FACTORS AFFECTING PINE RESIN PRODUCTIVITY AND ITS POTENTIAL AS SOURCE OF REVENUE IN THE FOREST SECTOR OF TANZANIA: A CASE STUDY OF SAO HILL FOREST PLANTATION

BELEKO SALEHE SALIM

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ABSTRACT

Tanzania is rich in pine forests which have the potential to produce valuable resin. In recent years Tanzania has embarked on commercial resin tapping at Sao Hill Forest Plantation. However, current information on resin tapping in the country is scanty and unreliable. Knowledge of factors that affect resin productivity is important for it is those factors that can be manipulated to enhance resin yield. The focus of this study was to fill this knowledge gap by exploring some pine tree stands in terms of capacity to produce resin, factors that influence productivity, optimum age of commencing resin tapping and finally the potential revenue gain from tapped trees. Two-stage sampling was used to obtain estimates of tree characteristics and resin yield by first selecting seven representative compartments. In the second stage, 21 sample plots of dimensions 12 x 12 m were systematically established, 3 in each compartment. All trees in each plot were measured for diameter at breast height (dbh). In addition, total height, stem height and crown size of the smallest, medium and largest trees were measured. All trees in a plot were tapped for resin. Dilute sulphuric acid (40%) was sprayed to the wounded part of stem to stimulate and maintain resin flow. Recording of resin weight and re wounding of trees were done after a minimum period of every ten days in ten sessions from October 2018 to January 2019. Annual resin yield ranged from 0.56 kg/tree to 1.32 kg/tree for *P. elliottii* and from 0.47 kg/ tree to 1.98 kg/ tree for *P. patula*. Dbh and crown diameter were found to be important predictors of resin at tree level while yield per ha could well be predicted using stand variables in particular age, volume and basal area per ha. The recommended minimum dbh for resin tapping is 20 cm while 15 years could be used as minimum age to commence tapping. TZS 4 589 884 350 can be raised annually through resin tapping from 2 618 568 mature trees in state owned plantations. Results of this study will be useful to pine tree stakeholders in realizing income while waiting for the

conventional rotation age for timber harvesting. Further research on effect of resin tapping on tree growth and wood quality can be very useful to tree growers.

DECLARATION

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

Beleko Salehe Salim Date

(MSc. Candidate)

The above declaration is confirmed by;

Prof. R. E. Malimbwi Date

(Supervisor)

Dr. W. A. Mugasha Date

(Supervisor)

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DEDICATION

This work is dedicated to my lovely children Issa, Yusra and the yet to come, for whom I will always pray for their journey towards successful life.

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LIST OF ABBREVIATIONS AND SYMBOLS

cm	Centimetre
Compt	Compartment
Dbh	Diameter at breast height
DRM	Director of Resource Management
FAO	Food and Agriculture Organization of the United Nations
G	Basal area per hectare (m^2/ha)
GDP	Gross Domestic Product
GN	Government Notice
H_2SO_4	Sulphuric Acid
ha	Hectare
HCL	Hydrochloric Acid
Hdom	Dominant height (m)
HQ	Headquarter
kg	Kilograms
m	Metre
m^3	Cubic metre
MNRT	Ministry of Natural Resources and Tourism
N	Number of stems per hectare
NBS	National Bureau of Statistics
NWFPs	Non-Wood Forest Products
Pe	*Pinus elliottii*
Pp	*Pinus patula*
R^2	Coefficient of determination
SE	Standard Error
Sph	Stems per hectare
Spp	Species
TFS	Tanzania Forest Services
TEITI	Tanzania Extractive Industries Transparency Initiative
TZS	Tanzania Shillings
URT	United Republic of Tanzania
V	Volume per hectare

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

The role of forest sector of Tanzania is to provide forest products and services to the society, and the nation (URT, 1998). Indeed, much of the population, especially those living in rural areas, rely on forests for medicine, food, clean water, energy and other subsistence provisions (Gumbo *et al.,* 2018). The forest sector of Tanzania constitutes much potential including natural and plantation forests and its function is critical in production, conservation, protection, social, cultural, spiritual and other services (Kanowski, 1995; Indufor, 2013), the roles which are recognized by many societies even outside Tanzania.

Studies show dwindling forest resource base mainly due to over exploitation and conversion of forest land into other land uses (Ngaga, 2011; MNRT, 2015). The sector has in recent years resorted to adjust harvestable timber volume from her plantations to reach sustainable levels while providing time for the industry to adjust to the deficit (Ngaga, 2011). Repercussions due to this policy are many but apparent decline in revenue from logging business is comparatively predictable.

Forest plantations of Tanzania are stocked with both soft and hardwood tree species. MNRT (2015) estimated that the country has 554 500 ha of forest plantations planted with pines (*Pinus patula, P. elliottii* and *P. caribaea*), cypress, eucalyptus and teak. Pines are the dominant species in most plantations occupying about 78% of the total planted area and the remaining 22% is shared by hardwoods and other softwood species (Ngaga, 2011). The main use of industrial plantation species among others is to provide raw material to wood industries for pulp and timber production. Pine forests also serve as sinks of atmospheric carbon, contributing to greenhouse effect mitigation. They are important sources of numerous useful products, including non-wood products used by the chemical, food, and pharmaceutical industries, as well as for bio refineries (Rodrigues *et al.*, 2007). Pine resin is one of the valuable plant extracts which is popularly tapped from 12 different pine tree species around the world (Coppen and Hone, 1995). Resins are described in Ciesla (1998) as sticky, liquid, organic substances that harden upon exposure to air into brittle, amorphous solids.

Recently, Tanzania has embarked on pilot commercial resin tapping from pine trees at Sao Hill Forest Plantation (SHFP) in the Southern Highlands. Introduction of resin tapping in commercial plantations is an innovative venture that has direct bearing with improvement of sector's capacity to provide goods and services through revenue collection and provision of employment. It is a feasible means of increasing economic value of the existing forest stands. Since August, 2017 to date a total of 1 454 150 kg of resin worth TZS 1 287 169 945/= has been collected and exported to China for further processing (TFS, 2019).

Quantity and quality of resin are important aspects when selecting trees for commercial resin tapping (Makupa, 1995; Coppen, 1995). These are determined by a number of factors ranging from biological and environmental, to those induced by the tapper during resin extraction (Neels, 2000).

In Tanzania, current information on resin tapping, productivity and quality is scanty and unreliable. There are no data documenting which factors are most crucial for resin productivity (Makupa, 1995). Knowledge of the factors that influence resin productivity is important since it is the management of those factors that can lead to increase in resin yield in pine stands. Evidences exist in Australia and South Africa that biotic and abiotic factors that affect oleoresin production can be manipulated genetically or through management practices so as to improve both wood production as well as enhance resin yield from pine trees (Coppen and Hone, 1995; Rodrigues-Correa *et al*., 2013).

1.2 Problem statement and justification

1.2.1 Problem statement

Tanzania has huge forest plantation resources in which pine trees are the dominant commercial tree species (MNRT, 2015). The main use of industrial pine plantations has been to provide raw material to timber and pulp wood industries. For many years, valuable residues including pine resin have been left un consumed, costing the sector through the lost revenue.

In recent years, Tanzania through a foreign company has introduced resin tapping from pine trees at SHFP where *Pinus patula* is a dominant species. However, there is a missing current detailed analysis of factors affecting resin productivity and its potential as a source of revenue, which are important in understanding production patterns for sound forest management planning. Knowledge of the factors that influence resin productivity is important since it is the management of those factors that can lead to increase in resin yield in pine stands.

The need to undertake studies on resin tapping is emphasized by Makupa (1995) and Coppen (1995). Further, the government of Tanzania through the National Forest Policy (URT, 1998) insists on resource assessment of Non-Wood Forest Products (NWFP) and incorporation of the accumulated information in forest inventories and resource assessment programmes for a sound forest management planning (URT, 1998). This study intended to explore some factors affecting pine resin productivity and its potential as source of revenue in pine forest plantations.

1.2.2 Rationale and justification of the study

This study will uncover the way some factors affect resin productivity in a commercially tapped pine stand. The knowledge obtained will help the government, investors and individual tree growers to improvise forest management techniques that will increase marginal benefits from resin tapping activities. Further, knowledge will be developed that will trigger more research on resin tapping from *P. patula*, the species which is reportedly not used in viable commercial tapping anywhere in the world.

1.3 Objectives

1.3.1 Main objective

To understand the factors related to pine resin productivity and its potential to contribute to revenue base in the forest sector of Tanzania.

1.3.2 Specific objectives

i. To assess production capacity (yield per hectare) of pine resin;
ii. To assess tree level and stand level factors that influence pine resin yield;
iii. To establish optimum age of commencing sustainable resin tapping in the study area; and
iv. To evaluate the potential financial gain from pine resin tapping.

1.4 Research questions

i. Is there any difference in average resin yield between pine species grown in the study area?
ii. What is the contribution of tree and stand variables in explaining variations in resin yield from pine trees?
iii. At which age can initial resin tapping be viable in the study area?
iv. What are the revenue prospects from resin tapped in the Tanzania's pine plantations?

1.5 Limitations of the study

A number of limitations were encountered during the study. Time allocated for data collection was too short such that the effect of seasonal and weather variations was not captured satisfactorily. As a result, influence of weather on resin production was not included in analysis and discussion of this study.

Small budget allocated for the study constrained spatial and temporal coverage of important information. Data were therefore collected from only three divisions of SHFP namely Division One, Division Two and Division Three. Division Four which is located in lower altitude was dropped because it is isolated from other three Divisions and it is about 80 km far from Plantation headquarters (HQ), hence expensive to access.

Further, for some reasons it was difficult to get good pairs of *P. elliottii* stands with ages similar to the selected *P. patula* stands, except age 10, in distances accessible using the available resources. It was agreed to use the three compartments of *P. elliotii* stands available in Divisions One, Two and Three and compare their data with those of *P. patula* trees of closer age. The use of information contained in this dissertation should therefore be confined to scenarios with similar scope of coverage.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Contribution of forest sector to the National economy

Forestry has high potential for revenue generation, export earnings and employment if put under sound management. However, forest sector of Tanzania has been denounced for its comparatively low contribution to the national economy. A range of different figures exists depending on the way in which the sector is defined. Ministry of Natural Resources and Tourism for instance, defines the forest sector more broadly than the Ministry of Finance and therefore calculates forestry's contribution to GDP to be 20% while generally accepted rate in the National Accounts of Tanzania Mainland in which combined contribution of forestry and hunting to the GDP over the decade remained at a constant rate of 2.5 % (TEITI, 2014). Policy review by URT (1998) established a closely related rate of contribution to GDP of 2 -3%.

Recent report by National Bureau of Statistics (NBS) of Tanzania indicated that contribution of forestry to the GDP in 2017 was 4.0%, with other contributors in the same category being crops (17.0%), livestock (6.9) and fishing (2.2%). Contribution by the forest sector to the macro economy is through revenue collected from sale of logs, charcoal, wood, and other non-wood forest products such as honey and beeswax.

Enhancement of revenue collection in Tanzania has become the main agenda and the cash flow figures are an important yard stick to assess sectoral performance. Statistics show that most revenue in the forest sector of Tanzania come from logging activities. Study by Ngaga (2011) established that 92% of the revenue in the forest sector is collected from royalties of wood based products.

Forest plantations form an important element of forestry (Race and Curtis, 1996; Kanowski, 1996). In Tanzania, large-scale plantation forests of mainly exotic species that grow rapidly into wood of desired quality were established after many successful species and provenance trials (Chamshama and Nwonwu, 2004; Tiarks *et al*., 1998). Forest plantations have been managed essentially for lumber, pulp and transmission poles as priority products with economic value (Asiad, 2016) and their inception was a country's strategy to limit pressure on natural forests (Chamshama, 2001).

2.2 Non-wood forest products (NWFPs)

The term non-wood forest product embraces a wide range of plant and animal products that may be obtained from the flora and fauna growing or living in the forest (FAO, 1993 in Makupa, 1995). It distinguishes non-wood products or minor forest products from those such as timber and pulp in which the log of the felled tree is the primary product. Apart from timber, forests also provide other products and benefits such as food, medicine, handcraft materials, spices, wildlife, gums, latexes and resins.

Forest sector of Tanzania does not pay much attention on the NWFPs as far as revenue collection is concerned (TEITI, 2014). Yet, it has been established that NWFPs play a significant role at household level and on the economy of many countries (Nimkar *et al.*, 2017). Resin commercialization from hard wood tree species such as *Acacia*, *Boswellia* and *Commiphora* has been instrumental in rural livelihood improvement in Ethiopia and Sudan (Abtew *et al.*, 2014).

