COMPARATIVE STUDY BETWEEN GOVERNMENT AND PRIVATE FOREST PLANTATIONS MANAGEMENT PRACTICES: CASE STUDIES OF SAO HILL AND GREEN RESOURCE FOREST PLANTATIONS, MUFINDI IRINGA TANZANIA

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DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF FOREST RESOURCES ASSESSMENT AND MANAGEMENT OF THE SOKOINE UNIVERSITY OF AGRICULTUERE. MOROGORO, TANZANIA.

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ABSTRACT

The study was carried out in Sao Hill and GRL for comparison of management practices applied between government and private forest plantations. The study focused at identifying existing management practices, examining cost involved in forest management practices, assessing forest stand parameters and identify challenges facing management practices in Sao Hill and GRL in five years from 2012 to 2016. Data were collected through direct measurement in the forest stand parameters, structured interview for key informants, review of documents and observation. To access the stand parameters, a systematic sampling with two stages stratified sampling technique was applied and strata of age 5, 10 and 15 years were established for *Pinus patula* and *Eucalyptus grandis.* With equal allocation 180 sample plots of 0.04 ha were laid out and measurements were taken for estimation of stem quality, diameter and height, stand density, volume and basal area per hectare. Data collected were analyzed using Microsoft Excel and SPSS computer programs for descriptive and inferential statistics tools. The findings indicate that Sao Hill and GRL forest plantations practices similar major forest management practices based on establishment, tending operations, and forest protection and nursery silviculture. Between 2012 and 2016 Sao Hill was paying an annual average cost rate of TZS 6 811.06/man/day task and planting cost of TZS 70 247.32/ha for casual labour. On other hand GRL was paying annual relative lower cost rate of TZS 4 917.30/man/day and planting cost of TZS 16 750.15/ha. However Sao Hill spent the lowest cost in nursery with average of TZS 92.29 per seedling compared to TZS 145.92 per seedling in GRL. The results showed that there was a significant cost differences between Sao Hill and GRL and therefore concluded that Sao Hill spent extra cost per unit area in many areas of forest operations which should also reflect the production efficiency. Study also indicated that Sao Hill and

GRL performed basic tending (weeding, pruning and thinning) as recommended in Technical Orders specifications. Stand density performance in *P. patula* was in moderate with Sao Hill having average of 692 sph in age 5 years' strata alongside GRL with 520 stems per hectare, and for *E. grandis* Sao Hill performed better in the strata of age 5 years with mean density of 614 sph, while GRL did well for age 10 years strata with mean of 519 sph. With applied spacing of 3m x 3m still both plantations could have achieved higher stand density per hectare under proper practices. In volume performances for *P. patula*, the significant variations were observed in age 5 and 15 years strata whereby GRL had higher mean volume of 53.6m^3/ha and 184m^3/ha compared to mean volume of 24.2m^3/ha and 154.1m^3/ha in Sao Hill. For *E. grandis* major volume variations were found at ages 5 and 15 years as Sao Hill respectively had higher mean volumes of 109.1m^3/ha and 261.3 m^3/ha compared to 67.6m3/ha and 112.4m^3/ha in GRL probably because *E. grandis* in Sao Hill was established under coppice regenerations. The implication of volume parameters for *P. patula* was associated with stem form quality of 96.43% straightness in Sao Hill and 92.79% in GRL while the *E. grandis* having 93.0% straightness form in Sao Hill and 92.89% straightness in GRL stands. Consequently from 2012 to 2016 Sao Hill and GRL plantation were prone to fire incidents and GRL lost 1592.5 ha of planted forests while Sao Hill lost at least 227.14 ha because of uncontrolled human activities and low technology in firefighting gears. Fund limitation was to some extent influencing management of Sao Hill and GRL forest plantations regarding fire and other issues.

DECLARATION

I, Elibariki Wilson Akyoo, do hereby declare to Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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LIST OF ABBREVIATIONS AND SYMBOLS

APO	Annual Plans of Operation
CI	Confidence Intervals between the sample margin error
DBH	Diameter at Breast Height
FAO	Food and Agriculture Organization
FBD	Forest and Beekeeping Division
FOSA	Forest Outlook Studies in Africa
FSC	Forest Stewardship Council
GRL	Green Resources Company Limited
Ha	Unit Area in Hectare
HT	Total Height of a Standing Tree
IFP	Idete Forest Plantation
ITTO	International Tropical Timber Organization
KFP	Kitete Forest Plantation
KVTC	Kilombero Valley Teak Company
MaFP	Masagati Forest Plantation
MDC	Mufindi District Council
MFP	Mapanda Forest Plantation
MNRT	Ministry of Natural Resources and Tourism
MPM	Mufindi Paper Mills
NAFORMA	National Forest Resources Monitoring and Assessment
NIPF	Non Industrial Private Forests
SAIF	Southern African Institute of Forestry
SE	Standard Error distribution of the sample mean
SHFP	Sao Hill Forest Plantation

SHI	Sao Hill Industries forest
Sph	Number of stems per hectare
SPM	Southern Paper Mills
SPSS	Statistical Package for Social Sciences
TAFORI	Tanzania Forestry Research Institute
TFS	tanzania forest srvises
TZS	Tanzanian Shillings
UFP	Uchindile Forest Plantation
URT	United Republic of Tanzania

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Establishment of plantation forestry in Tanzania started in the19th century during colonial era in order to manage multiple uses of forests in terms of supporting the local timber industry, recreational opportunities and water protection. The plantation census of 1943, showed that the central colonial administration had established 2 230 ha while local governments had 1 453 ha (Mtuy, 1996). However massive planting of exotic plantations forests in Tanzania reached its peak during 1960s and 1980s the purpose being to augment supply from natural forests, which were dwindling at a fast rate. Forest plantations play significant role in national economy as a source of raw material for wood based industries and contribute to job creation, export promotion and government revenue by taxation (Chamshama and Malimbwi, 1996).

According to National Forest Resources Monitoring and Assessment (NAFORMA) data, the total forest area in Tanzania's main land is estimated to be 48.1 million ha which is equal to 54.4% of the total land area of 88.3 million ha. Woodlands occupy 44.7 million ha which is 50.6 % of the total main land forest area while forests (lowland forests, montane forests, mangroves and plantations) occupy 3.5% of Tanzania mainland area. The plantation forests under government and private cover the area of 554 500 ha (1.2%) in Tanzania mainland (MNRT, 2015).

Management practices in forests are generally defined according to the extent of the forest's establishment and the management purpose of growing the forest, and because there is an extensive range of silvicultural practices applied in varying levels of forest management to achieve different objectives, (FAO, 2000). Management practices applied

in forest plantations have been outlined into establishment, weeding, pruning, thinning and harvesting general. Further; management practices includes forest health and protection, maintenances of long term site productivity and growth yield and rotation age (Mathu and Ng'ethe, 2011).

The ownership of industrial forest plantation in Tanzania is divided into government (central government), private forest plantations, villages and individuals owned forests. The area owned by government is estimated to 85 000 ha, private sector forest is about 40 000 ha and between 80 000 and 140 000 ha are under villages and individual farm plantations. The most important industrial plantation species are pines (*Pinus patula, P. elliottii* and *P. caribaea*), cypress, eucalyptus and teak (Ngaga, 2011).

Sao Hill forest plantation is among 18 existing government industrial forest plantations and was established since 1950s with the aim of supplying raw materials to Mgololo Southern Paper Mills (SPM) currently known as Mufindi Paper Mills (MPM) and Sao Hill Sawmills. Sao Hill cover an area of 45 000 ha which is almost 50% of the total area of the government forest plantations and currently Sao Hill is the major source of construction wood supply in Tanzania (URT 2013).

Green Resource Limited (GRL) is a subsidiary company of Norway and is a private and profit oriented company established in 1995. GRL with total area of 18379 ha in the southern highland manages two main plantations forests; Mapanda plantation 6 258 ha, and Uchindile 6 647 ha. The main objective of the company is to grow trees for a wide range of forestry products for profit (including wood for sawn timber and transmission poles), to mitigate climate change, to contribute towards socio-economic wellbeing and to promote environmental conservation (GRL, 2012).

Industrial forest plantations management practices among government and private sector differ in one way or another in some aspects of silviculture technique including the use of improved quality seed and application of fertilizers. State-owned forests are found to be poorly managed hence end up having trees of poor form, which do not supply enough quality wood to support the growing forest industries. This state of affair is due to among others, use of seeds of inferior genetic quality and low budgetary allocations resulting in the skipping of some silvicultural operations (MNRT, 2001; Nshubemuki *et al*., 2001).

High quality wood products and higher productivity from forest plantations depends on proper forest management practices. Good forest management is a result of practical application of scientific, technical and economic principles in forestry (MNRT, 2001). In other words forest management is costly and effective uses of resources are of paramount importance. Cost management strategies used by different forest plantation practitioners entail making decision on how much money will be spent to accomplish certain operations and differs considerably between government and private sector (Colin, 2004).

1.2 Problem Statement and Justification

URT (2010) reported that industrial forest plantations are fundamental in contribution to national economy and development. Yet the productivity of government plantations is generally low (15 m^3/ha/yr) wood volume production due to use of unimproved seed and low intensity management. Either government plantations are characterized by planting and replanting backlogs, low intensity site preparation techniques, poor quality trees due to use of un-improved seed and low survival due to poor species-site matching and delayed or low intensity weeding. It is also noted that they are generally neglected or have irregular pruning and thinning, constant fire, disease and pest attacks, and generally suffer

illegal felling and encroachments. However, the potentiality of government large scale forest farms can maximize yield under optimal management plans. With improved seed quality and good forestry practice a yield of up to $30m^{3/}$ha/yr is possible in government plantations (URT, 2010).

According to Iddi *et al.,* (1996), inabilities of natural forests to sustain wood production necessitate the promotion of management of forest plantations. The deficit in hardwood production was attributed by the slow growth of indigenous species and high population growth in rural- urban areas. Incapability of the natural forest to sustain growing demand for wood products prompted the government legislative review and national forest policy of 1998 to encourage the participation of private sector introduce plantations forests to improve fuelwood and timber supply in the country (URT 1998).

Many natural forests have been closed for environment conservation and protection purposes meanwhile there are mills that were designed to process logs from natural forests. There is no possibility for mills that depend mostly in wood processing from the natural forests to have good future unless effort to sustain the natural forests is enhanced. To address the issue National Policy review of 1998 introduced plantation forest management programme and encourage involvement of private forest sectors to enhance wood production to sustain the supply of raw materials in wood industries (MNRT, 2000).

It was expectation of the researcher that both government and private sector will improve the forest management techniques. The study aimed to justify the suitable options of existing management practices that will be adopted for management of industrial forest plantations. The findings from this study will contribute to the available useful knowledge for ideal forest management practices and cost efficiencies for Tanzania forest plantations

to enable decision makers identify areas of priorities to uplift forest produce and conservation services.

1.3 Objectives

1.3.1 Overall Objective

To compare between Government and Private management practices applied in exotic plantation forests.

1.3.2 Specific objectives

i. To asses management practices applied in Sao Hill and GRL plantation forests.
ii. To compare costs involved in management practices between Sao Hill and GRL plantation forests.
iii. To assess stand parameters by species and age strata at Sao Hill and GRL forests plantation's compartments.
iv. To assess challenges facing management practices of Sao Hill and GRL plantation forests.

1.3.3 Key research questions

1. What are the differences and similarities of management practices applied in Sao hill and GRL forest plantations?
2. What are the costs of management practices (nursery operations, planting, and protection and tending operation) in Sao Hill and GRL forest plantations?
3. What are the stocking density, volume and basal area per hectare by species at different ages in Sao Hill and GRL?
4. What are the factors affecting forest management activities within these particular forest plantations?

1.4 The Research Hypotheses

Null hypothesis: Management practices applied in government forest plantations are the same to those practiced by private sector forest plantations**.**

Alternative hypothesis: There is variation of between management practices applied in government and those practiced by private forest plantations**.**

1.5 Encountered Challenges

During data collection a researcher came across some limitations in the study area which in one way or another affected my research in aspects of data quality, time and cost.

There was inconsistence in data handling in Sao Hill office data management section because most of data were stored in form of hardcopy files. Also there was a case of unavailable or the researcher failed to access some data in GRL office regarding operations costs for period year 2012 and 2013.

There was two weeks delay for researcher to get permission to access data in both Sao Hill and GRL because of permission procedures. On research process during data collection there were two family issues events of losing my brother and sister in law in two occasions which required me to travel to Arusha for funeral ritual.

Regardless the challenges the researcher was able to accomplish his objectives of the study because of good cooperation shown by the management of Sao Hill and GRL forest plantations.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Concept of Management Practices in Plantation Forests

Management practices are so diverse that no clear picture emerges where a plantation forest has been established to grow commercial wood with multiuse products (Evans, 1992). For a long-term investment, management of planted forests require particular awareness and diligence at site preparation, establishment, silviculture, protection and harvesting interventions in order to avoid negative impacts (FAO, 2006). Silviculture interventions are necessary in sustainable management of forest plantations and depend foremost on the main production objective (conservation, fuelwood, fibre, or saw log production). Where wood production of high quality saw logs is the main objective, intensive silviculture treatments are probably justified (Whitmore, 1994).

Globally, establishment of forest involves a wide variation on the intensity of site preparation in forest plantations. In East Africa complete site preparation (ploughing and harrowing) or using herbicides is rare, and most public sector plantations are established through the ‘taungya’ system strip and spot cultivation, and slash burning (Chamshama, 2011).

Different nursery techniques have been used in different parts of the world to increase seedling survival and growth in site areas. In Malaysia and Indonesia for example, potted seedlings in polyethylene bags are used, as the bags are relatively cheap, not bulky and have no adverse effects on the seedlings (Thang, 1994; Gales, 1996). In Tanzania the nurseries establishment were based on **e**arly nursery cultural techniques tailored for

producing large, healthy and robust seedlings (Procter, 1968). Such seedlings survived and grew well as they were planted mainly in highland areas with comparatively fertile soils and less frequent water stress problems (Chamshama and Nshubemuki, 2011).

In South Africa, improved breeding methods, the use of improved seeds and germplasm and efficient management are key factors in the country's forest plantation success. The study has shown that ample research has been done and has produced genetically improved germplasm as well as routine of appropriate silvicultural practices, which are used in plantation development with high yields Chamshama and Nwonwu, (2004).

In East Africa plantation forests weeding ranges from intensive (chemicals or clean weeding by taungya farmers) to low intensity (spot, strip or slashing) with definite impacts on seedling survival and growth and often, spot and strip weeding are used. Even though less intensive weeding techniques are used, weeding backlogs have been reported in some countries, especially in the public sector plantations (Chamshama, 2011).

Management of plantation forests therefore recommends tree improvements through sound selection of species, provenances or hybrid materials of high genetic quality and use of appropriate and timely silvicultural practices for extremely production of high quality wood (Chamshama, 2011).

2.2 Management of Plantations Forests and Sustainable Supply of Forest Products

According to FAO (1999), the future potential supply of industrial round wood from forest plantations will depend upon a number of factors. The most crucial factor was the rate at which new planting is sustained, although improvements in fields such as plant breeding,

silvicultural techniques, plant survival and harvesting techniques, are all likely to contribute to greater productivity. The analyses has assumed that the latter variables will all remain unchanged and has concentrated on producing future scenarios for new planting, in order to forecast potential industrial round wood supply from forest plantations through to the year 2050 (FAO, 1999).

The area planted and total growing stock of the Tanzanian plantations has, until recently been declining and existing plantations are under-stocked. The estimated long-term wood-supply is 30-40% less than what could be expected from the area had the plantations been fully stocked with a normal age-class distribution (TFS, 2011). It has also been expected for exotic plantations to offset the declining of natural forests in the country but the recent data by NARFORMA (2015) reported that the current national deforestation rate is 373 000 ha per year (MNRT, 2015).

Reporting the status of forest plantations and woodlots in Tanzania Ngaga (2011) alarmed about the existing situation. “Given the age structure and current harvesting levels it is predicted that after year 2017 there will be severe deficits of wood supply for some ten years to come. Only after 20 years from today the harvesting can come back to current levels. Individual private plantations/woodlots, also known as non-industrial private forests (NIPF), are currently supplying an estimated 200 000 - 250 000 m^3 of round wood (Ngaga, 2011)”.

To ensure constant supply therefore, forestry production requires ecological integrity and maintenance of long term site productivity. In order to maintain site fertility and insurances of nutrient retention in the soil proper environment conservation techniques

must be followed. To avoid soil erosion and soil compaction proper logging and harvesting technique should be followed and maintained and avoid inappropriate establishment procedures such as the use of excessively heavy machinery or the use of intensive cultivation practices on land which is not suited for conservation purpose (Chamshama and Nwonwu, 2004).

As the natural forests of the tropics will not be able to sustain increasing domestic and international demands for wood and wood products, due to environmental concerns and social aspects, Nambiar (1996) suggested that tropical countries must move towards sustainable wood production systems on a more limited land area through plantation forestry. While wilderness or reserve forests satisfy desired conservation values, plantations are necessary on limited and defined land areas to meet increasing demand of wood products including firewood, pulpwood, and sawlogs (Brown *et al*., 1997). Plantation forestry not only offers opportunities for meeting wood demands and reducing deforestation by decreasing pressures on natural forests, but can restore degraded soils and enhance biodiversity (Parrotta, 1992).

2.3 Management Practices of Tree Nurseries for Forest Plantations

According to Evans, (1992) tree nursery is a place where plants are propagated and grown to usable size ready for planting in the field depending on the project goal. Most forest plantations in the tropics are established using nursery raised seedlings. The use of nursery raised plants is generally the most efficient and effective way of establishing a plantation, although direct seeding is practiced successfully by aircraft in inaccessible areas and where a protective tree cover is more important than wood production (Evans and Turnbull, 2004).

The production of nursery stock is a major expense of afforestation as it covers about 5-20% of total afforestation cost depending on costs of clearing and so must be efficiently managed. The nursery operations are geared for producing good quality seedlings that will give high field survival and fast initial establishment. Such seedlings produce root quickly to access soil nutrients and water and thus cope with normal environmental stresses. On the other hand, low quality seedlings grow more slowly after transplanting, add to weeding and maintenance costs, are more susceptible to diseases and insect pests and have reduced wood production (Evans, 1992).

Nursery seedlings are raised for a specific programme and they must be:

a) Of required species.
b) Ready at the right time at the beginning of the wet season.
c) Of the best quality in terms of size, sturdiness, root development and vigour.
d) Produced in sufficient numbers for the planting programme.

2.3.1 Types of tree nurseries

There are three main types of nurseries used in forest plantation namely flying, temporary and permanent nurseries with objective of raising good quality, healthy plants at the lowest cost.

i. Flying nurseries

Flying nurseries are normally located on a planting site. They are normally used for one season only. Flying nurseries are used for production of naked root seedlings and depend on irrigation entirely on rainfall. Flying nurseries do not require application of compost or fertilizer since land used for the purpose is normally virgin. Flying nurseries are mainly used for raising *Tectona grandis* (Chamshama, 2014).

ii. Temporary nurseries

Temporary nurseries are planned for a small area and are used for a few years only (< 5 years). The capital investment is low and are normally located on or near to the area being planted and due to the short time between lifting and planting eliminates risk related to: packing, handling, storage, overheating, windburn, loss of soil, bruising due to vibration and reduced transport costs (Chamshama, 2014).

By having many small nurseries, isolation of diseases and other damage is much easier. The soil of temporary nursery is generally of high fertility because it is from "virgin'' land no fertilizer is used as the nursery will rarely last more than a few years. The main requisite for a temporary nursery is a good supply of water. Problems of temporary nursery include: luck of permanent installations limits species grown or propagation techniques, untrained workers, long trekking due to dispersed nature, luck of close supervision may lead to damage and theft, poor stock quality and higher cost per seedling due to small scale of operation (Chamshama, 2014).

iii. Permanent nurseries

Permanent nurseries are established to supply seedlings to a large area in which afforestation will be carried out for many years. They have high capital costs (buildings, irrigation systems, electricity supply and are central to labour force and planting area). Supervision is easy and cost per seedling is low but the seedling transport cost is high. The centralized operations permit easier planning, maintenance of records and stock control which allow better forecasting of production and costs (Evans and Turnbull, 2004).

2.3.2 Nursery site selection

Nursery site selection must be done with considerable care and caution. Many ecological and economic factors influence the success or failure of a nursery. Each nursery must have

sufficient area, suitable climate (particularly micro climate), adequate energy and transportation facilities, suitable soils and topography, adequate quantity and quality of water, available labor and proximity to the planting site. A nursery site must be located with the realization that a perfect site does not exist and the choice of site will require compromise. A team approach for nursery site selection is probably best (Chamshama, 2014).

The following are the details information clarifying factors that must be taken into considerations when selecting nursery sites.

i. Climate and environment

Preferred sites are those with favorable climatic and environmental conditions. Windy areas should be avoided to minimize windy burn and desiccation effects on seedlings and disruption of irrigation sprays. Whipping of seedlings by wind is detrimental to growth. Frost hollows and areas subject to cold air drainage should also be avoided. Extremity of temperatures and severity weather conditions area conductive to disease outbreaks therefore should be avoided in siting the nursery.

ii. Location and essential facilities

Good access to and within a nursery at all times is key in management of tree nursery. The nursery should be located close to major afforestation areas, to ensure timely transportation of seedlings to the field. Nurseries should also be within proximity to towns, power sources, telephone systems and major roads for essential facilities if the possibility exists (Evans, 1992).

iii. Topography and soils

For drainage control and mechanization, nursery beds should have gentle slope $1\text{-}3^0$. Sites subject to flooding should be avoided. Avoiding strong desiccating conditions is an

important part of silviculture. In general, hill tops, and valley bottoms are unsuitable and locations on middle to lower slopes are preferable (Evans, 1992).

