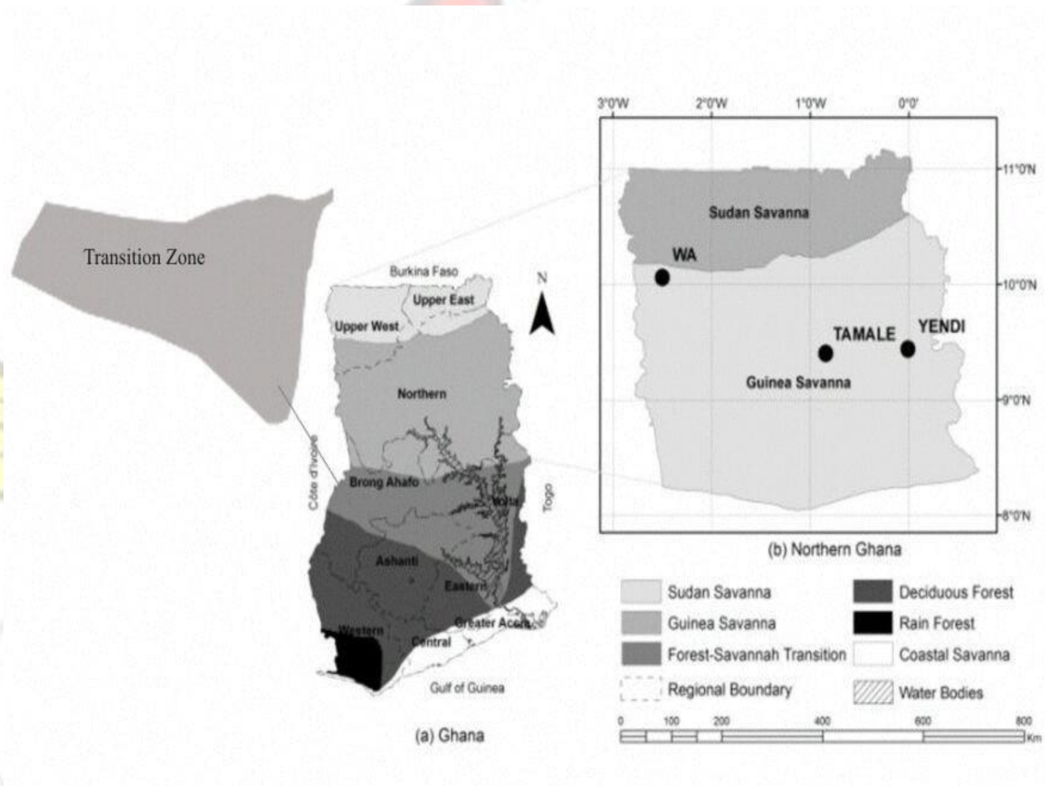


Figure 1: Map of Ghana with study areas highlighted

Figure 2 provides a map of the natural distribution range of African rosewood. It shows that the species is found primarily within the Transition, Sudan and Guinean Savannah and the Dry Semi Deciduous forest vegetative zones of Ghana.

3.2 RESEARCH DESIGN

This study is a mixed method study (Tashakkori and Teddlie, 1998, Tashakkori and Charles, 2003) and consists of both qualitative and quantitative methods. The study uses the embedded approach of the Concurrent Transformative Strategy (Creswell, 2009), which allows both qualitative and quantitative data to be collected at the same time.

Data collection process consisted of three parts: In the first phase, extensive quantitative secondary data, such TIDD reports, TIF forms, FSD species inventory data, grey literature and other data sources for the period 1994 to 2013 were collected, reviewed and expert consultation took place. The second phase consisted of the administration of semi structured and unstructured questionnaires to the following stakeholders: Managers of the Forestry Resource; Forestry Commission of Ghana (FC) and theForestry Services Division (FSD), Forestry Research Institute of Ghana, Timber contractors, illegal Timber gangs and Communities leaders. Field study locations were purposively selected for the interviews, observation and administration of questionnaires, forestry resource managers from the Brong Ahafo, Ashanti and Northern regions were interviewed. The views of the stakeholders were sought on general knowledge about the species, perceptions of usefulness and availability and trends of exploitation. Legal, governance and other issues related to the conservation and management of the species were collected. The third phase was the development of a tissue culture protocol in the laboratory to augment rates of regeneration and survival.

The triangulation framework is produced for the three most important data sources for each research question are represented in Table 3.

Table 3: Triangulation Framework

RESEARCH QUESTIONS	DATA SOURCE 1	DATA SOURCE 2	DATA SOURCE 3
a) What are the institutional factors driving exploitation?	Field study, Semi and unstructured interviews	TIDD reports 2004-2013	FSD TIF data
b) How significant are these factors on African rosewood stock?	Stocking inventory data 2012.	TIDD reports 2004-2013	FSD TIF data
c) How can tissue culture serve as a means for ensuring a sustainable supply of the resource?	Laboratory Work	Refereed journal papers.	

3.2.1 Sampling design and Data collection

i. Reliability and Validity of Data Sources

All study sites were selected upon the basis of data presented in the National Stocking inventory for Rosewood (RMSC-FC, 2012) in Ghana.

ii. Data Collection

A total of 40 respondents were purposively selected (Table 4), to persons with extensive knowledge and experience about forestry and African rosewood. The semi structured and unstructured questionnaires were administered to the Resource managers at the various district forestry and regional forestry offices. All other respondents were interviewed in the in the field.

Table 4: The Population and Sample Size

Forest District	Number of Respondents
Bolgatanga	3
Navrongo	2
Tumu	2
Lawra	1
Jasikan	4
Nkwanta	3
Kumawu	4
Atebubu	7
Dormaa	3
Kintampo	4
Sunyani	2
Bole	1
Buipe	2
Yendi	2
TOTAL:	40

Source: Author's Field Notes, 2012

iii. Coding and Clustering

Qualitative data for the study was collected through the unstructured, semi structured interviews and focus group discussions, with the following groups of persons:

- Managers of the African Rosewood resource: FSD/FC, CSIR-FORIG, RMSC-FC.
- Focal persons within communities in the distribution range of African Rosewood
- Persons involved in African Rosewood extraction: timber contractors, permit holders, illegal operator

iv. Instrumentation

The interview schedule sought to identify five (5) main factors: extent of trade in African rosewood, regulatory and administrative process, issues of resource governance, abuse of the legal process and the socio-political environment.

v. Analysis of Data

The information gathered from the semi structured and unstructured interviews was manually clustered and coded. It was then analysed using a Fishbone or Ishikawa Diagram, as developed by Kaoru Ishikawa (Ishikawa, 1976). This method presented the study with the ability to contribute to the understanding of the problem with a Process analysis and Root and Cause diagram.

All other secondary data on the African Rosewood population structure and export information was analysed using Statistical Package for Social Scientists (SPSS version 16, IBM) in the form of graphs or tables. The statistical tools used included inferential statistics and ANOVA. The results and recommendations obtained are presented in the Chapters 4, 5 and 6.

3.3 Tissue Culture

The materials used included:

Preparation Room

a. Autoclave (Express Autoclave: Model Number ST 19)

b. Water distillation unit

c. Hot plate with magnetic stirrer

d. pH meter

e. Analytical balance

f. Microwave oven

Transfer room

a. Laminar flow cabinets

b. Safety burners and Glass bead sterilizers

c. Microscope

Growth room

a. Air conditioners for temperature regulation

b. Thermometer for temperature recording

c. Artificial lighting: two(2) 65W cool daylight fluorescent tubes per shelf

d. Shelving unit frames made of wood and laminated shown in Figure 3.

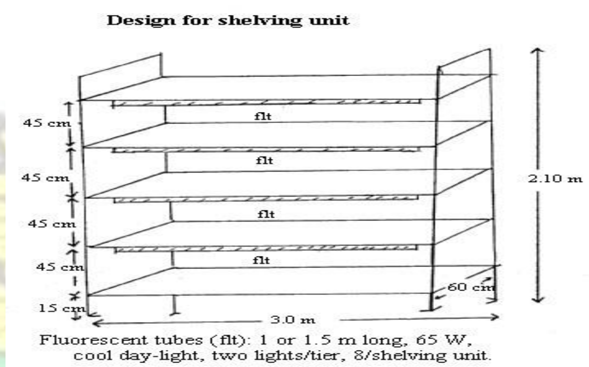


Figure 2: Design for Shelving Units

Consumables

A. Reagents for media preparation and explant sterilisation

a. Agar

b. Analytical grade sucrose

c. Antioxidants: activated charcoal.

d. MS stock solutions

e. Plant Growth regulators: Auxins: NAA, Cytokinins: Kinetin, BAP

f. Buffers for pH meter

g. 70% alcohol

h. Fungicide for surface sterilisation

i. 10% sodium hypochlorite or bleach

j. Sterile distilled water

B. Equipment for media preparation and explant sterilisation

a. Glasswаre

b. Pipettes (0-999µm), (1-2ml)

c. Surgical blades, knives, forceps, and scissors

d. Millipore filters

e. Culture bottles

f. Syringe

3.3.1 Experimental Methods

i. *Collection and management of plant material:* Plant materials used in this study were collected in the Atebubu forest district of Ghana and consisted of young vigorously growing shoots on mature trees, which possessed all the qualities of juvenile tissue. Sample preparation on site included surface sterilisation, washing the young shoots thoroughly and transporting them in cool boxes for subsequent transportation to the Forestry Research Institute of Ghana (CSIR-FORIG) at Fumesua.

ii. *Establishment of sterilization protocol:* All the glassware, metallic equipment and culture medium used for this section were sterilized by autoclaving at 121°C and 1.06 kg cm^2 pressure for 15 min before use. The study evaluated two methods in establishing the aseptic culture, these were scored for the number of contaminants observed after a two-week period and also the effects on the explants. The sterilisation regime was conducted to determine the most suitable or optimum sterilisation protocol (Table 5).

Table 5: Sterilisation Regime Table

Treatments	Hydrogen Peroxide 10%	0.1% Fungicide	Sodium Hypochlorite 10%
A			
B			

iii. *Explants preparation*: Explants in Treatment A were subjected to a two-step procedure: field sterilization and subsequent laboratory sterilization or Treatment B, as seen in Table 5. Untrimmed explants were washed in three changes of distilled water in the field, followed by moderate shaking in 10% hydrogen peroxide for 10 minutes. Explants were then rinsed thrice with sterile distilled water and transported to the laboratory and subjected to Treatment B given below.

Explants in Treatment B were subjected to only laboratory sterilization which included 0.1% Fungicide and 10% concentration of sodium hypochlorite. In the laboratory, untrimmed explants were washed with detergent water and sterile distilled water. The explants were then trimmed and subjected to the sterilisation regime as given below in the laminar flow hood:

a. 0.1% of fungicide was prepared by weighing 0.5g of Diethane and dissolving it in 500ml of sterile distilled water. The trimmed explants were put in the Diethane solution for 20 minutes, placed on an orbital shaker and were rinsed thrice with sterile distilled water.

b. The explants were then transferred to 10% sodium hypochlorite solution for 10 minutes and were rinsed thrice with sterile distilled water.

c. Explants were blotted or dried with pre sterilised blotting paper or tissue.

3.3.2 Media Preparation and Inoculation

The culture media was prepared with the protocol of Murashige & Skoog (1962) using 3% sucrose. The pH of the medium was adjusted to 5.79, before the addition of 4.8g/l of agar. This was autoclaved for 25 minutes at 121 ^{o}C and media were dispensed in 20ml aliquots (Plate 9 & 10).