Several countries including Tanzania and Zambia have substantial areas of pine but their suitability and capacity to support gum naval stores production has not yet been proved (Coppen and Hone, 1995). Experience from forest plantations in Tanzania shows large number of pine trees being felled annually for lumber and pulp. Those trees contain enormous amount of valuable resin that is not put into commercial use, costing the country through the lost revenue.

2.3 Principal sources and supply of pine resin

The words "gum" "resin" and "latex" have been used interchangeably to refer to plant exudates in general. Rubber, chicle, gum Arabic, damar, copal and naval stores, are examples of products that have been exploited and traded in the past, and continue in commerce today (Coppen and Hone, 1995). The distinct differences in these materials are presented in Table 1. Oleoresin is the conventional name given to resins from pine trees which contain large quantities of oil, such as the oleoresins of the naval store industry, the source of rosin and turpentine. Rosin is a brittle, transparent, glossy, faintly - aromatic solid used to produce adhesives, paper sizing agents, printing inks and detergents, while turpentine is a clear liquid with a pungent odour and bitter taste which is used as the raw material for varnishes, perfumes, disinfectants, solvents, cleaning agents, and others (Coppen, 1995; Wang *et al.*, 2006; Roger *et al.*, 2017).

Table 1: Brief overview of some exudates that are harvested for industrial and other uses

Exudate group	**Latex**	**GUM**		**Resin**	
Properties			**Hard resins**	**Soft resins**	**Fluid resins**
	Milky white fluid; elastic, water repellent, electrical resistance	Soluble in water to varying degrees, insoluble in organic solvents.	Insoluble in water, soluble in organic solvents	Insoluble in water, soluble in organic solvents	Properties of hard and soft resins, but contains high percentage of oil
Sub-Group			Copal, Damar	Elemi	Oleoresin, balsam

Source: Coppen, 1995 and Howes, 1949 in Neels, 2000.

Most pine species yield resin of some sort upon tapping. Table 2 presents a list of world's famous tapped tree species and countries where tapping is being done as presented in Coppen and Hone (1995) and Coppen (1995).

Table 2: List of world's tapped pine tree specie

S. No	Species	Country
1	*Pinus ellliottii*	USA, Brazil, South Africa, Zimbabwe, Kenya
2	*Pinus pinaster*	Portugal
3	*Pinus massoniana*	China
4	*Pinus merkusii*	Indonesia, Thailand
5	*Pinus caribaea*	South Africa, Kenya
6	*Pinus roxburghii*	India, Pakistan, Nepal
7	*Pinus oocarpa*	Mexico, Honduras
8	*Pinus sylvestris*	Russia
9	*Pinus radiata*	Kenya
10	*Pinus helepensis*	Greece
11	*Pinus brutia*	Turkey
12	*Pinus kesiya*	China

Source: Coppen and Hone, 1995.

Studies indicate shortage of resin in many parts of the world. It is estimated that the People's Republic of China dominates production and world trade of pine resin by almost one third (Xu and Liu, 1992; Coppen and Hone, 1995). The shortage of resin is due to a number of factors including depletion of natural pine forests especially in the far east due to over exploitation (Shi and Li, 1998; Wang *et al.*, 2006), the rise of labour and power costs in Europe, wide occurrence of forest fires, which affected particularly the age structure of pine stands, and the lack of technological innovation in pine tapping operations (Amelia *et al.,* 2012). Scholars recommend investment in resin timber plantations in Africa and Latin America due to the presence of large number of cheap surplus labour and conducive growing conditions for resin producing softwood trees (Bin and Xing, 1992; Wang *et al.*, 2006).

2.3 Optimum age of commencing resin tapping

Resin production is a result of biological processes of photosynthesis and metabolite production that take place in the leaves of resin producing trees (Ella and Tongacan, 1992, cited by Neels, 2000). It is essentially a defense response of a tree where the preformed oleoresin and resin duct systems are part of the initial defenses encountered by bark beetles and other herbivores (Langenheim 1990, and Trapp and Croteu, 2007, cited by Rodrigues *et al.*, 2007).

Continuous production of extra metabolites for resin which is tapped for commercial uses is done at a cost because they could otherwise be used to support growth of healthy plants, and further, tapped trees are stressed, leading to reduced vigour in growth and other related effects. Some studies showed that tapping Masson pine (*Pinus massoniana*) trees had a negative impact on radial growth while other researchers found that tapping slash pine (*Pinus elliottii Engelm*) in south China resulted in reductions in tree diameters and stocking volume (Roger *et al.*, 2017).

The sustainability of resin tapping activities relies on the interventions that will maintain resin production and individual tree health, both of which work towards the production of acceptable levels of resin yield for economic gain. With respect to resin production, most research works have concentrated on increasing or improving yields, with little emphasis on developing long-term sustained production methods (Neels, 2000). From this perspective, however, declining yields would indicate non-sustainable harvesting methods, and it is necessary to device mechanisms for adjustment, accordingly.

Sustainable resin tapping requires a number of controls that will limit exploitation including setting up of thresholds indicating minimum age, tree size and the amount of resin extracted from trees over a given period of time. This may however cause a tradeoff between the amount of resin that can be tapped profitably and the amount allowed without compromising normal tree growth. Important aspects in the sustainability of resin tapping is the question of minimum tapping age and diameter, which must be established for each species, below which high tree mortality would outweigh potential resin yield and the amount to be extracted (Rodrigues *et al.*, 2007). Although dbh can be used to reflect age, it is not a complete substitute due to its high sensitivity to competition. Nevertheless, most countries use different minimum dbh as criterion for safe resin taping.

In China, tapping of trees for resin begins when their dbh reaches 20 cm (Rodrigues *et al.,* 2007). Lohani, (1970), cited by Neels (2000) reported the standard minimum tapping diameter of 30 cm for Chir pine (*Pinus roxburgii*) in India that could be lowered only as far as 25 cm because the mortality of tapped trees between 15 and 25 cm dbh averaged 29.3% over three years of tapping compared to the 1.1% mortality over the same period for trees with dbh greater than 25 cm. In Nepal, resin tapping is allowed in trees that are above 30 cm in diameter at breast height (Bharat, 2014). In other countries, the limit is 20–25cm (Coppen and Hone, 1995; Wang *et al.*, 2006). Selection of groups of trees for tapping will be made on the basis of utilizing the oldest or largest trees available of the preferred species. Coppen & Hone (1995) reported that plantation pines are usually at least 15-20 years old before resin tapping commences.

Resin tapping in Tanzania is at its infancy and therefore there is no on site research backing to guide most operations related to secure and sustainable resin production including the age to commence resin tapping. However, the available information in the scientific body of knowledge could be used as a stepping stone to a better tapping practice while the countries' research base is being developed.

2.5 Resin tapping techniques

Resin tapping involves causing physical injury to the cambium layer and sap wood of the tree by making a blaze with a hook knife and collect the exuded resin using a plastic resin bag or metal pot (Coppen, 1995). Various methods of tapping have been adopted by different countries in accordance with development of technology, availability of labour and tapping trees (Alejandro, 2012). Each of the three leading countries in crude resin production, that is China, Brazil and Indonesia, has adopted a different resin tapping technique, as described in Alejandro (2012) as follows;

Chinese method

The resin tapping technique that involves wood chipping where downward-pointing V-shaped groove is cut every day, deep enough to reach the secondary xylem as shown in Plate 1. The first groove is cut about 1.2 m above the ground, and subsequent grooves are cut below it. The groove reaches roughly half way around tree's circumference. No chemical stimulant is used. This method is used mainly in China.

Plate 1: Wood chipping: A Chinese resin tapping technique.

Source: Source: Alejandro (2012).

American method

The technique used is bark chipping as shown in Plate 2, where a horizontal streak or groove is cut to remove the bark and the phloem every 15 to 18 days. The first streak is cut 20 cm above the ground and the subsequent streaks are cut upward. A stimulant such as Dilute Sulphuric acid is applied to enhance production of resin. This method is mainly used in Brazil, Argentina, Portugal and Spain.

Plate 2**: Bark chipping: An American resin tapping technique**
Source: Source: Alejandro (2012)

Rill method

A wood chipping method shown in Plate 3 is used where V shaped streaks, 2 to 3 mm wide are cut upwards every 3 to 7 days to remove bark, phloem and the first ring of wood in the xylem. Each streak is separated from the other by a thin space of un removed bark. A stimulant is applied in a form of a spray. This method is mainly used in Indonesia and India.

Plate 3: Rill method: Indonesian resin tapping technique;
Source: Alejandro (2012)

Adoption of a tapping technique will depend on several issues including efficiency in production (Table 3), country policy including environmental policy and resin tapping procedures set by the plantation owner. A poor tapping technique results in the rapid exhaustion of the forest resource.

Table 3: Yield and technical characteristics of the tapping operations

Location	**China**	**Brazil**	**Indonesia**
Tapping technique	Chinese	American	Mazek (Rill)
Faces tapped per tree	1	2	2
Pine resin (kg/year)	2.00	3.00	2.25
Streak frequency (days)	1 or 2	15	3
Stimulation	No	H_2SO_4	H_2SO_4 + HCL
Season	5/6 months	9 months	12 months
Yield per time (g/day)	11.2	19.7	5.8
Yield per area of streak (kg/m2)	25	40	0.7
Streak depth	Xylem	Cambium	Xylem

Source: Alejandro (2012)

A tapping technique can also be termed as light and continuous tapping or heavy tapping (GRTI, 2007) depending on the intensity of tapping and a tapping technique employed. For instance, in countries like Nepal light and continuous tapping is done in all trees above 9 cm in dbh. Trees with 9 to 18 cm in dbh are tapped in one channel and above 18 cm dbh in two channels for five years. And at the end of five years, a new channel is tapped leaving 10 cm space from old channels. On the other hand, heavy tapping or tapping to death is common in developed countries. Under this category, maximum possible quantity of resin is exuded by making many possible channels at 10 cm space. It is generally initiated five years in advance of rotation age when trees are due for clear felling.

2.6 Resin tapping process

Resin is obtained from the tree in a manner analogous to rubber tapping except that the exudate is more viscous and slow-running than rubber latex (Coppen and Hane, 1995). Tapping generally involves the following basic steps:

- Preparation of the face of the tree;
- Installation of the resin collection system;
- Wounding of the tree to induce resin flow;
- Application of a chemical formulation to stimulate and maintain resin flow (optional); and
- Collection of the resin, re-wounding of the tree, and application of the stimulant at suitable intervals.

In some countries, less efficient traditional methods of tapping are used which do not entail application of a chemical stimulant. The precise manner in which the above steps are carried out in the various producer countries has developed in different ways over the course of many years. Nevertheless, it is generally recognized that tapping should be carried out carefully and in such a way as to avoid permanent damage to the tree

(Bharat, 2014). The damage is unnecessary because in most resin-producing tree species resin canals are found in the bark in equal or greater numbers than in the sapwood (Bhatt *et al.*, 1989; Ella and Tongacan, 1992, Tsoumis, 1992).

Tapping remains essentially a manual operation whatever system is used, and although attempts have been made, notably in the United States, to introduce mechanization for some of the tasks, particularly those which are physically demanding such as the initial shaving of the tree and the removal of bark, they have been met with little success (Alejandro, 2012). The tools, materials and accessories required for resin tapping are relatively few and simple and they include the following list as obtained from ATY (T) International Company Ltd of Mafinga, Iringa, on personal request:

1. Bark shaving tool or guap knife
2. Cup or other form of receiver
3. Guttering
4. Nails to support cup and/or to fix guttering
5. Hammer
6. Bark hack
7. File or whetting stone (for sharpening bark hack)
8. Sulphuric acid-based stimulant (liquid or paste)
9. Bottle (plastic, for application of acid)
10. Bucket (into which resin from cup is emptied)
11. Funnel (for transfer of resin from bucket to drum)
12. Drum or barrel
13. Protective clothing and accessories (for tapper, including visor or goggles, acid proof Gloves, plastic apron or other garment, and rubber boots).

2.7 Effect of resin tapping on tree growth and timber quality

Studies show that traditional methods of tapping which involve some removal of wood from the tree may not be damaging to its survival. The risk of damage and suffocation, however, is undoubtedly heightened if wood is removed too deeply from the tree, or over too wide an area (Coppen, 1995).

Other studies indicate that the right tapping methods used at low intensity do not adversely affect the quality of the trunk wood, such that the plantation pines can be felled and utilized in the normal manner without sacrificing the desired timber benefits when tapping is stopped (Coppen and Hone, 1995). However, Coppen (1995) reported some loss of volume increment during the period of tapping especially when tapping entails removal of barks and use of chemical stimulants. But this is more than compensated for by the revenue earned from resin production. However, Dhananjaya (2008) reported great fear amongst societies and politicians in Nepal of possible deterioration of timber quality in tapped trees.