Soil is very crucial in selecting bare root nursery sites. Soils should be deep (1-2m), light to medium loamy sand or sandy loam (15-20% silt) with permeable subsoil. Such a soil has a good air-water relationship, easy to work, does not crack on drying and seedlings are easily lifted with minimum root damage. Clay soils are unsuitable. High organic matter facilitates working but soil should be relatively inert and free of weed seeds and pathogens. For containers, a supply of suitable soil must be near the nursery. Soil acidity or reaction (pH) is probably the single most important chemical property of nursery soils. It directly affects other chemical reactions in the soil, the behavior of seedlings' roots and soil micro-organisms around roots. Optimum pH varies with the species, but for many, neutral or slightly acid conditions are desired; broadleaved pH 5.5-7.0, conifers pH 4.5-6.0 (Chamshama, 2014).

iv. Water supply

Sufficient clean water year round of high quality (neutral pH as extremes result in damping off) is essential. The water supply should be regularly monitored to determine whether it contains excess salts or pollutants. Water requirement will depend on growing medium and nursery type being used, but will be at a ratio between 2 000-14 000 liters per 100 000 plants from seed sowing to maturity of seedlings (Zobel *et al.,* 1987).

v. Labour

Nurseries require skilled and unskilled labour, and must, therefore, be located close to cheap available labour sources. A lot of labor is required for the establishing of the

nursery and later on periodically for tasks such as soil transportation and pot filling. The nursery should be located where it is possible to obtain labor without great difficulty at most of the times of the year. Siting a nursery on a main trail near a village will also increase awareness among common people and will participate in reforestation programme (Evans and Turnbull, 2004).

2.3.3 Nursery basic operations practiced in forest plantations

In formal organizations nursery operations are implemented based on the nurseries calendar routine which takes place at each financial year from July to June. The annual number of seedlings raised in the nursery depends on annual planting target, available budget and goes hand to hand with forest annual allowable cut. The common nursery cultural techniques include:

i. Watering

Watering is necessary especially after sowing or pricking out (transplanting) and must be done regularly in morning and evening until transfer time to field. Water should be of pH less than 7, of low salt content and not cloudy with matter in suspension. Watering can done by fine rose gardener's watering can, knapsack pressure spray, oscillating spray with fine nozzle, rotary sprayers, open trench or flooding over bed and overhead sprinkler-perforated pipe, nozzle line jets, or rotary (Zobel *et al.*, 1987).

ii. Shading and shelter

Germinating seeds and young seedlings must be protected against direct sun or downpours of rain by sloping roof of grass, banana leaves, polythene, grass mulch, wood, split bamboo, veneer cut and shade cloths or natural sheds from trees in the nursery. Where

shading is used the intensity of shade (shading percent) is reduced gradually as seedlings grow until a stage reached whereby full light is provided.

iii. Root pruning/Wrenching and Topping

Root pruning or wrenching is carried out in the nursery with the objective of hardening seedlings to withstand shock during lifting and planting and to ensure high field survival and growth. Top pruning (cutting back the top shoot 15-25 cm) is sometimes used to create a favorable root shoot ratio and reduce transpiration stress at planting out (Chamshama *et al.*, 1996).

iv. Seeding nutrition

Production of healthy seedlings ensures good survival and growth in the field and reduced susceptibility to diseases and pests. Adequate supply of plant nutrients is therefore essential. In most cases, the potting mixtures or transplant beds mixtures provide adequate nutrients, but in some situations, additional fertilizers are provided at various stages while seedlings are in the nursery due to leaching loses and uptake by seedlings. The questions of what fertilizer and how much to apply are decided by local experimentation for the species and soil concerned.

The effects of nursery fertilization, (notably of nitrogen and potassium supply) on the drought hardiness of seedlings are well for a number of temperate species (Pharis and Malcolm, 1977). Less is documented on the effects of seedling nutrition on the drought hardiness of species grown in the tropics and especially those intended for arid and semi-arid areas.

v. Inoculation

Many tree species require a particular soil mycorrhizal, rhizobium or frankia association for successful growth in the nursery and good field survival and growth. Conifers are

among the many species groups requiring mycorrhizae as an aid in the uptake of nutrients from the soil, while nitrogen fixing trees require bacteria rhizobium and Casuarinas requires fungus frankia (Alexander, 1977).

vi. Weed, Pest and Disease control

Weed control is prerequisite to free nursery seedlings from competitions for light, nutrients and moisture. Weed competition results into depressed growth of seedlings. The following are the main weed control methods:

a) Uprooting by hand – this is safe and simple
b) Hand cultivation/mechanized cultivation in bed to break loose soil aeration and drainage
c) Herbicides- pre sowing (e.g. glyphophate or roundup, paraquat).
d) Pre –emergence (e.g. propazine)
e) Post emergence (e.g diphernamid)
f) Fumigants (e.g. methyl bromide)
g) Sterillants (e.g. formalin).

Chemicals (herbicides) used to kill grass/herbs will also kill broad leaved species and are thus restricted to conifers. The use of chemicals is cheaper than most other methods but requires greater care, supervision and environmental considerations (Chamshama, 2014).

2.4 Forestry Cultural Management Practices

Proper cultural practices such as site preparation, planting spacing, planting pit, weeding, pruning, thinning, and harvesting are among important determinant for improved growth and yields in plantation forests. Studies have shown increase in growth and yield of *Pinus patula* as the land preparation intensity increases (Kalaghe and Mansy, 1989).

2.4.1 Land site preparation practices

Several studies have been carried out on the effects of diverse site preparation techniques on early survival and growth in Tanzania forest plantations (Chamshama and Nshubemuki, 2011). Results show that rigorous site preparation such as complete cultivation (ploughing and harrowing) result in improved survival and early growth of planted seedlings (Chamshama and Hall, 1987; Kalaghe and Mansy, 1989; Mhando *et al.*, 1993). Site preparation can also improve access for forest management, fire protection and eventual forest harvesting activities. It can also greatly simplify the re-establishment of subsequent forest crops in future rotations (ITTO, 1993).

In most public sector plantations including Sao Hill, before planting land preparation are usually done by casual labour under supervision of foresters. This is done by clearing, heaping and burning of debris. The "taungya" system is also used in areas where people prefer to grow seasonal crops before tree planting. The activity commences after the long rains. It has also been observed that squatters are involved in land preparation besides cultivating the land for food crops like in Ukaguru Forest plantation. In extension areas, the natural vegetation is cleared, trees are cut and piled. The heap is given time for drying until it is burnt to coincide with short rains (Ngaga, 2011).

In private forest plantations of Tanzania several techniques of site preparation have been applied. At KVTC site preparation involves vegetation clearing and burning, and pre-planting herbicide (Glyphosate roundup 3 l/ha) application (Bekker *et al.,* 2004). At Tanga Forests Ltd, site preparation is done by strip or complete ploughing (Mnangwone, 2010). In Idete, Kitete, Mapanda, Taweta and Uchindile forest plantations, chemical site preparation is used and involves application of roundup (3 l/ha) to the grass followed by screefing before pitting and planting (Mussami, 2010).

Poorly planned or inadequately supervised site preparation can cause serious environmental damage through soil compaction, erosion, loss of top soil nutrients and other forms of land degradation. However, the long-term effects of cultivation, drainage and other intensive forms of site preparation need to be carefully evaluated as they have a significant potential to lead to site decline and unwanted side effects (FAO, 2006).

2.4.2 Planting and pitting size

Proper pitting and planting is necessary to ensure high initial survival and growth and the following general rules apply. Pits should be large: 30 cm deep x 30 cm diameter. Roots are inserted into the pit up to the root collar, avoiding breaking, bending or crushing them. The soil is gently firmed around the roots to eliminate air pockets and bring the earth into intimate contact with the roots (Chamshama and Nsubemuki, 2011).

Another study has shown increase in growth and yield of Eucalyptus species with increase in planting pit size (Nshubemuki, 1980). While planting techniques are followed, the main problem in public sector plantations has been low planting rates leading to backlogs. Ukaguru forest plantation for example has a replanting backlog of 1 100 ha (Angyelile, 2010). Other replanting backlogs have been observed in Kiwira, Buhindi and Kawetire (Balama, 2010).

2.4.3 Initial planting spacing in forest plantations

Planting spacing plays an important role in tree growth as it influences competition for nutrients, moisture and light between trees and between trees and weeds, costs of various operations and the quantity and quality of wood produced (Iddi *et al*., 1996). It has been also observed an increase in growth and yield of *Pinus patula* with increase in spacing (Malimbwi *et al.,* 1991).

The spacing regulation by tree species and the treatment schedules throughout the life of the forest stand should be designed by calculating backward from the desired features of the target mature crop, by applying appropriate stand growth. From planting until harvesting consistently regulation of spacing (density and pattern) of the plantation is necessary to keep rates of biomass and energy turnover at the maximum compatible with production targets in order to achieve adequate elastic stability of the whole ecosystem (ITTO, 1993).

Tanzania forest plantations planting programme was reviewed based on Technical Orders perspectives. The current spacing rule of 3.0 x 3.0 m favors commercial production saw logs for *Pines species* and requires only twice thinning routine from establishment until final cut. For Eucalyptus species initial spacing of 2 x 2 m for pulp and poles, and 2.5 x 2.5 m for saw logs were recommended. Study shows that if correct forest practices are followed, yield will continue up to three rotations (Chamshama *et al.*, 2009). Different spacing for Tanzania industrial plantations has been presented in Table 1.

Table 1: Showing initial spacing for industrial forest plantations in Tanzania according to Technical Order No. 1 (2003).

Tree species.	**Type of end product**	**Initial spacing (m)**
Pinus species	Saw logs	3.0 x 3.0
Cupressus lusitanica.	Pulp wood logs	2.0 x 2.0
Tectona grandis	Saw logs	2.5 x 2.5
Grevi*llea robusta*	Saw logs	2.5 x 2.5
	Saw logs	3.0 x 3.0
Eucalyptus species	Pulp wood & poles	2.0 x 2.0
Acacia melanoxylon	Poles & saw logs	2.0 x 2.0
Olea carpensis	Poles & saw logs	2.0 x 2.0

Source: URT 2013

2.4.4 Weeding practices

Weeding in young plantation is necessary in order to reduce or eliminate competition for light, soil moisture and nutrients from undesirable species. In general weeding is usually done manually using hand tools. The types of weeding used in Tanzania include clean weeding (in some places using the taungya system), strip weeding, spot weeding, slashing and climber cutting (Isango and Nshubemuki, 1998). Several studies have been carried out on the effects of weeding types/intensities on seedling survival and growth, the results revealed that of clean weeding is superior weeding system.

Despite the superiority of clean weeding (manual or chemical) on survival and growth, spot and strip weeding are often used depending on the site, species and financial availability (Abeli and Maliondo, 1992). Chamshama *et al.* (1992) reported that taungya system is beneficial in terms of tree survival, food crop production, financial income to the peasant farmers and reduction of forest plantation establishment cost. The system however requires close supervision, so that roots and stems are not injured. The system may also encourage soil erosion due to cultivation; burning and clean weeding of steep lands and results in removal of nutrients in harvested crops and slash-burning (Maliondo and Abeli, 1992). Table 2 shows types of weeding techniques applied in some of industrial forest plantations in Tanzania.

Table 2: Weeding techniques used in some forest plantations in Tanzania

Ownership/Plantation	**Type of weeding techniques used**	
Public sector	**First year operation**	**Second year operation and there after**
Sao Hill	Taungya during first year,	Manual spot weeding
Meru	Taungya	Manual slashing
Ukaguru	Taungya	Manual spot weeding
Matogoro	Manual spot weeding	Manual slashing
Mtibwa	Manual spot weeding	Manual slashing
Private sector		
KVTC	Chemicals	Manual spot weeding
GRL	Strip weeding and chemical weeding	Manual spot weeding

Source: Ngaga (2011)

2.4.5 Fertilizer application

Fertilizers have been used on a routine basis in some part of world including New Zealand exotic forests since the mid-1950s (Conway, 1962). During the first decade of commercial forest fertilisation operations, the emphasis was placed on the fertilisation of established stands. Principally the aerial application of superphosphate to P-deficient stands of *Pinus radiata* was applied on highly weathered clay soils in the Auckland region. However, it became apparent in the late 1950s, following establishment of the second crop on poor sites in both the Auckland and Nelson regions, that the growth rate of exotic pines could be seriously limited by nutritional deficiencies from time of planting (Conway, 1962).

A number of literatures have indicated nutrient deficiencies in first rotation stands in Tanzania (Procter, 1968; Cannon, 1985; Tangwa *et al.,* 1988). The limiting nutrients include N, phosphorus (P) and boron (B) (Maliondo and Chamshama, 1996). In Tanzania however, so far fertilisers have not been used in government forest plantations Chamshama and Nshubemuki, 2011). Forest fertilisation is gaining prominence with the extension of plantations into more marginal sites and the need to enhance tree growth and maintain productivity of second and subsequent rotations. Preliminary results from a trial involving *P. patula* interplanted with *Leucaena diversifolia* established at Shume, Tanzania in 1998, and assessed for four years, showed that the cumulative growth performance of the second rotation pine plantations in pure stands were generally superior to those recorded in the mixtures with *Leucaena* trees - mainly resulting from the underground competition for limited nutrient resources (Maliondo *et al.,* 2007). These results were considered preliminary as further monitoring is going on (Chamshama and Nshubemuki, 2011).

2.4.6 Pruning

Pruning is a deliberate removal, preferably while still live of some of the branches from the lower trunk (bole) of a tree, with an objective of improving woody quality by reducing knots in sawn timber and similar finished products (SAIF, 2000). Ideally, pruning schedules are expected to vary with species, timber pricing and cost of pruning. Pruning is also done according to intended tree size, timber grading rules and mill requirements and also the influence of market. For the moment, pruning schedules in Tanzania are based on research findings and collaborate with the neighboring countries (Chamshama *et al.*, 1996).

In Tanzania, Pruning initiatives was issued in 1956 (Technical Order No. 2) and was revised in 1962 (Technical Order No. 17) and 1968 (Technical Order No. 22). Two types of pruning are administered in Tanzania namely; Lower (access) and high pruning (Nshubemuki *et al*., 2001). Low pruning (1.5-2.0 m above ground) is carried out to provide free access into the plantation and reduce fire risk and as high pruning to produce knot free timber. High pruning to allow more light for the food crops reduces tree vigour and thus need close supervision (Chamshama *et al.,* 1996). However, government owned industrial plantations are generally neglected or have irregular pruning. This is due to inadequate financial allocation; most forest management activities are neglected resulting in poorly managed forest plantations (Chamshama and Nwonwu, 2004). Table 3 represent pruning schedules for *Pinus patula and Cupressus lusitanica* species of Tanzania forest plantations.

Table 3: Tanzania current pruning schedules for *P. patula and C. lusitanica* (spacing 3 x 3 m)

Type of pruning	Site classes								
	L			Ll			Lll		
	Age (yr)	Mean height (m)	Pruning height (m)	Age (yr)	Mean height (m)	Pruning height (m)	Age (yr)	Mean height (m)	Pruning height (m)
P. patula									
First (WC)	3	5.5	2.7	3.5	4.9	2.4	-		
Second (S)	5	9.8	5.8	5.5	7.3	4.6	7	6.1	3.7
Third (S)	7	13.7	8.2	7.5	10.4	6.1	9	7.9	4.9
C. lusitanica									
First (WC)	1	2.4	1.2	2	2.4	1.2	-		
Second (S)	3	6.7	3.4	4	5.5	2.7	5	4	2
Third (S)	5	10.1	6.7	6	7.3	4.9	7	5.2	3.4
Fourth (S)	7	12.8	8.5	8	9.1	6.1	9	6.4	4.3

WC= whole crop; S= selective pruning

Source: FBD (2003)

2.4.7 Thinning

The major objectives of thinning are to reduce the number of trees in a stand so that the remaining ones have more space for crown and root development to encourage stem diameter increment and reach a utilisable size sooner; to remove trees of poor form; prevent severe stress which may induce pests, diseases and stand instability; and to provide an intermediate financial return from sale of wood from thinnings. More trees are initially established than the required final crops, mainly to ensure sufficient trees from which the final crop can be selected, enhance early canopy closure to suppress weed growth and to utilise the site better ((Evans, 1992; SAIF, 2000).

While thinning is an important silvicultural operation, which must be done timely and at the right intensity, the country reports show that thinning operations in many public

plantations do not follow the prescribed schedules. Where thinnings have been carried out, they have been fewer and lighter than recommended, resulting in the standing volume being distributed on too many small trees rather than fewer ones of greater value per cubic metre Chamshama (2011). The main reasons given for the neglect of thinnings include shortage of funds, lack of markets for small logs from thinnings, lack of plantation management skills and experience, foresters' traditional attitude against waste and lack of processing plants (Chamshama, 2011). Table 4 shows the recommended thinning schedules for industrial pubic plantations of Tanzania.

According to Bekker *et al*. (2004); and Mussami (2010) private sector plantations, thinning schedules do not differ from the public sectors'. See Table 5 underneath presenting thinning schedules for GRL *Pinus patula* forest plantations in Tanzania.

Table 4: Thinning regimes for different tree species in industrial forest plantations, Tanzania

Species	Age (Years)	Stems per Hectare
P. caribaea, P. elliottii, P.	0	1 111
Patula, P. tecunumanii and C.	10	650
lusitanica(all planted at 3.0 x 3.0	15	400
m spacing)	25-30	0

Table 5: Thinning schedule for *Pinus patula* at Idete, Kitete, Mapanda, Taweta and Uchindile

Species	Age (Years)	Stems per Hectare
Pinus patula,	0	1 600
	10	800
	14	500
	18	300
	25	0

Source: FBD (2003)

CHAPTER THREE

3.0 METHODOLOGY

3.1 Description of the Study Area

3.1.1 Location

Sao Hill and GRL plantation forests are found in southern highlands part of Tanzania and situated within the same district of Mufindi. Mufindi district has an area of 7 122 km^2 and lies between latitudes 8° 00’ - 9° 15’ S and longitudes 35° 35’- 35° 55’ E. It is bordered to the north by Kilolo and Iringa urban districts, to the south by Njombe district, to the east by Mlimba district and to the west by Mbarali. The head offices of the two forest projects are located at Ihefu just 17 km from Mafinga Township the district headquarters (MDC, 2008).

Sao-Hill plantations extend in several division and wards of Mufindi and it lies between latitude 8° 18’- 8° 33’ south and longitudes 35° 6’ - 35° 20’ East (Mawinda, 2010). The plantations are distributed between the lower altitudes plateau of Mufindi from 1400 and upper altitudes plateau at 2000 meters above sea level (Researcher, 2016). Figure 1 present map of study area of Mufindi District.

GRL manages two main plantations of Mapanda and Uchindile Forest Projects. Uchindile Forest Project (UFP) is located on the lower elevation of Mufindi Escarpment, between latitudes 8°39′ - 8°44′ S and longitudes 35°23′ - 35°32′ E. The altitude is between 1100m and 1437m above sea level. The MFP project is located on the lower elevation of Mufindi escarpment, within latitudes 8° 24′ - 8° 33′ S and longitudes 35^0 39’ - 35^0 44’ 5 E. The altitude varies from 1400 m to 1753 m above sea level. The external boundaries are rivers and Sao Hill Forest plantation in the western. UFP and MFP occupy Kibengu division, Mapanda ward, Chogo and Uchindile villages. Mapanda plantation is located105 km east of Mafinga Township along the road to Lower Kihansi Hydropower Project (GRL, 2012).