Plate 6: Axillary Bud of African Rosewood

Plate 7: Bead Steriliser for maintaining sterile instruments

Plate 8: Media Preparation

Plate 9: Media dispensing

Axillary buds of trimmed explants were aseptically excised in the laminar flow hood (Plate 7, 8 & 11) and transferred to MS agar culture media (Murashige & Skoog, 1962) as prepared below and were supplemented with plant growth regulators according to Table 6. Explants were incubated at 25°C with a 16-h photoperiod using cool daylight fluorescent tubes.

Plate 10: Explants been excised under aseptic conditions

3.4 Stock Solutions Preparation

3.4.1 Preparation of Major and Minor Nutrients Solutions

Table 6: Major and Minor Mineral salts concentration in MS media formulation

Stock Solutions	mg/L
Solution 1	
Potassium Nitrate (KNO_3)	1900
Ammonium Nitrate (NH_4NO_3)	1650
Solution 2	
Copper Sulphate Pentahydrate ($CuSO_4.5H_2O$)	0.025
Magnesium Sulpahte Heptahydrate ($MgSO_4.7H_2O$)	370
Manganese Sulphate ($MnSO_4$)	16.9
Zinc Sulphate Heptahydrate ($ZnSO4.7H_2O$)	8.6
Solution 3	
Potassium iodide (KI)	0.83
Calcium chloride ($CaCl_2.2H_2O$)	440
Cobalt Chloride Hexahydrate ($CoCl.6H_2O$)	0.025
Solution 4	
Boric Acid (H_3BO_3)	6.2
Potassium dihydrogen phosphate (KH_2PO_4)	170
Sodium molybdenate dehydrate ($NaMoO_4.2H_2O$)	0.25
Solution 5	
Iron (ii) Sulphate Heptahydrate ($FeSO_4.7H_2O$)	27.8

Sodium EDTA	37.3
Solution 6	
Glycine	2.0
Meso-Inositol	100
Nicotinic Acid	0.5
Pyridoxine HCL	0.5
Thiamine HCL	0.5

(Murashige and Skoog, 1962)

The stock solutions were prepared by weighing out the above listed quantities in Table 6 into volumetric flasks and dissolving them in 1000ml of distilled water.

3.4.2 Preparation of Plant Growth regulators solutions

In order to obtain a final concentration of 1g/L or 1mg/ml, the following steps were followed:

a) Preparation of 6-Benzylaminopurine stock solution:

i. 0.025g of BAP were weighed and placed in a beaker ii. 5mls of 1M dilute HCL was added to dissolve it iii. The resulting solution was topped up to 25mls in a pre-sterilised falcon tube with sterile distilled water and filtered using a Millipore filter of 22µm diameter. The stock solution was aliquoted and stored in the freezer.

b) Preparation of Kinetin stock solution:

i. 0.025g of Kinetin was weighed ii. A few mls of IN NaOH was added to dissolve it iii. The resulting solution was topped up to 25mls in a pre-sterilised falcon tube with sterile distilled water and filtered using a Millipore filter of 22µm diameter. The stock solution was aliquoted and stored in the freezer.

c) Preparation of NAA stock solution:

i. 0.025g of NAA was weighed ii. A few mls of IN NaOH was added to dissolve it iii. The resulting solution was topped up to 25mls in a pre-sterilised falcon tube with sterile distilled water and filtered using a Millipore filter of 22µm diameter iv. The stock solution was aliquoted and stored in the freezer.

d) Preparation of IBA stock solution:

i. 0.025g each of IBA was weighed

ii. About 5mls of methylated spirit was added to dissolve it iii. The resulting solution was topped up to 25mls in a pre-sterilised falcon tube with sterile distilled water and filtered using a Millipore filter of 22µm diameter. The stock solution was aliquoted and stored in the freezer.

3.5 Experimental Variables

3.5.1 Experimental design

The sample size was 150, with 10 explants each per treatment. Environmental conditions were maintained at a constant on the shelves and growth room. The experimental units were randomized on the shelves. The control was a negative control that had no plant growth regulators present. Cultures were prepared using the standard MS protocol, and were kept under the same conditions. The cultures were incubated at 25°C under a 16 hour photoperiod with a light intensity of 34.2µmol/m²/s.

3.5.2 Treatments

The variables examined to optimize the micropropagation protocol included: the determination of the optimum concentration of cytokinins: BAP (6-Benzylaminopurine) and Kinetin media on shoot growth of African rosewood.

Plant Growth Regulators (PGRs) used at 3 different levels or concentrations for shoot growths were given below:

a. BAP (6-Benzylaminopurine)

b. Kinetin

c. NAA (1- Naphthalene acetic acid)

Table 7: Concentrations and Combinations of Plant growth regulators used Shoot apex culture

		Kinetin		
BAP	**Levels in mg/L**	**0**	**0.5**	**1.0**
	0	0 +0	0 + 0.5	0 + 1
	1	1 +0	1 + 0.5	1 + 1
	2	2 +0	2 + 0.5	2 + 1
	5	5 +0	5 + 0.5	5 + 1
NAA	**0.4**	1 + 0.5 + 0.4	2 + 1.0 + 0.4	5 + 1.0 + 0.4

There were fifteen (15) treatments in total, this included the control, five (5) single plant growth regulator treatments and nine (9) combination treatments (Table 7).

3.5.3 Data Collected

Data collected included growth performance characteristics (bud elongation, shoot growth, root growth, root growth, etc) and the presence of contamination, etc (Mize *et al*., 1999).

Plate 11: Explants randomised on the shelves in the growth room

3.5.4 Statistical methods of Analysis

A statistical design of Completely Randomised Design was used with three replicates (Plate 12). This was generated using the Microsoft Excel® Rand function. Data was analysed using the following:

a. ANOVA: for continuous data such as shoot length.

b. Poisson Regression: for count data, such as the presence or absence of contamination (Compton & Mize, 1999, Mize *et al.*, 1999).

c. Logistic regression; for data such as, shoot, root, callus or nothing formed (Compton &Mize, 1999).

CHAPTER FOUR

4.0 RESULTS

4.1 Institutional determinants of African Rosewood trade

A total of six types of institutional determinants that affect the management and conservation of African Rosewood in Ghana were identified. These were:

a. Regulatory and Administrative

b. Legal and Governance

c. Political

d. Business dynamics

e. Sociocultural

f. Socioeconomic

These categories are analysed on an Ishakawa or fishbone diagram (Ishakawa, 1976) (Figure 4). The positions of the various categories are not weighted or prioritised on the Ishakawa diagram.

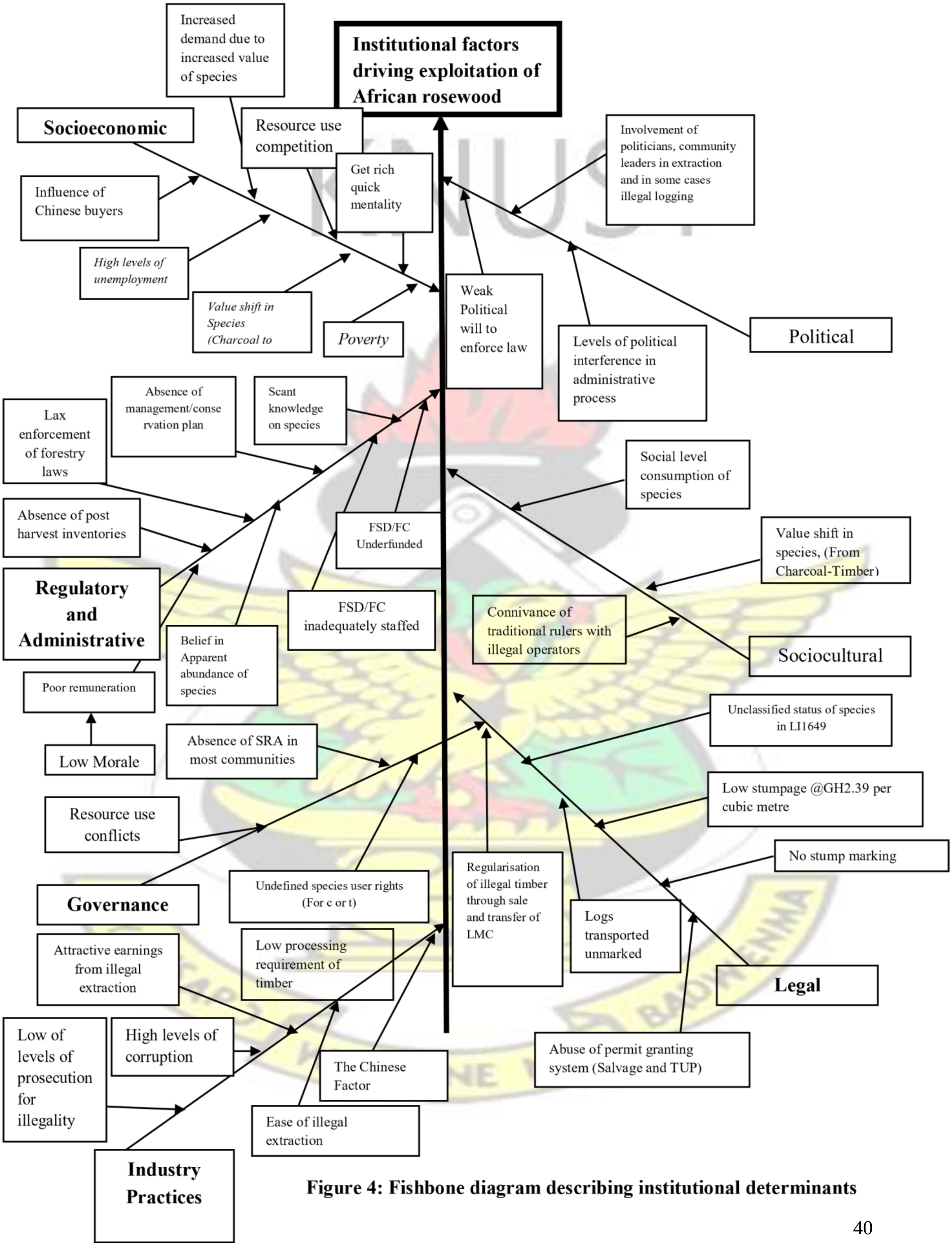


Figure 4: Fishbone diagram describing institutional determinants

Figure 4 shows the impact of these factors on the conservation and management of African Rosewood. This is seen to range from the desire to get rich quick to complex issues such as the level of political interference in administrative and regulatory issues. These factors do not act in isolation or individually, but act in concert with each other to negatively impact the conservation and management practice of African rosewood. There were also significant degrees of interrelatedness within and amongst the various Category classes.

4.1.1 Governance

Plate 12: Conveying Harvested African Rosewood in Gurunkpe near Buipe

The following governance pitfalls: undefined user rights, resource use conflicts and the absence of Social Responsibility Agreements (SRA), were identified in most communities visited. In most communities, most persons including traditional rulers interviewed believed that their access to African rosewood as timber should not be hindered by law, because they possessed unfettered access to it for use as charcoal, fuelwood, fodder and for medicinal purposes. This led to numerous resource use competitions and conflicts nationwide, in particular in the Gurunkpe Township, Fakwasi and Dwan Stool Lands (Plate 13). In these communities, contractors were compelled to negotiate “fees” with townsfolk before they were allowed to convey harvested timber. In some cases it led to outright conflict in certain cases between the communities and officials of the FSD/FC, requiring the presence of the military to enable harvested timber to be conveyed (Plate 13).

4.1.2 The Legal process

There have been wholesale abuses of large sections of the Timber Resources Management Regulations (LI1649), 1998 (LI1649, 1998) and the Timber Resources Management Act (Act 547), 1998 (Act 547, 1998). These have ranged from illegal chainsaw operations to the failure of the Forestry Commission of Ghana (FC) to revise the stumpage fee per cubic metre in response to the increasing price per cubic metre of Rosewood logs. This and other factors have resulted in an extremely low stumpage value of GH¢2.39 and a resultant artificially low log price.