2.8 Resin quality and yield characteristics

In spite of the fact that all pines are capable of producing resin, the quality and quantity of both rosin and turpentine can be strongly determined by genetic traits, intrinsic of each species (Makupa, 1995; Rodrigues-Correa *et al.*, 2013). Tapping operation can therefore be economic if the quantity obtained is sufficient and its quality acceptable to processing industries (Coppen, 1995).

Coppen and Hone (1995) reported that suitable species grown under favourable conditions can yield 3-4 kg of resin per tree annually. However, *P. elliottii* has been recorded to have the highest annual yield of 4-6kg while *P. sylvestris* and *P. Siberica*, have the lowest record of 1-1.5 kg (Coppen, 1995). In Nepal, the yield of pine resin is reported to be around 3-5 kg per tree per year (GRTI, 2007). Dhananjaya (2008) reported that a chir pine trees in Nepal yields approximately 4.5 kg of resin annually. Spanosa *et al.* (2010) reported a maximum resin production of 5.9 kg/tree/year and the minimum of 2.3 kg/tree /year in pine trees in Greece.

P. patula, although widely planted as an exotic species in Africa and elsewhere, does not give good yields of resin and the quality of the turpentine and rosin is rather poor (Rodrigues-Correa *et al*., 2013). As a consequence, it is not used in viable commercial tapping anywhere in the world (Coppen, 1995; Rodrigues- Correa *et al.,* 2013). In Thailand, where natural stands of both *P. merkusii* and *P. kesiya* exist, only the former is tapped; yields of resin from *P. kesiya* are too low to put it under commercial production (Coppen, 1995).

In commercial tapping, minimum acceptable resin yield is around 2 kg/tree (Coppen, 1995). It is therefore unlikely that yields much below 2 kg could support a viable resin tapping operation. Additionally, productivity can be increased by excluding less productive tree classes through enumeration prior to extensive tapping (Papajiannopoulos, 1997; Papajiannopoulos, 2002; Spanos *et al.,* 2002).

2.9 Factors that affect resin yield

Extensive research has been conducted globally to determine variables that influence resin production in the commercially tapped tree species. Two kinds of variables that affect resin yield are identified: those concerning the characteristics of the trees and the surrounding environment, termed as biological and environmental variables, and those induced on trees by the harvester, also termed as imposed variables (Lombardero *et al*., 2000; Neels, 2000; Aguiar *et al.,* 2012).

2.9.1 Biological and environmental factors

Some of the tree characteristics and environmental factors that have been investigated for their influence on resin yield have been categorized into tree species, tree morphology and locality and climatic factors as discussed below:

2.9.1.1 Tree species

Resin yield varies within a species and between species due to the inherent capacity of an individual tree to produce resin (Rodrigues-Correa *et al*., 2013). Seed origin and tree genetic component allow two trees of approximately the same size, in similar physical condition and located in the same site to have completely different resin yields (Gonzales *et al.,* 1986). Tree species such as *Pinus roxburghii*, *P. elliottii*, *P. mercusii*, *P. caribaea* and *P. massoniana* give better yield than *Pinus patula* and *P. kesiya* (Coppen and Hone, 1995).

2.9.1.2 Tree morphology

Trees with large stem diameter, large crown diameter, large crown height and twist are likely to produce more resin (Rodrigues *et al.*, 2007). Studies on the relationship between dbh and resin yield have generally concluded that larger diameter trees give higher resin yields (Chaudhari *et al.,* 1992; Ella and Tongacan 1987, Gonzales *et al.,* 1986). In some studies, however, yields were found to be lower for some of the trees in the larger dbh classes than for trees in the smaller dbh classes (Chaudhari *et al.,* 1992, Gonzales *et al.*, 1986, Orallo and Veracion 1984). Orallo and Veracion (1984) speculated that it could be the advanced age of large trees that made them less productive, while Gonzales *et al.* (1986) suggested that smaller diameter trees might be physiologically more active than larger trees.

Crown size has been shown to have significant effects on resin yield. Similar to the relationships seen with dbh, higher crown ratio resulted in higher yields as reported in a study conducted by Schopmeyer and Larson (1955), cited by Neels (2000) and Rodrigues, (2007). Ella and Tongacan (1992) and Papajiannopoulos, (2002) further submit that crown density is important because the processes of photosynthesis and metabolite production take place in the leaves, and that when more metabolites are produced, more are available for resin production. In general, the greater the diameter of the tree tapped and the bigger the proportion of live crown, the greater the resin yields (Coppen and Hone, 1995).

2.9.1.3 Locality and climatic factors

Site characteristics including stand density, soil conditions of drainage, moisture, and air temperature, humidity and rainfall have influence on resin yield (Ella and Tongacan, 1992). Areas with warm climate are conducive to good resin flow while areas with cool climate and those with prolonged periods of high rainfall are not (Coppen and Hone, 1995).

2.9.2 Induced factors

Induced factors refer to how yield is affected by different tapping techniques or by using various chemical stimulants. Many experiments generally showed that more intense tapping techniques give higher resin yields. Intense tapping may refer to wide blazes or high wood surface area exposure, high concentration of chemicals (Rodrigues-Corr^ea and Fett-Neto, 2012) and high frequency of re - wounding (Neels, 2000). Most studies show higher yield responses with the application of chemicals such as dilute Sulphuric acid (20 – 40 %), in comparison to tapping without chemical application (Coppen and Hone, 1995).

2.10 Benefits of resin tapping

2.10.1 Employment

Naval stores operation is an industry based on renewable natural resources that has several attractions for a developing country with suitable pine resources. The tapping operations are labour intensive and can therefore offer employment opportunities to people in rural areas (Coppen and Hone, 1995; Perez *et al.*, 2013; Bharat, 2014) through resin tapping and associated activities such as site preparation, blazing, and marking of trees to be tapped, marking of seed trees which must be left untapped, resin collection from trees and transportation (Dhananjaya, 2008).

2.10.2 Source of revenue

Royalty charged on tapped resin, business licenses, export and other fees generally collected from the business make good revenue source for governments and private tree growers. In countries where most resin produced is for export, the product becomes a good contributor of foreign currency (Coppen and Hone, 1995; Bharat, 2014). Resin tapping activities provide incentives to small scale tree farmers for them to stop cutting immature trees for subsistence reasons (Dhananjaya, 2008; Subedi, 2010 cited by Bharat, 2014).

2.10.3 Handing over of technology

Provision of employment to women and members of local households in resin collection schemes and employment of local supervisors are common practices in resin collection. Skills development training provided before the resin collection helps to transfer the new technology and innovation to local people of rural areas (Bharat, 2014).

2.10.4 Reduction in forest crime

Activities associated with resin tapping require very close supervision. As the tapping companies carry out resin collection they also provide regular supervision of works which controls activities like illegal logging and wild fires (Kelkar *et al.*, 2005; Amelia *et al.*, 2012). In some areas tapping companies participate in plantation hygiene activities such as sanitary slashing (Personal observation at SHFP).

2.10.5 Raw material for other industries

Rosin and turpentine which are primary products of resin are important raw materials for the manufacture of many industrial products such as paper, rubber, paints, perfumes and many other mainstream derivatives for domestic and industrial consumption (Coppen and Hone, 1995; Roger *et al.*, 2017).

2.10.6 Enhancement of per unit land productivity

The qualities of the land may change substantially depending on what can additionally be grown or extracted from it. In contrast to the traditional forest function of timber production, introduction of activities such as resin tapping in a pine stand may provide synergies and improvement for integration of multiple forest function (Kindler, 2015 cited by Mayer and Schulz, 2017). Introduction of multiple production of wood, pulp and resin on the same piece of land is likely to increase value of a forest land (Wang *et al.*, 2006).

2.10.7 Enhancement of business and other economic activities

Resin tapping can influence money circulation in rural areas where forest activities are mostly found. Activities and income of labourers and other employees lead to establishment of businesses like shops, restaurants, transport and even security services in rural areas (Coppen and Hone, 1995; Bharat, 2014).

2.11 Challenges facing resin tapping

The challenges have been categorized into three aspects namely environmental, technical, and socio-economic issues as discussed in the following subsections:

2.11.1 Environmental issues

i. High concentration of acid mixture applied as stimulant

Acid mixtures such as Dilute Sulphuric acid (40%) and Dilute Nitric acid (20%) which are applied to trees as a stimulant to form rill for resin tapping may negatively affect growth and development of tapped pine trees if the mixtures are concentrated more than the permitted levels. Majority of resin tapping people are relatively poor, so they may spray heavily with the hope of more resin extraction and hence making more money. Acid mixtures flow from trees during rainfall and cause severe effects to soil as well as growing vegetation (Dhananjaya, 2008).

ii. Dying pine trees

A poor tapping technique results in the rapid exhaustion of the forest resource, and if it is applied to natural growing forests with poorly trained labour force, the operation is unsustainable (Alejandro, 2012). Some studies revealed death of pine trees from which resin is extracted, although the death was also associated with extraction of diyalo as torch light from heartwood of the resin extracted trees or even natural death of trees (Dhananjaya, 2008).

iii. Fire control

Fire that occurs in a tapped stand causes damage to vegetation, wild life and resin itself (Dhananjaya, 2008). If the timber stand suffers defoliation and severe stem burn, it is likely that resin production may be discontinued. Fire-injured trees yield little resin and are highly susceptible to attacks by bark beetles (Harrington, 1966). This occurs mostly when resin tapping companies, range posts and communities are not paying much attention on fire prevention and controls. Resins are fire hazard due to combustible compounds they contain.

iv. Mother trees

In some countries resin collection procedures require that mother trees up to 5 trees per ha are selected and given identity as a seed source. There is a notion that tapped trees produce seeds and timber of poor quality (Dhananjaya, 2008).

2.11.2 Technical issues

i. Selection of trees to be tapped

Monitoring by forest officers in tapped stands more often observed that some under sized pine trees are also tapped which is against resin tapping procedures (Rodrigues *et al.*, 2007; Bharat, 2014; Coppen and Hone, 1995 and Wang *et al.*, 2006). Generally, young and small diameter trees have low capacity to produce surplus resin therefore subjecting them to tapping may cause stress and impair normal tree growth (Cheng, 1997, cited by Wang *et al.*, 2006).

ii. Control of heavy tapping and leakage

Forest officers are needed to control heavy tapping which is the cause for stress on tapped trees. This is done by making proper instructions to tapping companies so that they make rill size, and angle, groove etc., as per resin collection procedures. They are also advised to arrange necessary training to labour and manpower and to do regular supervision so as to improve technical aspects of rill making and collection in time to avoid spilling on the ground which may become fire hazard (Dhananjaya, 2008).

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iii. Low quality timber from tapped trees

It is suspected that resin tapped trees yield low quality timber, although a thorough study in this aspect is lacking (Dhananjaya, 2008).

2.11.3 Socio – economic issues

i. Low wage for labour

In many cases wage rate for labour on resin collection activities such as coup formation, clearing grounds, tree marking, rill making, resin tapping and transportation to depots is very low leading to poor living standard of resin tappers (Dhananjaya, 2008).

ii. Investment on social sector development

Resin tapping is mostly done in rural areas where infrastructures for social services are underdeveloped. Civil societies and people demand that resin companies should expend some percentage of benefit for social sector development at local level like construction of hospitals, schools, bridges and so on (Dhananjaya, 2008).

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Description of the study area

This study was conducted at Sao Hill Forest Plantation (SHFP) which is located between latitude 8°18’ and 8°33’ South and longitude 35°6’ and 35°20’ East. The area is elevated to 1 700 – 2 000 meters above sea level. The SHFP is a state owned plantation with its larger part falling in Mufindi District in Iringa region in the southern highlands of Tanzania, and a small portion is found in Kilombero District, in Morogoro region.

The area receives rainfall between 600 and 1 300 mm annually (Mgeni, 1986). Temperatures are fairly cool, reaching close to freezing point between June and August. The mean monthly minima and maxima temperatures are 10ºC and 23ºC respectively. Soils are relatively homogenous and are mainly dystricnitosols (Ngegba, 1998). SHFP is the largest of all forest plantations in the country, having planted area of about 59 520 ha out of total gazetted area of 135 903 ha (SHFP, 2018). For managerial convenience, SHFP is divided into four divisions each headed by a divisional manager who reports to the Plantation Manager.