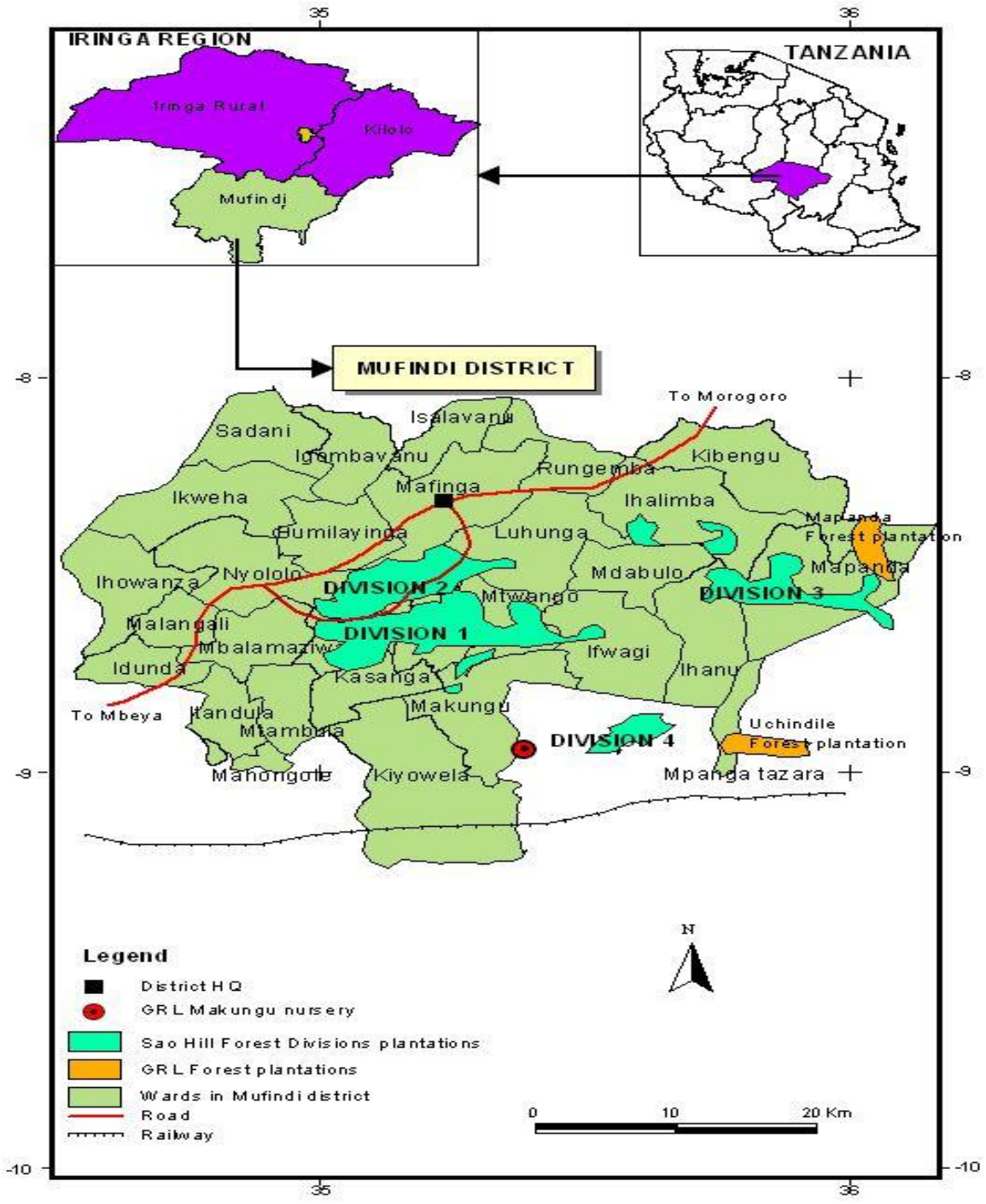

Figure 1: A map of Mufindi district showing location of study areas

3.1.2 Climate

Mufindi experience the highland climatic conditions with an average rainfall of 600 – 1 500 mm and temperature ranging between 10^0C and 28°C per annum. Sao Hill plantation area receives the mean annual rainfall of 1300mm, starting from November to April and corresponding mean air temperature is 14°C. GRL plantation receives mean annual rainfall of 1050 mm with the rainy season from December to April with the mean temperature 14^0C (Mawinda, 2010).

3.1.3 Topography and hydrology

Mufindi district is found at elevation of between 1 600 and 1 800 m above sea level. The eastern zone lies between 1 600 and 1 800 m from sea level whereas the western zone lies between 1 000 and 1 600 m above sea level. The Sao Hill forest plantation area is found in the area of rolling plateau with low hills and wide flat - bottomed valleys, within Ihalimba, Luhunga, Makungu, and Mafinga wards (Mlowe, 2007) whereas GRL forest plantations lies at an attitude between 1 400 m and 1 760 m, (GRL, 2012).

3.2 Research Design

The study was designed to compare the population parameters of two independent forest plantations of Sao Hill and GRL hence cross sectional design was preferred because in cross sectional design data are collected at single point in time without repetition from a sample selected to represent some large population (Kothari, 2008). The design is also useful for descriptive and determination of relationship between the independent and dependent variables Saunders *et al*., 2007). Socio economic data were collected using structured checklist while review of documents was used to explore general information.

3.3 Forest Stand Sampling Techniques

3.3.1 Sampling method and procedure

Two stage stratified sampling technique was applied for establishing and allocating number of plots required in selected forest compartments**.** In first stage 120 compartments were selected whereby every $1/10^{th}$ compartments were randomly singled to obtain the required 12 compartments. From each plantation (Sao Hill and GRL) two species (pines and eucalyptus) were chosen in the selected compartments and subdivided into strata of age class 5, 10 and 15 years. A fixed number of 15 sample plots of size 0.04 ha were assigned to each age and species stratum, in the compartments of minimum size of 22.5 ha. A stratum needed not be continuous but rather it could be constituted by more than one small compartment of the same species and similar age.

The second stage involved lying of sample plots in regular manner in the selected compartments at an interval of 100 meters plots by 150 meters transects. The first plot was placed randomly while the rest were established systematic along transects. Then from each plots the stand variables were quantified for estimation of stem density, volume, basal area and stem quality per hectare.

3.3.2 Sampling size and shape

The selected sample size and desired level of precision depended on the population size and research cost and 95% margin error was chosen. The sample size of 180 plots comprising of 45 plots for each stratum of *P. patula* and *E. grandis* in Sao Hill and GRL plantations were measured in randomized 12 compartments, six from each plantation as illustrated in Table 6a and 6b. Fixed circular plots designs of 0.04 ha were applied in sampling pattern because of its convenience during measurement in the plot. Ideally the

overall sample size needed to achieve a desired degree of precision at a specified probability level for stratified sampling was attained by formula below:

$$n = \frac{(\text{NiSi})}{\frac{N^2E^2}{t^2} + NiSi^2}$$

$Si = \sqrt{s^2}$ x (stratum i sample)

Practically; equal allocation sampling method for stratified sampling was used to determine sample size required for each stratum

$$ni = \frac{n}{m}$$

Where:

n = sample size; *ni* = number of sampling units allocated to stratum i

m = number of strata; *Ni* = sampling frame for stratum i

Si= standard deviation of stratum i and; S^2 = Individual sample variance observations

Table 6a: Sampling scheme for *P. patula* and *E. grandis* data collection in Sao Hill forest plantation

Name of plantation	Cpt	Species	Age strata (yrs)	Distances		No. plots/copt	Min. Area (m^2)
				Inter plots (m)	Inter transects (m)		
Sao Hill	2/s15a	*P. patula*	5	100	150	15	225000
	I/G1/3	*P. patula*	10	100	150	15	225000
	I/ID2/a4	*P. patula*	15	100	150	15	225000
	4/LUG6/6	*E. grandis*	5	100	150	15	225000
	I/G2/4	*E. grandis*	10	100	150	15	225000
	4/KT1/6	*E. grandis*	15	100	150	15	225000
					Total	**90**	**1350000**

Table 6b: Sampling scheme for *P. patula* and *E. grandis* data collection in GRL forest plantations

Name of plantation	Cpt	Species	Age strata (yrs)	Distances		No. plots/cpt	Min. Area (m^2)
				Inter plots (m)	Inter transects (m)		
GRL	MFP/J257a	*P. patula*	5	100	150	15	225000
	MFP/H159b	*P. patula*	10	100	150	15	225000
	UFPa61-63	*P. patula*	15	100	150	15	225000
	MFP/J263	*E. grandis*	5	100	150	15	225000
	UFP-B1/15a-A166	*E. grandis*	10	100	150	15	225000
	MFP/B046a	*E. grandis*	15	100	150	15	225000
					Total	**90**	**1350000**

3.3.3 Equipment and tools used for measurement

Plantation maps, survey compass and GPS were used for referencing, tracking and locating the coordinates in the field. Instruments used for measurements in the plots were; diameter calliper, tape measure and Suunto hypsometer. Field plot form, note book, and pencils were used for recording and computer was used for data storage, processing and analysis. Camera was used for taking field photos to supplement the study information.

3.4 Data Collection

The study collected both primary and secondary data.

Primary data

Primary data involved direct measurement of forest stand parameters in selected forest compartments, extraction of data from official reports in form of documents, key informant interviews and observations. The official data were in form of action plans,

annual plan of operations, direct fire reports and management plan from Sao Hill and GRL plantation forests. The stand parameters data collected included stem density and volume, basal area and stem quality. The key informants included project managers, division managers, section heads, subordinates and supervisors in GRL and Sao Hill.

Secondary data

Secondary data were obtained from the literature books, journals and official documents. The information was obtained through different sources including SNAL, websites and supervisor's supports.

3.5 Data Analysis

3.5.1 Qualitative data analysis

Content analysis technique was used for determine the qualitative data which couldn't be directly analyzed through quantitative basis in the study in the initial stage. The analysis was used to analyze the components of information which was collected through verbal discussions with key informants. As suggested by Kajembe (1994), the information collected through verbal discussions from key informants should be broken down into smallest meaningful units of information or themes and tendencies.

3.5.2 Quantitative data analysis

Quantitative data were analyzed under descriptive and inferential statistical analysis using Microsoft Excels and Statistical Package for Social Services (SPSS). Testing the hypothesis, simple t-test was run to test whether there is a significant difference of parameters studied between Sao Hill and GRL Forest populations. Frequencies, percentage and graphs were used to explain results and equation modals were applied for volume determination and diameter- height relationship.

3.5.2.1 Analysis of inventory data

i. Number of stems and basal area

Microsoft excel program was applied to calculate number of stems and basal area per hectare by using standard procedures such given number of stems and basal area per plot divided to constant plot size.

$$\mathrm{N} = \frac{\text{Number of stems per plot}}{\text{Plot size in meter square } (m^2)}$$

$$\mathrm{G} = \frac{\text{Sum of stem crossectional basal area in the plot } (\mathrm{cm}^2)}{\text{Plot size in meter square } (\mathrm{m}^2)}$$

Where:

N= Number of individual trees per hectare

G = Estimated individual total basal area per hectares

ii. Height diameter relationship modals

Pinus patula height equation

To determine single tree volume; height-diameter equations are often used to predict the mean total tree height for trees when only diameter at breast height (dbh) is measured. Microsoft Excel was applied for sorting diameter and heights raw data to fit height diameter modals for Sao Hill and GRL *Pinus patula* stands. Malimbwi *et al.* (2016) equation for Sao Hill *Pinus patula* Yield Tables was then applied to estimate height-diameter relationship.

Height =1.3[+DBH$^{\wedge 2}$/(13.63898+0.026482xDBH]$^{\wedge 2}$)).

Eucalyptus grandis height equations

Two height-diameter curve linear equations were developed to fit *Eucalyptus grandis* stands in Sao Hill and GRL forest plantations. After collecting the raw data for tree diameter and height Microsoft Excel functions was applied to fit height-diameter models and the following equations were derived.

Height = [EXP (2.0427 + (0.41 × LN (DBH))] for Sao Hill *E. grandis*.

Height = [EXP (1.6519 + (0.51 × LN (DBH))] for GRL *E. grandis*.

iii. Single tree volume estimation

***Pinus patula* volume equation**

Microsoft Excel and SPSS program were applied to calculate, compare and analyze volume means between Sao Hill and GRL. Malimbwi *et al., (*2016) modal for Sao Hill *Pinus patula* Yield Tables was applied for estimation of single tree volume. The equation was preferred because is applicable for commercial *Pinus patula* plantations and don't include branches and twigs.

V = EXP (-9.04925 + 1.14781 x LN (HT) + 1.5496 x LN (DBH)).

***Eucalyptus grandis* volume equation**

In determining single tree volume for *Eucalyptus grandis* Malimbwi and Mbwambo (1990) modal for *Eucalyptus grandis* Local Volume Tables at Sao Hill Forest Project was applied.

$V= 0.000065 \times DBH^{\wedge 1.633} \times HT^{\wedge 1.137}$.

Where:

V = volume estimation for a single tree bole for normal yields tables.

EXP = an exponential function form for the input variables diameter and heights.

LN = LN (X) Natural logarithm is the logarithm to the base exponent of a number height and diameter respectively.

HT = tree height measured from the ground level up to the tip.

DBH = estimated single tree diameter at the breast height (1.3 m).

3.5.2.2 Analysis of cost data

Microsoft Excel and SPSS program were applied to calculate, analyze and compare cost data mean between Sao Hill and GRL. Descriptive statistical analysis was used in exploring central tendencies and dispersion. Frequencies, percentage and graphs were used to explain results. Levene test for equality of variance and mean was employed in testing and comparing the significance variation and confidence intervals of the population variance.

$$t = \frac{\bar{\bar{x}} - \mu}{s/\sqrt{n}}$$

$$t = \frac{\bar{d}}{\sqrt{s^2/n}}$$

Where:

t = paired sample t -test with n-1 degree of freedom (student t-test) applied when

(n) = or < 30

$\bar{d}$ = the mean differences between the populations mean parameter

$\bar{\bar{x}}$ = parameter sample means at a specified age stratum in the compartments

n = number of observations of the sampling units

s^2= sample variance

μ= mean of the population at a specified age

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

This chapter presents and discusses results for comparative study including identification of forest management practices, cost comparisons, assessment of forest stand parameters and challenge facing management practices in Sao Hill (Government) and GRL (Private) plantations forests.

4.1 Management Practices Applied in Sao Hill and GRL Forest Plantations

Research revealed that management practices accomplished by Sao Hill and GRL forest plantations are divided into 12 main areas of forest operations as listed in Table 7 and elaborated in the Appendix 4 for activities and sub activities. Sao Hill and GRL plantations practices almost similar forest operations with some variations observed between Irundi and Makungu nurseries applied techniques. The details of nursery regimes for Sao Hill and GRL plantations are explained in Appendices 12 and 13 respectively.

Table 7: Comparative summary of management practices applied between Sao Hill and GRL forest plantations

S/N	Sao Hill Forest Plantations Activity Name	GRL Forest Plantation Activity Name	Units of measure
1	Nursery operations	Nursery operations	Seedlings
2	Planting activities	Planting operations	Ha, Person
3	Weeding activities	Weeding activities	Ha
4	Tending operations	Tending operations	Ha
5	Thinning/harvesting	Thinning/harvesting	Ha
6	Forest Roads Rehabilitations	Forest road works	Km
7	Forest Protection general	Forest Protection	Person
8	Forest Fires fighting	Forest Fires fighting	Person
9	Forest harvesting inspection and supervision	Forest harvesting inspection & supervision	Person
10	Forest resurveying and mapping	Forest mapping and survey	Person
11	Forest resource assessment	Forest Inventory	Person
12	Rehabilitations of water sources	Not practiced or indicated	Ha

4.1.1 The management of tree nurseries

Sao Hill plantation manages three permanent nurseries named Irundi, Kitasengwa and Usokami located at division one (Irundi), three (Ihalimba) and four (Mgololo) with capacity to raise 6 million, 4 million and 1.8 million seedlings per year respectively. Major tree seed suppliers for Sao Hill are TTSA, Kenya, Zimbabwe, and South Africa tree seed agencies. Figure 2 presents important Sao Hill nursery of Irundi in Division One forest showing the *Pinus species* seedling terraces.

Figure 2: Ground potted terraces of *Pinus patula* seedlings at Irundi nursery Sao Hill Nov 2016

GRL manage and operates Makungu tree nursery; the mechanized one and the most modern in the region, with various silviculutural operations. The nursery carrying capacity is 5 million seedlings per annum although production rate depends on the required target and budget. The major tree seeds suppliers to GRL are; Tanzania Tree Seed Agency, Zimbabwe, South Africa, Kenya, Costa Rica, Argentina and Brazil. The average price for imported improved tree seed is costing around 1 000 USD per 1kg.

In general the operations performed in Sao Hill and GRL nurseries do not differ and can be put into five major operations including nursery preparation, nursery germination, sowing, growth and transfer to field. The activities are sub divided into several sub activities as indicated in Sao Hill Irundi and GRL Makungu nursery regime Appendices 12 and13.

4.1.1.1 Nursery source of water supply

Sao Hill Kitasengwa (Division four) and GRL Makungu nurseries obtains its water from the same source of streams originating from escarpment of Mufindi highlands flowing towards Kilombero River basin. On the other side Division one Irundi nursery is situated alongside the upper (little) Ruaha course and obtains its water from the tributaries of the Ruaha watershed while Usokami nursery in Division three obtained its water from the regular flowing water springs.

GRL Makungu nursery is often affected by irregular water supply due to water use competition with its neighbor MPM and to overcome the problem the office have installed water tanks reservoir supplied by underground motor pump.

4.1.1.2 Nursery tending techniques

Sao Hill and GRL major nurseries practices include the following activities; Top soil collection; Site preparation; Soil mixing/ingredients; Sowing/seeding; Pricking out; Watering; Weeding; Beating up; Sorting of seedlings; Root pruning; Top dressing and boostering; Hardening off; Transplanting; Loading/offloading of seedlings for planting in the prepared forest compartment.

i. Soil mixing and seedling potting

In general germination of eucalyptus and pines seeds in Sao Hill and GRL nurseries starts after 5 to 10 days respectively after sowing and before sowing pines seeds are soaked in cold water (1- 8 days) or hydrogen peroxide (1-4 days) to improve germination. The main species raised are Pine and Eucalyptus species and according to the plantation nursery calendar, seedlings to be planted in December/March are raised starting from April/May (URT 2013; GRL, 2014).

In Sao Hill seedlings are raised in polythene tubes of size 10 cm diameter and gauge 250 mm using soil mixture of 5 parts top forest soil and 2 mycorrhizal. Seedlings potting is done manually by hands and the amount of soil ingredients filled in pots provides enough nutrients to the seedling which stay in the nursery for at most six to seven months after which they are planted out. NPK fertilizer is then added at the ratio of 28 gms per 20 ltrs of soil mixture. Soil pot filling is mainly done by women and the task for a person per day is 1 000 soil pots per man day while task for seedlings planting per day is 4500 seedling pots per man day.

The GRL nursery uses crushed coconut peat from industrial food wastes substrate for pot filling and as soil ingredient mixing. Soil-mycorrhizae and Rice husks for carbonization are also used as ingredients and for nutrients inoculation. The ingredient mixture is used for filling special tray pots instead of using top soil and manure as ingredients. The 28 grams of NPK fertilizer is added to coconut substrate mixture to get ingredient required for young pricked out seedlings. Pot filling and seed sowing of the pines and eucalyptus seeds in Makungu nursery is done by machine whereby semi-automated mechanism is applied for directly seeding the seeds into prepared tray pots controlled by 16 persons. The

GRL nursery production capacity is 1 500 trays x 98 seedlings = 9187.5 seedling production per day.

ii. Watering regimes

In Sao Hill nurseries watering frequency depends on the season of the year. During dry season, watering is done twice per day, early in the morning and late in the evening consecutively for 6 months. After six months, seedlings are subjected to hardening off for three months before shifted for planting in the prepared compartment. In 2016 Sao Hill Irundi nursery had 638 seedling beds operated by 33 casual workers in task ratio of 1 person watering 19.3 seed beds per day.

As for GRL nursery, daily routine is followed by watering the plants once per day until when the seedlings is ready for transfer to the field. The modern shading applied over young seedlings minimizes evapotranspiration and therefore reduces watering frequency and task. Until 2016 GRL had a total of 24 terraces of seedling bench tray pots operated by 6 workers every day and watering is done using sprinkled nozzles attached to main boom sprayers.

iii. Sanitary/Health operations

Sao Hill and GRL practices same nursery health operations including regularly weeding to free young seedlings from weed competition. The surroundings are kept clean to avoid pests, and weeding in seedling pots is done by hand picking while hoe is used to dig grasses in the open ground. Fungicide and insecticides application is done in the nurseries to overcome the problem of fungi and insects. All other non-required items are removed from the nursery, as they often tend to harbour unwanted insects and animals. To protect

the nurseries against any destructive agents like wandering animals, playing children etc. the fences, hedges and gates are always maintained.

iv. Pricking out

Pricking out of seedlings is done by hand immediately after seedlings attaining first two leaves in the seedbed. The filled pots are watered for two days before transplanting so as to stabilize the soil. Seedlings are held by the cotyledon to avoid damage of the stems. Pricked out seedlings are planted in polythene pots arranged in a transplant beds. The pricking out technique is practiced by both Sao Hill and GRL though direct sowing in tray pots (performed by machine) is the main method applied in GRL Makungu nursery.

v. Root pruning

In Sao Hill nurseries, root pruning is done using knives or sometimes by shifting pots. Pruning exercise is done fortnightly and normally 3 months after transplanting in pots until seedlings are ready for lifting out to the field. Seedlings are subjected to hardening off by reducing the frequency of watering and increasing frequency of root pruning.

Ground root pruning is rarely done in GRL Makungu nursery. The main technique used is suspension mechanism by using the bench seedling trays raised 50-60cm (two feet) from the ground surface. Suspension root method has advantage compared to knives or shifting pruning mechanism because it serves cost and time.

vi. Clone/cuttings sorting

Clone/cuttings sorting are only practiced by GRL Makungu nursery as vegetative seedling production for Eucalyptus species. Clone or cuttings is a vegetative sprout technique by the stocks of the mother tree into prepared site to hasten the growth rate. Mother trees are

first left for growing in special garden for 8 months before clone cut and transferred for planting in a new area. Mother plants are trimmed at 30 cm height to let sprouts and then painting is coated to the stocks to prevent bacterial infections. The harvested sprouts have ability to reproduce earlier roots to withstand growth when transferred into a new site. The clone sprouts are careful cut from mother plants using garden knives ready for planting in prepared field. Planting depth should be 40 cm to 60 cm for easy rooting and retention of enough moisture.

vii. Nursery shading

There is no shading applied for potted seedlings in Sao Hill nurseries but rather they do apply grass mulching in the seedbed during germination stages. GRL Makungu nursery uses modern synthetic shades constructed with metallic poles and roofing fibre materials. The shade is constantly used to regulate shading for seedlings at different age depending on the day weather conditions. Figure 3 present the GRL Makungu nursery showing *Pinus species* seedlings in the bench tray pots and the modern roofing shade.