There were also been significant abuses of the permit granting system through the use of Salvage and Timber utilisation permits (TUP) in harvesting harvest timber in all forestry districts visited. However, in the Tain Forestry district due to the construction of the Bui dam, some areas were under salvage permit. These permits by law are to be used in the small scale harvesting of timber for social or community purposes in the case of the TUP, most importantly timber from these permits cannot be sold or exported

In all Forestry districts visited, it was observed that these two permits appeared to be a means by which African Rosewood was harvested. The implications of this are that all African Rosewood timber harvested and exported under these permits stands a high risk of being deemed illegal. Even though this issue was confirmed by Global Witness (Global Witness, 2013), it has been denied categorically by the Forestry Commission of Ghana in an advertiser's announcement (F.C., 2013).

There were also issues of the regularisation of illegal rosewood timber through the sale or transfer of LMC or conveyance permits for the transfer of timber harvested without permits, to the Tema Port. Other issues were related, but not limited to the absence of stump and log marking after harvesting and other factors.

4.1.3 Socioeconomic Interplay

Plate 13: Large scale felling of African Rosewood in Kintampo Forest District

The study observed a free–for–all grab of Rosewood timber as a result of this increased demand by all manner of persons, including politicians and traditional leaders. Large areas were clear felled of the species to satisfy this huge demand in communities across the distribution zone of the species (Plate 14).

4.1.4 Political and Sociocultural factors

During the study period, an extremely high occurrence of involvement of politicians, traditional rulers and community leaders were witnessed in the legal and mostly illegal extraction of African rosewood. Traditional rulers routinely connived with illegal operators by selling them land. This land was then harvested of its rosewood timber. In some cases, there was the tacit involvement of traditional leaders in the extraction as witnessed in the Atebubu forest district (Bandoh & Dumenu, 2014). The severity of this involvement transcends not just involvement in extraction, but interference in the administrative processes of the FSD/FC by such individuals. Evidence abounds of instances in which some Districts Managers of FSD received orders sometimes from above to give person "X", the right to harvest or buy rosewood timber. These usually came in the form of phone calls, permits issued from Accra, etc.

4.1.5 Regulatory and Administrative Lapses

In almost all the FC-FSD offices visited, inadequate logistics and funding of the resource manager by the central government was witnessed.

4.1.6 Industry Practice

High levels of corruption coupled with low levels of prosecution for illegally harvesting timber were witnessed in most of the forest districts visited. This was compounded by the flow of money from the Chinese buyers who paid well for the timber from African rosewood and lubricated the gears of the regulatory institutions.

4.2 African Rosewood Products types and Volumes Exported

4.2.1 Direction of Export

Over 90% of all Rosewood exports from Ghana are destined for China, namely to the ports of Guangdong, Guangzhou and Hong Kong (Figure 5). From the ports, it is actively traded using the trade name: Paduak through a network of middlemen and timber importing firms for the production of luxury furniture, musical instruments and woodwork to meet the growing demands of the rapidly expanding Asian middle class.

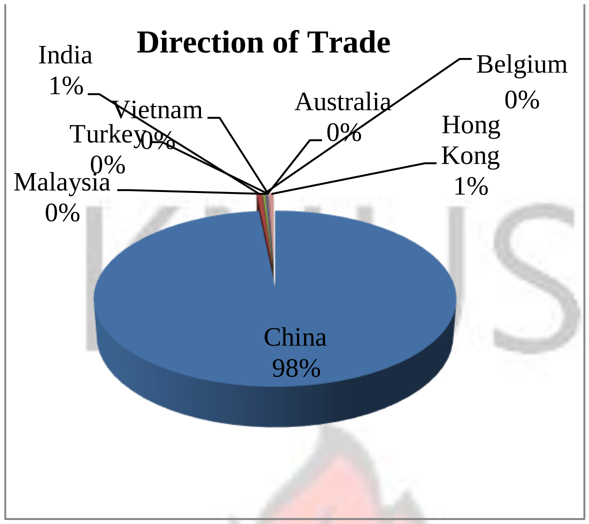


Figure 5: Destination of Rosewood Exports

4.2.2 Wood Product Types

Figure 6 shows the eight (8) wood product types exports of African Rosewood; namely Air dried lumber, Kiln dried lumber, Profile Boards, Sliced Veneer, Plywood (Overland), Poles, Lumber Overland and Processed L/Moulding.

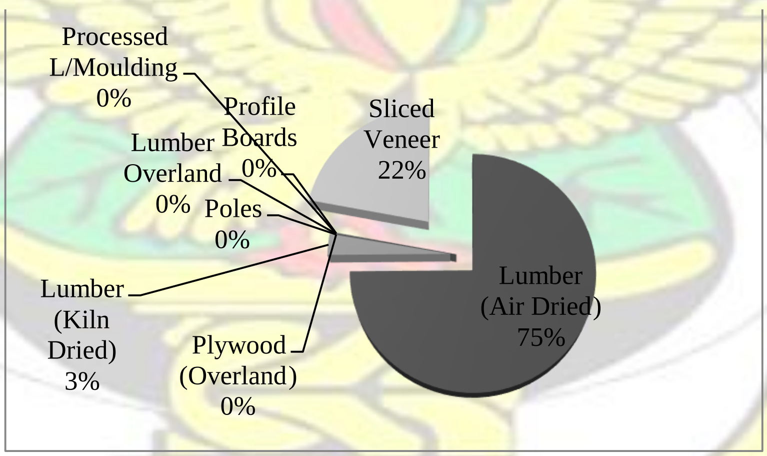


Figure 6: Percentages of Wood Product Type Exported (TIDD 2004-2013)

Air dried lumber is the predominant wood product type and constitutes over 75% of all exports for the decade (2004-2013) under consideration.

4.2.3 Price at Tema Port of Exit

The active export of African rosewood in Ghana begun in 2004. Figure 7 shows the increasing premium of African Rosewood using the Tema Port of Exit price per cubic meter.

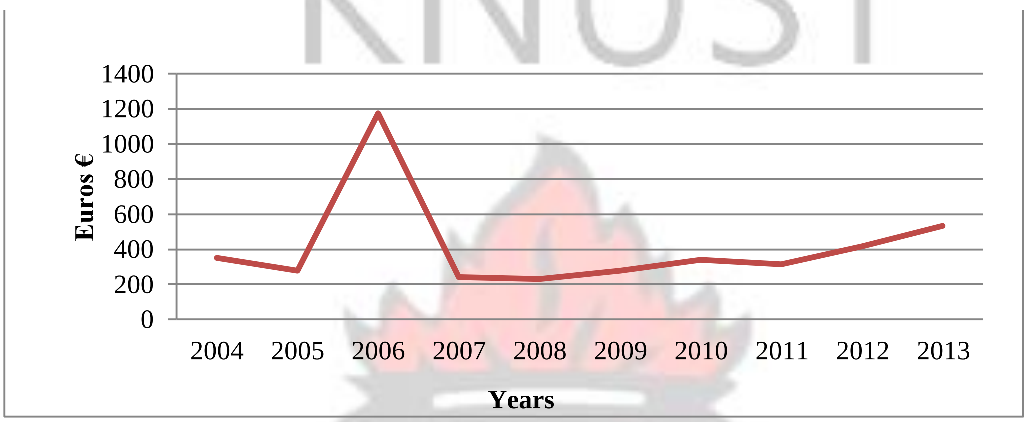


Figure 7: Average Price/m³ of African Rosewood air dried lumber for 2004-2013 (TIDD, 2013)

Comparing the initial export value of €350.639 in 2004 to €533.85 in 2013, the price of African Rosewood air dried lumber shows volatility over the past decade, averaging €416.079 over the decade period and attaining a high of €1,175 in 2006.

4.2.4 Exported Volumes

From Figure 8, the highest volume of export of African rosewood was seen in June 2013 (12,956.79m^3), followed by 2009 (10,114.37m^3). It is also seen that as of June, 2013 over 12,956.79m^3 of African rosewood with a value of €6,919,815.84 had been traded representing a 70,000% increase in volume and 100,000% increase in value (Figure 7 & 8).

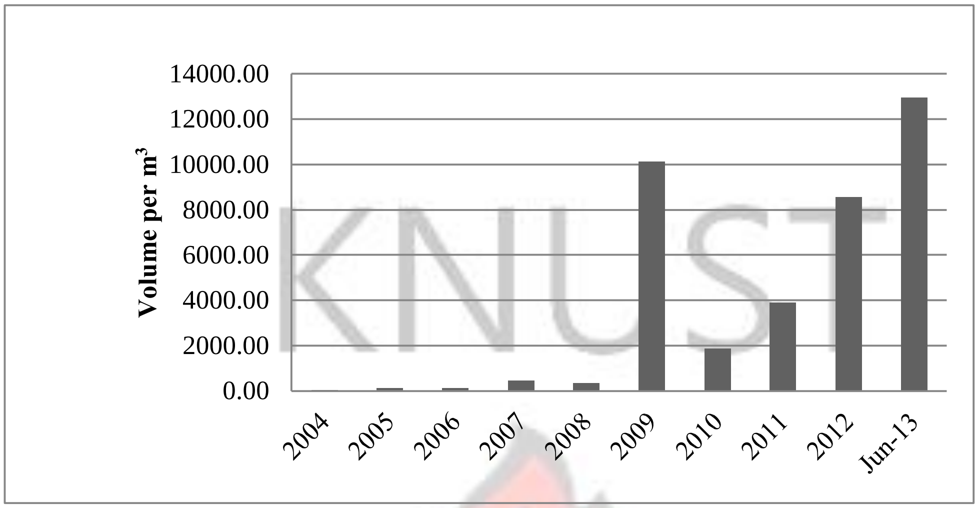


Figure 8: Annual Volume appreciation Jan 2004-June 2013 (Source: TIDD 2004-2013)

4.3 Population Structure of African rosewood In Ghana

4.3.1 Diameter class distribution

Below are the plot of mean stem numbers per 1ha on a regional and national basis for the natural distribution range of African rosewood.