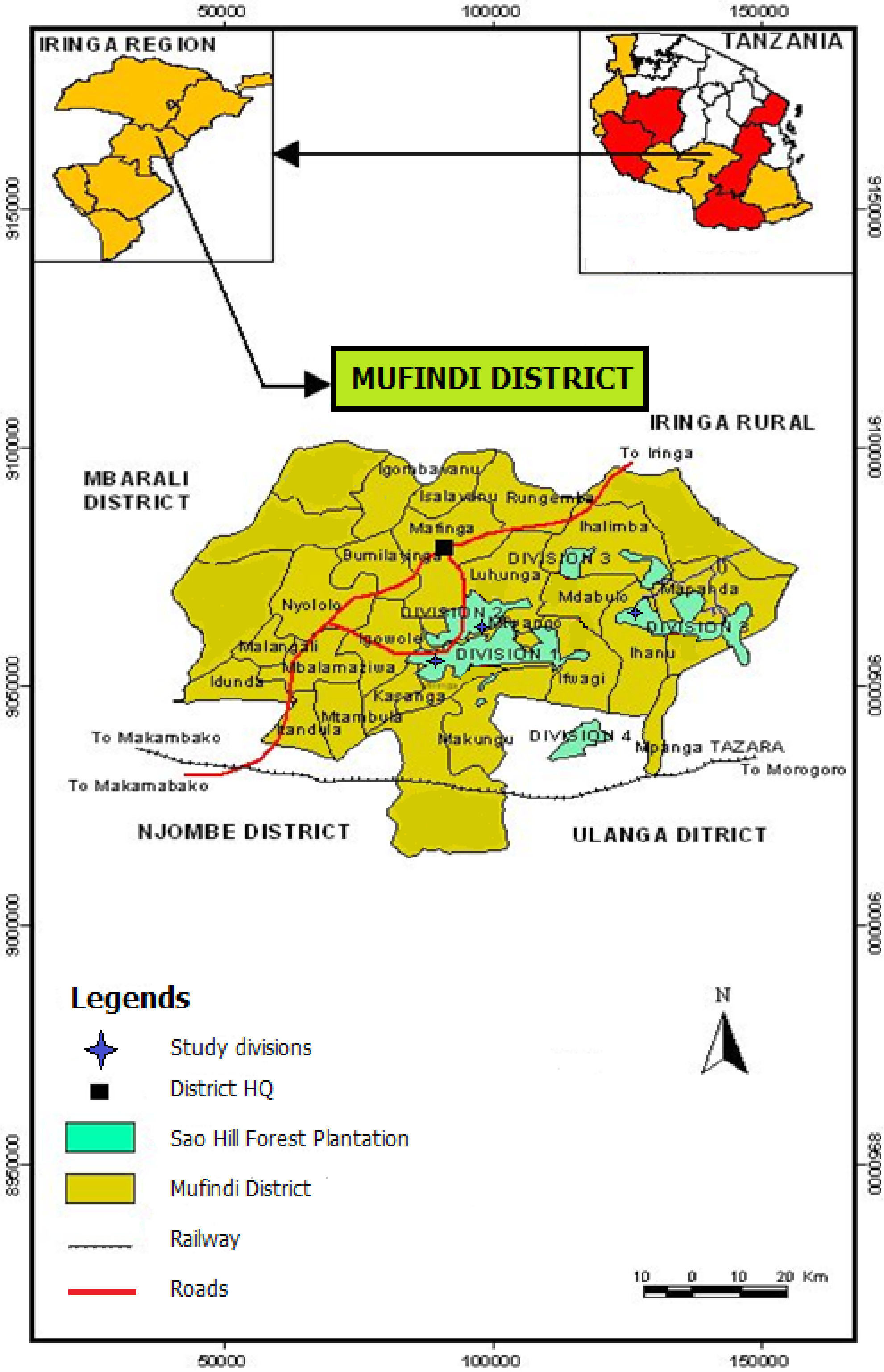

Figure 1: Map of location of study area in Mufindi district showing study sites: Division 1, 2 and 3 of Sao Hill Forest Plantation.

3.2 Study design

Both primary and secondary sources of data were used in this study. The primary data on resin yield and tree growth were collected through sampling while standing tree and resin prices and taxes were obtained from Government gazette and reports. The secondary data on plantation condition, harvesting plans and number of tappable pine trees were obtained from management plans, annual reports and other non-published documents in government files including safari reports and gazetted technical material and manuals.

3.3 Sampling design

The SHFP was purposely selected as a study site because of its size, being the largest forest plantation with pine trees, supplying over 80% of raw material consumed by forest industries in Tanzania. For the purpose of this study, divisions, ranges and compartments with tree species and age of choice were selected purposively. Pine species included in this study are *Pinus patula* which is the most predominant species at SHFP and many other plantations in Tanzania, and *Pinus elliottii* which is one of the most preferred species in resin production although they occupy small area in most plantations in the country, including the study area.

Two-stage sampling technique commonly used to obtain estimates of tree characteristics for large forests composed of many stands in a relatively short time frame or with minimal expense (Shiver and Borders, 1996) was employed. The first stage was selection of representative compartments in terms of age and species. Stands of age difference of 5 years; 5 years, 10 years, 15 years and 20 years were desired for the species under study. However, current plantation composition could not give the desired age classes for *P. elliottii,* hence three available ages in particular 10 years, 12 years and 25 years were purposively selected.

The second stage was installation of sample plots of dimensions 12 x 12 m which were systematically selected as the second sampling units. At a spacing of 3 x 3 m this should form a plot of 4 x 4 trees = 16 trees for the younger age, un thinned plots. For older plots where thinning has taken place, the remaining trees coincide with that stipulated in technical order No.1 of 2003 (Appendix 4). Each plot is surrounded by several rows of trees to control edge effect on the measured trees. The first resin plot was established at least 50 m from the compartment border and subsequent plots located 50 m apart. Three plots were randomly established for each age class each with its control plot of similar size which were not tapped. This sampling strategy has considered the homogeneity of plantation as well as time and fund availability. Seven compartments were conveniently selected (Appendix 1) based on availability of stands with desired species and easy of accessibility using the available resources. These included four compartments of *Pinus patula* with ages 5 years, 10 years, 15 years and 20 years and three compartments of *Pinus elliottii* aged 10 years, 12 years and 25 years, hence all plots together become 7 x 3 = 21. Identification tags were prepared and tied up to trees at all four angles of each plot. To easy tree identification process and for monitoring purposes, each individual tree was given a number written on the trunk and on the aluminum plate.

Measurements

Tree parameters were captured using standard tree measurement principles presented in Malimbwi (1997). The following parameters were measured and recorded during the study:

i. Diameter at breast height (dbh)

All trees within a plot were measured for diameter at breast height (dbh) which is the average stem diameters, outside bark at a point 1.3 m above ground, usually measured from the uphill side of the stem. The measurement was taken using a graduated aluminum caliper.

ii. Tree height (ht)

Three trees, i.e. small, medium and the largest were identified within a plot and their heights measured using Suunto Hypsometer. Distance equivalent to average tree height was used as a rule of thumb in choosing the readings in the hypsometer.

iii. Stem height (sh)

This is height (m) of a tree to the first live branches measured using Suunto hypsometer.

iv. Crown height (Crh)

This is the difference between tree height and stem height obtaining by subtracting.

v. Crown diameter (Crd).

Average diameter of a tree crown was obtained by measuring from the ground, the widest point and the narrowest point of the crown using a tape measure. The obtained values were added together and divided by two.

vi. Resin yield

Tapping intensity of at most 50 % was used bearing in mind that tapping is done on stands destined for timber and pulpwood production, and not for oleoresin production. The common tapping procedure as described by Coppen and Hone, (1995) and Spanos *et al*. (2010), was followed. The major steps include:

1. Preparation/shaving of the tapping face of the tree;

2. Guttering of the tree to induce resin flow;

3. Installation of the resin collection system; and

4. Collection of the resin and re-wounding of the trees.

Dilute Sulphuric acid (40%) was used to stimulate and maintain resin flow for a longer period (Coppen and Hone, 1995). This was purposely done to avoid shorter wounding frequencies which are tedious and costly especially when time and other resources are scarce.

With the exception of *P. elliottii* which has limited dominance in SHFP, selection of tree ages for data collection was in line with local management planning cycle and also based on literatures that resin tapping normally takes place in pines with dbh from 20 cm and above and that most preferred age for resin tapping ranges from 15 to 20 years. It is assumed that trees with dbh of 20 cm will be obtained from ages between 5 and 25 years.

The weight (in grams) of resin collected each time from candidate trees was recorded using a data sheet (Appendix 3). There were ten collection sessions and material from different plots and species were stored separately. Re-wounding and resin collection was carried out every 10 days throughout the experiment period except the last session in which resin collection was prolonged to three weeks to honour the request of research assistants who wanted to join their families in end of the year festivals. Data on the 10-day average temperature and rainfall corresponding to each resin collection period were obtained from local meteorological station.

3.4 Data analysis

Quantitative methods of data analysis were employed. Yield data were analysed using descriptive statistics such as means where charts, frequency tables and graphs were used to present the results. Significance of selected set of factors was analysed using simple and multiple regression methods. Data on stocking, age, dbh, basal area, tree height, tree volume, crown size and resin weight were summarized in order to estimate various plot and stand variables including:

i. Stems per hectare (SPH).

The average number of stems per hectare was obtained by counting the number of trees in 3 representative plots of area size 0.0144 m^2 then a formula by Malimbwi (1997), was employed;

$$N = 1/m \Sigma \frac{n_i}{a_i} \quad \text{……… Equation 1}$$

Where: N = Number of stems per hectare;

m = number of sample plots;

n_i = number of trees per plot and

a_i = plot area

ii. Basal area per hectare (G)

Basal area per hectare which is sum per hectare cross sectional areas of all trees estimated at breast height was determined using the following formulas by Malimbwi (1997);

$g_{ij} = \pi d^2_{ij}/4$

$Gi = \Sigma(g_{ij}/a_i)$

$G = \Sigma (G_i/ n)$ ……… Equation 2

Where: d_{ij} = dbh of the j^{th} tree in the i^{th} plot, (cm)

g_{ij} = cross sectional area of tree d_{ij}, m^2

a_i = area in hectares of plot i, ha

G_i = basal area of plot i, m^2/ha

n = number of sample plots

G = average basal area per ha of the stand, m^2/ha

iii. Tree height (Ht)

Height of trees that were measured for dbh alone was estimated using height equation by Malimbwi et al., (2016).

$$Ht ¿ 1.3+\frac{dbh^2}{13.63898+0.026482*dbh^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots$$

Equation 3

Where: Ht = estimated tree height (m)

dbh = Measured diameter at breast height (cm)

iv. Stand volume (m^3)

Stand volume (V) was estimated using single tree volume model for SHFP developed by Malimbwi *et al.* (2016).

Vol = exp (-9.04925 + 1.14781* ln (Ht) + 1.5496 * ln dbh………………Equation 4

Where: vol = tree volume (m^3)

Height = tree height (m)

Dbh = tree diameter measured at breast height (cm)

Volume of each tree in a plot was first divided by plot size and then by number of plots to obtain tree volume per hectare per plot which was then summed up to get volume per hectare.

v. Crown size

-Average crown diameter was obtained by calculating average of wider and shorter diameter of crown base.