Figure 3: GRL Makungu nursery tray pots bench's terraces of *Pinus species* seedlings ready for field transfer. Photo taken at December 2016

viii. Seedling transfer to field

Seedlings transfer to field at Sao Hill and GRL is ready by December to January nine months since preparation of nursery of soil for seedlings sowing. Loading, unloading and distribution of seedlings in the field is done mainly with casual workers under supervision of permanent workers. Seedling pots (Sao Hill) and tray containers (GRL) are lifted, loaded and transported by truck ready for distribution in the prepared planting sites. Hardening off is done for two weeks before the transfer of seedlings to planting field, to enable seedling to endure field shock after planting.

4.1.2 Tree planting activities

4.1.2.1 Land/site preparation

Tree planting in Sao Hill and GRL plantations takes place in either new areas or replanting after clear cut and the activity are preceded by land preparations. For new planting areas the identification of planting sites is the first priority. The area to be planted is surveyed and divided into compartment and mapped. Each compartment has distinct boundaries and there is no standard size of the compartment. Mapping is also incorporates infrastructures such roads and fire breaks, fire towers and other buildings.

Objective of site manipulation is to secure both high survival and rapid early growth as result of improved soil moisture retention caused by reduced weed competition and increased water infiltration and storage. As reported by Chamshama and Nshubemuki, (2011), several techniques applied for site preparation at Sao Hill and GRL include taungya and bush clearing which is done through manual slashing of grasses and cutting of smaller shrubs and trees. Burning is another technique where fire is used as a silvicultural tool in combination with chopping of grass/shrubs. Vegetation must be dry and well

compacted for burning to be successful and importantly this must be done during calm weather (late hours of the day or when rains have started). The advantage of using fire is that, it is relatively cheap and when controlled, it is very efficient in clearing vegetation and reducing debris on site thus improving access.

A chemical (herbicides) like Glyphosphate (roundup) is applied to control competing vegetation before planting. The use of chemicals is mostly applied in site preparation by GRL forest. Taungya system is only applied during replanting in Sao Hill and this is practiced once for every annual planting season to avoid killing the seedlings.

4.1.2.2 Planting regime

The adopted rotation period for Sao Hill and GRL plantation trees is 25-30 years but if the current stocking allowable will not be regulated situation may lead to reduce the time period even to 15-18 years age. Planting season begin in December to March during the long rains when the soil has reached moisture build up from 35 mm – 100 mm. Pine and eucalyptus planting is done when the seedlings have attained a plant-able size of at least 30 cm height or at least six months old. Seedlings normally are undergoing hardening off before planting. Spacing used for *Pine species* is 3.0 m. x 3.0 m for saw logs and *Eucalyptus* spacing 2.5 m x 2.5 m is for pulp and poles. Pitting size applied is 10-20 cm depth by 30 cm diameter in Sao Hill while GRL seem to use more appropriate pitting size of 30 cm depth and 40 cm diameter.

Permanent staff and casual worker are used in preparing land for planting and replanting in the harvested areas. However, the areas are then allocated to permanent staff and nearby villagers to cultivate food crops mainly maize. Particularly, this technique (taungya system) of land preparation for replanting is precisely practiced by Sao Hill forest

plantations. The side effect of the method is the killing of the young plants during the weeding operations by taungya contractors.

4.1.2.3 Survival assessment and beating up

In plantation forests beating up precede planting of new areas to ensure that the beaten up seedlings catch up with those planted the previous year. Advantage of early beating up in forest stand is to create homogenous and evenness of the crops to minimizes the costs of operation in maturation period.

In Sao Hill the survival assessment is carried out 9 months after planting. Normally beating up is done if survival is greater than 50% but less than 80%. If the survival is below 50%, the plots will be replanted with the same species in the following planting season.

At GRL beating up or blanking of planted seedlings is done shortly 3 to 4 weeks after planting so that newly planted seedlings catch up with the rest. Beating or blank filling is done if survival range from 50-80% in the compartment and if survival is below 50% the area is replanted.

4.1.3 Fertilizer application after planting

Fertilizer application is carried out soon after survival assessment is done within a period of one to two years after planting. Between 2012 and 2015 total area of 576.2 ha were planted and applied with fertilizers in GRL whereby 352.5 ha were planted in Mapanda, 201.6 ha Uchindile1 and 22.2 ha in Uchindile II forest plantations as described in Table 8.

Either, there was no application of fertilizer reported in Sao Hill forest plantation past five years between 2012 and 2015.

Table 8: Mapanda and Uchindile forest plantations areas applied with inorganic fertilizer after planting in the past five years from 2012 to 2016

		Period time in years					
Activity	**Name**	**2012**	**2013**	**2014**	**2015**	**2016**	**Total**
	Mapanda FP	352.5	0	0			352.5
	Uchindile FP	8.0	26.0	129.9	37.6	0	201.6
Fertilizer at planting (Ha)	UchindileII FP	0.0	0	0	22.2	0	22.2
Total		**360.5**	**26.01**	**129.9**	**59.8**	**0**	**576.2**

4.1.4 Tending operations

4.1.4.1 Weeding practices

Weeding operation in Sao Hill and GRL plantations is manually done in all young forest compartments, using contract casual labours and permanent staff. Most used weeding techniques include sanitary slashing, spot weeding, line weeding (GRL only) and uprooting of invasive species of black wattle mostly practiced in Sao Hill. Weeding is carried out after 1-2 years since planting and is done once a year consecutively until the compartment attains first pruning at the age of 4-5 years old soon after long rains.

Singling in Sao Hill is complementary to weeding and is done in area where there are unwanted and regenerated plants. Taungya system is one of o0weeding technique practiced in SHFP among other public forest plantations. Moreover, taungya is carried out at the early stage of seedlings development during planting season between December and March under close supervision of staff and field supervision workers.

4.1.4.2 Pruning schedules

The study shows that pruning operations in Sao Hill and GRL forest plantations is carried out during dry season to reduce the chances of fungal and insect attack through wounds. Further observation indicated that Sao Hill applies first pruning at age 3-5 years and

second pruning was done from 6-8 years. In GRL first pruning starts at the age of 3-4 while pruning is carried out at age 5-6 years. Table 9 illustrates pruning routine accomplished in Sao Hill and GRL compartment strata during the case studies.

In general, forest operation reports revealed that both Sao Hill and GRL were able to implement first and second pruning schedules in the strata of *Pinus patula* stands as suggested by Technical Order 2003 for industrial plantations of Tanzania, while for *Eucalyptus grandis* stands only access pruning was carried out as single operation because most eucalyptus species are self-pruning.

Table 9: Pruning schedules implemented in Sao Hill and GRL forest plantations in past five years between 2012 and 2016 as per Technical Order (2003).

Group names Strata description		**Sao Hill Forest plantation**				**GRL Forest plantation**			
		Compartment's pruning schedules observations							
Species	**Age**	**Copt**	**1rst**	**2nd**	**3rd**	**Copt**	**1rst**	**2nd**	**3rd**
P.patula	5	2/s15a	1	0	0	MFP/J257a	1	0	0
P.patula	10	l/G1/3	1	1	0	MFP/H159b	1	1	0
P.patula	15	l/lD2/a4	1	0	0	UFP/A62-63	1	1	0

1: Indicates that, pruning schedules was performed at a specified compartment species and age
0: Indicates, no any pruning schedules performed at specified compartment species and age.

4.1.4.3 Thinning regime

Thinning operations is mainly done in pines stands to improve tree size for saw logs while for eucalyptus species thinning is rarely done in order to regulate tree size for poles. The study showed that *Pinus patula* in Sao Hill and GRL forest plantations were established in the spacing of 3 m x 3 m as per Technical Order No. 1 (2003) and both followed thinning rules for age 10 and 15 *Pinus patula* stands.

However it was observed that first selective thinning was conducted in the *Eucalyptus grandis* of age 5 years in GRL plantations for economic purpose. Table 10 shows *Pinus patula* thinning schedules carried out in Sao Hill and GRL while Figures 4 and 5 complement the field information.

Table 10: Thinning schedules implemented in Sao Hill and GRL forest plantations in past five years between 2012 and 2016 as Technical Order (2003).

Group names		**Sao Hill forest plantation**				**GRL forest plantation**			
Strata description		**Compartment's thinning schedules observations**							
Species	**Age**	**Copt**	**1rst**	**2nd**	**3rd**	**Copt**	**1rst**	**2nd**	**3rd**
P.patula	5	2/s15a	0	0	0	MFP/J257a	0	0	0
P.patula	10	l/G1/3	1	0	0	MFP/H159b	1	0	0
P.patula	15	l/lD2/a4	0	1	0	UFP/A62-63	0	1	0

1: Indicates that, thinning schedules was performed at a specified compartment species and age

0: Indicates, no any pruning schedules was performed at specified compartment species and age.

Figure 4: Sao Hill *Pinus patula* stand compartment of age 10 years after first thinning operation. A field photo taken on January 2017

Figure 5: GRL Mapanda *Pinus patula* stand compartment of age 10 years at second thinning operation. Feld photo was taken on November 2016 during study

4.1.5 Forest Protection and Conservation

Forest plantations in Sao Hill and GRL are protected from fire and other illegal human activities by employing fire crews and filed patrol men during the annual operation plan period. In the past five years between 2012 and 2016 the total area of 50 724 ha of planted forest and catchments in Sao Hill were protected using an average of 90 742 casual man days. Within the same period GRL plantation covered 12 905 ha of forest by spending average of 48 513 casual man days per annum as shown in Appendix 5 and 6 for Sao Hill and GRL total area covered. The plantations have standby fire unit operated under supervisions of forest fires officers in order to prevent fire occurrence**.**

The following measures are undertaken to prevent and control forest fire occurrences and eventually put off fires.

i. Cleaning fire breaks before the fire season to remove highly combustible wood and grass;

ii. Purchasing and maintaining firefighting equipment in a good working condition ready for use in case of fire.

iii. Preventing the use of fire for land preparation by taungya farmers;

iv. Keeping a roster of firefighting crews and a standby vehicle during the fire season; and

v. Training plantation staff and community members from adjacent village on firefighting techniques.

4.1.6 Forest Roads Maintenances

In five year plan period between 2012 and 2016 Sao Hill and GRL forest plantations carried out regular annual maintenances and construction of new forest roads including fire lines. In that particular period Sao Hill was able to maintain 2 356.6 kilometers of forest roads and fire strips while 278.52 kilometers of forest roads and fire breaks received annual maintenances in GRL forest plantations. The maintenance depended on the intensity of rainfall and type of road damages and emphasis was put on roads that were highly damaged. The most employed method of road maintenance was manual, using simple hand tools. Machine and plants such as motor graders were used in the road grading while bulldozers were employed in the case of severe road damages. The units of kilometer covered by roads are indicated in the Appendices 5 and 6 and the road costs per kilometer are presented in Table 12.

4.2 Cost Involved in Management Practices

Costs of forest operations was assessed based mainly on casual labors and compared in categories of nursery costs per seedlings, activity costs per unit areas in hectare and kilometer, cost units per man days and contribution of each forest activities to the total

costs. Results of cost comparisons have been presented through descriptive, inferential and graphs methods.

4.2.1 Nursery total costs of production per seedlings

Results presented in Table 11a, show that Sao Hill spent relatively less cost than GRL for forest nurseries in seedling production. From year 2014 to 2016 Sao Hill nurseries spent an average cost of TZS 923 102 337.35 for raising the average of 10 008 000.00 seedlings per annual, equivalent to cost rate of TZS 92.20 per seedling. The GRL Makungu nursery spent an average cost of TZS 536 900 302.33 to raise 3 679 500 seedlings per year, which is equivalent to TZS 145.92 per seedling.

Seed purchasing and contribution to the costs

Both Sao Hill and GRL obtained seeds from local seed centers and through importation. The local prices was TZS 50 000 per kg while imported seed cost was USD 1 000 000 per kg. Study indicated that average annual seed purchasing costs in Sao Hill was TZS 72 000 000 equivalent to (7.87%) of the nursery costs while in GRL the annual seed purchase costs was TZS 32 500 000 (6.05%) of production cost. The cost of seed purchasing alone is merely over 5% of the nursery total costs in Sao Hill and GRL nursery as indicated in Table 11a.

Cost rate of annual production per seedlings

Table 11a results show that Sao Hill consumed relatively lower annual average cost in seedling production by spending TZS 92.21 compared to TZS 145.29 in GRL. The reason for low cost per seedling in Sao Hill was because large amount of seedlings was raised per

year. Also other unrecorded data revealed that Sao Hill nurseries purchases large amount of seeds from local center and therefore reduced nursery cost.

Table 11a: Distribution of nursery costs and production rate per seedling in Sao Hill and GRL forests plantation from 2012 to 2016

Cost Centres		Annual Nursery Costs of Seedlings Production						
	Period Years	**2012**	**2013**	**2014**	**2015**	**2016**	**Average**	**P/tage**
No. of seedlings/yr (000,000)		7.5	10.8	10.8	11	9.94	10.01	
SHFP	Operation costs (000,000)	702.91	667.85	970.14	1 367.60	543.71	850.44	92.13
	Seed purchase cost (000,000)	64	76.3	76.78	81.06	65.16	72.66	7.87
	Total cost (000,000)	**766.91**	**744.15**	**1 046.92**	**1 448.66**	**608.87**	**923.1**	**100**
	Cost per seedling	**102.25**	**68.9**	**96.94**	**131.7**	**61.25**	**92.21**	
No. of seedlings/yr (000,000)				3.86	2.88	4.3	3.68	
GRL	Operation cost (000,000)			866.8	308.11	338.29	499.38	93.01
	Seed purchase cost (000,000)			20	20	57.5	32.5	6.05
	Total cost (000,000)			**886.8**	**328.11**	**395.79**	**536.9**	**100**
	Cost per seedling			**230.01**	**113.81**	**92.04**	**145.29**	

However, the inferential analysis of costs per seedlings as indicated in Table 11b show that there was no significant difference between Sao Hill and GRL nursery cost when t test was run at p (value < 0.05) of the significances (2 tailed) probability level.

Table 11b: Independent samples t-test comparing cost rate per seedlings between Sao Hill and GRL from year 2014 to 2015

Plantation Name	**Operation years**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**CI**
Sao Hill	3	96.6	35.2	20.3	87.5
GRL	3	145.3	74.2	42.8	184.3
t - value	-1.0263134				
Df	4				

Sig.(2-tailed)	Mean difference	Std. Error Difference	95% CI of the Difference	
			Lower	Upper
0.36	-48.66	47.41	-180.29	82.97

4.2.2 Costs of forest operations per unit area

Table 12 shows five year distributions of forest operation costs per unit area (hectare and kilometer) in Sao Hill and GRL forest plantations from 2012 to 2016. The operations cost units involved planting, weeding, pruning and thinning, forest protection and forest roads.

4.2.2.1 Tree planting cost per hectare

Table 12 summary of operation costs per unit area show that Sao Hill spent higher budgets per hectare using average planting cost of TZS 72 247.32/Ha in contrast to GRL average planting cost of TZS 16 750.60/Ha. The rates of payment per casual man day in Sao Hill forest was based on the government regulation on cost per task units. In 2016 Sao Hill for instance was paying TZS 9 231.50 per casual man day comparing to TZS 5 686.50 per man day in GRL which didn't follow the government rates henceforth lead to cost deviations.

Table 12: Summary of forest operation costs (TZS) per unit area in Sao Hill and GRL forest plantations from 2012 to 2015

Name of Activity/Unit		Planting (ha)	Weeding (ha)	Pruning (ha)	Thinning (ha)	Protection (ha)	Roads (km)
Cost unit (TZS)		Cost/ha	Cost/ha	Cost/ha	Cost/ha	Cost/ha	Cost/km
Sao Hill	**2012**	53 839.20	60 641.7	72 448.1	28 885	10 542.22	72 722.5
	2013	64 404.10	59 058.1	62 401.5	13 728	12 113.33	551 80.4
	2014	65 883.80	54 277.7	109 381.6	54 319	13 755.56	74 173.9
	2015	96 862.20	91 111.3	107 520.7	49 073	30 184.44	104 069.8
	2016		98 514.4			5 020	532 110.1
Average costs per units		**70 247.32**	**72 720.7**	**82 830.8**	**36 501.35**	**14 323.11**	**167 651.3**
GRL	**2012**	14 855.90	23 126.1	28 662.9	23 065.00	3 672.99	565 494.6
	2013	15 412.9	24 430.4	30 302.0	30 652.73	3 502.52	44 400.6
	2014	18 826.60	25 582.3	50 786.2	195 640.20	41 030.61	69 0574.3
	2015	17 905.20	28 508.9	36 932.4	172 119.52	25 091.05	469 798.7
	2016		30 253.2			46 772.57	2 307 692.3
Average costs per units		**16 750.15**	**26 380.2**	**36 670.9**	**105 369.36**	**24 013.95**	**815 592.1**

Statistics in Table 13 show that there was a significant difference in planting cost per hectare between Sao Hill and GRL when tested at (p-value < 0.05) with 2 tailed 0.001 probability level. Sao Hill incurred extra TZS 53 497.18/Ha than GRL due to variation in the task rates between two plantations as indicated in the Appendices 11 and 12.

Table 13: Independent samples t-test comparing planting operation cost per hectare between Sao Hill and GRL from 2012 to 2015

Plantation Name	Operation years	Mean	Std. Deviation	Std. Error Mean	CI
Sao Hill	4	70 247.32	18 536.09	9 268.04	29 495.08
GRL	4	16 750.14	1 916.83	958.41	3050.03
t - value	5.742				
Df	6				

Sig.(2-tailed)	Mean difference	Std. Error Difference	95% CI of the Difference Lower	Upper
0.001*	53 497.17	9317.47	30698.151	76296.20

Note: When a statistic t test value at sig. (2-tailed) is less than (p-value < 0.05) it indicates there are significant differences and the opposite.

4.2.2.2 Weeding operation costs

Table 12 of forest operation costs shows that Sao Hill spent higher cost in weeding using TZS 72 720.7 per hectare while GRL spend TZS 26 380.2/Ha in performing the same operation. Variation of costs between Sao Hill and GRL was attributed by different rates of payment according to each organization tasks rates. In Sao Hill weeding task is costing 10 man days per hectare while GRL is charging only 7 man days as shown in Appendices 11 and 12 of operation tasks units.

The analysis in Table 14 shows that Sao Hill spent higher cost at weeding operation than GRL forest plantation. There was significant mean difference by TZS 46 340.5/Ha at (p-value < 0.05) with 2 tailed p (value 0.001) level to support the above information.

Table 14: Independent samples t-test comparing weeding operation cost per hectare between Sao Hill and GRL

Plantation name	Operation years	Mean	Std. Deviation	Std. Error mean	CI
Sao Hill	5	72 720.71	20 470.97	9 154.90	35 508.02
GRL	5	26 380.21	2939.33	1314.51	4 242.19
t - value	5.01				
Df	8				

Sig.(2-tailed)	Mean difference	Std. Error Difference	95% CI of the Difference	
			Lower	Upper
0.001*	46 340.5	9 248.79	25 012.76	67 668.24

Note: * indicates a significant difference (p-value <0.05).

4.2.2.3 Pruning cost per hectare

Description of cost per unit area in Table 12 indicates that Sao Hill spend extra double cost in pruning by consuming the average of TZS 82 830.30/Ha in contrast to TZS 36 670.9/Ha in GRL from the year 2012 to 2016 in the same pruning operation. The cost variation between Sao Hill and GRL forest operations was mainly because these two forest plantations were managed under different organizations financial regulations. However Sao Hill cost units followed the government financial regulation by paying the lowest government payment rates per day for workers.

When the t - test was run at p (value < 0.05) with 2 tailed significance 0.008 probability level, the analysis indicated the mean cost difference of TZS 51 267.1/Ha. The inferential result's concluded therefore that Sao Hill consumed more money than GRL in performing pruning operations as indicated in Table 15.

Table 15: Independent samples t-test comparing pruning cost per hectare between Sao Hill and GRL from 2012 to 2015

Plantation Name	Operation years	Mean	Std. Deviation	Std. Error Mean	CI
SAO HILL	4	87 937.97	24 051.06	12 025.53	38 270.60
GRL	4	36 670.87	10 066.46	5 033.23	16 017.98
t - value	3.933				
Df	6				

Sig. (2-tailed)	Mean difference	Std. Error of Difference	95% CI of the Difference	
			Lower	Upper
0.008	51 267.1	13 036.36	19 368.27	8 3165.93

4.2.2.4 Thinning /harvesting cost per hectare

Study shows that between 2012 and 2016 GRL had operated thinning with relative higher cost units per hectare using the average of TZS 105 369.36/Ha. In implementing the same pruning operation Sao Hill spent lowest cost by using the annual average of TZS 36 501.3/Ha as indicated in Table 12.

The cause of cost variation was due to fact that GRL spend many casual labour tasks for thinning and few permanent staff for inspection/supervision. In contrary Sao Hill spent many employed staff for inspection/supervision and few casual labors in operation.

As indicated in Table 16 when costs were compared and analyzed under t -test at p (value < 0.05) results showed the significant cost variation between Sao Hill and GRL with (2 tailed) 0.19 probability values.