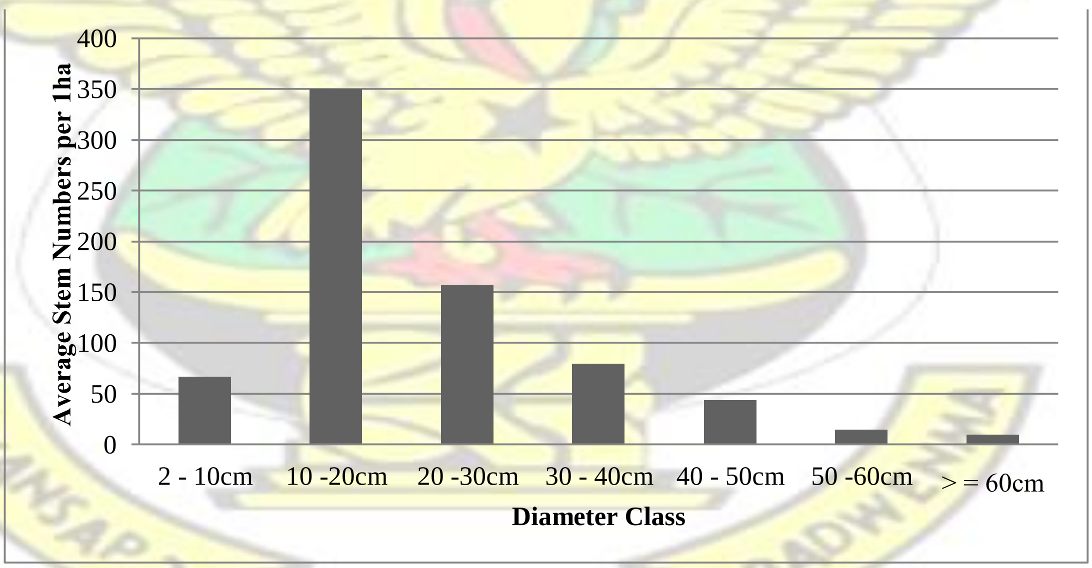


Figure 9: Plot of National Mean Stem Numbers per 1ha

From Figure 9, the number of average individuals of African Rosewood nationally per 1ha increased from 67 stems per 1ha in the 0-9.9cm diameter class to 350 stems per 1ha in the 10-19.9cm diameter class. The number of individuals subsequently decreased with increasing diameter to 9.39 stems per 1ha in the 60cm diameter class. The 2-10cm diameter class is indicative of the poor rates of regeneration present in the national population. Assessing this on a regional basis:

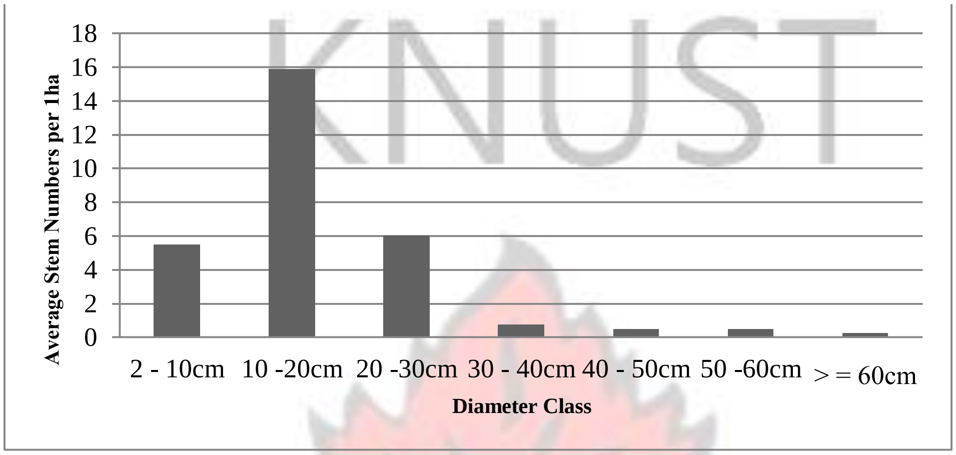


Figure 10: Plot of Ashanti Region Mean Stem Numbers per 1ha

The Ashanti region displays the lowest national mean stem numbers per 1ha across the various diameter classes (Figure 10).

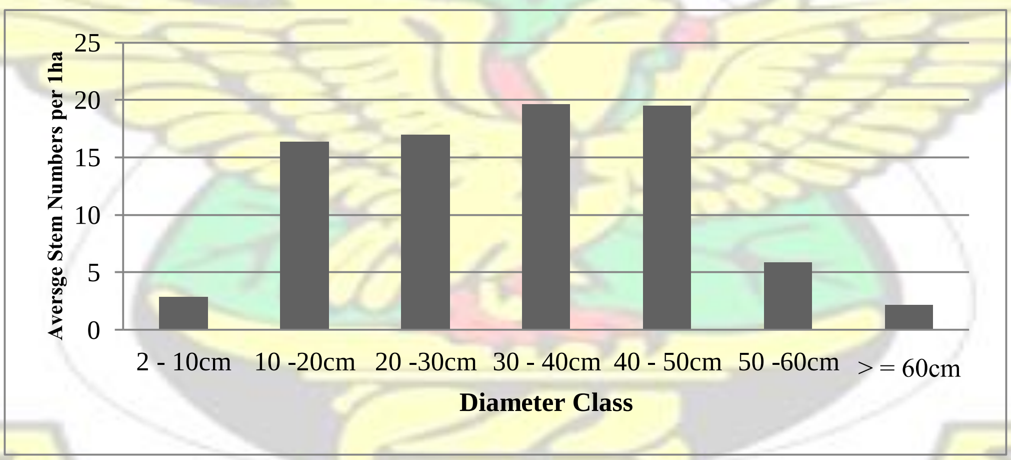


Figure 11: Plot of Upper East Region Mean Stem Numbers per 1ha

The plot of mean stem numbers for the Upper east region as shown in Figure 11, shows a bell shaped curved distribution, indicative of a very high proportion of tress within the 10-20cm dbh to 50-60cm dbh diameter classes.

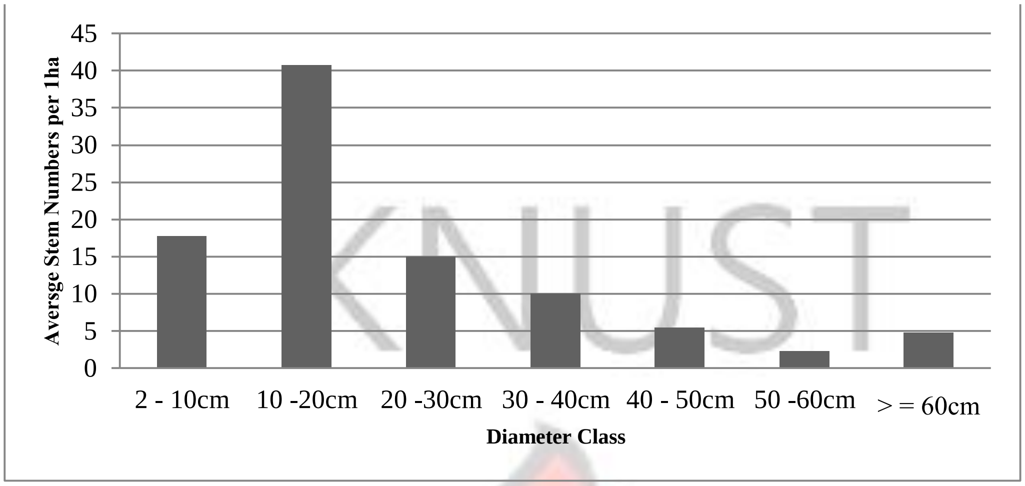


Figure 12: Plot of Volta Region Mean Stem Numbers per 1ha

The Volta, Upper West, Northern and Brong Ahafo regions present similar trends within their plot of means of stem numbers per 1ha, there are low densities for the 2-10cm diameter class which increase at the 10-20cm diameter class and subsequently decline to the 60cm+ diameter class. The Volta region is the only region which showed an increase at the 60cm+ diameter class, this is evidence of a high proportion of 60cm+ stems (Figures 13, 14 & 15).

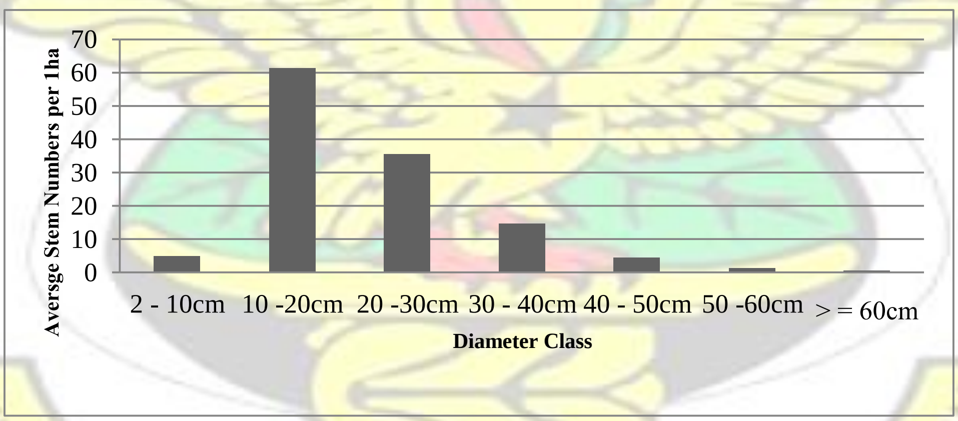


Figure 13: Plot of Upper West Region Mean Stem Numbers per 1ha

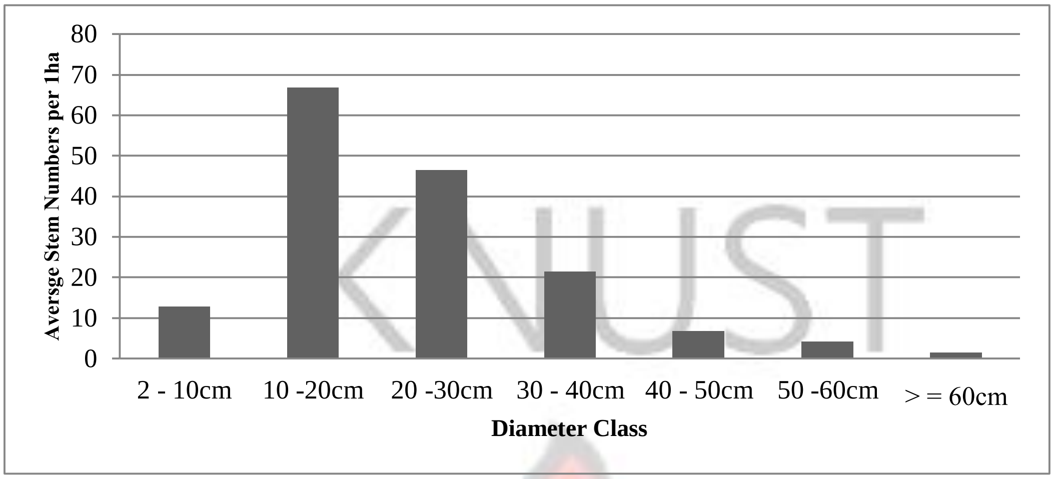


Figure 14: Plot of Northern Region Mean Stem Numbers per 1ha

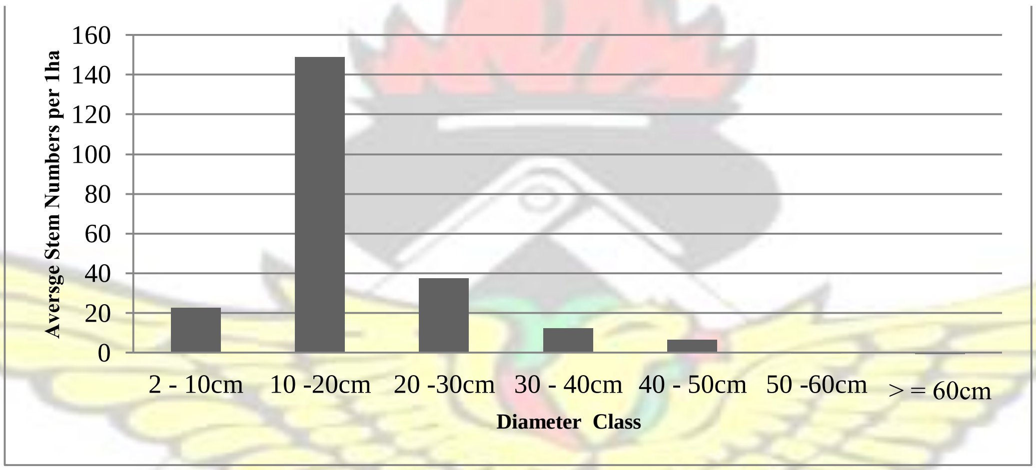


Figure 15: Plot of Brong Ahafo Region Mean Stem Numbers per 1ha

Table 8: Mean Stem Numbers per Diameter Classes (Source: FSD/RMSC, 2012)

Class	Ashanti	Volta	Brong Ahafo	Upper East	Upper West	Northern
0-9.9cm	550	1775	2275	288	488	1288
10-19.9cm	1588	4075	14875	1638	6138	6688
20-29.9cm	600	1500	3763	1700	3538	4651
30-39.9cm	75	1000	1238	1963	1475	2138
40-49.9cm	50	550	663	1951	463	676
50-59.9cm	50	225	50	588	126	413
> = 60cm	25	475	25	213	50	151

4.3.2 Stem abundance and Volume distribution of African Rosewood in Ghana

The mean volume of African rosewood was highest in Upper East and Northern regions (Table 8). However, the Brong Ahafo had the highest number of mean stems (32%), followed by the Northern regions (22%) respectively of national stocks (Table 9).