-Crown height (m) was obtained by subtracting tree trunk from tree height.

vi. Resin yield (kg/ha)

The average weight of resin per tree for each age class for 102 days of the study period was obtained by first determining mean resin weight per each plot through descriptive statistics at 95.0% confidence level. The calculated mean was multiplied by number of stems per hectare to get the average resin yield per hectare. The per hectare yield figures were verified using the following formula:

$$Y = 1/n \sum \frac{y_i}{a_i} \quad \text{.. Equation 5}$$

Where Y = Yield per hectare;

n = number of sample plots

y_i = yield per plot and

a_i = plot area

In order to obtain annual yield, number of tappable days per year were assumed to be 365 as opposed to 224 days adopted by Makupa (1995). Pilot tapping at Sao Hill has been done uninterrupted for two successive years without significant decline in flow rate during cold months (Edson, M. ATY Co Ltd. Personal communication, 2019).

vii. Optimum age for commencing resin tapping

Data sets for two dbh levels of 20 cm and 30 cm which were used as a decision criteria for determination of minimum tapping age in this study. In each criterion trees were grouped into two dbh classes, < 30 cm, ≥ 30 cm and < 20 cm, ≥ 20 cm for the first and the second criterion, respectively. Tree count of each of the two dbh classes was calculated and percentage number of trees falling under upper class was established. Selection of minimum age of resin tapping was done on the assumption that the age with higher

(≥ 50 %) proportion of upper dbh class could be considered optimum for commencing resin tapping.

viii. Significance of factors affecting resin yield

Regression analysis was employed in comparing treatments where descriptive statistics such as frequencies, percentages and average were generated. The test included the significance variation of resin production with selected set of variables at tree level (dbh, tree height, dominant height and crown diameter) and stand variables at plot level (basal area per ha, timber volume per ha, stocking, age and average height).

ix. Potential financial gain from pine resin tapping in forest plantations in Tanzania

Average annual resin yield (kg/per) tree of mature *P. patula* from the study area was used to estimate minimum yield that can be collected in other plantations under assumption that those plantations are basically located in climatic regions which are more or less warmer than SHFP where this study was conducted. The expected total resin production from the established number of mature trees (Table 16) was then multiplied by unit price of TZS 885 (VAT inclusive) derived from government tariff with GN No. 255 of 2017.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Overview

In this chapter, research findings are discussed in line with the study objectives and questions formulated in chapter one. The main purpose is to provide information on the supplementary capacity of pine plantations to contribute in the development of forest sector in the country as well as in livelihood of forest dependent community through tapping and trade of oleoresin. The chapter is organized in four parts; 1. Resin resource yield assessment; 2. Factors that influence resin yield; 3. Optimum age for commencing resin taping, and 4. Potential financial gain from pine resin tapping in forest plantations in Tanzania.

4.2 Resin resource yield assessment

4.2.1 Resin yield

Resin flow time series are presented in Figure 2 and Figure 3. These figures indicate variations in resin yield from session to session over the study period. *P. elliottii* showed modest resin flow at the onset of tapping followed by a pronounced increase in yield in the second up to the forth sessions. Resin flow continued in trivial fluctuations until the 9th session which experienced a sharp drop to the 10th session due to a prolonged tapping because of end of the year holidays. The cause of yield fluctuations from session to session and yield drop on 10th session could not be established because it was not part of the study although it is suspected to be due to delay in cause and effect relation of resin formation due to re wounding and evaporation of water from resin in the resin bag due to prolonged exposure to dry weather, respectively.

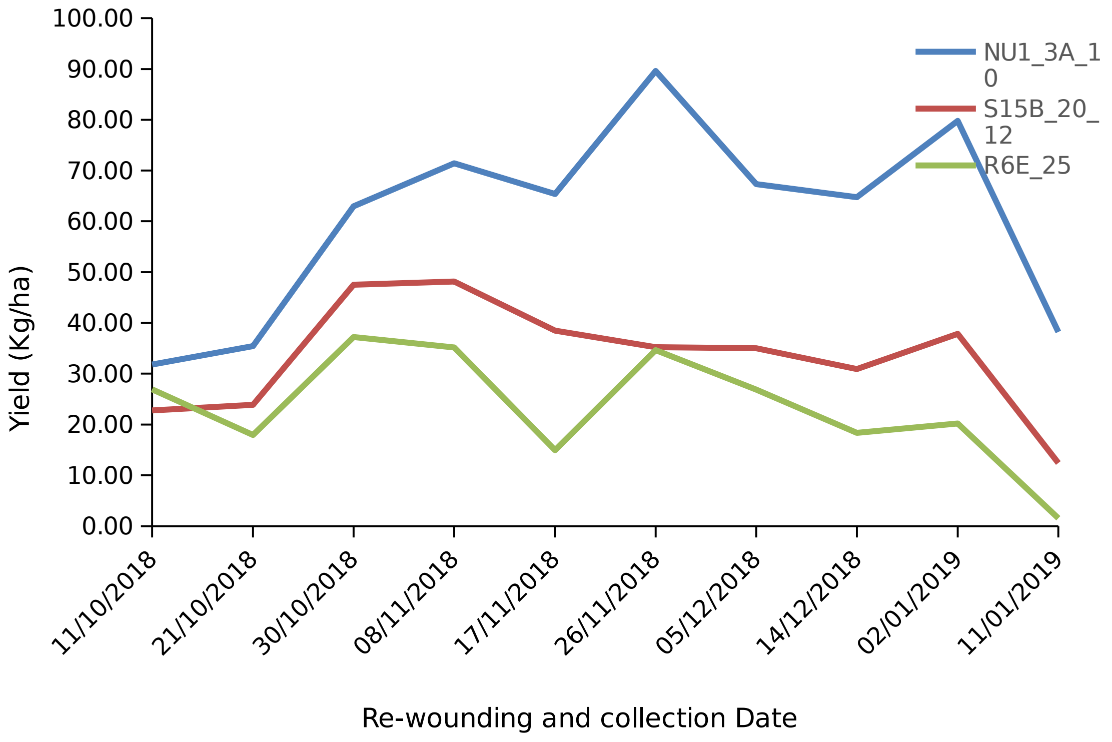

Figure 2: Temporal variation of resin flow in *P. elliottii* during 102 days of study period.

P. patula on the other hand, commenced with sharp decrease in yield from first to the second session which was followed by increase in resin flow close to initial readings in all four age groups. The flow fluctuated constantly up to the 7th session which was followed by general decrease in flow in the last three sessions.

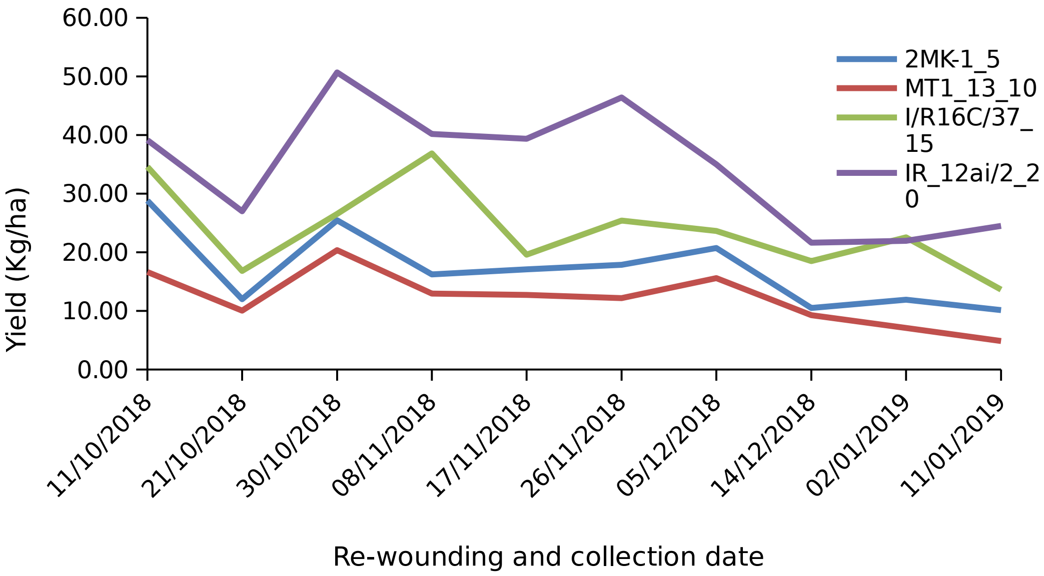

Figure 3: Temporal variation of resin flow in *P. patula* during the 102 days of study period.

The results also indicated differences in yield within and between species and between age classes. Projecting production on yearly basis, the average production per tree in a 10 years *P. elliottii* stand located at Nundwe in Division 3 was estimated to be 1.32 kg of resin per annum which is a bit higher than 1.19 kg per annum produced by another tree from a stand of the same species aged 12 years located at Sao Hill in Division 2, as shown in Table 4.

Table 4: Resin yield for *P. elliottii*

Compt.	Age (years)	Yield per tree (kg) for 102 days	Confidence limit at 95%	Annual yield (kg/tree)	Stocking (Stems/ha)	Annual Yield (kg/ha)
NU1_3A	10	0.37	0.05	1.32	1 644	2 170.08
S15B_20	12	0.33	0.06	1.19	996	1 185.24
R6E	25	0.15	0.02	0.56	1 505	842.80

A 10 years old *P. patula* tree in compartment MT_13 located at Matanana in Division 2 on average produced 0.47 kg annually which was similar to the average resin yield by a 5 years tree of the same species in compartment 2MK-1 located at Makalala in Division 2, as shown in Table 5.

Table 5: Resin yield for P. patula

Compt.	Age (years)	Yield per tree in 102 days (kg)	Confidence Limit at 95%	Annual yield (kg/tree)	Stocking (stems/ha)	Annual yield (kg/ha)
2MK-1	5	0.13	0.02	0.47	1 366	642.02
MT1_13	10	0.13	0.03	0.47	926	435.22
I/R16C/37	15	0.34	0.07	1.23	695	854.85
IR_12ai/2	20	0.55	0.11	1.98	625	1 237.50

Results suggest a significant variation in resin yield between species where the magnitude of per hectare resin yield was generally higher in *P. elliottii* when compared to that of *P. patula*. This is demonstrated by yield values presented in Table 4 and Table 5 above where annual production of one hectare of 10 years and 12 years of *P. elliottii* stands was estimated to be 2 170.08 kg and 1 185.24 kg, respectively, while annual resin production of one hectare of *P. patula* stands at age 10 years and age 15 years was estimated to reach 435.22 kg and 854.85 kg respectively, which is comparatively low. However, a plot of resin yield (kg/ha) against age (years) for *P. elliottii* shows general decrease of resin production with increase in age as shown in Figure 4.

Figure 4: Resin yield variation with age in *P. elliottii* for 102 tapping days

On the other hand, *P. patula* demonstrated a different pattern where resin yield generally increased with age as presented in Figure 5. The conflicting results in yield pattern between species signifies existence and role of multiple factors which might have an influence on the way resin yield in different tree species responded to variations as well as interaction of those factors.

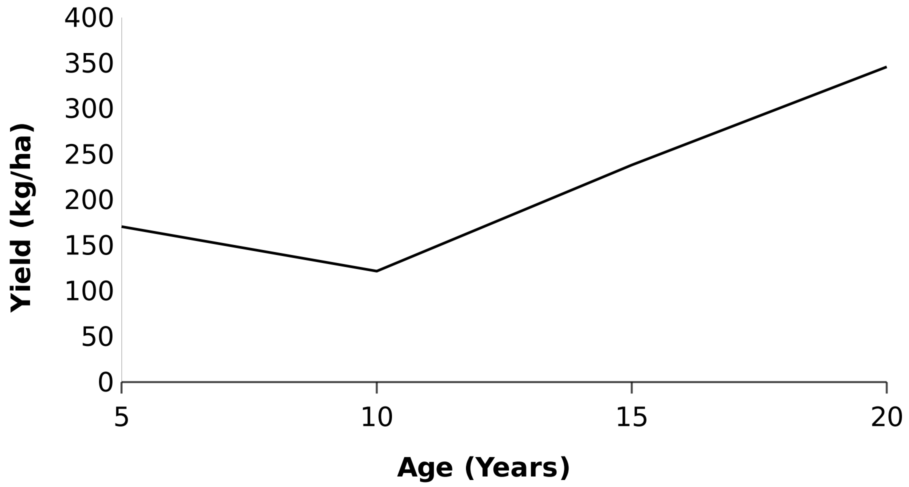

Figure 5: Resin yield variation with age in *P. patula* for 102 tapping days

It was beyond the scope of this study to establish exact reason for the antagonistic yield trend with regard to age of the two species but a complex play of various factors is suspected to cause this variation since stands from which data were collected are not homogeneous and they grow in different conditions and locations.

Nonetheless, results from this study indicated that both *P. elliotii* and *P. patula* grown at SHFP have the potential to produce resin. The average yield per year ranged from 0.56 kg/tree to 1.32 kg/tree for *P. elliottii* and from 0.47 kg/tree to 1.98 kg/tree for *P. patula*, as summarized in Table 3 and Table 4. Assuming a tapping season of 365 days, descriptive statistics of plot level yield data at 95% confidence level indicated that annual resin yield would scale up to 1.47 kg/tree for *P. elliottii* from 10 years stand and up to 2.39 kg/tree for *P. patula* from 20 years stand, as shown in Table 6.