Table 16: Independent samples t-test comparing thinning cost per ha between Sao Hill and GRL from 2012 to 2015

Plantation Name	Operation years	Mean	Std. Dev.	Std. Error Mean	CI
SAO HILL	4	36 501.3	18 727.4	9 363.7	29 799.5
GRL	4	105 314.3	91 277.2	45 638.6	145 242.5
t - value	-1.477				
Df	6				

Sig.(2-tailed)	Mean difference	Std. Error of Difference	95% CI of the Difference	
			Lower	Upper
0.19	-68 813	46 589.3	-182 812.8	45 186.8

4.2.2.5 Forest protection cost per hectare

The findings as prescribed in Table 12 shows that Sao Hill spent relatively low cost in forest protection activities compared to GRL plantation. Within five years period from 2012 to 2016 Sao Hill used an annual average cost of TZS 14 323.11/Ha in protection of forest compared to TZS 24 013.95/Ha spent by GRL forest plantation. The variation in costs was possibly influenced by the functions of number of man days and cost per unit area and because Sao Hill plantation has the coverage area of 45 000 ha to protect compared to area of 18 379 ha GRL plantation forest (URT, 2013; GRL, 2012).

However, when the t test was run at (p-value > 0.05) the analysis indicated there was no significance cost difference in forest protection between SHFP and GRL forest plantation as shown in the below Table 17.

Table 17: Independent samples t-test for comparison in forest protection cost per hectare between Sao Hill and GRL forest plantation

Plantation name	Operation years	Mean	Std. Deviation	Std. Error Mean	CI
Sao Hill	5	14 323.11	9 455.56	4 228.65	11 740.62
GRL	5	24 013.95	20 267.92	9 064.09	25 165.95
t - value	-.969				
Df	8				

Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
			Lower	Upper
0.361 **	-9690.84	10001.96	-32755.40	13373.73

Note: ** indicates no significant difference at (p-value>0.05).

4.2.2.6 Road maintenance cost per kilometer

The previous Table 12 summary shows that, from 2012 to 2016 GRL spent higher cost in forest roads using an annual average of TZS 815 591.1/ Km. The same operation was performed with the minimum cost of TZS 167 651.3/Km in Sao Hill forest plantation. According to field observation it was realized that GRL incurred more costs in roads service compared to Sao Hill because some extra cost was used in new roads construction.

The analysis test in Table 18 confirmed that there was significant cost difference between GRL and Sao Hill forest roads at (p-value < 0.05) in 2 tailed p value 0.143 level. The road cost mean difference between GRL and Sao Hill was TZS - 647 940.74/km.

Table 18: Independent samples t-test for Forest roads maintenance cost per km

Plantation Forests	Operation years	Mean	Std. Deviation	Std. Error Mean	CI
Sao Hill	5	167 661.5	204 494.5	91 452.7	253,913.5
GRL	5	815 592.1	868 742.01	388 513.2	1,078,685.7
t - value	-1.623				
Df	8				
Sig.(2-tailed)	Mean difference	Std. Error Difference	95% CI of the Difference Lower	Upper	
0.143	-647 940.74	399 131.72	-1 568 340.16	272 458.67	

4.2.3 Annual trend of payment rate per casual man day

Figure 6 shows the trend rates of annually payment for casual labour man day in Sao Hill and GRL forest plantations from 2012 and 2016. Study shows that Sao Hill had stead annual increment from mean TZS 5 192.35/man day in 2012 up to TZS 9 231.48/man in 2016. GRL had relatively lower cost of TZS 4 600/man days in payment per casual labour in the year 2012 up to TZS 5 686.5/man days in 2016.

However the variation costs per man day depended on the rules of each organization whereby Sao Hill payment was based on government rates and GRL rates per casual worker depended on its organization financial ability.

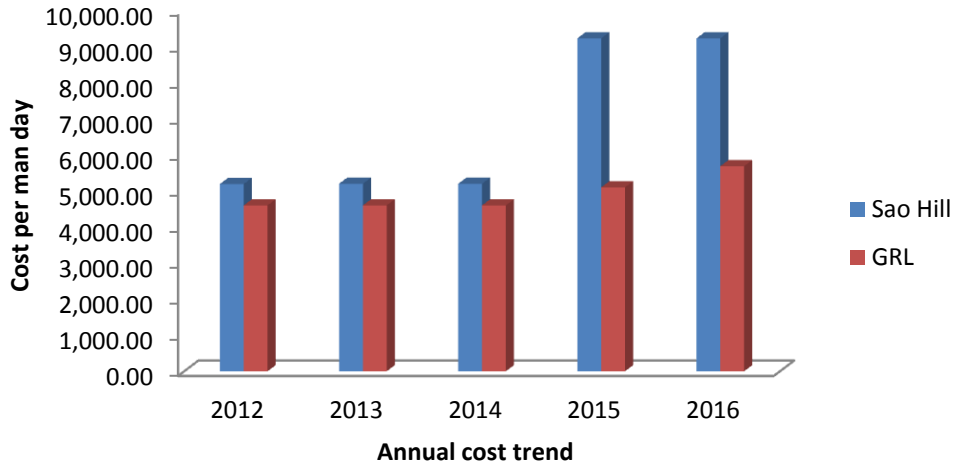

Figure 6: The annual trend of costs of casual man day as implemented in Sao Hill and GRL forest plantations from 2012 to 2016

4.2.4 Contribution of forest operations to the annual total costs

Table 19a and 19b shows the summaries of grand annual average costs of forest operation for five years from 2012 to 2013 in Sao Hill as TZS 4.34284 billion and TZS 0.8207 billion for GRL forest plantations. The cost contributions by each forest activities to the annual expenses by percentage in Sao Hill and GRL have been combined and presented in Figure 7.

Based on the annual total costs in Sao Hill, weeding operations contributed highest expenditure by (29%) followed by 18 % of the total cost by nursery operations. Forest protection accounted for 14% of the costs while 12% was contributed by planting activities and the lowest cost expenditure operation was 1% in rehabilitation of water catchment.

Table 19a: Sao Hill forest plantation annual total cost and contribution of each activity to the total from year 2012 to 2016

Period (Yrs.)	2012-2013		2013-2014		2014-2015		2015-2016		2016-2017		Overall mean
Activity cost centre	Cost	%	Cost	%	Cost	%	Cost	%	Cost	%	Cost
	(00 000)		(00 000)		(00 000)		(00 000)		(00 000)		**(000 000)**
Nursery	7 669	18	7 442	20	10 469	23	14 487	20	1 867	9	**838.68**
Planting	5 219	12	5 478	15	6 280	14	9 438	13	199	1	**532.28**
Weeding	13 115	31	11 726	31	12 847	28	14 494	20	7 361	36	**1 190.86**
Tending	5 235	12	2 809	7	3 128	7	8 888	12	4 056	20	**482.32**
Protection	4 744	11	5 451	15	6 190	13	13 583	19	2 259	11	**644.54**
Catchment	1 059	3	452	1	563	1	758	1	92	0	**58.48**
Forest roads	1 381	3	1 667	4	1 706	4	4 296	6	2 320	11	**227.4**
Forest fire	2 602	6	1 647	4	3 603	8	3 350	5	2 167	11	**267.38**
Harvesting	1 067	3	779	2	1 136	2	1 828	3	237	1	**100.94**
Total (TZS)	**42 091**	**100**	**37 449**	**100**	**45 923**	**100**	**71 121**	**100**	**20 558**	**100**	**4 342.84**

In GRL, the highest cost expenses was contributed by nursery operations with 39.3% of the total cost followed by forest protection having 37.8% of the total mean annual costs. Tree planting costs was 6.7% and weeding cost contributed 5.7% of the total cost while the lowest cost of operations was 0.8% in forest inventory activities as indicated in the Table 19b of forest operations.

Table 19b: GRL forest plantations annual total cost and contribution of each activity to the total from year 2012 to 2016

Period (Years)	2012-2013		2013-2014		2014-2015		2015-2016		2016-2017		Overall mean
	Cost	%	Cost	%	Cost	%	Cost	%	Cost	%	Cost
Activity cost centers	(00 000)		(00 000)		(00 000)		(00 000)		(00 000)		(00 000)
Nursery	-	0	-	0	8868	46	3281	42	3958	37	**5 369**
Planting activities	405	19	229	22	887	5	108	1	720	7	**469.8**
Tending operations	144	7	-	0	194	1	156	2	671	6	**291.25**
Weeding	796	37	301	29	579	3	258	3	797	7	**546.2**
Forest protection	474	22	452	44	5295	27	3238	41	6036	35	**3 099**
Harvesting	60	3	10	1	614	3	528	7	512	5	**344.8**
Road works	275	13	45	4	570	3	210	3	30	0	**226**
Inventory	7	0.3	1	0.1	12	0.1	53	1	259	2	**66.4**
Grand cost	**2161**	**100**	**1038**	**100**	**17019**	**88**	**7833**	**100**	**12984**	**100**	**8 207**

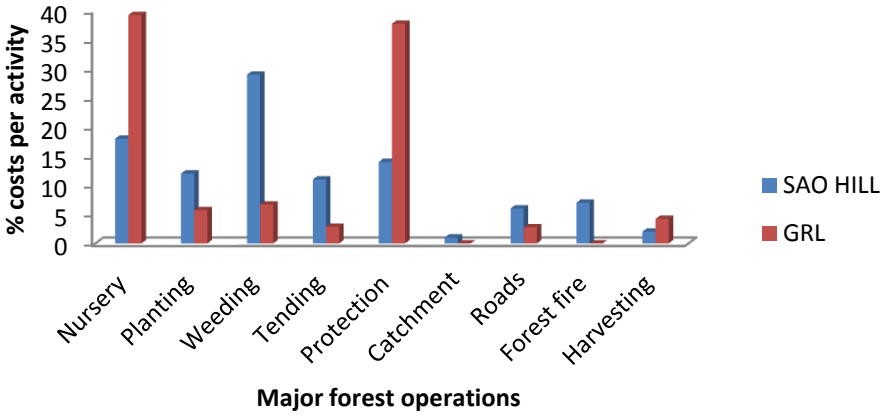

Figure 7: Graphical presentation of forest operations total costs by percentage in Sao Hill and GRL plantations from 2012 to 2016

4.3 Comparisons of Stand Parameters

This part includes analysis of stand parameters carried out based on two species strata of *Pinus patula* and *Eucalyptus grandis* which were further divided into three strata of age 5, 10 and 15 years. The comparison also included analysis of tree stem form and quality.

4.3.1 Statistics of stand parameters

4.3.1.1 Statistics for *Pinus patula* stands

Variables analyzed for *Pinus patula* stands in Sao Hill and GRL included mean diameter and heights; number of stems, volume and basal area per hectare; and the species were divided into three strata by age 5, 10 and 15 years. Compartments sampled in Sao Hill were 2/s15a, l/G1/3 and l/lD2/a4 and at GRL the compartments were J/257a, H/159b and A/61a.

i. Age 5 strata: *Pinus patula*

Table 20a shows description of age 5 *Pinus patula* stand parameters performance in mean diameter and height, stand density, volume and basal area per hectare. The results show

that Sao Hill compartment 2/s15a had higher mean number of stems per hectare than GRL J/257 while GRL had higher mean volume and basal area than SHFP at GRLJ/257. The higher volume per hectare has implication of higher wood recovery rate per individual stems and higher timber market return at the final cut.

The mean volume of 53.6m^3/Ha in GRL compared to 24m3/Ha in Sao Hill were influenced by mean dominant heights of 10.4 m and 6.5 m in GRL and Sao Hill respectively depending the site classes. According to site index curves for *P. patula* at Sao Hill established by Malimbwi, (2016), the *Eucalyptus grandis* stands of age 5 years in GRL and Sao Hill were established in different quality sites of class I and class III. The relationship was supported by heights of 10.4 m (site class I) in GRL compared to mean height 6.5 m (site class III) in Sao Hill.

Table 20a: Summary statistics of stand parameters in age 5 *Pines patula* at Sao Hill and GRL forest plantations

Study area	Variables	Min.	Max.	Mean	SD	SE	CI
Sao Hill 2/s15a	DBH (cm)	6.4	10.8	8.9	1.24	0.32	0.68
	HT (m)	4.2	8.3	6.5	1.17	0.30	0.65
	N (stems)	475.3	800.4	692.1	94.84	24.49	52.52
	V, (m^3)	9.7	36.8	24.2	7.70	1.99	4.26
	G, (m^2)	2.6	6	4.5	1.00	0.26	0.55
GRL J/257a	DBH (cm)	10.7	15.2	12.7	1.41	0.36	0.78
	HT (m)	8.3	12.9	10.4	1.45	0.38	0.80
	N (stems)	400.2	650.4	520.3	78.65	20.31	43.56
	V, (m^3)	27.8	87.3	53.6	19.27	4.98	10.67
	G, (m^2)	4.2	9.9	7.0	1.86	0.48	1.03

However inferential (t test) analysis in Table 20b indicates there is no significance difference between Sao Hill 2/s15a and GRL J/257a for mean diameter, heights, number of stems, volume and basal area per hectare when test at ($p<0.05$) 2 significance level.

Table 20b: Independent samples test comparing between Sao Hill and GRL mean stand parameters for 5 age *Pinus patula*

Statistics parameters	F	Sig.	T	Df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff	95 % C1 Diff	
								Lower	Upper
DBH (cm)	1.003	0.33	-7.99	28	0	-3.86	0.48	-4.85	-2.87
HT (m)	2.222	0.15	-8.11	28	0	-3.9	0.48	-4.89	-2.92
N (stems)	0.254	0.62	5.4	28	0	171.77	31.81	106.6	236.93
V, ($m^{3)}$	13.082	0	-5.47	28	0	-29.31	5.36	-40.29	-18.34
G,($m^{2)}$	7.833	0.01	-4.57	28	0	-2.49	0.54	-3.6	-1.37

Note: The probability value less than ($p < 0.05$) at sig. (2-tailed) indicates a significance variation and the values above/equal ($p \geq 0.05$ indicate no variation between sample means of the variables.

ii. Age 10 strata: *Pinus patula*

As described in Table 21a the compartments l/G1/3 of age 10 years *Pinus patula* in Sao Hill had higher mean stand density compared to GRL H/159b. On the other hand GRL had higher performance in mean volume and basal area per hectare compared to Sao Hill stands. The higher volume per hectare in GRL stands infers individual stem higher recovery rate for both pulp and sawn timber.

However, the higher mean values in diameter and heights of *Pinus patula* stands strata of age 10 years in GRL compared to Sao Hill lead to variation of stands performance in volume. As GRL *Pinus patula* stands had mean dominants heights of 16.0 m (site class II) compared to mean heights of 14.2 m (site class III) in Sao Hill stands. Hence the performance of stand variables was contributed by the effect of site class quality though management aspects could have also played role.

Table 21a: Summary statistics of stand parameters in age 10 *Pines patula* at Sao Hill and GRL forest plantations

Study area	Variables	Min.	Max.	Mean	SD	SE	CI
Sao Hill l/G1/3	DBH (cm)	13.20	19.10	16.6	1.84	0.47	1.02
	HT (m)	10.80	16.80	14.2	1.86	0.48	1.03
	N (stems)	275.20	750.40	482	164.69	42.52	91.20
	V, (m^3)	69.30	138.40	98.2	21.00	5.42	11.63
	G, (m^2)	6.80	14.10	10.4	2.28	0.59	1.26
GRL H/159b	DBH (cm)	12.70	21.30	18.3	2.77	0.72	1.54
	HT (m)	10.30	18.70	16.0	2.74	0.71	1.51
	N (stems)	225.10	525.30	402	93.35	24.10	51.69
	V, (m^3)	33.50	179.90	114.7	48.19	12.44	26.69
	G, (m^2)	4.50	16.40	11.1	3.98	1.03	2.21

However the hypothesis results shown in Table 21b indicated that there were no significance differences for tree stand mean statistics variables per hectare between Sao Hill l/G1/3 and GRL H/159b in forest stands when tested at p value 0.05 level of significance.

Table 21b: Independent samples test comparing Sao Hill and GRL mean stand parameters for 10 age *Pinus patula*

								95 % C1 Diff	
Statistics parameters	F	Sig.	T	Df	Sig. (2-tailed	Mean Diff.	Std. Error Diff	Lower	Upper
DBH (cm)	1.93	0.176	-2.06	28	0.05	-1.77	0.86	-3.53	-0.007
HT (m)	1.55	0.224	-2.03	28	0.05	-1.73	0.85	-3.48	0.015
N, stem	9.9	0.004	1.64	28	0.11	80.05	48.88	-20.08	180.17
V, m^3	12.87	0.001	-1.21	28	0.24	-16.47	13.57	-44.27	11.337
G, m^3	6.6	0.016	-0.62	28	0.54	-0.74	1.19	-3.17	1.687

iii. Age 15 strata: *Pinus patula*

Table 22a description for age 15 years *Pines patula* stand parameters shows that, GRL had higher mean volume and basal area per hectare in compartment A/61-63 compared to Sao

Hill I/ID2/a4 mainly due to higher mean number of stems per hectare. The finding also shows that there was no major mean variation in diameter and heights between Sao Hill and GRL *Pinus patula* stands. The similarity performance in mean diameter of 19 cm and dominant height of 16.5 m (site class III) is probably influenced by even age and site factor though management aspect could have also contributed.

Table 22a: Summary statistics of stand parameters in age 15 *Pines patula* in Sao Hill and GRL forest plantations

Study area	Variables	Min.	Max.	Mean	SD	SE	CI
	DBH (cm)	16.8	22	19	1.57	0.41	0.87
	HT (m)	14.4	19.3	16.5	1.43	0.37	0.79
Sao Hill	N (stems)	250.1	650.4	479	136.31	35.19	75.48
I/ID2/a4.	V, (m^3)	81.2	295.6	154.1	49.48	12.78	27.4
	G, (m^2)	7.8	25.5	14.3	4.22	1.09	2.33
	DBH (cm)	15.6	24.4	19.1	2.26	0.58	1.25
GRL	HT (m)	13.3	20.8	16.5	1.96	0.51	1.09
A/61-63	N (stems)	350.2	975.5	558.6	174.5	45.06	96.64
	V, (m^3)	93.9	391.7	184.4	80.15	20.69	44.38
	G, (m^2)	9.6	31.4	17	6.15	1.59	3.41

Hitherto t test results by Table 22b indicates there was no any variation for mean number of stems, volumes and basal area per hectare between Sao Hill l/lD2/a4 and GRL A/61-63, when tested at ($p>0.05$ significant level.

Table 22b: Independent samples test comparing Sao Hill and GRL mean stand parameters for 15 age *Pinus patula*

Statistics parameters	F	Sig.	T	Df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff	95 % C1 Diff	
								Lower	Upper
DBH (cm)	0.369	0.55	-0.09	28	0.93	-0.07	0.71	-1.52	1.39
HT (m)	0.271	0.61	-0.04	28	0.97	-0.03	0.63	-1.31	1.26
N/Ha	0.429	0.52	-1.4	28	0.17	-80.04	57.17	-197.15	37.07
V/Ha, m^3	2.572	0.12	-1.25	28	0.22	-30.29	24.32	-80.11	19.52
G/Ha, m^2	2.746	0.11	-1.39	28	0.18	-2.68	1.93	-6.63	1.27

4.3.1.2 Statistics for *Eucalyptus grandis* stands

The analysis of stand variables in *Eucalyptus grandis* was carried out to compare the performance of diameter and heights, number of stems, volume and basal area per hectare in the strata of age 5, 10 and 15 years. In Sao Hill Sample plots were collected from compartments 4/LUG6/6, l/G2/4 and 4/KT1/6 and from GRL compartments J/263, B1/15a and Bo/46a were assessed.

i. Age 5 strata: *Eucalyptus grandis*

The results in Table 23a shows that Sao Hill stands of *Eucalyptus grandis* in the strata of age 5 years in 4/LUG6/6 had large mean diameter and heights resulting into higher mean volume and basal area compared to GRL stands. Either the findings indicate that Sao Hill sample plots had higher mean number of stems per hectare which also contributed to volume and basal area productivity against GRL.

However, the field observation discovered that selective thinning for light poles was taken place in GRL compartment J/263 age 5 years *Eucalyptus grandis* which also reduced stand density level and wood volume per hectare, though in economic point of view it implies there was marketing opportunity values for eucalyptus species for that age class.

Table 23a: Summary statistics of stand parameters in age 5 *Eucalyptus grandis* in Sao Hill and GRL forest plantations

Study area	Variables	Min.	Max.	Mean	SD	SE	CI
Sao Hill 4/LUG6/6	DBH (cm)	10.2	18.2	14	2.13	0.55	1.18
	HT (m)	19.9	25.2	22.5	1.42	0.37	0.79
	N (stems)	375.2	900.5	614	148.84	38.43	82.43
	V, (m^3)	51.8	169.7	109.1	29.39	7.59	16.27
	G, (m^2)	4.7	15.2	9.9	2.57	0.66	1.42
GRL J/263	DBH (cm)	8.4	19	13.5	3.13	0.81	1.73
	HT (m)	14.8	23.4	19.1	2.54	0.66	1.41
	N (stems)	225.1	600.3	408.6	104.71	27.04	57.99
	V, (m^3)	18.7	124	67.6	31.68	8.18	17.54
	G, (m^2)	2	12.2	6.9	3.09	0.8	1.71

Inferential (t-test) statistics at p (value < 0.05) as shown in Table 23b indicates significance differences in the mean volume and basal area per hectare between Sao Hill and GRL *Eucalyptus grandis* stands. The variation in stand variables has implication of practical discrepancies between Sao Hill and GRL management practices.