Table 9: Stem abundance and Volume of African rosewood on a regional basis

	Percentage Volumes per 1ha		**Stem Abundance per 1ha**	
Region	Volumes m^3	% Stem Volume	Abundance	% Stem Abundance
Ashanti	9.29	2.380342318	29.38	4.07767
Upper East	98.08	25.13067541	83.41	11.5765
Volta	63.95	16.38567183	96	13.3239
Upper West	58.65	15.02767244	122.78	17.0407
Northern	89.65	22.97068771	160.05	22.2134
Brong Ahafo	70.66	18.10495029	228.89	31.7678

From Table 9, it is seen that the Ashanti region showed the lowest abundance of stems per 1ha (29.38 stems per 1ha) and the lowest stem volumes nationwide (9.29m^3per 1ha). A gradual increase in mean stem numbers and volumes can be seen throughout the various regions with Brong Ahafo showing the highest abundance of mean stems,

228.89per 1ha and mean stem volumes (70.66). Though the abundance of African Rosewood in the Upper East region was relatively low (83.41 mean stems per 1ha), the region's stem volume was the highest amongst the regions. This suggests that African rosewood trees in the region had many large diameter stems.

4.3.3 Interim Felling Limit and African rosewood stem abundance

The interim felling limit for African Rosewood has been given by the Forestry Commission of Ghana to be 20cm dbh. From Table 10, total stem numbers above 20cm present a mixed picture throughout the various regions, ranging from 8 stems per 1ha in the Ashanti region to 80 stems in the Northern region.

Table 10: Mean volumes in m^3 below and above felling limit per 1ha on a regional basis

	Stem Numbers Below 20cm	**Stem Numbers Above 20cm**
Ashanti	21.38	8.0
Volta	58.5	37.5
Upper West	66.26	56.52
Upper East	19.26	64.15
Northern	79.76	80.29
Brong Ahafo	171.5	57.39
Total Stem Numbers	416.66	303.85
% Stem Numbers	**57%**	**43%**

The total proportion of stems above 20cm dbh per 1ha nationwide which are available for harvest are shown to be 43% of total African rosewood stocks (Table 10). The effect of the 20cm dbh interim felling limit is also seen from the highly significant p values in the 20cm, 30cm, 40cm, 50cm and 60cm+ diameter classes.

4.4 Analysis of Tissue Culture data

The study was conducted to assess regeneration potential of African rosewood to tissue culture technique using MS medium. It determined the optimal concentrations and combinations of three (3) plant growth regulators in the medium for efficient micro propagation via axillary bud culture. The results obtained are presented below.

4.4.1 Effectiveness of Sterilization Protocol

Table 11: Contamination Rates and Explant Mortality in Sterilization Protocol Establishment

Treatment	Concentration (ml) %	Exposure Times/min	Percentage Contamination	Explant Mortality
A	20% Hydrogen peroxide	10	19.2	83.5%
	10% Sodium hypochlorite	10		
	0.1% Fungicide	20		
B	10% Sodium hypochlorite	10	38	41%
	0.1% Fungicide	30		
Control	Sterile Distilled Water		97	0.0%

Table 11 shows the rates of contamination and explant mortality during the establishment of the protocol. The effectiveness of the protocol to adequately control microbial contamination in the explants was seen to be dependent on two factors: the duration of the exposure period and the components of the sterilisation protocol. This was especially so, when contact time for the fungicide was increased from 20 minutes in Treatment A to 30 minutes in Treatment B. This factor is particular importance due to the reason that the explants were harvested from the field and were not grown in a controlled environment.

However, long total exposure times to the sterilants as observed in Treatment A, were seen to negatively impact on the survival and mortality of the explants. From Table 11, the optimum sterilisation treatment is Treatment B, with a percentage contamination of 38% and an explant mortality of 41%. The high mortality of explants in both setups can be attributed to the very long distances travelled in harvesting and transporting the samples to and from Ejura-Atebubu to Fumesua.

4.4.2 Rates of Contamination

Extremely high rates of contamination were seen on all three (3) replicates of the tissue culture experiment within the experimental period, regardless of the optimized sterilisation protocol designed and implemented. The plot of the frequencies is shown below for the first three weeks.

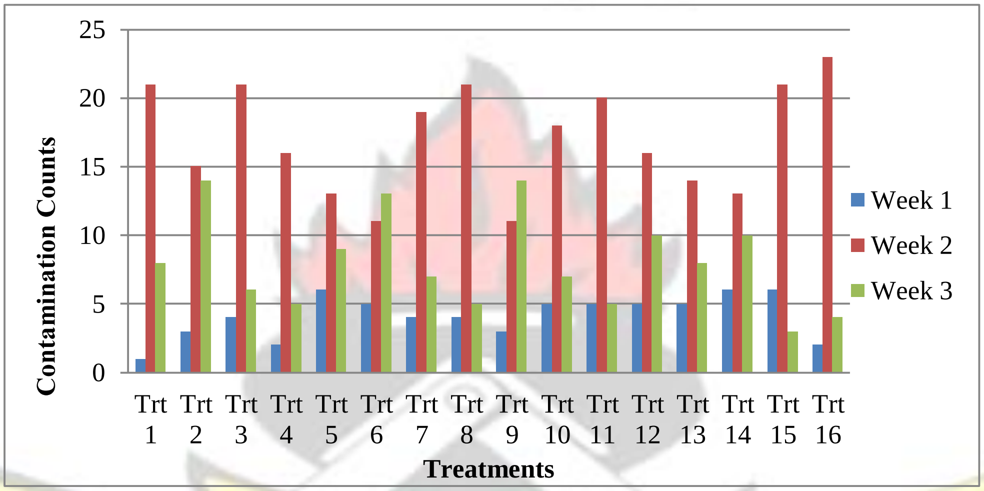


Figure 16: Frequency Graph for Contamination rate

It is observed that consistently all experimental units within the sixteen (16) Treatments and replicates showed skewed distribution for the levels of contamination or rates (Figure 16 & 17). The level of contamination increased from Week 1, peaked in Week 2, finally declining in Week 3. The rates of contamination are seen not to vary widely between experimental units in treatments for each given week. The mean rate of count of contamination was given as 3.2361, with a standard deviation of 2.99180.

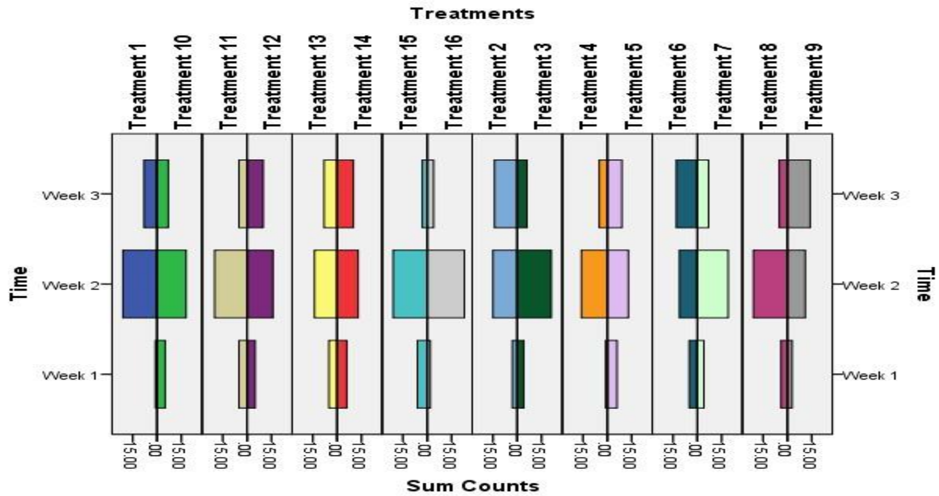


Figure 17: Population Pyramid Plot of Individual Treatments and Rates of Contamination

The contaminants were identified and characterized to be fungi*; Aspergillus flavus* and *Cladosporium herbarium* as can be seen in Plate 15.

Plate 14: Plate of Fungal growth in an Experimental Unit

A Poisson regression using Statistical Packages for Social Scientists (SPSS, version 16) of the count rates of contamination was conducted to understand the nature, trend and extent of contamination of the replicated weekly count data obtained for the period. Even though this was recommended method of analysis in literature, upon analysis it was seen that the mean differed from the variance significantly (Table 12). This indicated that the data was over dispersed, invalidating the premise of the Poisson regression that the mean must be equal to the variance. In order to correct this, a negative binomial regression was modeled to run for the data

Table 12: Variable mean and Standard Deviation of rates of contamination

		N	Minimum	Maximum	Mean	Std. Deviation
Dependent Variable	Counts	144	.00	10.00	3.2361	2.99180

Using the negative binomial regression model; **y=b+cx**; the various parameters were fit into the equation.

$$\boldsymbol{Log_{(Counts)} = Intercept + C_{1(Time\ 1)} + C_{2(Time\ 2)} + C_{3(Time\ 3)}}$$

The Goodness of Fit table (*Appendix*) gives the deviance (111.677) distributed with the model degrees of freedom (141) as 0.792 and the Pearson Chi square test as0.546, it is safe to conclude that because the Goodness of fit test is not statistically significant the Negative binomial model form fits the data.

The Likelihood Chi-square of the model, (65.687, p=0.00, 2 df) and the Test of Model effects (Wald Chi square 63.457, p=0.00, 2 df) indicates that as a whole, the variable "Time" is a highly significant predictor of the count data model. The parameter estimates also show that compared to Time 3 (Reference group) of the count data, the expected log count of Time 1 decreases by 0.678. Comparing Time 3 to Time 2, the expected log count of the Time 2 increased by 0.757. By further comparing the contamination incident rate in Exp B column of the parameter estimate table, shows that the contamination incident rate for Time 1 is 0.508 times the incident rate for the reference group of Time 3.

Likewise, the incident rate for Time 2 is seen to be 2.133 times the incident rate of the reference group Time 3 holding all the other variables constant. The correlation of the parameter estimates table also indicates a between Time 1 and 2 of 0.488. The results tables are summed in Table 13.

Table 13: Summary of Negative Binomial Regression

Summation of Results				
	Value	Df	Value/df	Sig.
Deviance	111.677	141	.792	
Scaled Deviance	204.482	141		
Pearson Chi-Square	77.006	141	.546	
Scaled Pearson Chi-Square	141.000	141		
Likelihood Chi-Square	65.687	2		0.00
Wald Chi-Square	63.4572	2		0.00
Correlation of the parameter estimates	0.488			

4.4.3 Effects of Plant Growth Regulators on Regeneration of Shoots

The experimental setup was run for a total of 12 weeks in spite of the challenges, subsequent data that was collected includes number of explants forming shoots, and the average shoot length of the cultured nodal explants (Table 14).