Table 6: Maximum annual resin yield per tree for P. elliottii and P. patula

Compt. name	Spp	Age (Years)	Mean yield per tree for 102 days (kg)	Upper Confidence Level (95%)	Max yield per tree for 102 days (kg)	max annual yield/tree (kg)
1/R16c/37	Pp	15	0.34	0.07	0.41	1.47
IR_12ai/2	Pp	20	0.55	0.12	0.67	2.39
MT1_13	Pp	10	0.13	0.03	0.16	0.57
2MK_1	Pp	5	0.13	0.02	0.15	0.54
RE6	Pe	25	0.15	0.02	0.17	0.61
S15B_20	Pe	12	0.33	0.06	0.39	1.40
NU1_3A	Pe	10	0.37	0.04	0.41	1.47

Resin yields from the study area are slightly lower than those reported in the literature. The study by Coppen & Hone (1995) concluded that species grown under favourable conditions can yield 3-4 kg of resin per tree annually, with *P. elliottii* having the highest yield of 4-6 kg. Makupa (1995) reported average annual resin yield of 2.1 kg and 1.8 kg/tree for *P. elliottii* and *P. patula,* respectively.

4.2.2 Characterization of the forest stands

The analyzed data shows variations in stand characteristics which are important in the interpretation of the study results. Technical order No.1 of 2003 sets standards for forest stand establishment and management where initial spacing for conifers is 2.44 x 2.44 m and 3.0 x 3.0 m for trees planted before and after year 2003, respectively. Trees are subjected to thinning at ages 10, 14 and 18 years for those planted before 2003 and at ages 10 and 15 years for trees planted after year 2003. Results presented in Table 7 indicated deviations from scheduled stocking levels where trees in all the studied compartments exceeded the required number of stems per hectare.

Table 7: Stocking level (Sph) in the study area

Compt. name	Spp.	Age (Years)	Scheduled stock (Sph)	Actual stock (Sph)	Over (+) or Under (-) stocked
2MK_1	Pp	5	1111	1 366	+255
MT1-13	Pp	10	650	926	+276
1/R16c/37	Pp	15	400	695	+295
IR_12ai/2	Pp	20	490	625	+135
NU1_3A	Pe	10	650	1 644	+994
S15B_20	Pe	12	650	996	+346
6RE	Pe	25	490	1505	+1015

Overstocking was reported by MNRT (2016) which established that most compartments in 15 studied plantations, including SHFP where this study was conducted, were overstocked. Deviations from scheduled stocking level due to failure to follow standard silvicultural practices, in particular those stipulated in Technical Order Number 1 of 2003, or for any other reasons may result into stands with trees distributed into small dimensions and closed canopies which have effect on the tree physiological functions associated with resin formation. For instance, stand history showed that compartment R6E was established through natural regeneration and it only received one light singling treatment but denied of scheduled thinning and pruning which are standard treatments for a healthy crop for better stems. As a result, this compartment is characterized with high tree density, small diameter stems, closed canopy with bigger portion of dead branches and needles.

These stand characteristics could have contributed to low resin yield as inferred in this study. The aforementioned features are said to hinder resin yield as illustrated in Zanski, (1970), Moulalis (1981), Philippou (1986) and Papajiannopoulos (1997; 2002). A review on resin features in radiata pine by Cown *et al.* (2014) presented evidence that silvicultural treatment, particularly thinning, is likely to increase the incidence of resin formation. Studies by McConchie, (1997, 2003) about trees, logs and sawn timber in spacing trials revealed that the incidence of resin formation increases when stocking rates are lower. Coppen and Hone (1995) established that the greater the diameter of the tree tapped and the bigger the proportion of open live crown, the higher the resin yields.

A number of studies by Veracion (1984), Low and Abdul Razak (1985), Orallo and Gonzales *et al.* (1986), Ella and Tongacan (1987), Halimahton and Morris (1989), Chaudhari *et al.* (1992) and Coppen and Hone (1995) that attempted to determine the relationship between a number of factors including dbh and resin yield generally concluded that suitable species grown under favorable conditions of site and forest management could result into larger diameter trees with large crown size which give higher yields of resin.

4.3 Factors that influence resin yield

4.3.1 Influence of different factors at tree level

a) *Pinus elliottii*

Coefficients of equations relating resin productivity and tree diameter, tree height, dominant height and crown diameter in *P. elliottii* are presented in Table 8.

Table 8: Regression coefficients of tree variables with resin yield in *P. elliottii*

Compartment	**Equation**	**R^2**	**SE**	**P value**
S15B_20	y = 0.0224 Dbh - 0.0665	0.36	0.15	< 0.0001
	Y = 0.1516 CrD - 0.0649	0.55	0.19	0.04
	Y = 0.0353 Ht + 0.0158	0.23	0.25	0.23
	Y = 0.1058 HDom - 1.1593	0.83	0.17	0.27
R6E	Y = 0.0077 Dbh - 0.0190	0.21	0.08	<0.0001
	Y = 0.0092 Ht - 0.0327	0.45	0.05	0.02
	Y = 0.006 Hdom+ 0.0567	0.05	0.08	0.06
	Y = 0.0345 CrD + 0.0143	0.46	0.05	0.02
NU1_3A	Y = 0.0246 Dbh - 0.0159	0.28	0.16	<0.0001
	Y = 0.9052 - 0.0289 HDom	0.96	0.06	0.13
	Y = 0.3242 - 0.0001 Ht	0.0000023	0.22	0.99
	Y = 0.1172 CrD + 0.0624	0.15	0.20	0.30

Diameter at breast height (dbh)

Coefficients of determination (R^2) were found to be relatively low in most compartments, meaning that contribution of tree diameter in explaining variations in resin productivity per tree was 36% in compartment S15B_20, 21% in R6E and 28% and 28% in NU1_3A, while other random factors contribute to the remaining variations. However, the variation in resin yield explained by tree diameter is highly significant in all three compartments of *P. elliottii* as shown by the *p*-value of the slope (P = <0.05).

Tree height

Similarly, the contribution of height in explaining resin yield variations in *P.elliotii* was generally low in all studied compartments. The coefficients of determination (R^2) for each compartment were found to be 23%, 45% and 0.00023% for S15B_20, R6E and NU1_3a, respectively. Influence of height in resin production was found to be significant (*p*-value of the slope = <0.05) in compartment R6E, but not significant (*p*-value of the slope = >0.05) in compartment S15B_20 and NU1_20.

Dominant height (Hdom)

Coefficients of determination (R^2) for dominant height were found to be high in compartments S15B_20 and NU1_3A, meaning that contribution of Hdom in explaining resin yield variability are 83% and 96% for the two compartments, respectively. However, P values indicate that the influence of Hdom on resin yield is not significant (P = > 0.05)

Crown diameter (CrD)

Results indicated small coefficients of determination (R^2) in all three compartments meaning that Crown diameter has low contribution in explaining yield in these stands. However, influence of crown diameter in resin yield was highly significant in compartments S15B_20 (P = 0.04) and R6E (p = 0.02). Crown diameter appeared to influence resin productivity in compartment NU1_3A although the contribution was statistically insignificant (p = 0.3).

b) *Pinus patula*

Coefficients of equations relating resin productivity and tree diameter, tree height, dominant height and crown diameter in *P. patula* are presented in Table 9.

Table 9: Regression coefficients of tree variables with resin yield in *P. patula*

Compartment	Equation	R^2	SE	P value
MT1_13	Y = 0.0126Dbh - 0.0496	0.46	0.06	< 0.0001
	Y = 0.0349Ht - 0.2326	0.48	0.09	0.05
	Y = 0.0477 Hdom - 0.4037	0.90	0.06	0.21
	Y = 0.0295 CrD + 0.0741	0.15	0.11	0.35
IR_12ai-2	Y = 0.0280 Dbh - 0.1939	0.43	0.22	<0.0001
	Y = 0.1171 CrD - 0.1811	0.84	0.09	0.0005
	Y = 0,03835 Ht - 0.4003	0.51	0.16	0.029
	Y = 0.0165 HDom + 0.1356	0.25	0.08	0.67
IR16C_37	Y = 0.0269 Dbh - 0.2621	0.42	0.14	< 0.0001
	Y = 0.043 Ht - 0.497	0.10	0.24	0.41
	Y = 0.1098 HDom - 1.8795	0.51	0.18	0.49
	Y = 0.0652 CrD + 0.1021	0.12	0.24	0.36
2MK-1	Y = 0.0097 Dbh - 0.0185	0.21	0.06	0.0003
	Y = 0.039 Ht - 0.3091	0.48	0.06	0.038
	Y = 0.2015 HDom - 0.1115	0.77	0.08	0.77
	Y = 0.044 CrD - 0.002	0.30	0.07	0.12

Diameter at breast height (dbh)

Results show that influence of dbh on resin yield per tree in all studied compartments was highly significant. This is shown by the variations (P value < 0.05) presented in Table 8. With the exception of observation in compartment 2MK-1, coefficients of determination (R^2) generally show good contribution of dbh in explaining resin yield from pine trees in these compartments.

Tree height

Height was found to be significant in influencing resin productivity in some *P.patula* stands in the studied area. Resin productivity variations explained by height is statistically significant in compartments MT1_13 (P = 0.05), IR_12ai2 (p = 0.03) and 2MK-1 (P = 0.04). Height was also found to influence resin yield in compartment IR16C_37 although the influence was too low to be statistically significant (P = 0.4). It was observed that the studied compartments had good coefficients of determination (R^2) except compartment IR16C_37 having small coefficient (R^2 = 10%) which tells nothing than low contribution of height in explaining resin yield variability in the studied stand.

Dominant height (Hdom)

Results generally show good coefficients of determination (R^2) in most compartments indicating fairly high contribution of dominant height and hence site in explaining resin yield variability in trees in the studied *P. patula* stands. In most compartments, P values were found to be larger than 0.05 meaning that the influence of dominant height is statistically insignificant in those stands.

Crown diameter (CrD)

Influence of crown diameter in resin production in the studied *P.patula* stands was found to be insignificant (P > 0.05) in all studied compartments except IR_12ai-2 with P value = 0.001. Contribution of crown diameter in explaining yield variations was very high in compartment IR_12a 2 ($R^{2\,=}$ 84%), while the contribution was small in all other compartments.

4.3.2 Influence of different factors at stand level

a) *P. elliotii*

Coefficients of equations relating resin productivity with a set of stand variables in *P. elliottii* are presented in Table 10. Results of regression between resin yield with individual stand variables indicated generally low coefficients of determination (R^2), meaning that only a small proportion of resin yield per ha in a *P. elliottii* stand is correctly explained by a particular stand factor. For instance, contribution of age in explaining resin yield in *P. elliottii* stand is 55%. The remaining proportion is explained by other random variables.

Table 10: Regression of individual stand variables with resin yield in *P. elliottii* stands

Stand variables	Equation	R^2	StE	RMSE	P value
Age (Years)	Y = 227.6667 - 6.2140*Age	0.55	42.1690	37.1896	0.02
Stems per ha	Y = 0.2091*N + 34.0607	0.22	61.4169	49.1094	0.20
basal area /ha G	Y = 186.8142 - 4.0829*G	0.17	57.3674	50.5933	0.28
Volume (m^3/ha)	Y = 184.06 - 0.3710*V	0.25	54.7658	48.2989	0.18
Height (m)	Y = 193.1565 - 4.3051*Ht	0.05	61.4169	54.1646	0.56

When all the selected stand variables were regressed with resin yield from a *P. elliottii* stand (Table 11), the multiple regression equation was obtained:

Y = 138.7491 + 10.2157*Ht + 0.1374N + 1.7561V - 16.2335 Age -15. 9622G..Equation 6

Where Y = resin yield; Ht = tree height; N stems per ha; V = timber volume per ha;

G = basal area per ha.

Table 11: Multiple regression of stand variables with resin yield in *P. elliottii* stands

	Coefficients	Standard Error	t Stat	P-value
Intercept	138.7490617	49.08591561	2.826657301	0.07
Age	-16.23351348	3.443261726	-4.714574368	0.02
Height (m)	10.21568692	3.998457313	2.554907086	0.08
SPH	0.137379992	0.223580778	0.614453502	0.58
G	-15.96223436	35.25015443	-0.452827 36	0.68
V	1.756122285	2.491989971	0.704706803	0.53

Only age was found to influence resin yield significantly (P = 0.02) as shown in Table 11. Multiple regression seemed to improve coefficient of determination (R^2) to 98% (Appendix 5), meaning that 98% of variability in resin production in *P. elliottii* stand is collectively explained by the selected stand level factors. The remaining proportion is explained by other random factors not considered in this study.

b) *P. patula*

Coefficients of equations relating resin productivity with a set of variables in *P. patula* stands are presented in Table 12. Results show that age, basal area per ha, stand volume and height have significant influence (P < 0.05) on resin yield in *P. patula*. Coefficient of determination (R^2) values indicate that the contribution of individual stand variables in explaining variability in resin yield in the studied *P. patula* stands ranged from fairly high to very high.