Table 23b: Independent samples test comparing Sao Hill and GRL mean stand parameters for 5 age *Eucalyptus grandis*

								95 % C1 Diff	
Statistics parameters	**F**	**Sig.**	**T**	**Df**	**Sig. (2-tailed)**	**Mean Diff.**	**Std. Error Diff**	**Lower**	**Upper**
DBH (cm)	1.85	0.19	0.43	28	0.67	0.42	0.98	-1.58	2.42
HT (m)	4.15	0.05	4.41	28	0	3.31	0.75	1.77	4.85
N	1.96	0.17	4.37	28	0	205.13	46.99	108.88	301.38
V, (m^3)	0.4	0.54	3.72	28	0.001	41.46	11.16	18.61	64.31
G, (m^2)	1.08	0.31	2.89	28	0.007	3	1.04	0.88	5.13

ii. Age 10 strata: *Eucalyptus grandis*

Study show that *Eucalyptus grandis* stands of age 10 years in Sao Hill plantation was based on coppice management systems while GR stands established under seed system. Table 24a statistics shows that GRL compartment B1/15a-A/166 had higher volume and basal area as the function of mean diameter 16.7cm and height of 21.5m (site class I). On other side Sao Hill l/G2/4 had relatively lower mean volume and basal area associate to mean diameter of 15.9 cm and height of 23.7 m site (I) class.

The performance variation of the stand parameters between Sao Hill and GRL plantations has the implication of management practical nonconformity regardless the stands located in the same classes I sites. There is possibility of coppice managed to perform better than seed established stands as it has been observed for *Eucalyptus grandis* performance mean heights of 23.7 m and 21.5 m in Sao Hill and GRL respectively.

Table 24a: Summary statistics of stand parameters in age 10 *Eucalyptus grandis* in Sao Hill and GRL forest plantations

Study area	Variables	Min.	Max.	Mean	SD	SE	CI
	DBH (cm)	12.00	20.80	15.9	2.40	0.62	1.33
Sao Hill	HT (m)	21.10	26.60	23.7	1.47	0.38	0.81
l/G2/4	N (stems)	275.70	700.40	503.6	125.38	32.37	69.43
	V, (m^3)	56.90	178.60	114.4	30.26	7.81	16.76
	G/Ha, (m^2)	5.20	15.90	10.2	2.65	0.68	1.46
	DBH (cm)	12.90	20.40	16.7	1.98	0.51	1.10
GRL	HT (m)	18.90	23.80	21.5	1.36	0.35	0.75
B1/15a-A/166	N (stems)	275.10	775.40	518.6	125.59	32.43	69.55
	V, (m^3)	81.60	212.60	132.7	40.29	10.40	22.31
	G, (m^2)	8.00	19.80	12.9	3.73	0.96	2.07

However inferential results shown in Table 24b revealed that there is no significant difference in number of stems and volume between Sao Hill l/G2/4 and GRL B1/15a - A/166 stands of *Eucalyptus grandis* of age 10 years when tested at p (value > 0.05) level of significance.

Table 24b: Independent samples test comparing Sao Hill and GRL mean stands parameters for 10 age *Eucalyptus grandis*

Statistics parameters	F	Sig.	T	Df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff	95 % C1 Diff	
								Lower	Upper
DBH (cm)	0.135	0.72	-1.05	28.00	0.31	-0.84	0.80	-2.49	0.81
HT (m)	0.001	0.97	4.41	28.00	0.00	2.28	0.52	1.22	3.34
N, (stems)	0.037	0.85	-0.33	28.00	0.75	-15.01	45.82	-108.87	78.86
V, (m^3)	1.579	0.22	-1.41	28.00	0.17	-18.37	13.01	-45.01	8.28
G, (m^2)	2.106	0.16	-2.25	28.00	0.03	-2.65	1.18	-5.07	-0.23

iii. Age 15 strata: *Eucalyptus grandis*

Statistics parameters in Table 25a is again comparing the coppice stands of *Eucalyptus grandis* age 15 years at 4/KT1/6 in Sao Hill and seed established stands in the Bo/46a in

GRL compartment. Results shows that Sao Hill stands had higher mean stems, volume and basal area per hectare compared to GRL compartments. The stand volume in Sao Hill were influenced by mean diameter of 21.2 cm and height of 26.6 m site (class 1) and GRL had comparatively lower mean diameter of 17.6 cm and height of 21.8 m site (class 1).

Judging from the differences in performance of the two management systems between coppice and seed generation, there is great possibility that the management of *Eucalyptus grandis* under coppice regeneration in Sao Hill is more productive and appropriate for economic return in the second rotation age.

Table 25a: Summary statistics of stand parameters in age 15 *Eucalyptus grandis* in Sao Hill and GRL forest plantations

Study area	Variables	Min.	Max.	Mean	SD	SE	CI
	DBH (cm)	17.57	26.71	21.2	2.12	0.55	1.17
	HT (m)	24.7	29.2	26.6	1.12	0.29	0.62
Sao Hill	N (stems)	325.2	825.4	547	143.96	37.17	79.72
4/KT1/6	V, (m^3)	147.3	488.3	261.3	108.13	27.92	59.88
	G, (m^2)	12.7	41	22.4	9.06	2.34	5.02
	DBH (cm)	8.1	24	17.6	3.89	1	2.15
GRL	HT (m)	15	25.8	21.8	2.64	0.68	1.46
Bo/46a	N (stems)	125.1	650.4	364	154.15	39.8	85.37
	V, (m^3)	7.2	262	112.4	63.94	16.51	35.41
	G, (m^2)	0.8	24.1	10.7	5.87	1.52	3.25

Statistic result in Table 25b infers the strong significance differences between Sao Hill and GRL *E. grandis* stand variables at (p value > 0.05) significance. Analyses therefore conclude that Sao Hill strata 4/KT1/6 of age 15 years *Eucalyptus grandis* had higher mean performance of stand variables compared to GRL Bo/46a.

Table 25b: Independent samples test comparing Sao Hill and GRL mean stands parameters for 15 age *Eucalyptus grandis*

Statistics parameters	F	Sig.	T	Df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff	95 % C1 Diff Lower	Upper
DBH	3.989	0.06	3.23	28	0.003	3.69	1.14	1.35	6.03
HT	5.156	0.03	6.36	28	0	4.71	0.74	3.2	6.23
N (stems)	0.001	0.98	3.37	28	0.002	183.43	54.46	71.88	294.99
V, m^3	4.525	0.04	4.59	28	0	148.88	32.44	82.44	215.32
G, m^2	3.468	0.07	4.21	28	0	11.75	2.79	6.04	17.46

4.3.2 Stocking status related to thinning schedules

Thinning is necessary to enhance diameter increment for saw logs and is mainly applied in *Pinus species* and *Cupressus lustanica* tree stands. The study discovered that the for *Pinus patula* sample plots compartments assessed in Sao Hill and GRL forest plantations were at under stocked status. Eucalyptus species in this case was not included here because it was not annexed in the Technical Order for Industrial plantations for thinning schedules Tanzania, though in GRL and other Eastern African countries like Uganda, Burundi and Ethiopia thinning is practically applied for eucalyptus species.

Table 26 descriptions shows the mean stand density per strata for *Pinus patula* stands in Sao Hill and GRL forest plantations. The field observations discovered that inconsistence in spacing and tree mortality rate was possibly the cause for stand under stocked. Either the remarks have been provided according to stocking situation.

Table 26: Stocking status for Sao Hill and GRL *Pinus patula* stands in compartments of age 5, 10 and 15 years

	Sao Hill *Pinus patula* stands density status						
Cpt	**Age (yrs)**	**Initial spacing (m2)**	**Standard density (N/Ha)**	**1rst thinning**	**2nd thinning**	**Actual stem/Ha**	**Status/Remarks**
2/s15 a	5	3 x 3	1111			692	Not due for thinning/understoked
l/G1/ 3	10	3 x 3	1111	650	400	482	Already thinned but understocked
l/lD2/ a4	15	3 x 3	650	650	400	479	Need thinning of 79 stems/ha
Cpt	**GRL *Pinus patula* stands density status**						
J/257 a	5	3 x 3	1111			520	Not due for thinning/understoked
H/15 9b	10	3 x 3	1111	650	400	402	Already thinned but understocked
A/61 a-63	15	3 x 3	650	650	400	559	Need thinning of 59 stems/ha

4.3.6 Tree form and quality

The assessment of tree stem quality was based on the number of bole straightness, forking and crookedness and the stem were grouped according to species and age strata.

4.3.6.1 Comparison of stem form between Sao Hill and GRL *Pinus patula* compartments

Findings indicate that Sao Hill had a bit higher performance in *Pinus patula* stem form per strata with average count of 316 (96.43%) straightness, 7 (2.42%) forked and 4 (1.15%) crooked. On other hand GRL's average count per strata was 273 (92.79%) straightness, 21 (6.55%) forked and 2 (0.65%) crookedness as illustrated in Table 27.

Forking in tree stands might be caused by several factors including poor choice of species progeny and provenance matching. Improper handling of seedlings during planting and animal bruising can cause damage and contribute to stem malfunction. Still there could be possibility of other unknown causes which may require further research and at the same time must be properly controlled through physical, chemical and biological mechanisms.

Table 27: Comparison of stem form between Sao Hill and GRL *Pinus patula* stands

Field name		Sao Hill Forest Plantation				Green Resource Forest Plantation				
Age (yrs)		Tree form average counts %					Tree form average counts %			
	Copt	Straight	Forked	Crooked	Total	Copt	Straight	Fork	Crooked	Total
5	2/s15a	97.83	1.20	0.96	**415**	J/257a	98.72	0.64	0.64	**312**
10	l/G1/3	97.23	1.73	1.04	**289**	1/59b	96.68	2.90	0.41	**241**
15	l/lD2/a4	94.22	4.33	1.44	**277**	H/159b	82.99	16.12	0.90	**335**
Average count		**316**	**7**	**4**	**327**		**273**	**21**	**2**	**296**
Average count %		**96.43**	**2.42**	**1.15**	**100**		**92.79**	**6.55**	**0.65**	**100.00**

4.3.6.2 Comparison of stem form between Sao Hill and GRL *Eucalyptus grandis* stands

Table 28 descriptions indicate that Sao Hill again had higher average number of stem quality for *Eucalyptus grandis* stands. The average counts per strata in Sao Hill were 310 (93.0%) for straightness, 17 (5.21%) forked and 6 (1.79%) crooked. In GRL the average count per strata was 239 (92.89%) straightness, 11 (4.32% forked and 8 (2.79%) crooked. The reason for stem malfunctions could be contributed by management aspects although other factor like tree genetics, site factors including soil and winds effects may contribute.

However stem quality can be improved through proper tending and protection against any destructive agents including physical damage and diseases. The use of improved seed and site matching species provenance may results into individual and species higher performance.

Table 28: Comparison of tree form in *Eucalyptus grandis* stands between Sao Hill and GRL forest plantations

Field name		Sao Hill Forest Plantation				Green Resource Forest Plantation				
Age (yrs)	Copt	Tree form average counts %				Copt	Tree form average counts %			Total
		Straight	Fork	Crooked	Total		Straight	Fork	Crooked	
5	4/LUG6/8-10	95.11	4.62	0.27	368	J/263a	94.69	2.04	3.27	245
10	l/G2/6-9	93.05	4.30	2.65	302	A/168	91.32	4.50	4.18	311
15	4/KT1/6	90.85	6.71	2.44	328	Bo/46a	92.66	6.42	0.92	218
Average count		**310**	**17**	**6**	**333**		**239**	**11**	**8**	**258.0**
Average count %		**93.00**	**5.21**	**1.79**	**100**		**92.89**	**4.32**	**2.79**	**100**

4.4 Challenges facing Management of Sao Hill and GRL Forest Plantations

The findings observed several issues that affect management of Sao Hill and GRL forest plantations. Major challenges identified included fire events due to internal source and adjacent communities, low technology in firefighting gears and fund inadequate. The fire issues appears to have great impact in the management practices of both Sao Hill and GRL forest plantations therefore will be mainly discussed in this perspective.

4.4.1 Forest fire trends in Sao Hill and GRL forest plantations

Figure 8 presents fire events from year 2012 to 2016 in Sao Hill and GRL plantations forests. GRL forest plantations were more affected by fire incidence and lost 1592.5 ha of forest stands and Sao Hill forest plantation losing at least 227.14 ha of forest stands. The details information for Sao Hill and GRL is shown in Tables 29 and 30.

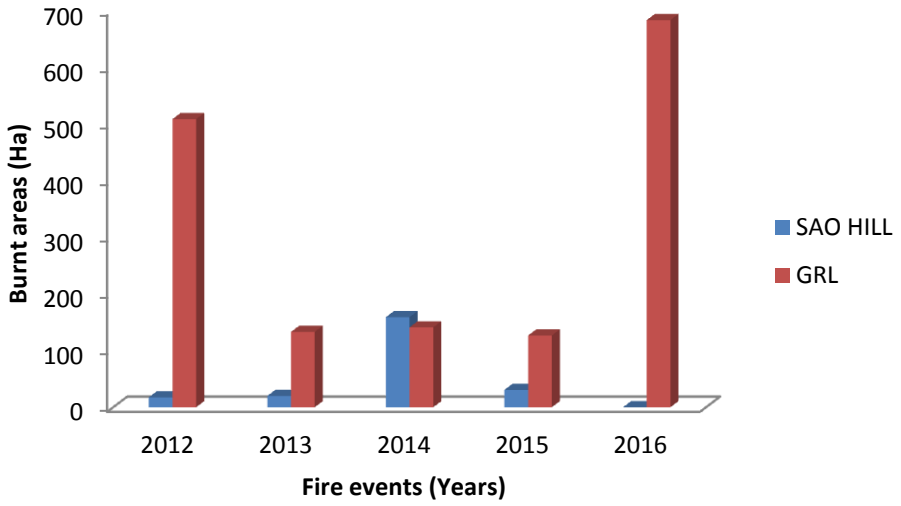

Figure 8: Events of forest fire distribution between the year 2012 and 2016 in Sao Hill and GRL forest plantations

4.4.1.1 Fire events in Sao Hill forest plantations between the year 2012 and-2016

The information provided by Sao Hill fire unit reported that 227.14 ha of forest were burnt at different Sao Hill forest divisions between years 2012 and 2016. However there was shortcoming regarding sources of fire not recorded in documents, though verbal information's by informants said that some fire occurred accidentally during fire line/land preparations.

Sao Hill forest plantation management is argued to improve firefighting gears and fire recording system for quick control and check. Both great care and close supervision must be taken during early controlled burning and land preparations in forest compartments by using of fire as the management tool.

Table 29: Showing forest fire events reported in Sao Hill forest division's compartment between year 2012 and 2016

Years	Events counted	Fire location	Fire source	Area burnt (Ha)	% burnt
2012	1	Not indicated	Unreported	17.5	7.7
2013	3	D 1,2 & 3	Unreported	20	8.8
2014	2	D 4 & 1	Unreported	159	70
2015	3	D 4 & 3	Unreported	30.64	13.49
2016	0	Nil	Nil	0	0
Total	9			227.14	100

4.4.1.2 Fire events in GRL forest plantation between year 2012 and 2016

Table 30 shows the summary of fire occurrences in different parts of GRL forest plantations. Most of fire cases reported in GRL plantations were caused by various human activities carried out in the adjacent areas while other fire occurred accidentally from management activity of fire lines and land preparation. The most areas affected by fire in GRL included Ukami/Chogo, and Sao Hill Industries together making 683.3 ha (42.9%) and Idete/ Incomet summing up 508.5 ha (31.9%) of the whole (1 592.5 ha) burnt area.

Further field observation shows that compartment layout in Mapanda, Ukami/Chogo and Uchindile didn't consider the prevention of fire and wind aspects. The fire zone and difficult topography in areas of wind corridor facing the South-East ward directions require fire line of spacing between 100 m to 300 meters. Care must be taken during land preparations by fire and also weather conditions should be considered (low temperature and cloudy weather) for safe controlled burning.

Table 30: GRL forest plantations fire events in recent five years 2012-16

Year	Plantation name	Fire source reported	Total area burnt Area (Ha)	(Ha) %
2012	Idete, Incomet FP	Fire from outside	508.5	31.9
2013	Uchindile1, Mapanda FP	Accidental - FL preparation	133.0	8.4
2014	Idete, Mapand FP	Arson, & accidental fire	141.0	8.9
2015	Idete, Uchindile 1&2, Masagati, Mapanda, Ukamai/Chogo FP	Lightening & accidental fire	126.7	8.0
2016	Uchindile1&2, Idete, Kitete, Masagati, Ukami/Chogo, SHI FP	Lightening, accidental fire	683.3	42.9
	Total		**1 592.5**	**100.0**

4.4.2 Sao Hill and GRL relationship with communities

4.4.2.1 Sao Hill forest plantation and communities

Sao Hill forest plantation is surrounded by different community groups including Sao Hill Wood Industries and Mgololo Paper Mills, Primary Schools and Villages, Religion Groups, Mafinga JKT, and Other Institutions. The plantation is significantly contributing the wellbeing of those community groups through social facilities, economic and environment services including the Sao Hill staff who benefits from the project in many ways including a taungya farming system allowed in the harvested compartments.

There are about 43 villages adjoined the plantation which benefits from direct employment, taungya farming and receive health services. Other welfares include tree seedlings services, induction on fire protection and environmental care programme. Yet the presence of adjacent communities affects the management of Sao Hill forest plantations in both positive and negative ways. The plantation receives cooperation of communities by provision of casual labour in forest operations and protection during fire incidences. However, the inappropriate human activity including poor

farming techniques and other socio economic activities activates fires rates to plantation (URT, 2013).

Sao Hill forest plantation as a national asset contributes large to the country economy and holds many ends of Tanzanian citizens. In order to sustain the existing of the plantation holistic effort and joint relation between Sao Hill management and adjacent communities is required.

4.4.2.2 GRL forest plantation relationship with communities

GRL forest plantation activities at various stages of planning and operational processes encourage participation of government institutions, local communities, individuals and other stake holders. In order to identify community priority the plantation continues to work close to village government and other developments agencies in the area. The social development areas work out together with local villages through a Participatory Rural Appraisal (PRA) approach (GRL, 2014).

GRL has the community program to raise the living standard in the areas around the plantation through employee's earnings to improve their houses, take their children to school and improve their nutrition and health standards in the households. For instance; during the annual budget plan 2015/16 Mapanda Forest Plantation employed an average of 100 contract workers from the surrounding villages.

The plantation has also the program that continues to assist selected projects which are beneficial to entire community such as schools, dispensaries, water supply systems, roads and bridges. The company in undertaking community projects in supplementing government efforts and developing rural areas saves money that will be available for other need projects in the country (GRL, 2012).

4.5 Final Facts about Management Practices in Sao Hill and GRL Forest Plantation

The study covers final summary of management practices between the two plantations regime comprising objects of existing forest practices, cost of forest operations, stand parameters performances and challenge factors involved as shown in the Table 31.