Table 14: Effect of PGR's on regeneration of shoots on MS medium after four weeks

Growth regulators (mg/L)	Explants forming Shoots (%)	Mean number of shoots/explants
Control	8	0.20 ± 0.0
BAP		
1.0	28	1.30 ± 0.19
2.0	45	1.90 ± 0.28
5.0	26	1.20 ± 0.15

Kinetin		
0.5	23	1.20 ± 0.03
1.0	40	1.54 ± 0.18
BAP + Kinetin		
1.0 + 0.5	21	1.10 ± 0.07
1.0 + 1.0	27	1.30 ± 0.08
2.0 + `0.5	30	1.70 ± 0.11
2.0 + 1.0	54	4.90 ±0.57
5.0 + 0.5	17	1.50 ± 0.11
5.0 + 1.0	16	1.10 ± 0.09
BAP + Kinetin + NAA		
1 + 0.5 + 0.4	19	1.40 ± 0.40
2 + 1.0 + 0.4	14	1.15 ±0.67
5 + 1.0 + 0.4	9	0.40 ± 0.69

(Values are mean ± SD of 10 experimental units each of three replicates)

A. Shoot Induction

Shoot induction begun after Week 4 for all PGRs either singly or in combination. There were however varying differences in the mean number of shoots per explant for each PGR treatment. Shoot induction can be seen in Plate 13 by the end of the fourth week of culture. Though shoots initiated from all treatments of PGR used; either singly or in combinations, it is seen from Table 14 that the number of shoots varied with regards to the PGR type.

i. Effects of BAP on shoot induction and elongation

The optimum shoot induction treatment using BAP is 2mg/L. The results show that 45% of all explants in this treatment formed shoots as is seen from Table 14. The percentage decrease of explants that formed shoots was from 45% to 26%, producing up to 1.20 ± 0.15 mean shoots per explant in the 5mg/L treatment level. These results indicate that an increasing concentration of BAP appeared to stimulate the production of a higher mean number of shoots until the optimum concentration was achieved. As for shoot elongation, MS containing 5.0 mg/l BAP gave the highest shoot length and the lowest frequency of shoot production when compared with other concentrations.

ii. Effects of Kinetin on shoot induction and elongation

The experimental setup examined only two levels of Kinetin treatment; 0.5mg/l and 1.0mg/L. The results show that out of the two levels of treatment 1.0mg/L of Kinetin produced the most proliferation of up to 40% of shoots and longest length of shoots, 1.54cm at the end of Week 12.

iii. Effects of BAP and Kinetin on shoot induction and elongation

Overall shoots on media with both BAP and kinetin showed better than average rates of shoot induction and elongation. The optimum combination treatment of PGR is the Treatment of 2.0mg/L BAP and 1.0 mg/L Kinetin (Table 14), with 54% of explants forming shoots and a mean of 4.9 shoots per explant.

iv. Effects of BAP, Kinetin and NAA on shoot induction and elongation The combination treatment with NAA are observed to have given low mean shoots per explants. The presence of 0.4mg/L NAA in combination with BAP and Kinetin, did however improve bud break. In addition, it was also observed that culture treated with these combinations required longer gestation period to initiate shoot multiplication for both sources.

Plate 15: Shoot induction of African rosewood after 4 weeks of culture

B. Comparisons of PGR Treatments

Between the two single treatments BAP and Kinetin; the explants were more responsive to increasing concentrations of BAP from 1.0-5.0mg/L, than they were to treatments of Kinetin, producing higher numbers of shoots per explants as observed. Comparing the response (mean shoot length of *in vitro* explants) of PGRs treatments using Turkey's test, significant differences were observed (Table 15)between the various treatments. It is seen that Treatment of 2 mg/L BAP exhibited the most significant increase in shoot elongation compared to any other treatment (Table 15).

Table 15: The mean shoot length of microshoots induced from explants cultured

	SHOOT LENGTH (cm)		
Treatment (mg/L)	**Week 4**	**Week 8**	**Week 12**
Control	1.01 ± 0.010^{a}	1.10 ± 0.007^{a}	1.12 ± 0.029^{a}
BAP			
1.0	1.24 ± 0.022^{bcdefgh}	1.36 ± 0.070^{de}	1.39 ± 0.073^{de}
2.0	1.20 ± 0.027^{bcdefgh}	1.35 ± 0.057^{cde}	1.39 ± 0.051^{bcde}
5.0	1.25 ± 0.025^{defgh}	1.45 ± 0.033^{cde}	1.47 ± 0.036^{cde}

Kinetin			
0.5	1.20 ± 0.021^{bcdefgh}	1.36 ± 0.071^{cde}	1.38 ± 0.066^{e}
1.0	1.28 ± 0.027^{fgh}	1.39 ± 0.013^{cde}	1.44 ± 0.036^{cde}
BAP + Kinetin			
1 + 0.5	1.16 ± 0.015^{bcde}	1.23 ± 0.016^{abcde}	1.28 ± 0.009^{abcde}
1.0 + 1.0	1.19 ± 0.020^{bcdefgh}	1.25 ± 0.021^{abcde}	1.33 ± 0.025^{bcde}
2.0 + `0.5	1.27 ± 0.027^{efgh}	1.31 ± 0.006^{a}	1.39 ± 0.018^{abcde}
2.0 + 1.0	1.20 ± 0.021^{bcdefgh}	1.24 ± 0.025^{abcde}	1.28 ± 0.016^{abcde}
5.0 + 0.5	1.19 ± 0.014^{bcdef}	1.24 ± 0.017^{abcde}	1.23 ± 0.016^{abc}
5.0 + 1.0	1.13 ± 0.021^{ab}	1.21 ± 0.014^{abcd}	1.21 ± 0.014^{ab}
BAP + Kinetin +NAA			
1 + 0.5 + 0.4	0.6 ± 0.121^{cdefgh}	0.9 ± 0.026^{bcde}	1.1 ± 0.025^{bcde}
2 + 1.0 + 0.4	1.22 ± 0.015^{h}	1.27 ± 0.028^{cde}	1.30 ± 0.041^{bcde}
5 + 1.0 + 0.4	1.16 ± 0.014^{bcde}	1.21 ± 0.014^{abc}	1.24 ± 0.010^{abc}
Mean values within a column followed by the same letter are not significantly different by Turkey's test ($P \geq 0.05$).			

Combinations of PGR's with high concentrations (5 and 1.0 mg/L) of BAP and Kinetin, demonstrated low shoot elongation rates as compared to the other cytokinin combination treatments. This treatment can be seen to be the least effective combination treatment. It may also be possibly as a result of the mature nature of tissue used in the experimental setup.

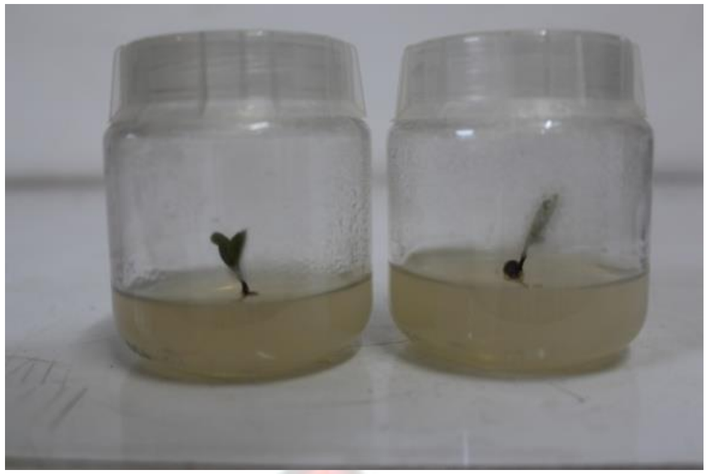


Plate 16*: Direct shoot formation from axillary bud explants*

Root induction

No explants rooted in the experiment, due in part to the high rates of endophytic contamination that continued to plague the experimental setup.

CHAPTER FIVE

5.0 DISCUSSION

The study demonstrates through the use of empirical data; how institutional factors have driven the unbridled exploitation of African rosewood for over a decade. It further shows the consequential effects on sustainability of the resource base, more so in the absence of a comprehensive management or conservation strategy. Given the low rates of regeneration as evidenced by literature and ongoing work (Duvall, 2008, Sawadogo, 2006, Kabore, 2004 and Bonkoungou *et al.*, 1998 and Appendix, photographs of 14 month old seedlings at less than 30cm high), this section concludes on the amenability of in vitro propagation as a means of augmenting supply. By integrating tissue culture of African Rosewood into national forestry management plans, stocking levels of the species can be greatly boosted whilst ensuring sustainability of the resource base.

5.1 Institutional Factors Driving the Exploitation of African Rosewood

Contrary to Duvall (2008), international trade in African Rosewood was initiated by Chinese buyers about a decade ago along the West African Coast (TIDD 20042013).Nationally, its extraction and trade has been driven mainly by an interplay of the following factors: socioeconomic, sociocultural, political, regulatory and administrative lapses, governance pitfalls, abuses of the legal process and the dynamics of the Rosewood timber extraction industry itself. These factors have led to the enforcement of three (3) extraction and exportation bans in 2012, 2013 and 2014.

5.1.1 Legal Process

The failure of the FC to stem abuses of the legal system through the permit granting system, the inability to review the stumpage upwards and the abuses of the Timber Resources Management Act and Regulations have had considerable effect on management and conservation actions for African rosewood. In comparison to species such as Mahogany, Odum, Sapele or the reddish star species which are safeguarded by law and are the focus of active research: conservation and management programmes, species such as African rosewood with little or no legal support do not often come up for consideration in such programmes. As such they are subjected to significant and uncontrolled exploitation.

Crucially, these levels of abuse influence the high levels of corruption and illegal extraction using chainsaw from natural forests. This raises key questions on the sustainability and management of the African Rosewood timber harvest in Ghana. In the light of the points above, efforts such as tissue culture to address a sustainable supply of quality planting material for use in plantations and wood lots should be actively encouraged.

Other issues of concern to this study included the absence of anti-illegal timber legislation and international agreements such as the FLEGT/Voluntary Partnership Agreement (VPA), EU act and the Lacy Act, in the destination countries; China, Thailand, Vietnam, etc. leading to out flux of large quantities of Rosewood timber of questionable origin from Ghana to these countries. It remains that in the absence of these laws such as exists in Europe and USA, concrete steps must be taken to ensure the legality of the timber harvest from African Rosewood, whilst factoring in sustainability concerns using tissue culture.

5.1.2 Governance

The "evolution" of African rosewood from its use as fuelwood to premium timber, is in direct conflict with the local use of the species for charcoal production. This could lead to significantly higher pressures on the resource base. This factor is compounded by existing timber laws in Ghana which reveal a legislative structure that favours timber exploitation rather production (Treue, 2001), by providing very little incentive for communities within the distribution range of African rosewood to protect and tend naturally occurring rosewood trees on their lands. All communities within the distribution zone of the African rosewood rather tried to cash in on the financial windfall that could be made by selling these trees to the Chinese through illegal chainsaw extraction.

Bandoh and Dumenu (2014) reported that the exploitation patterns for African rosewood in the communities indicate a preference for stems below 20cm dbh for both charcoal and fuelwood consumption. Placing this in tandem with the levels of extraction for timber (Felling limit 20cm dbh), the exploitation pressure is placed on the species from both ends of the spectrum: firstly, as young and dynamic stock and secondly as mature trees. This evidently does not auger well for sustainability of the species.

In the current circumstance, however communities are not harvesting the species for charcoal and fuelwood, but are also illegally harvesting it for timber. These dual consumption patterns will continue to impact negatively on the stock of rosewood, if management and conservation priorities are not revised. Issues of ownership, equity in benefit sharing, widespread education and role sharing in sustainably managing the resource must be tackled as practically as possible (Kyereh-Boateng *et al.,* 2009), since the inability to manage these issues will have dire consequences for the sustainable management of the resource. Given the price dynamics and profitability margins (Bandoh &Dumenu, 2014), it is clear that there will continue to exist the dual consumption patterns, escalating levels of resource conflict and the potential for fuelwood/charcoal producers to lose out in the long term.