Table 12: Regression of individual stand variables with resin yield in *P. patula* stands

Stand variables	**Equation**	**R^2**	**StE**	**RMSE**	**P value**
Age	Y = 19.5062 + 4.2824*Age	0.68	18.1571	16.5751	0.001
Sph	Y = 121.0876 - 0.1597*N	0.31	26.5172	24.2067	0.06
G	Y = -17.7266 + 10.2249*G	0.92	8.9576	8.1772	< 0.0001
V	Y = 8.7196 + 0.6888*V	0.97	5.9358	5.4187	< 0.0001
Ht	Y = 5.6616*Ht - 12.36	0.82	13.6134	12.4272	0.0001

Results from multiple regression of the stand variables with resin yield (Table 13) indicated high coefficient of determination (R^2 = 97%), meaning that 97% of the variations in resin yield is collectively explained by the stand variables while the remaining proportion is explained by other random factors. The following multiple regression equation was obtained:

Y = 2.1350*Age + 0.2331*Ht + 0.0757*N + 0.7460*G + 0.4865*V - 31. 9824………. Equation 7

Where Ht = height; N = number of stems per ha; G –basal area per ha; V = volume per ha.

Table 13: Multiple regression of stand variables with resin yield in P. patula stands.

	Coefficients	Standard Error	t Stat	P-value
Intercept	-31.98239956	37.46112555	-0.853749029	0.43
Age	2.135016012	1.601187821	1.333395111	0.23
Height (m)	0.233076187	1.658498122	0.14053449	0.89
N	0.075663787	0.088586549	0.85412275	0.42
G	0.746010844	10.65720595	0.070000603	0.95
V	0.486477942	0.849608905	0.572590446	0.58

Literature review has revealed many studies that investigated the effect of various factors on resin yield and the hypothetical influence of those factors is well documented. Results from this study indicated that the factors that most significantly influenced resin yield are similar to those in previous research works but differs in the magnitude of influence depending on the biological and environmental conditions of the researched trees or forest stand. Of all variables assessed at SHFP at tree level, dbh was found to be a good predictor of resin yield, followed by crown diameter. Although used a different methodology where a tree was a sampling unit, Makupa (1995) in his study to examine factors affecting resin yield came up with almost similar observation. Chaudhari *et al.* (1992), Ella and Tongacan (1987), Gonzales *et al.* (1986), Halimahton and Morris (1989) and Orallo and Veracion (1984) in their studies that determined the relationship between dbh and resin yield established that larger diameter trees give higher yields of resin. Some cases were observed in this study that trees in larger dbh classes had lower resin yields than trees in the smaller dbh classes. Orallo and Veracion (1984) had the same observation and they speculated that it may be the advanced age of large trees that made them less productive, while Gonzales *et al.* (1986) suggested that smaller diameter trees might be physiologically more active than larger trees. According to Schopmeyer and Larson (1955), Harrington (1969), Coppen and Honne (1995), influence of crown size on resin yield lies on the fact that large, healthy crowns are associated with increased bio synthetic capacity to produce the metabolites which are the precursors of resin. Other studies by Papajiannopoulos (2002), Spanos (2010) suggested that photosynthetic and other physiological processes affect resin accumulation.

Tree spacing plays an important role in tree growth (Zobel *et al.*, 1987; Evans, 1992), cited by Chamshama (2011), leading to increment in tree girth, height and crown size, the factors that play an important role in resin production. Yield per ha therefore can well be predicted using stand variables in particular age, height, basal area per ha. This means that for better resin yield, intra and inter tree relationships controlled by the current management regime targeted to improve stand wood volume for timber production are very important.

4.4 Optimum age for commencing resin tapping

Results presented in Table 14 indicate that only two compartments, IR_12ai/2 and R6E, have trees with dbh that exceeds 30 cm. However, none of these compartments have proportion of trees with dbh ≥ 30 cm that equals or exceeds 50%, disqualifying this criterion based on the set assumption.

Table 14: Proportion of trees with dbh ≥ 30 cm in the study area

Compartment Name	Age	Species Name	Tree counts (dbh<30 cm)	Tree counts (dbh≥30 cm)	Total	% trees (dbh ≥ 30cm)	SPH
2MK-1	5	*P. patula*	59		59	-	1366
I/R16C/37	15	*P. patula*	30		30	-	694
IR_12ai/2	20	*P. patula*	18	9	27	33.33	625
MT1_13	10	*P. patula*	40		40	-	926
NU1_3A	10	*P. elliottii*	71		71	-	1644
R6E	25	*P. elliottii*	61	4	65	6.15	1505
S15B_20	12	*P. elliottii*	43		43	-	995

Basing on the second criterion where 20 cm is assumed the minimum dbh for commencing resin tapping, three compartments namely I/R16C/37 of *P. patula* aged 15 years, IR_12ai/2 of *P. patula* aged 20 years and R6E of *P. elliottii* aged 25 years were found to have above 50% proportion of trees with dbh ≥ 20 cm, as shown in Table 15.

Table 15: Proportion of trees with dbh ≥ 20 cm in the study area

Compartment Name	Age	Species Name	Tree count (dbh<20 cm)	Tree count (dbh≥20 cm)	Total	% trees (dbh≥ 20 cm)	Sph
2MK-1	5	*P. patula*	56	3	59	5.08	1366
MT1_13	10	*P. patula*	35	5	40	12.50	926
I/R16C/37	15	*P. patula*	9	21	30	70.00	694
IR_12ai/2	20	*P. patula*	4	23	27	85.19	625
NU1_3A	10	*P. elliottii*	57	14	71	19.72	1644
S15B_20	12	*P. elliottii*	33	10	43	23.26	995
R6E	25	*P. elliottii*	18	47	65	72.31	1505

This suggests that if ≥ 20 cm is taken as the minimum tapping tree diameter, tapping licenses would be issued for compartments having 15 years and above. Stands with age bellow 15 years have very small proportion of trees with dbh ≥ 20 cm such that they cannot be subjected to resin tapping basing on the set criterion. They have trees which are not mature enough to withstand stress due to resin tapping and the proportion of trees with preferred dbh is too small for commercial tapping. The minimum age obtained in this study agrees with the minimum age reported in Coppen and Hone (1995), Wang *et al.*

(2006) and Rodrigues (2007) where it is stated that plantation pines are usually at least 15-20 years old before tapping commences, and some countries have regulations which limit tapping to trees with diameters greater than 20-25 cm Coppen and Hone (1995).

4.5 Potential financial gain from pine resin tapping in forest plantations in Tanzania

Geographically, most pine plantations in the country are located in more or less similar ecological zones, and the use of one Technical Order in all state-owned pine forests subjects all stands to similar treatment. It is therefore unlikely for productivity in other plantations to differ significantly from what has been established in the study area. This assumption can literally be used in the projection of the sector's potential to produce oleoresin and associated revenue from its pine plantations.

Tanzania Forest Services (TFS) Agency owns a bigger share of tappable mature pines in the forest sector of Tanzania. However, it was learnt during the study that the government is doing a pilot study on resin tapping which is restricted to overdue trees that are already incorporated into the timber and pulp harvesting plans. Since the establishment objective of the current crop in pine plantations is production of timber for lumber and pulp, inclusion of trees that have not attained rotation age in resin tapping activities was prohibited due to fear of the unknown effect of resin tapping on the growing stock in terms of tree growth and wood quality.

The recent survey and inventory done by TFS (2018) estimated that in the next three years a total of 2 618 568 pine trees in 11 government plantations will be due for clear felling. A bigger contribution comes from SHFP where this study was conducted. The allowable cut for each government plantation with mature pine trees for the coming three years is presented in Table 16.

Table 16: Projected resin yield and potential financial gain from resin tapping in 11 Government pine plantations for the period 2019/2020-2021/2022

No.	Region	Spp	Plantation	Total number of trees	Projected resin yield (kg)	Unit price with 20% VAT (TZS/kg)	Potential revenue (TZS)
1	Iringa	*P. patula*	SHFP	1 725 648	3 417 801	885.00	3 024 753 885
2	Kilimanjaro	*P. patula*	N. Kilimanjaro	134 680	266 746	885.00	236 070 210
3	Kilimanjaro	*P. patula*	W. Kilimanjaro	117 800	233 314	885.00	206 482 890
4	Arusha	*P. patula*	Meru	128 600	254 704	885.00	225 413 040
5	Tanga	*P. patula*	Shume	112 040	221 905	885.00	196 385 925
6	Mwanza	*P. tecunumanii*	Rubya	102 280	202 575	885.00	179 278 875
7	Mwanza	*P. caribaea*	Buhindi	77 520	153 535	885.00	135 878 475
8	Kagera	*P. caribaea*	Rubare	16 680	33 036	885.00	29 236 860
9	Mbeya	*P. patula*	Kawetire	28 360	56 170	885.00	49 710 450
10	Mbeya	*P. patula*	Kiwira	107 000	211 923	885.00	187 551 855
11	Morogoro	*P. patula*	Ukaguru	67 960	134 601	885.00	119 121 885
	Total			**2 618 568**	**5 186 310**	**885.00**	**4 589 884 350**

Source: Office of the DRM, TFS: Safari report on official visit to resin tapping and processing firms in China (13 – 22 April, 2019).

It was learnt during the study that *Pinus elliottii* has higher potentials for resin business due to good quality and yield of its resin. However, the species received low preference in establishment by plantation management due to a number of reasons believed to discourage its use in lumber and pulp production, as follows;

1. They are brittle and easy to break on logging leading to low recovery rate.
2. They contain too much resin which makes it difficult to work.
3. Timber from *P. elliottii* are susceptible to fungal (blue stain) attack.
4. The spp has thick bark that lowers timber recovery and exaggerate log prices when measured over bark.
5. High resin content increases chemical consumption in craft paper making (Sulphate pulping).

As a result, *P. elliottii* stands were always in a priority list in harvesting plans in order to get rid of the species.

Based on the allowable cut and under assumptions that:

1. The highest yield per tree obtained for each species is considered, that is 1320 g and 1 980.59 g for *P. elliottii* and *P. patula*, respectively;
2. All mature trees can be subjected to tapping from the first year;
3. 1000 trees can provide labour to 1 person.

TFS for the coming three years may have annual production of 5 186 310 kg of pine resin with additional annual earning of TZS 4 589 884 350.00, tax inclusive, under the price Government Notice (GN) number 255 of 2017 where fee rate before tax is TZS 750.00 per kg of raw resin. Substantial amount of revenue will be collected if tapping age is lowered to 15 years as more trees will be available for resin tapping. In addition, resin harvesting activities will create jobs to more than 3000 local people who will be employed in site preparation, blazing, marking of trees to be tapped, marking of seed trees which must be left untapped, fire protection, resin collection from trees and transportation.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Data collection for this study was intended to explore how some factors affect pine resin productivity and its potentials as a source revenue in the forest sector of Tanzania. It was established that despite the poor stand condition, both *P. elliottii* and *P. patula* at the study area produce resins that can be traded and add value to the plantations as well as increase the contribution of forest sector to the national economy. However, resin yields from the study area are slightly lower than the average specified elsewhere by other researchers.

It was found during the study that tree and stand variables such as dbh, crown size, age, basal area per ha, tree height, spacing and basal area per hectare that are important for better yields of wood biomass are the same variables that determine resin yield in pine trees. This means that for better resin yield, intra and inter tree relationships controlled by the current management regime targeted to improve stand wood volume for timber and pulp production are very important.

Being in the very early stage of resin taping business, Tanzania requires a lot of precautions to avoid possible damage caused by uninformed tapping practice to the growing stock. Using the available information, this study has established 15 years to be the optimum age of commencing resin tapping to both *P. elliottii* and *P. patula* which should however, be used at low tapping intensity.

Although this study was confined to a small area of SHFP, integration of resin tapping into the current schemes of timber and pulp wood may be a smart decision not only for improving the contribution of the forest sector in the economic growth but also in improving forest management practices for healthier forest resources.

Further, introduction of resin tapping activities in state owned plantations and private farms may be an attractive option for early income generation before trees attain the rotation age. For the coming three years, state owned plantations may produce 5 186 310 kg of pine resin with additional annual earning of TZS 4 589 884 350 under the current tariff. More revenue would be collected if tapping age is lowered to 15 years as more trees will be available for resin tapping. However, lowering tapping age should be accompanied by proper implementation of thinning schedule so that trees attain minimum size of 20 cm dbh for tapping. In addition, resin tapping activities in state plantations will create jobs to more than 3000 local people.

Results of this study are preliminary but assuming there is an indefinite resin trade and market in the country and globally, they are on one hand sufficient to identify several important information that will trigger resin tapping business and on the other hand to justify a need for more detailed resource assessment for sustainable development of this new forest practice in the country.