Table 31: Showing the comparative facts summary of management practices implemented by Sao Hill and GRL forest plantations

Attribute	Sao Hill	GRL	Comments
1. Management Practices			
Nursery operations			
Nursery status	Permanent nursery	Permanent nursery	
Production level	10 008 000 seedlings pa	3 679 580 seedlings pa	
Seed sources	TTSA Zimbabwe, Kenya, South Africa	TTSA, South Africa, Zimbabwe, Costa Rica, Brazil, Argentina.	
Major species	*P. patula, P. caribaea, P. Kessia, E. grandis, E. saligna, C. lusitanica*	P. *patula, P. caribaea, P. radiata, P. tecumanii E. grandis, E. saligna,*	
Major operations	Nursery preparations	Nursery preparations	
	Germination processes	Germination processes	
	Sowing manual	Sowing manual	
		Sowing mechanical	
	Tending/growth	Tending/growth	
		Clones replication	
	Transfer to field	Transfer to field	
Planting activities			
Land preparation	Manual bush clearing	Manual bush clearing	
	Strip ploughing	Strip ploughing	
	Taungya system	Chemical/herbicides	
	Vegetation burning	Vegetation burning	
Planting regime	December to March	December to March	
Beating up	Survival is below 50%,	Survival is below 50%,	
Fertilization after planting	Not applied	Applied	
Weeding operations			
Techniques	Sanitary slash	Sanitary slashing	
	Spot weeding	Spot weeding	
	Uprooting of invasive species	Line weeding	
	Chemicals are rarely applied	Chemical/herb killer are applied	
Pruning schedules			
S*eason schedule*	Conducted in dry season	Conducted in dry season	

First pruning	At age of 3-5 years		At age of 3-4 years		
Second pruning	At the age of 6-8 years		At age of 5-6 years		
Pruning technique	Done by hand using panga and local matchet		Done by hand using panga and local matchet		
Thinning regime	Line thinning		Line thinning		
First thinning	At age 10 years		At age 9 years		
Second thinning	At age 15 years		At age 13 years		
Forest protection					
Area coverage	50 724 hectares		12 905 hectares		
Operation mode	Fire section officers		Under fire section officer		
	Division fire crews		Division fire crews		
	Plantation patrol men		Plantation patrol men		
Community induction	Adjacent village member		adjacent village member		
Forest roads					
Area coverage	2 356.6 km		278.52 km		
Season	Regular after rain		Regular after rain		
Technique	Manual using hand tools		Manual using hand tools		
	Graders and bulldozers		Graders and bulldozers		
2. Management Practices Cost of Operations (TZS)					
Nursery cost per seedlings	92.21		145.29		
Planting cost per hectare	70 247.32		16 750.15		
Weeding cost per hectare	72 720.7		26 380.2		There is sig. cost different
Pruning cost per hectare	82 830.8		36 670.9		
Thinning cost per hectare	36 501.35		105 369.36		
Forest protection (ha)	14323.11		24013.95		
Forest roads (km)	167 651.3		815 592.1		Sig. cost different
Cost per casual day	6 811.06		5 686.50		
3. Stand Parameters Status					
***P. patula* strata**					
Diameter	DBH (cm)		DBH (cm)		
Age 5 years		8.9		12.7	variation
Age 10 years		16.6		18.3	
Age 15 years		19		19.1	
Height	HT (m)		HT(m)		
Age 5 years		6.5		10.4	variation
Age 10 years		14.2	16		
Age 15 years		16.5		16.5	
Stand density	N (stems)		N (stems)		Under

Age 5 years		692.1		520.3	stocked
Age 10 years		482		402	
Age 15 years		479		559	
Volume	(V, m3)		(V, m3)		Sig. volume
Age 5 years		24.2		53.6	variation
Age 10 years		98.2		114.7	
Age 15 years		154.1		184.4	
Basal area	(G, m2)		(G, m2)		
Age 5 years		4.5		7	Variation
Age 10 years		10.4		11.1	
Age 15 years		14.3		17	
***E. grandis* strata**		14		13.5	
Diameter					
Age 5 years		21.2		17.6	
Age 10 years		15.9		16.7	
Age 15 years		21.2		17.6	
Heights					
Age 5 years		22.5		21.8	
Age 10 years		23.7		19.1	
Age 15 years		26.6		21.5	
Stand density					Under
Age 5 years		614		408.6	stocked
Age 10 years		503.6		518.6	
Age 15 years		547		364	
Volume					
Age 5 years		109.1		67.6	Variation
Age 10 years		114.4		132.7	
Age 15 years		261.3		112.4	
Basal area	(G, m2)		(G, m2)		
Age 5 years		9.9		6.9	variation
Age 10 years		10.2		12.9	
Age 15 years		22.4		10.7	variation
Tree form quality					
P. patula strata	Straightness 96.43%		Straightness 92.79%		
E. grandis strata	Straightness 93%		Straightness (92.89%)		
4. Challenge Facing Management Practices in Sao Hill And GRL					
Fire incidents	227.14 ha were burnt		1 592.5 ha were burnt		variation
Fire Equipment	Old technology		Old technology		
Fund	Inadequate		Inadequate		

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on establishment, tending operations and protection, with exception of few nursery silviculture techniques study decided that Sao Hill and GRL practices similar forest management practices. GRL nursery is automated operating by using for example raised benched tray pots nurtured under artificial modern shading instead of ground earth ports as practiced in Sao Hill. GRL nursery also practices both seeding and vegetative clone in seedling production. Major tree species raised in nursery for planting by Sao Hill and GRL plantations includes *Pinus patula, Pinus caribaea, Eucalyptus grandis and Eucalyptus saligna*.

The findings discovered that there was significant costs difference between Sao Hill and GRL forest management practices and in many areas of forest operations Sao Hill spend extra costs, including planting activities, protections and tending operations. Planting cost per hectare for instance in Sao Hill cost TZS 70 247.32 while in in GRL it is only TZS 16 750.15 per hectare. However production cost of seedling in Sao Hill nursery was lower by average of TZS 92. 21 compared to TZS 145.29 per seedlings in GRL forest plantation. It was also observed that in five year period from 2012 to 2016 Sao Hill paid the average rate of TZS 6 811.06 per casual man day compared to TZS 4 917.50 per man day GRL forest plantation.

Assessing stands parameters of the same age strata and site classes study found that *Pinus patula* strata in GRL had relatively higher performance in volume and basal area per

hectare compared to Sao Hill due to function of higher average diameter and height. Strata of age 5 for example in GRL had average diameter of 12.7 cm and height of 10.7 m comparing to average diameter of 8.9 cm and height of 6.5 m in Sao Hill. Contemporarily most of *Pinus patula* stands in Sao Hill are in the second stage crops rotation while GRL crops are in first rotation stage which in my opinions may cause the variation among yields performance.

The valuation of *Eucalyptus grandis* strata of the same age and similar sites discovered that Sao Hill stands comprises greater volume and basal area per hectare than GRL. The practices of coppices system management of *E. grandis* in Sao Hill was probably reason of good performance comparing to seed established system of *E. grandis* in GRL. Site I class of *Eucalyptus grandis* for example in Sao Hill had mean height of 22.5 m compared to mean height of 21.8 m in GRL of the same site and age strata of 5 years.

However the stem form performance in both Sao Hill and GRL for all age strata had higher mean scored of beyond 95% for straightness, 3% forked and below 2% crooked stems in *Pinus patula* and *Eucalyptus grandis* species.

The management of Sao Hill and GRL plantations was influenced by several challenges which comprises frequent fire occurrence, fund insufficient and low level of technology in firefighting equipment's and machines. The most common crisis observed within five year period between 2012 and 2016 was forest fire events and GRL lost 1592.5 ha of forest compartments and at the same period Sao Hill losing 227.14 ha forest stands by uncontrolled fires most occurring from outside the plntations. However both plantations had good relationship with adjacent communities.

5.2 Recommendations

i. Management practices in forest plantations should deliberately be improved to meet forest programme goals and objectives. The current situation of forest plantation requires suitable management techniques to favor high quality forest produce and products for economic, social and environmental aspects.

ii. Operation costs in plantation forests should periodically be appraised to optimize production in forest services. In other words they can further achieve the lowest unit costs in production services and in turn raise motivation for stakeholders.

iii. The current forest plantations volume stocking, woody quality and supply is not so promising for feeding the local market wood industry and exports. Quantity and quality wood products can be achieved under appropriate forestry techniques as prescribed under principles of plantation management techniques.

iv. Issue of frequent fires in forest plantations should be the priority subject that inclusive and strategic must be addressed under government, private sector and community together.

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APPENDICES

Appendix 1: Key informants checklist for Sao Hill and GRL forest plantations

PART 1: The checklist of forest management practices applied at Sao Hill and GRL forests plantations

1. Plantation names……..
2. The total area of your plantation forest……
3. Main species planted in your plantation forest……..
4. The rotation period for this the plantation tree species

   Pines species ……

   Eucalyptus species ……..

   Others …….
5. Reserved area for expansion purpose and the size of the area …….
6. The main objectives of the management of this particular plantation forest?
7. Management practices adopted and practiced in your forest plantation?
8. If the plantation forest operate according to management plan and management regimes? yes/no
9. If this forest project/plantation have its own tree nursery? yes/no
10. The main sources of the seeds you sow in your forest nursery?

    Seed orchard? ……..

    Seed agency? …….

    Locally collected? …….

    Other sources ……
11. List the main tree species raised in the nursery for plantations?
12. The methods used to raise and tend tree nurseries?
13. The method used for site preparation for tree planting?
14. What is planting establishment method used in the establishment of your plantation?
15. What is a planting spacing adopted for different tree species?

    Pines species …….

    Eucalyptus species ……

    Cypresses species ……

    Others …….

16. What are the methods used in weeding practices in the forest plantation operation?
    Manual?
    Mechanical?.
    Herbicides/insecticide (chemical)?
17. At which in the following age do you conduct weeding routine?
    Age class 0-5 ……. Age class 6-10 …….. Age class 11-15 ……
18. Do you apply fertilizer in the nursery/plantation trees? yes/no
19. The type of fertilizers applied before and after planting? ……
20. Mention method and tools used in the fertilizer application…….. .
21. What is the unit level and amount of fertilizer is applied per tree and per hectare respectively?
22. What are your pruning schedules in the plantation?
    Access pruning ……..
    Low pruning…….
    High pruning …….
23. The method and main tools used in pruning operation?
24. What are your thinning schedules in the plantation?
    First thinning ……
    Second thinning……
    Third thinning…….
25. What techniques do you use to ensure long term site productivity for your plantation forest?
26. How do you sustain your forest according to conservation principles:
    Forest rotation periods …….
    Harvesting and logging method ……
    Environmental (soil) conservation method ……
27. In issues of forest protection how do you control and deal with the following aspects;
    Pest management …….
    Human encroachment in forests …….
    Fire control and preventive measures ……..
    Disease and pathogen control methods …….
28. Source and availability of labour force for performing different forest operations?
29. Is the plantation forest having any environmental conservation programs?

PART 2: The checklist for comparison of management practices costs involved at Sao Hill and GRL forest plantations

1. What are the costs categories involved in the forest nurseries operations?
2. How much costs involved in those forest nursery categories/operations?
3. What is the cost per hectare for tree planting in plantation?
4. What is the cost per hectare for weeding activities in planted areas?
5. The pruning cost per hectare for different pruning schedules?
6. Thinning cost per hectare as per specified thinning schedules?
7. The rate of forest road construction and or maintenance costs per kilometer?
8. What are the average costs per hectare involved in forest harvesting operations?
9. Does the plantation project have monitoring mechanism to ensure the quantity and price charged to the harvested trees work properly? yes/no
10. What mechanisms applied for quality and quantity price control in harvesting?
11. What mechanisms used in control of trees harvesting allowable cut accordingly?
12. What is the trend in the mean annual allowable cut in volume cubic meters?
13. What is the mean annual increment (MAI) and current annual increment (CAI) per hectare?

PART 3: The checklist to asses factors affecting management practices in Sao Hill and GRL forest plantations

1. What are common factors which affects your forest management daily activities? Mention some challenges …….
2. How does the surrounding communities benefit from this particular forest plantation?
3. What measures can be taken to improve the current forest growing stock and the final yield?
4. Does the plantation have an effective control mechanism for ensuring that trees are harvested in accordance with the approved forest management plan? Explain
5. General conditions of the forest

   Under stocking …….

   Overstocking ……..

   Normal stocked ……..

   Diseased …….

   Burnt ……

Appendix 2: Plantation field data plot form

Plot form

Location: District……..

Name of Forest …….

Age: ……Species ……..

Plot No …….

Plot area……..……

Slope……Elevation……

Longitudes……Latitudes…….

General condition of the forest…….

Tree No.	DBH (cm)	Ht (m)	Stem form			Remark
			1	2	3	
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
Mean						

Stem form: 1= straight stem 2= intermediately crooked, forked 3= crooked, forked

Appendix 3: General compartment form for Sao Hill and GRL forest plantation

Compartment index. ……

Area …….

Planting year ……..

Species ……

Topography ……

Ground cover …….

Soil depth ……..

Soil type …….

Registration by …….

Date ……

What work should be given the highest priority? .....

Planting (ha)……

Beating up (ha)……..……..

Climber cutting (ha)……,

Pruning (ha)…….

Weeding (ha)……,

Previous pruning:

All stems pruned up to (m)……..

Comments: …….……

Pruning …… stems per ha up to (m)…….……..

If not all stems were pruned

Stems pruned per ha ……. Up to ……..

Comments: ……

Is there a need for further pruning? ……...

Projected year …… for the stems to be pruned

Stems per ha …… up to …… m

Comments: ……..

……..

Thinning Type	**Year**
1st	……..
2nd	……..
3rd	……..

Stand density …….

Priority for thinning …….

Next thinning ……...

Is any more thinning required? ……..

Quality of next thinning…….

Main utilization …….

Other silviculture operations ……

Stand characterization

State of Health……

Stem quality ……...

Comments ……..

Proposed time for clear felling Year ……..

Comments on main utilization ……

…….

Appendix 4: Categories of forest management practices as applied in Sao Hill and GRL forest plantations APO from 2012 to 2017

SAO HILL FOREST PLANTATIONS			GREEN RESOURCE FOREST PLANTATIONS	
Activity Name	**Sub activities**	**Units**	**Activity Name**	**Sub activities**
1. Nursery activities	Nursery preparation	various	1. Nursery	Nursery preparation
	Nursery sowing	Sdlgs		Nursery sowing
	Nursery germination	Sdlgs		Nursery germination
	Nursery growth	Sdlgs		Nursery growth
	Nursery sold to external	Sdlgs		Nursery sold to external
	Nursery transfer to field	Sdlgs		Nursery transfer to field
2. Planting activities	Bush/grassland burning	Ha	2. Planting activities	Bush clearing – Manual
	Land preparation	Ha		Pre-Planting Burning
	Seedling distribution	Ha		Pre-Plant manual Herbicide Spraying
	pitting	Ha		Pre-plant tractor herbicide spraying
	Planting in extension areas	Ha		Mark and pitting
	Replanting	Ha		Replant – Manual
	Beating up	Ha		Beating up / Blanking
				Fertilize at Planting
				Watering – Manual
				Seedling distribution
3. Weeding operations	Sanitary slashing	Ha	3. Weeding operations	Line weeding
	Spot weeding	Ha		Spot Weeding
	Uprooting of invasive species in forest compartment	Ha		Invasive control in open areas
	Coppice reductions	Ha		Invasive control in compartment
	Singling	Ha		Maintenance of ritual sites
		Ha		Graves management
4. Tending operations	Access pruning	Ha	4. Tending operations	1st Pruning
	High pruning	Ha		2nd Pruning
5. Thinning/harvesting	Marking for thinning(pines)		5.Thinning/harvesting	Marking for thinning(Eucs)
	Marking for thinning(Eucs)	Ha		Marking for thinning(pines)
	1st thinning(Pines)	Ha		1st thinning(Eucs)
	1st thinning(Eucs)	Ha		1st thinning(Pines)
	Clearfelling Pines	Ha		2nd thinning(pines)
	ClearfellingEucs	Ha		3rd thinning pines
		Ha		ClearfellingEucs
				Fell to waste
6. Forest Roads Rehabilitations	Road side drains	Km	6. Forest road works	Coppice reduction Culvert construction
	Opening of internal roads	Km		Road mitre drains opening
	Road slashing	Km		Road side slashing
	Road grading (mechanical)	Km		Road murraming

	Road construction	Km		Chech stick installation
	Bridge maintenance	units		Road grading (light grading)
	Bridge construction	units		Road mitre drains construction
	Culvert installation	units		Mechanical road construction
				Bridge construction
				Bridge repair
				Manual road construction
7. Forest Protection	Plantation patrol	Pax	7. Fire Protection	Forest Patrol
	Manning of CC & FT	Pax		Dispatchers control centers and fire towers
	Manual slashing of fire lines	Km		Fire line slashing
	Manuascreefing of fire lines	Km		Fire line Screefing
	Mechanical screefing of fire lines	Km		Controlled burning of fire lines
	Maintenance of radio call stations	units		Fire line screefing in compt
	Control burning	Km		Fire line slashing in compts
	Installation of solar power	units		New fire lines
	Maintenance of forest boundaries	Km		Fire crew standby
	Replacement of beacons	units/km		
	Fire crew standby	Pax		
	Special protection crews	Pax		
8. Forest Fires fighting	Forest fire crews	Pax	8.Forest Fires fighting	Forest fire crews
	Special protection crews	Pax		All workers
	All workers	Pax		
9. Forest harvesting inspection & supervision	Conducting supervision in harvesting areas	Pax	9. Forest harvesting inspection & supervision	Carryout logging supervision
	Carryout logging supervision	Pax		Collection of revenue from selling volumes of standing trees and sawlogs
	Collection of revenue from selling volumes of standing trees and sawlogs	Pax		Monitoring and supervising established logging checkpoints
	Monitoring and supervising established logging checkpoints	Pax		
10. Forest resurveying and mapping	Forest area resurveying and mapping	Pax	10. Mapping	Boundary Marking/Surveying
	Foretcompartmentation	Pax		Area verification
	Installation of integrated forest management	Pax		
11. Forest resource assessment	To conduct forest resource assessment	Pax	11. Forest Inventory	TSP or Full Enumeration
	Preparation of management plans	Pax		Survival Assessment (second)
				Survival Assessment (First)
12. Rehabilitation of water sources				PSP Measurement/establishment
	Remove invasive species along water sources and valleys		Not practiced	
	Planting indegenous species along water sources			
	To protect and maintain water safety and hygienic			

Appendix 5: Total unit area covered by annual forest operations at Sao Hill forest plantation in the annual budget 2012-2016

ACTIVITY	2012-13	2013-14	2014-15	2015-16	2016-17	Average
Nursery seedlings	7 500 000	10 800 000	10 800 000	11 000 000	9 940 000	10 008 000
Planting activities (ha)	9 694	8 506	9 533	9 744		9 369.25
Weeding (ha)	21 627	19 855	23 669	15 908	7 472	177 06.2
Tending (ha)	6 780	7 698	4741	8428	4415	6412.4
Protection (ha)	50 724	50 724	50 724	50 724	50 724	50 724
Water catchment (ha)	875	869	-	944	250	674
Forest fire control (ha)	755					755
Harvesting/thinning (ha)	3 694	5 673	2 091	3 725		3 795.75
Protection (km)	2 801	3 756	7 183	3 910	3 893	4 308.6
Forest roads (km)	1 899	3 021	2 300	4 128	436	2 356.8

Appendix 6: Total unit area covered by annual forest operations at GRL forest plantation in the annual budget 2012-2016

ACTIVITY	2012-13	2013-14	2014-15	2015-16	2016-17	Average
Nursery seedlings			3 860 000	2 883 000	4 300 000	3 681 000
Planting activities (ha)	2 724.25	1 484.71	4 709.44	605.35	4 015.18	2 707.786
Weeding (ha)	3 441.99	1 232.07	2 263.28	904.98	2 634.43	2095.35
Tending (ha)	502.39		640.22	307.17	1 816.83	816.6525
Protection ha)	12 905	12 905	12 905	12 905	12 905	12 905
Thinning/harvesting (ha)	259.41	33.2	314	307.4	769.41	336.684
Inventory (ha)	302.02	34.91	542.04	2 068.29	690.24	727.5
Fire protection (km)	116.72	110.1	153.67	103.19	24.73	508.41
Road works (km)	48.63	101.35	82.54	44.7	1.3	278.52

Appendix 7: Summary table of mean stands parameter for *Pinus patula* stands taken in Sao Hill & GRL forest plantations from Nov to Dec 2016

				SAO HILL FOREST PLANTATION						GREN RESOURCE FOREST PLANTATION						
				COPT STANDS MEAN PARAMETER							COPT STANDS MEAN PARAMETER					
Copt name	**Age**	**Species**	**Plot no**	**Tree counts**	**DBH (cm)**	**HT (m)**	**N**	**V, m3/ha**	**G, m2/ha**	**Copt name**	**Tree counts**	**DBH (cm)**	**HT(m)**	**N**	**V, m3/ha**	**G, m2/ha**
2/s15a	5	Pp	1	31	6.4	4.2	775.4	9.7	2.6	MFP/J257a	23	14.3	12.1	575.3	76.1	9.4
2/s15a	5	Pp	2	29	7.7	5.4	725.4	17.4	3.7	MFP/J257a	16	13.1	10.9	400.2	45.1	5.8
2/s15a	5	Pp	3	32	7.4	5.0	800.4	15.7	3.6	MFP/J257a	24	11.5	9.1	600.3	47.8	6.7
2/s15a	5	Pp	4	27	9.3	7.0	675.4	29.4	5.1	MFP/J257a	19	12.0	9.5	475.3	37	5.5
2/s15a	5	Pp	5	32	8.7	6.3	800.4	26.3	5.1	MFP/J257a	17	10.7	8.3	425.2	27.8	4.2
2/s15a	5	Pp	6	26	9.2	6.7	650.4	24.9	4.6	MFP/J257a	18	12.1	9.7	450.2	38.3	5.4
2/s15a	5	Pp	7	32	9.1	6.7	800.4	30.5	5.6	MFP/J257a	16	12.2	9.8	400.2	32.9	4.8
2/s15a	5	Pp	8	25	7.2	4.9	625.3	10.8	2.7	MFP/J257a	26	11.6	9.2	650.4	49.1	7.2
2/s15a	5	Pp	9	31	8.7	6.3	775.4	26.5	5	MFP/J257a	25	12.1	9.7	625.3	57.2	7.7
2/s15a	5	Pp	10	26	9.9	7.4	650.4	29.2	5.2	MFP/J257a	20	11.8	9.4	500.3	38.1	5.6
2/s15a	5	Pp	11	27	10.2	7.8	675.4	36.8	6	MFP/J257a	21	14.3	11.9	525.3	72.4	8.7
2/s15a	5	Pp	12	19	10.8	8.3	475.3	28.2	4.5	MFP/J257a	21	15.2	12.9	525.3	86.3	9.9
2/s15a	5	Pp	13	28	8.6	6.2	700.4	21.5	4.3	MFP/J257a	23	11.3	9.0	575.3	45.3	6.4
2/s15a	5	Pp	14	22	10.1	7.6	550.3	27.2	4.6	MFP/J257a	22	14.7	12.4	550.3	87.3	9.9
2/s15a	5	Pp	15	28	9.5	7.1	700.4	29.5	5.3	MFP/J257a	21	13.8	11.5	525.3	62.6	8
Sum of stratum 1				**415**	**132.8**	**96.9**	**10380.6**	**363.6**	**67.9**		**312**	**190.7**	**155.4**	**7804.2**	**803.4**	**105.1**
Stratum Mean				**27.7**	**8.9**	**6.5**	**692.0**	**24.2**	**4.5**		**20.8**	**12.7**	**10.4**	**520.3**	**53.6**	**7.0**
l/G1/3	10	Pp	1	13	18.9	16.6	325.2	95.3	9.3	MFP/H159b	20	20.0	17.6	500.3	173.4	16.1
l/G1/3	10	Pp	2	14	17.5	15.3	350.2	82.4	8.5	MFP/H159b	19	20.8	18.4	475.3	179.9	16.4
l/G1/3	10	Pp	3	12	19.1	16.8	300.2	91.9	8.8	MFP/H159b	15	20.8	18.4	375.2	141.8	12.9
l/G1/3	10	Pp	4	24	16.8	14.5	600.3	138.4	14.1	MFP/H159b	18	19.8	17.5	450.2	151.2	14.1
l/G1/3	10	Pp	5	11	17.1	14.7	275.2	69.3	6.8	MFP/H159b	20	19.5	17.1	500.3	162	15.3
l/G1/3	10	Pp	6	27	17.3	15.0	400.2	92.3	9.6	MFP/H159b	16	20.5	18.1	400.2	146.9	13.4