5.1.3 Socioeconomic Interplay

The interplay of socioeconomic forces on conservation and sustainable management of biodiversity is a key concern noted by The Winnipeg Principles on Trade and Sustainable Development (IISD, 1998). The socioeconomic interplay was seen to be the main driver behind the unbridled exploitation of African rosewood. Factors such as the value shift in the species from charcoal to timber, the levels of poverty, the "get rich quick" mentality, high levels of unemployment, were largely tied in with the influence of Chinese buyers (the "Chinese" factor) (Kozak & Canby, 2007).The cumulative effect of these factors resulted in an increased demand and value of the species.

The net effect of this unbridled harvesting of the species as timber and for fuel wood were destructive. According to Dumenu and Bandoh (2014), these trade activities raise concerns which are critical to the conservation and management of the species nationally, since trade can have either positive or negative effects on the survival of a species.

5.1.4 Political and Sociocultural factors

The social consumption pattern of the species for use as charcoal, fuelwood, fodder, herbal medicine and a livelihood generating resource also poses significant challenge in the sustainable management of the species. This is because it is inherently difficult to police the resource and enforce the timber laws of Ghana, since the managers of the forestry resource are unable to distinguish between African Rosewood been harvested for timber and that been harvested for charcoal production.

Even though these present serious challenges to the sustainable management of the species, the increasing average FOB price of African Rosewood currently at €540 per m^3must provide the impetus to kick-start attitudinal and social changes with respect to the laws governing Rosewood extraction and trade. They also provide the opportunity to begin awareness and educational campaigns targeted at communities within the distribution zone of African rosewood.

5.1.5 Regulatory and Administrative Lapses

The multifaceted problem of rosewood exploitation is compounded by a key administrative lapse: inadequate logistics and funding of the resource managers (FC/FSD), by government. This problem appears to be a pivot around which most of all the other administrative problems sway: poor remuneration leads to low morale and inadequate staffing and underfunding affect the ability of the FSD/FC to conduct postharvest inventories and successfully enforce the forestry laws and police the resource. The low level of knowledge by staff of the FSD/FC on African Rosewood over the past decade, until about 14 months ago has in no way aided the management and conservation of the species. In fact, even with the current ban of the species, in force now, there is still no comprehensive management or conservation plan by the FSD/FC to conserve

germplasm, aid regeneration and survival of the species or ensure the future sustainability of the rosewood stock by including African rosewood in national re-afforestation programmes or even to encourage the private sector to develop plantations or woodlots of the species.

Doubts over the future sustainability of the species are very much lurking in the background in view of these factors. An opportunity to build tissue culture into management and conservation programmes will allow for accelerated development of stock levels through the development of plantations, woodlots and fodder banks using high quality planting material established from such tissue culture.

5.2 Implications on Species Sustainability Using Species Export Data

5.2.1 African rosewood product types and volumes exported

Available export data from the Timber Industry Development Division (TIDD), shows that even though export volumes of African rosewood have increased significantly from an initial export volume of $18.47m^3$ in 2004, to over $12{,}000m^3$ by June 2013: there has not been a corresponding increase in the number of stems of African rosewood nationally. Export values have similarly demonstrated increases, from an initial value of €6,457.73 in 2004 to €6,919,815.84 by June of 2013.

The witnessed high rate of extraction of African rosewood from natural forests to supply these exports, has been largely due to the export of one primary wood export type: Air dried lumber. Air dried lumber has driven the market - over 75% of all exported wood products are air dried lumber. Other primary value added products from African Rosewood, such as kiln dried lumber constitute approximately 3% of all exports, whilst secondary value added products such as sliced veneer constitute 22% of exports. This lopsided nature of export presents problems for the conservation and management of the species, because of the minimal processing required for Air dried lumber (as a non-value added export product).

Given the high preference for African rosewood in the destination markets (Gerety, 2009), there is a strong indication that rates of demand will continue rising since the projected demand of the Chinese and Asian middle class for luxury goods from raw materials such African Rosewood is expected to expand by16-20% (Farell *et al.*, 2006, Barton *et al.*, 2013). This implies that demand for Rosewood and the low log prices has serious consequences for conservation and management of rosewood in Ghana from
natural stands.

The potential for a tissue culture based method to provide quality planting material of superior stock for trade management programme may lie in the gains that can be made over the short to medium term. By offering the ability to reduce seedling growth time and augment regeneration, with the ability to produce a large number of seedlings in a short time, may be an attractive option both the public and private sector in supporting the future harvest of the species.

5.3 Implications on Species Sustainability Using Species Inventory Data

5.3.1 Population Structure, Stem and Volume Abundance of African rosewood in Ghana

The findings of this study revealed that the diameter class distribution of African rosewood nationally does not follow the inverse J-shape curve. The inverse J shape is consistent with sustainability of the species for timber production and other consumption patterns (Adams *et al.*, 2006).Its occurrence in plant diameter distribution has been linked to good regeneration of species. Thus the diameter class distribution observed for African rosewood in this study is indicative of poor regeneration (Omeja *et al.*, 2004) and the unsustainability of the species for timber production and other consumption patterns (Adams *et al.*, 2006; Dale *et al.*, 2001)

5.3.2 Felling Limit

The interim felling limit of 20cm dbh was adopted by RMSC-FSD to regularise the extraction and management of the species in the absence of extensive study (RMSC-FSD, 2012), because prior to this, all export oriented extraction of Rosewood was done on an adhoc basis devoid of any conservation or management practice. The results indicate that the diameter classes below the 20cm dbh felling limit constitute up to 57% of the total stem numbers nationwide. The regional groups showed clear differences at this level, with the Brong Ahafo region making up over 41% of the total stem numbers per 1ha (171.50 stems per 1ha) in the diameter classes below 20cm dbh felling limit. The Ashanti region, however had 21.38 stems per 1ha, the lowest regional count.

Seydack (1995) states that, where felling limits are set too low the number of potential trees required to maintain adequate natural regeneration may be insufficient. Given the low rates of regeneration and the slow growth rates, the 20cm dbh felling limit for African rosewood may be detrimental to the sustainability of the species as a source of timber and may not permit the 57% of total stems to grow into the felling limit. This because the silvicultural disadvantages of even well-established felling limits are theoretically well known and are usually related high grading, a lack of consideration of residual stand considerations, the development of an unbalanced structure and changes to species composition (Adams *et al.*, 2006).

This question on sustainability is further coupled with the preference of charcoal and fuelwood producers for the small diameter growing stock below the 20cm dbh felling limit, due mainly to their" convenient sizes" and the rudimentary machetes or axes used in felling these trees.

Given the relatively slow rate of growth of the species and the dual pattern of consumption from both ends the diameter classes, the adoption of the 20cm dbh felling limit may be inadequate to permit sufficient regeneration of the species. Further research may be needed to establish an accurate felling limit.

5.4 Shoot Apex Tissue Culture as a Conservation and Management Option In attempting to develop a method for in vitro propagation of African rosewood the primary justification was cost and ease of application (IAEA, 2004). This informed the choice of the method; Shoot apex culture (Murashige, 1974). However, in this study the use of juvenile explants from mature sources in the wild presented a key obstacle to successful regeneration of the species, a point highlighted by Biondi and Thorpe (1981).

5.4.1 Effects of age of explants on regeneration

The inability of the study to establish a mother plant nursery in the stipulated time due to the slow growth and high mortality characteristics of African rosewood led to the use of juvenile looking explants from mature plants. Montenius (1987) states that the ability to clone woody plants is greatly influenced by the maturation stage and by the physiological stage of the initial explants. A qualitative observation made on one month old shoots showed clearly that shoots from more juvenile looking explants were greener and prolific when compared to those from older looking explants, even though all the explants came from the same mature parent stock picked in the wild. This is also consistent with similar observations made by Vibha *et al.*, (2014).

5.4.2 Direct shoot induction: Effect of BAP, Kinetin and NAA.

a) Effects of 6-Benzylaminopurine(BAP) only on shoot induction and elongation The findings of this study are consistent with earlier results by Rajeswari *et al.*, (2008), which indicate that the rate of shoot formation decreases as the concentration of BAP in the growth medium increases. Comparing the various levels of BAP used singly, the optimum level of BAP was 2.0mg/L indicative of the rather high levels of cytokinin needed to stimulate the mature tissues used in experimental set up. These results also point to the inhibitory effect of cytokinins such as BAP at high concentrations resulting in the decrease in percentage shoot production at the high concentrations (Chand *et al.*, 2004). The decrease in percentage shoots and mean shoot per explants at the higher concentrations of the cytokinin treatment can be also attributed to the use of explants from mature trees, a finding corroborated by Rai *et al.* (1988) and Biondi and Thorpe (1981). With regards to shoot elongation, Joshi and Dhar (2003) state that shoot elongation is retarded in cultures with increased number of shoots. Thus even though the 5mg/L level of BAP was inhibitory to shoot induction, the mean shoot elongation of this treatment level was higher than the optimal treatment level of 2.0mg/L which produced more mean shoots.

b) Effects of Kinetin only on shoot induction and elongation

Few authors, including Chand *et al.* (2004) and Anis *et al.*, (2005) have also used kinetin in micropropagation of *Pterocarpus* spp., due to its inability to induce multiple shoot formation and the fact that only elongation of single shoot will take place with no significant response. This study confirmed the inability of previous studies to successfully propagated species of the *Pterocarpus* genus with single treatment of Kinetin.

c) Effects of both BAP and Kinetin on shoot induction and elongation

The optimum combination cytokinin treatment for the experimental set up is observed from the results to be 2.0mg/L BAP and 1.0mg/L Kinetin. The synergistic effect of both cytokinins at moderate concentrations is a phenomenon that has been observed by Swamy *et al.* (1992) in micropropagation of *Dalbergia latifolia*. This combination also provided the second highest mean shoot length, preceded by single treatments of Kinetin and BAP. It may be prudent to further explore the role the combination cytokinin concentration plays in shoot formation in African rosewood.

d) Effects of BAP, Kinetin and NAA on shoot induction and elongation

Even though it was expected that this level of treatment will provide the optimum treatment level, as is consistent from literature (Ahmad *et al.,* 2012, Anis *et al.,* 2005, Joshi & Dhar, 2003), the experimental setup did not yield similar results. Visually, however, treatment with NAA did however appear to improve bud break. This treatment also, appeared to decrease the number of shoots per explant, shoot length similarly decreased in the presence of the auxin, even though this has been reported by a number of authors, such as Lin *et al*., (1997), this observation requires further exploration.

5.4.3 Root Induction

Subsequent subculture of explants to either fresh media or media without PGRs resulted in loss of explants. All the attempts to induce roots on stabilized *in vitro* shoots failed.

5.4.4 Rates of Contamination

Montenius (1987) highlight the fact that woody plants of dry areas such as the transition and savannah are very sensitive to injuries and sterilization process, often exhibiting excessive browning and darkening at their cut ends due to the high percentage of phenolics. This may explain the high rates of contamination witnessed, as explants were harvested from the wild in the Atebubu forest district.

In assessing the rates of contamination, it was observed that there were relatively little or no contaminated experimental units within the initial days of set up of cultures. However, this shot up within the second week in a manner similar to a bloom. This may be as a result of endophytic contamination, which is very hard to eradicate. The effects of surface sterilisation on fungi and bacteria that are hidden in the tissues of the explant are negligible (Odutayo *et al.,* 2007). Thus there must be struck a fine balance between harming the explant by destroying cell integrity and eradicating pathogens: Destruction of plant cell integrity leads to exudation of plant cell contents (Mng'omba *et al.,* 2012) and higher mortality rates of the explants. The source of plant tissue from the Atebubu forest district, appeared to have very high rates of the fungi *Cladosporium herbarium* and *Aspergillus flavus*, even though different mother trees were used in subsequent experiments.

The long total exposure times to the sterilants as observed, were seen to negatively impact on the survival and mortality of the explants by inhibiting the uptake of nutrients and PGR's through weakening of the cell wall and membranes (Mng'omba *et al.,* 2012). The long exposure periods to the fungicides could also lead to aluminium toxicity in explants, due largely to the use of aluminium foil for covering the explants during the sterilisation process (Mng'omba *et al.,* 2012).

The Negative Binomial regression model of the nature, trend and extent of contamination demonstrated the nature of the rate of contamination amongst the cultures. In conjunction with the analysis and graphs, this provides statistical credence to the 'microbial bloom' observed amongst the cultures in replicates within the culture period. It is possible that these fungi may grow in association with this nitrogen fixing tree and may act in symbiosis with African rosewood. This is a relationship that may have to be explored.

The demonstrated amenability of tissue culture to be successfully applied to African rosewood, is a boost to efforts in conservation, management and for commercial production of African rosewood plantlets. Thus through the provision of high quality tissue culture planting material, rates of natural regeneration can be boosted to augment existing stocks of the species in Ghana.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

"Resources are not, they become". In laying the foundations for understanding the paradoxical nature of resources; there is required a shift in perception: that the development or discovery of resources is no longer viewed as a static activity, but as an evaluation of nature in the light of man's culture. The implications of this are that resources such as African Rosewood must be seen as largely dynamic and functional, evolving through a process borne out of the interaction of man, nature and culture.

6.1 Summary

Examining the institutional variables of national African rosewood trade in the light of sustainable resource use, efficiency and development was essential to developing an in vitro protocol for its propagation. It permitted the essential questions to be asked; whether the trade in African Rosewood undermines the cardinal tenet of natural resource utilisation: as a tool for development. Secondly, it allowed the exploration of alternative conservation and management measures such as the amenability of tissue culture to the species.

6.2 Conclusions

The institutional variables of African rosewood trade show that the high levels of resource use competition are indicative of the importance of the species to livelihoods with the distribution range. In particular, the issues of governance; undefined user rights, social responsibility agreements (SRA) and equity in benefit sharing coupled with regulatory lapses, legal abuses and prevailing industry practice are largely symptomatic of the larger National Forestry Sector. These institutional variables have been shown in this thesis to impact on the sustainability of African rosewood populations and structure.

The impact of the interim felling limit on the population structure and sustainability is twofold: African rosewood populations nationally do not follow the inverse J-shape curve, whilst the percentage of species stems below and above the felling limit have been shown to demonstrate an in balance in harvesting and growing stock. This fact coupled with the low natural regeneration of the species calls in to question the sustainability of the species.

The study further shows that in some instances the recommended quantitative methods of analysis such as Poisson regression may not be suited for the count data. In this case, a negative binomial regression was better suited to model for count contamination data, due to tendency for the data to be over dispersed when there is the presence of endophytic contamination. The inability of the study to stabilise the invitro shoots on rooting media, does not negate the implications of the study but rather enforces them.

6.3 Recommendations

The following are my recommendations:

1. Estimates of the real cost of logging African Rosewood for timber and the subsequent loss of biodiversity, genetic diversity and losses in community utility for medicinal and other purposes should be made to provide input into policy formulation.
2. Market forces can place pressure on the livelihoods of local communities and may be in conflict with communities dependent on the resource for security and survival. It may be necessary to explore alternative sources of raw materials for charcoal and fuelwood producers, whilst exploring alternative livelihoods for disadvantaged communities.
3. Stumpage fees must as a matter of necessity be reviewed and increased by the Forestry Commission of Ghana to reflect prevailing market forces and prices.
4. Further research may be needed to establish a felling limit based on sound silvicultural and ecological principles, so also will further research be needed on the structure, density and regeneration characteristics of African rosewood.
5. It may be necessary to revise our current systems of policing forestry, due to their inadequacy in the face of underfunding and understaffing of the regulatory agencies, and community aspirations of ownership. Social forestry models which are currently proving to be all encompassing may provide an answer.
6. In vitro propagation using pathogen free tissue such as buds or seeds should be encouraged to ensure a protocol for tissue culture is developed, as this will aid in augmenting the low rates of natural regeneration, through its use in plantations, woodlots and fodder banks.

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APPENDICES

A: IAWA Hardwood code of African rosewood

Wood anatomical description

Growth Rings:

2: growth rings boundaries indistinct or absent

Vessels:

5: wood diffuse-porous

13: simple perforation plates

22: intervessel pits alternate

23: shape of alternate pits polygonal

26: intervessel pits medium (7-10µm)

29: vestured pits

30: vessel-ray pits with distinct borders, similar to intervessel pits in size and shape throughout the ray cell

41: mean tangential diameter of vessel lumina 50-100µm 42:

mean tangential diameter of vessel lumina 10-200µm

46: ≤ 5 vessels per square millimetre

58: gums and other deposits in heartwood vessels

Tracheids and fibres:

61: fibres with simple to minutely bordered pits

66: non septate fibres present

69: fibres thin to thicked walled

Axial Parenchyma

76: axial parenchyma diffuse

77: axial parenchyma diffuse in aggregates

80: axial parenchyma aliform

82: axial parenchyma winged-aliform

83: axial parenchyma confluent

86: axial parenchyma in narrow bands or lines up to three cells

91: two cells per parenchyma strand

Rays:

96: rays exclusively uniserate

97: ray width 1-3 cells

104: all rays procumbent

116: ≥ 12 rays per mm Storied

Structure:

118: all rays storied

120: axial parenchyma and/or vessels elements storied

121: fibres storied

Mineral Inclusions

136: prismatic crystals

142: prismatic crystals in chambered axial parenchyma cells

B: SEMI-STRUCTURED INTERVIEWS QUESTIONS

1) How widespread is the species?

2) What is its distribution?

3) What are the stocking levels?

4) What is the species classification?

5) What is the trend of exploitation?

6) What is the nature of exploitation?

7) What is the estimated volume of extraction per annum?

8) Does your organisation have any management or conservation actions in place for the species?

9) When were these actions implemented?

10) Which body is responsible for the implementation?

11) Has the body been able to assess or evaluate the effectiveness?

12) Do the communities support these actions?

13) Are there any collaborative management efforts between FSD and the communities?

14) Are you aware of any other groups working on the conservation of the species?

15) Which other conservation strategies, aside that mentioned are you undertaking presently?

    a. Augmenting natural regeneration

    b. Domesticating in plantations

    c. Domesticating on farm

    d. Any other actions……………………………………………………………………

16) Do you have any idea of the perceived usefulness of the species?

17) Who do you think are the main stakeholders in the management or conservation of the species?

    a. FSD

    b. Research

c. Communities

d. Others: ………………………………………………………………………..

Other Questions included

18) What is the size of the company
19) How many years of experience do you have in the timber business?
20) Size of TUP allocated
21) The size of workforce
22) Are your workers natives or migrants? (Reword)
23) In which areas do you harvest your timber?
24) Which timber do you harvest? Do you harvest other forms of timber aside Rosewood?
25) Do you have any idea of where the market for your timber is? Is it local or international
26) Are there fluctuations of the prices on the local market?
27) What are the prices of Rosewood on the local market? How much are you paid/make per container? Can you provide us with the genesis of prices since you started??
28) How do you cope with these fluctuations?
29) Do you have any idea of the price of rosewood on the international market? 30) Do you export it yourself? Or to whom do you supply the timber to?
31) Do you know of any use for this timber on the local market? Aside charcoal
32) What is the approx weight and size of one log of Rosewood?
33) How many logs can a mature tree of Rosewood yield?
34) How often do you get such trees which can yield two or more logs?
35) How are your trees felled? Manually or by using a chainsaw?
36) How many trees do you fell per day or how many logs do you produce per day
37) How are trees transported to the point of conveyance and also to the ports?

38) How many trees or logs fit into a container?

39) How many containers do you manage to supply/exported per week?

40) Do you provide a social responsibility/ benefits/'incentives' to communities or key stakeholders in the communities?

41) Is this your only business?

42) How do contractors obtain permits? Through competitive bidding, etc

43) For how long are permits valid

44) What kinds of permits are required to harvest Rosewood

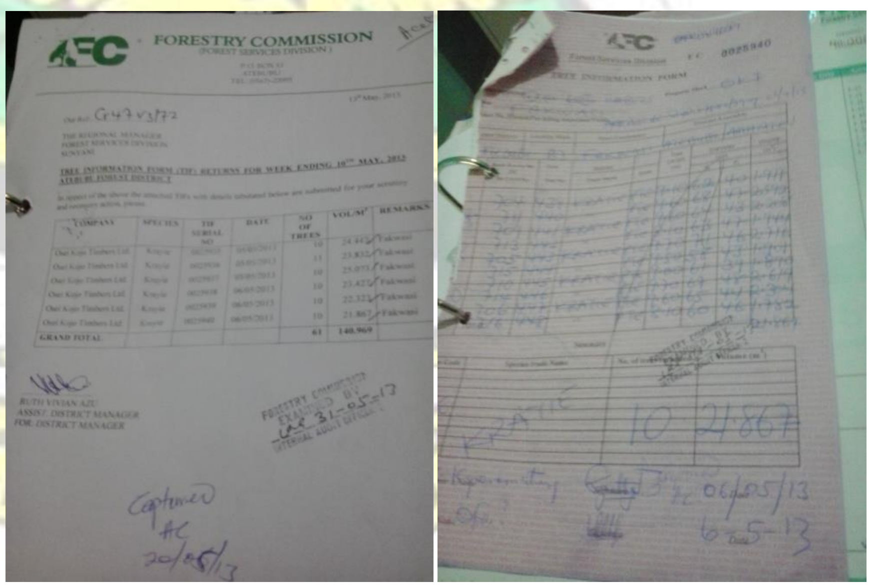
45) How are the TUP allocated? Without inventory or management plan

46) Has anyone been prosecuted for harvesting Rosewood illegally?

47) Does transported Rosewood bear any marking?

C: Photo Gallery

Plates some of TIF forms used in Analysis

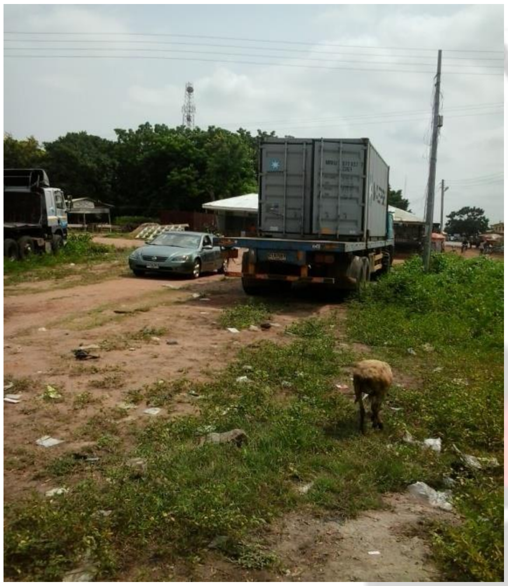


A Cross section of Stakeholders at the District Forestry Office InAtebubu:

Meeting Held on the 15th of August, 2013

Views of a select District Forestry Offices

Hired Articulated Trucks waiting to be loaded; Location: Park adjacent to the Atebubu Police station



Confiscated Truck and Container of Illegally Harvested African rosewood

Markings made to permit counting of Lumber

Some Seized logs of African rosewood

Extraction and Processing of African Rosewood

PICTURES OF SEEDLINGS TAKEN AT SIXTEEN (16) MONTHS OLD