l/G1/3	10	Pp	7	27	15.7	13.4	675.4	128	13.8	MFP/H159b	9	18.3	16.0	225.1	64	6.2
l/G1/3	10	Pp	8	23	13.2	10.8	575.3	73.8	8.7	MFP/H159b	10	21.3	18.7	250.1	105.4	9.3
l/G1/3	10	Pp	9	30	14.2	11.8	750.4	101.3	12.3	MFP/H159b	12	18.1	16.0	300.2	77.9	7.9
l/G1/3	10	Pp	10	13	17.3	15.0	325.2	77.7	7.9	MFP/H159b	13	12.9	10.6	325.2	33.5	4.5
l/G1/3	10	Pp	11	17	18.7	16.4	425.2	124.8	12.1	MFP/H159b	15	12.7	10.3	375.2	34.5	4.8
l/G1/3	10	Pp	12	16	17.6	15.2	400.2	100.3	10.1	MFP/H159b	16	20.2	17.8	400.2	141.5	13.1
l/G1/3	10	Pp	13	18	15.9	13.6	450.2	85.6	9.3	MFP/H159b	18	15.5	13.2	450.2	76.3	8.7
l/G1/3	10	Pp	14	26	14.0	11.7	650.4	90.4	10.7	MFP/H159b	19	16.9	14.6	475.3	104.9	11
l/G1/3	10	Pp	15	29	14.9	12.6	725.4	121.6	13.5	MFP/H159b	21	17.4	15.1	525.3	126.9	12.9
Sum of stratum 2				**300**	**248.2**	**213.4**	**7228.9**	**1473.1**	**155.5**		**241**			**6028.3**	**1720**	**166.4**
Stratum Mean				**20**	**16.5**	**14.2**	**481.9**	**98.2**	**10.3**		**16.1**			**401.9**	**114.7**	**11.1**
l/lD2/a4	15	Pp	1	16	19.8	17.3	400.2	143.6	13	UFP/A61	39	15.6	13.3	975.5	183.6	19.8
l/lD2/a4	15	Pp	2	21	17.9	15.6	525.3	148.5	14.2	UFP/A61	27	21.5	18.7	675.4	304.9	26.2
l/lD2/a4	15	Pp	3	18	19.4	16.5	450.2	172.1	15.1	UFP/A61	34	18.5	15.9	850.5	272.6	25.1
l/lD2/a4	15	Pp	4	23	17.5	15.1	575.3	148	14.6	UFP/A61	25	24.4	20.8	625.3	391.7	31.4
l/lD2/a4	15	Pp	5	22	17.7	15.5	550.3	139.3	14	UFP/A61	18	18.6	16.3	450.2	133.4	12.8
l/lD2/a4	15	Pp	6	11	18.8	16.5	275.2	81.2	7.8	UFP/A61	18	18.9	16.4	450.2	144.8	13.4
l/lD2/a4	15	Pp	7	15	19.6	17.2	375.2	124.4	11.6	UFP/A61	14	19.8	17.2	350.2	126.8	11.5
l/lD2/a4	15	Pp	8	22	17.4	15.0	550.3	142.8	14	UFP/A61	20	19.2	16.6	500.3	167.4	15.4
l/lD2/a4	15	Pp	9	22	16.8	14.4	550.3	135.4	13.3	UFP/A61	16	19.2	16.6	400.2	137.8	12.6
l/lD2/a4	15	Pp	10	11	20.6	18.0	275.2	109	9.7	UFP/A61	16	17.1	14.9	400.2	93.9	9.6
l/lD2/a4	15	Pp	11	19	19.4	16.7	475.3	175.3	15.7	UFP/A61	19	19.1	16.5	475.3	158.8	14.6
l/lD2/a4	15	Pp	12	10	21.8	18.9	250.1	115.2	9.9	UFP/A61	21	18.2	15.9	525.3	146.2	14.2
l/lD2/a4	15	Pp	13	16	22.0	19.3	650.4	295.6	25.5	UFP/A61	22	18.3	16.0	550.3	157.3	15.2
l/lD2/a4	15	Pp	14	25	18.5	15.9	625.3	200.2	18.4	UFP/A61	19	22.0	19.3	475.3	214.9	18.6
l/lD2/a4	15	Pp	15	26	18.1	15.7	650.4	181.2	17.6	UFP/A61	27	15.9	13.6	675.4	132.1	14.2
Sum o stratum 3				**277**	**285.3**	**247.6**	**7179**	**2311.8**	**214.6**		**335**	**286.3**	**248**	**8379.5**	**2766**	**254.6**
Stratum Mean				**18.5**	**19.0**	**16.5**	**478.6**	**154.1**	**14.3**		**22.3**	**19.1**	**16.5**	**558.6**	**184.4**	**17.0**

Appendix 8: Summary table of mean stands parameter for *Eucalyptus grandis* stands taken in Sao Hill & GRL forest plantations from Nov to Dec 2016

SAO HILL FOREST PLANTATION										GREN RESOURCE FOREST PLANTATION						
				COPT STANDS PARAMETER MEAN							COPT STANDS PARAMETER MEAN					
Copt name	**Age**	**Species**	**Plot no**	**Tree Counts**	**DBH (cm)**	**HT (m)**	**N**	**V, m3/ha**	**G, m2/ha**	**Copt name**	**Tree count**	DBH (cm)	HT (m)	**N**	**V, m3/ha**	**G, m2/ha**
4/LUG6/6	5	Eg	1	28	16.3	24.1	700.4	169.7	15.2	MFP/J263	17	16.5	21.6	425.2	95.6	9.6
4/LUG6/6	5	Eg	2	23	15.7	23.6	575.3	135.6	12.1	MFP/J263	9	19.0	23.4	225.1	65.1	6.4
4/LUG6/6	5	Eg	3	22	14.6	22.7	550.3	117.8	10.5	MFP/J263	17	14.4	19.9	425.2	77.9	7.9
4/LUG6/6	5	Eg	4	19	18.2	25.2	475.3	148.2	13.1	MFP/J263	22	13.6	19.3	550.3	91.7	9.3
4/LUG6/6	5	Eg	5	24	15.2	23.4	600.3	123.8	11.2	MFP/J263	16	16.3	21.2	400.2	95.7	9.4
4/LUG6/6	5	Eg	6	21	14.1	22.5	525.3	101.7	9.1	MFP/J263	13	13.4	19.2	325.2	52.3	5.3
4/LUG6/6	5	Eg	7	33	10.2	19.9	825.4	77.7	7.2	MFP/J263	21	10.3	16.6	525.3	47.4	5.1
4/LUG6/6	5	Eg	8	15	12.3	21.4	375.2	51.8	4.7	MFP/J263	16	8.4	14.8	400.2	26.9	2.9
4/LUG6/6	5	Eg	9	25	12.7	21.7	625.3	91.4	8.4	MFP/J263	15	11.1	17.6	375.2	36.8	3.9
4/LUG6/6	5	Eg	10	36	11.4	20.7	900.5	109.7	10.1	MFP/J263	15	12.8	18.5	375.2	59.1	6.0
4/LUG6/6	5	Eg	11	21	15.1	23.2	525.3	113.4	10.2	MFP/J263	19	17.7	22.5	475.3	124.0	12.2
4/LUG6/6	5	Eg	12	26	11.7	20.9	650.4	82.8	7.6	MFP/J263	24	15.6	21.1	600.3	116.0	11.8
4/LUG6/6	5	Eg	13	21	13.9	22.6	525.3	88.3	8.0	MFP/J263	9	9.3	15.4	225.1	18.7	2.0
4/LUG6/6	5	Eg	14	34	12.5	21.6	850.5	119.2	10.9	MFP/J263	15	13.4	18.9	375.2	62.7	6.3
4/LUG6/6	5	Eg	15	20	15.1	23.3	500.3	105.4	9.5	MFP/J263	17	10.9	17.1	425.2	44.7	4.7
Sum of stratum 1				**368**	**209.0**	**336.8**	**9205.0**	**1636.7**	**147.7**		**245**	**202.5**	**287.0**	**6128.3**	**1014.6**	**102.9**
Stratum Mean				**24.5**	**13.9**	**22.5**	**613.7**	**109.1**	**9.8**		**16.33**	**13.5**	**19.1**	**408.6**	**67.6**	**6.9**
l/G2/4	10	Eg	1	18	18.7	25.5	450.2	146.5	12.9	UFP-B1/15a	21	17.7	22.2	525.3	149.2	14.4
l/G2/4	10	Eg	2	20	16.3	24.1	500.3	121.8	10.9	UFP-B1/15a	20	13.8	19.4	500.3	86.0	8.7

l/G2/4	10	Eg	3	24	14.6	22.9	600.3	120.8	10.8	UFP-B1/15a	21	16.1	21.3	525.3	119.3	11.8
l/G2/4	10	Eg	4	25	15.3	23.5	625.3	134.8	12.1	UFP-B1/15a	23	18.8	23.1	575.3	179.7	17.3
l/G2/4	10	Eg	5	22	15.5	23.6	550.3	120.0	10.8	UFP-B1/15a	13	17.4	21.8	325.2	96.9	9.2
l/G2/4	10	Eg	6	27	14.2	22.8	675.4	123.1	11.1	UFP-B1/15a	21	20.4	23.8	525.3	212.6	19.8
l/G2/4	10	Eg	7	28	16.5	24.2	700.4	178.6	15.9	UFP-B1/15a	25	15.2	20.5	625.3	126.5	12.7
l/G2/4	10	Eg	8	21	15.1	23.2	525.3	114.1	10.2	UFP-B1/15a	23	12.9	18.9	575.3	81.6	8.4
l/G2/4	10	Eg	9	20	15.4	23.6	500.3	107.8	9.7	UFP-B1/15a	23	16.2	21.1	575.3	132.0	13.0
l/G2/4	10	Eg	10	19	13.1	22.1	475.3	70.5	6.5	UFP-B1/15a	31	16.4	21.2	775.4	197.2	19.1
l/G2/4	10	Eg	11	17	12.0	21.1	425.2	56.9	5.2	UFP-B1/15a	19	18.8	23.0	475.3	150.4	14.5
l/G2/4	10	Eg	12	15	14.8	23.1	375.2	75.2	6.8	UFP-B1/15a	17	17.7	22.1	425.2	122.7	11.8
l/G2/4	10	Eg	13	23	15.3	23.5	575.3	119.8	10.8	UFP-B1/15a	11	17.8	22.3	275.1	84.3	8.0
l/G2/4	10	Eg	14	11	20.1	26.3	275.1	102.8	9.0	UFP-B1/15a	17	15.9	20.8	425.2	109.5	10.5
l/G2/4	10	Eg	15	12	20.8	26.6	300.2	122.8	10.7	UFP-B1/15a	26	15.2	20.4	650.4	143.1	14.0
Sum of stratum 2				**302**	**237.7**	**356.1**	**7554.1**	**1715.2**	**153.3**		**311**	**250.2**	**321.9**	**7779.2**	**1990.9**	**193.2**
Stratum Mean				**20.1**	**15.8**	**23.7**	**503.6**	**114.3**	**10.2**		**20.73**	**16.7**	**21.5**	**518.6**	**132.7**	**12.9**
4/KT1/6	15	Eg	1	16	19.19	25.1	400.2	157.6	13.6	MFP/Bo46a	12	24.0	25.8	325.2	183.7	16.6
4/KT1/6	15	Eg	2	26	26.71	29.2	650.4	488.3	41.0	MFP/Bo46a	19	16.5	21.0	450.2	125.8	12.0
4/KT1/6	15	Eg	3	26	19.53	25.6	650.4	264.4	22.8	MFP/Bo46a	26	15.9	21.0	650.4	147.9	14.6
4/KT1/6	15	Eg	4	27	21.40	26.8	675.4	309.9	26.7	MFP/Bo46a	7	21.2	24.3	175.1	76.0	7.0
4/KT1/6	15	Eg	5	24	19.55	25.6	600.3	243.1	21.0	MFP/Bo46a	22	19.2	23.2	550.3	190.8	18.1
4/KT1/6	15	Eg	6	15	21.47	26.6	375.2	178.8	15.4	MFP/Bo46a	5	20.8	24.2	125.1	49.0	4.6
4/KT1/6	15	Eg	7	19	20.72	26.1	475.3	223.6	19.1	MFP/Bo46a	9	18.5	22.4	225.1	81.1	7.5
4/KT1/6	15	Eg	8	33	22.61	27.3	825.4	434.9	37.2	MFP/Bo46a	13	13.3	19.1	325.2	51.4	5.2

4/KT1/6	15	Eg	9	13	21.17	26.6	325.2	147.3	12.7	MFP/Bo46a	16	15.9	21.0	400.2	93.1	9.1
4/KT1/6	15	Eg	10	29	23.23	27.7	725.4	399.7	34.1	MFP/Bo46a	15	16.3	21.4	375.2	86.4	8.6
4/KT1/6	15	Eg	11	20	17.57	24.7	500.3	148.2	13.1	MFP/Bo46a	6	8.1	15.0	150.1	7.2	0.8
4/KT1/6	15	Eg	12	20	20.56	26.3	500.3	210.5	18.2	MFP/Bo46a	12	19.2	22.8	300.2	109.7	10.3
4/KT1/6	15	Eg	13	18	21.78	27.0	450.2	212.8	18.3	MFP/Bo46a	17	15.5	20.1	425.2	112.1	10.7
4/KT1/6	15	Eg	14	17	20.45	26.2	425.2	178.4	15.4	MFP/Bo46a	17	16.8	21.6	425.2	109.4	10.7
4/KT1/6	15	Eg	15	25	22.61	27.4	625.3	321.3	27.5	MFP/Bo46a	26	22.0	24.6	550.3	262.0	24.1
Sum of stratum 1				**328**	**318.54**	**398.3**	**8204.4**	**3918.8**	**336.2**		**222**	**263.1**	**327.4**	**5453.0**	**1685.6**	**159.9**
Stratum Mean				**21.9**	**21.24**	**26.6**	**547.0**	**261.3**	**22.4**		**14.8**	**17.5**	**21.8**	**363.5**	**112.4**	**10.7**

Appendix 9: Calendar for annual nursery operations–Sao Hill division 1 (Irundi) plantation

Month / Operations	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June
Soil ingredients collection	■	■	■									
Soil mixture preparation				■								
Procurement of nursery materials				■	■	■						
Nursery area cleaning							■	■	■	■	■	■
Seed bed or transplant bed preparation								■	■	■		
Seed sowing									■	■	■	
Pot filling									■	■	■	
Transplanting										■	■	
Beating up	■	■										■
Watering of seedlings	■	■	■	■	■	■				■	■	■
Weeding and general cleanliness										■	■	■
Top dressing	■	■	■									
Control of insects and other pest										■	■	■
Sorting /root pruning			■	■	■							
Hauling of seedlings for planting						■						

Appendix 10: Calendar for annual nursery operations–GRL Makungu forest nursery July – June 2012-2017

Activities	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Purchase of nursery material												
Nursery Preparations												
Clone cleaning and sorting												
Murram/sand collection												
Rice husks Carbonisation												
Trays washing/empting												
Sandbed construction												
Soil/Mycorrhizae/ingredient collection												
Cutting back& weeding mother trees												
Pot cutting & garden general cleaning												
Germinations and sowing												
Pricking out Pine & Eucs												
Outing trays and bird manning and stacking												
Trays /pots filling and feeding												
Sprout collection/ harvesting												
Clone planting and cutting preparation												
Substrate/Soil ingredient/cocopeat/ sieving and mixing												
Seed Sowing tray sorting												
Mycorrhizae sieving												
Growth/tending operations												
Clone/cuttings and seedling/garden watering												
Fertilizer application/Mycorhhizae appl/fungicide application												
Cuttings pruning/clipping												
Seedlings/pot weeding												
Seedlings/pot sorting (Live)												
Root pruning and seedbed watering												
Water pumping & seedling/pots grading (curls)												
Seedling/pots grading (dead)												
Seedlings transfer to field												
Seedlings/tray/material loading /offloading to field												
Seedling sold to external												

Appendix 11: Operation task per man day for Sao Hill forest plantation from 2012-2016

Activity description	Description of inputs	Measurement units	Annual target	Cost per unit	Unit Cost/Mdy	YR
Land preparation	CL	Ha	366.12	15mds/ha	5192.35	2012
Planting in new area		Ha	264.13	8mds/ha	5192.13	
Replanting		Ha	1335.52	12mds/ha	5192.35	
Beating up		Ha		6mds/ha		
Spot weeding		Ha	1335	10mds/ha		
Sanitary slashing		Ha	4342.86	12mds/ha		
Uprooting of weeds		Ha		10mds/ha		
Coppice reduction		Ha		15mds/ha		
Access pruning		Ha		12mds/ha		
High pruning		Ha		14mds/ha		
Singling		Ha		15mds/ha		
Rehabilitation of water courses		Ha	330	20mds/ha		
Plantation patrol		Mds	11856	Person		
Slashing of fire lines		Km		10mds/ha		
Screefing of fire lines (manual)		Km		10mds/ha		
Control burning		Km		10mds/ha		
Fire crew standby		Mds		Person		
Manning of control centre		Mds		Person		
Harvesting supervision		Ha	366.12	mdys		
Roadside slashing		Km		10mds/km		
Side drains opening		Km		6mds/km		
lnternal roads opening		km		10mds/km		
Bridges and culverts maintenance	bridges	unit		Days	500 000.00	
Culverts construction & mtce	culverts	unit		Days	250 000.00	
Road construction		km	108			

Appendix 12: Operation task per man day for GRL forest plantation from 2012 to 2016

OPERATION TASK	task	Unit of measurement	unit		costs/mdy
General cleanliness	2	man-day	day	2mdys/day	5686.5
Bush clearing	6	man-day	Ha	6mdys/ha	
Preplant burning	2	man-day	Ha	2mdys/ha	
Pre plant manual herbicide spraying	2	man-day	Ha	2mdys/ha	
Pre plant tractor herbicide spraying	7	Day	Ha	5ha/day	
Marking for pitting	2	man-day	Ha	2mdys/ha	
Manual Pitting	4	man-day	Ha	4mdys/ha	
Marking and pitting	6	man-day	Ha	6mdys/ha	
Mechanized Pitting	2	man-day	Ha	2mdys/ha	
Hydrogel/Aquasoil application	2	man-day	Ha	2mdys/ha	
Pesticide application	2	man-day	Ha	2mdys/ha	
New Planting	4	man-day	ha	4mdys/ha	
Re-Planting	4	man-day	ha	4mdys/ha	
Beating up/blanking	4	man-day	ha	4mdys/ha	
Fertilizer application	2	man-day	ha	2mdys/ha	
Spot weeding	7	man-day	ha	7mdys/ha	
Line weeding	9	man-day	ha	9mdys/ha	
Sanitary slashing	7	man-day	ha	7mdys/ha	
1st Pruning	6	man-day	ha	6mdys/ha	
2nd Pruning	9	man-day	ha	9mdys/ha	
1st thinning	10	man-day	ha	10mdys/ha	
2nd thinning	9	man-day	ha	9mdys/ha	
3rd thinning	12	man-day	ha	12mdys/ha	
Fire line slashing	8	man-day	km	8mdys/km	
Fire line screefing	12	man-day	km	12mdys/km	
Controlled burning of buffer zones/valley bottoms	4	man-day	ha	4mdys/ha	
Controlled burning of fire lines	6	man-day	km	6mdys/km	
Survival assessment	0.5	man-day	ha	0.5mdys/ha	
Invasive species control in OA	4	man-day	ha	4mdys/ha	
Bridge construction	40	man-day	bridge	40mdys/bridge	
Bridge repair	15	man-day	bridge	15mdys/bridge	
Coppice reduction	15	man-day	ha	15mdys/ha	
Area verification	1	man-day	ha	1mdy/ha	
Road miter drain opening	0.07	man-day	miter drain	0.07mdy/mitre	
New mitre drains opening	0.14	man-day		0.14mdy/mitre	
Harvesting extraction	25	man-day	logs	25logs/mdy	

TSP/full enumeration	0.5	man-day	plot	0.5mdys/plot	
PSP establishment	0.5	man-day	plot	0.5mdys/plot	
Invasive species control in compartments	4	man-day	ha	4mdys/ha	
Marking for thinning	2	man-day	ha	2mdys/ha	
Seedling distribution	2	man-day	ha	2mdys/ha	
Culvert installation	4	man-day	culvert	4mdys/culvert	
Road slashing	150	man-day	m	150m/mdy	
Road murraming	3	man-day	trip	3	