5.2 Recommendations

1. Forest plantation management in the study area should capitalize on the introduction of resin tapping business by planting more *Pinus elliottii* spp for its resin as primary objective as it is currently ignored by timber and pulp wood millers.

2. In order to improve resin productivity and associated revenue in the study area, it is important that forest stand establishment and management adhere to silvicultural best practices such as use of good planting material, site selection, timely planting, pruning and thinning.
3. Studies with wider spatial and temporal coverage must be carried out at the study area and in other plantations in the country in order to capture the effect of more variables such as weather, seasonality and altitude on resin productivity.
4. Since resin tapping is a new forest practice in Tanzania, assurance studies have to be conducted in order to clear many perceived doubts including negative effect of resin tapping on tree growth, wood quality, phenology, quality of seeds collected from tapped trees.
5. The real value of pine resin in the country should be established through a separate pricing mechanism and avoid the current generic pricing which gives equal value to all gums and resins despite their differences in nature, source and investment environment.

REFERENCES

Aguiar, A. V., Shimizu, J. Y., Sousa, V. A., Resende, M. D. V., Freitas, M. L. M. and Moraes, M. L. T. (2012). *Genetics of Oleoresin Production with Focus on Brazilian Planted Forests.* Research Signpost, Kerala, India. 106pp.

Amelia, P., Miguel, P. and Anamaria, A. (2012). Pine resin sector in Portugal – weaknesses and challenges. National Institute of Biological Resources. *Forest Ideas Journal* 18(43): 10 – 18.

Asiad, S. (2016). Verification of the extent and expansion potential of forest plantations in Tanzania. Dissertation for Award of MSc Degree at Sokoine University of Agriculture. Morogoro, Tanzania, 75pp.

Asmamaw, A. A., Jürgen, P., Laura. S. and Tarig, E. M. (2014). Contribution of small-scale gum and resin commercialization to local livelihood and rural economic development in the drylands of Eastern Africa. [www.mdpi.com/journal/forests] site visited on 20/8/2019.

Bharat, G. (2014). Sustainable resin collection and trade practices in mid hills of Nepal. *The Initiation* 5: 128 – 137.

Bhatt, J. R., Nair, M. N. B. and Ram, H.Y. M. (1989). Enhancement of oleo-gum resin production in *Commiphora wightii* by improved tapping technique. *Current Science* 58: 349 – 357.

Chamshama, S. A. O., Nwonwu, F. O. C., Lundgren, B. and Kowero, G. S. (2009). *Forest Plantations in sub Saharan Africa*. Food and Agriculture Organization, Rome, Italy. 55pp.

Chamshama, S. A. O. (2011). *Forest Plantation and Woodlots in Eastern and North Eastern African Countries*. Working Paper Series No. 18. African Forest Forum, 72pp.

Chaudhari, D. C, Sheel, S. K., Uniyal, D. N. and Bist, R. S. (1996). Supplementing resin production by retapping healed up channels. *Indian Forester* 122: 746 – 750.

Chaudhari, D. C. (1995). *Manual of Rill Method of Resin Tapping from Pines*. Forest Research Institute, Dehradun, India. 120pp.

Ciesla, W. M. (1998). *Non-wood Forest Products from Conifers. Non-Wood Forest*. Food and Agriculture Organization, Rome, Italy. 123pp.

Coppen, J. J. W. (1995). *Flavours and Fragrances of Plant Origin. Non-Wood Forest Products Products1, Turpentine from Pine Resin*. Food and Agriculture Organization, Nations, Rome. 108pp.

Coppen, J. J. W. and Hone G. A. (1995). *Gum Naval Stores: Turpentine and Rosin from Pine Resin' Non-Wood Forest Products* 2. Food and Agriculture Organization, Rome. 71pp.

Cunningham, A. (2012). *Pine Resin Tapping Techniques.* Research Signpost, Kerala, India. 8pp.

Dave, J. C., Lyoid, A. D. and Geofrey, M. D. (2011). A review of resin features in radiate pine. *New Zealand Journal of Forestry Science* 41: 41 – 64.

Dhananjaya, P. (2010). Sustainable resin tapping in Nepal. Challenges and opportunities. (A case from Salyan District). *The Initiation* 2(1): 172 – 179.

Ella, A. B. and Tongacan, A. L. (1987). Tapping of Palosapis [*Anisoptera thurifera* (Blanco) Blume sp. *thurifera*]. *Forest Products Research and Development Institute Journal* 16: 15 – 26.

Ella, A. B. and Tongacan, A. L. (1992). Techniques in tapping almaciga [*Agathis philippinensis* Warb.] for sustained productivity of the tree: The Philippine experience. *Forest Products Research and Development Institute Journal* 21: 73 – 79.

Gianno, R. (1986). The exploitation of resinous products in a lowland Malayan forest. *Wallaceana* 43: 3 – 6.

Gonzales, L. L., De La Cruz, V. C. and Uriarte, M. T. (1986). Effects of seasonal variation and sulfuric acid treatment on the resin yield of almaciga (Manila copal). Sylvatrop Philipp. *Forest Research Journal* 11: 43 – 54.

GRTI (2004). *Environmental Impact Assessment Related to Resin Tapping for the Rolpa, Salyan, Puythan and Dang Districts*. Ganpati Rosin and Turpentine Industries Ltd., Kapilvastu, Nepal.12pp.

GRTI (2007). *Progress Report of Environmental Impact. Assessment Implementation.* Ganpati Rosin and Turpentine Industries Ltd., Kapilvastu, Nepal. 220pp.

Gumbo, D. J., Dumas, J., M., Muir, G., Boersler, F. and Xia, Z. (2018). *Sustainable Management of Miombo Woodlands. Food Security, Nutrition and Wood Energy*. Food and Agriculture Organization, Rome, Italy. 64pp.

Halimahton, M. and Morris, M. D. (1989). Preliminary analysis of yield and composition of latex from Alstonia angustiloba. *Journal of Tropical Forest Science* 2: 142 – 149.

Harrington. T. A. (1969). Production of oleoresin from southern pine trees. *Forest Products Journal* 19(6): 31 – 35.

Harris, J. M. (1991). Structure of wood and bark. Properties and Uses of New Zealand Radiata Pine. *Wood Properties* 1: 2 – 16.

INDUFOR (2013). *Background to Forest Financing in Least Developed Countries.* (LDCs) Research Signpost. Kerala, India. 8pp.

Kanowski, P. J. (1995). The complex future of plantation forestry. *Proceedings International Union of Forest Research Organization Conference Eucalypt Plantations: Improving Fibre Yield and Quality*. Hobart, Tasmania. 64pp.

Karaoglanogloy, A. and Koukios, E. G. (2002). *Scientific Meeting of the TWIG Project on 'Innovative and High Added Value Pine Oleoresin Products.* National Technical University, Athens, Greek.

Koch, P. (1972). *Utilization of the Southern Pine.* Agriculture Handbook No. 420. United States Department of Agriculture-Forest Service, Washington DC, USA. 744pp.

Larson, P. R., Kretschmann, D. E., Clark, A. and Isebrands, J. G. (2001). *Formation and Properties of Juvenile Wood in Southern Pines.* A Synopsis No. 129. United States Department of Agriculture Forest Service, Washington DC, USA. 46pp.

Lin, J., Hu, Y., He, Y. and Ceulmans, R. (2001). Systematic survey of resin canals in Pinaceae. *Belgian Journal of Botany* 135(2): 3 – 14.

Lombardero, M. J., Ayres, M. P., Lorio, P. L. and Ruel, J. J. (2000). Environmental effects on constitutive and inducible resin defences of Pinus taeda. *Ecology Letter* 3: 329 – 339.

Makupa, E. (1995). Factors affecting gum oleoresin yielding potential and quality in Pinus Elliottii and Pinus patula at Sao Hill Forest Plantation, Tanzania. Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 128pp.

Malimbwi, R. (1997). *Fundamentals of Forest Mensuration. A Teaching Compendium.* Sokoine University of Agriculture. Morogoro. 104pp.

McConchie, D. L. (1997). Wood quality in the Puruki experimental forest. In: (Edited by Ridoutt, B. G.). *Proceedings 2nd New Zealand Wood Quality Workshop*

Managing Variability in Resource Quality 12 September, 1997, New Zealand. pp. 1 – 5.

McConchie, D. L. (2003). *Field Guide to Assist Recognition and Classification of Resinous Defects on the Bark of Radiata Pine*. Report No. 12. Rotorua, Wood Quality Initiative, New Zealand. 2pp.

Meyer, M. A., and C. Schulz (2017). Do ecosystem services provide an added value compared to existing forest planning approaches in Central Europe? *Ecology and Society Journal* 22(3):6. 15 pp.

Mgeni, A. S. M. (1986). Planning of forest investments with aid of quantitative models: A case study at Sao hill forest project in Tanzania. Dissertation for Award of PhD Degree at University of Wales, Bangor, Great Britain, 312pp.

MNRT (2015). *National Forest Resources Monitoring and Assessment Main Results. Tanzania Forest Services*, Ministry of Natural Resources and Tourism, Dar es Salaam, Tanzania. 106pp.

Moulalis, D. (1981). Variation in resin production of Aleppo pine in Kassandra Chalkidiki. *Science Annual* 19: 467 – 488.

Neels, S. (2000). Yield, sustainable harvest and cultural uses of resin from the copal tree (protium copal; burseraceae) in the carmelita community forest concession, Peten, Guatemala. Dissertation for Award of MSc Degree at University of British Columbia. 166pp.

Ngaga, Y. (2011). Forest plantations and woodlots in Tanzania. *African Forest Forum* (16): 1 – 80.

Ngegba, M. S. (1998). Effects of forest plantations on selected soil properties at Sao Hill Forest Plantation, Tanzania. Dissertation for an Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 100pp.

Orallo, C. A. and Veracion, V. P. (1984). Comparison of four methods of tapping Benguet pine (Pinus kesiya Royle ex Gordon) for oleoresin production in Benquet. *Sylvatrop Forest Research Journal* 9: 55 – 64.

Papajiannopoulos, A. (1997). The future of resin tapping in Greece. *Science Annual* 37: 279 – 299.

Papajiannopoulos, A. (2002). *Leaflet of Resin Tapping*. PRISMA Ltd., Athens, Greek. 233pp.

Patel, R. N. (1971). Anatomy of stem and root wood of pinus radiate. *New Zealand Journal of Forestry Science* 1(1): 37 – 47.

Philippou, I. (1986). *Chemistry and Chemical Technology of Wood*. Giachoudi Giapouli Publication, Greek. 68pp.

Perez, S. O., Garcia. R. F., Ayuga, T. E. and Fullana, B. C. (2013). Effects of the crisis in the resin sector on the demography of rural municipalities in Spain. *Forest Systems* 22(1): 39 – 46.

Race, D. and Curtis, A. (1997). Socio-economic considerations for regional farm forestry development. *Australian Forestry* 60(4): 233 – 239.

Rodrigues, K. C. S., Azevedo, P. C. N., Sobreiro, L. E., Pelissari, P. and Fett-Neto, A. G. (2007). Oleoresin yield of Pinus elliottii plantations in a subtropical climate: Effect of tree diameter, wound shape and concentration of active adjuvants in resin stimulating paste. *Elsevier journal of Industrial Crops and Products* 27: 322 – 327.

Rodrigues-Correa, K. C. S., and Fett-Neto, A. G. (2012). *Physiological Control of Pine Resin Production*. Research Signpost, Kerala, India. 48pp.

Rodrigues-Correa, K. C. S., Lima, J. C. and Fett-Neto, A. G. (2012). Pine oleoresin: tapping green chemicals, biofuels, food protection, and carbon sequestration from multipurpose trees. *Journal of Food and Energy Security* 1(2): 81–93.

Rodrigues-Correa, K. C. S., Lima, J. C. and Fett-Neto, A. G. (2013). Oleoresins from pine: production and industrial uses 136. *Journal of Natural Products Phytochemistry* 136: 1 – 25.

Roger, W., Callie, N. and Jiawei, Z. (2017). The effects of resin tapping on the radial growth of masson pine trees in South China. *Agricultural Research and Technology* 8(2): 1 – 4.

Schopmeyer, C. S. and Larson, P. R. (1955). Effects of diameter, crown ratio and growth rate on gum yields of Slash and Longleaf pine. *Journal of Forestry* 53: 822 – 826.

SHFP (2018). *Annual Report 2017/18.* Sao Hill Forest Plantation, Mafinga Iringa, Tanzania.

Shi, K. and Li, Z. (1998). *The Development of China's Forestry: Review and Prospects.* The Environmental Science Press, Beijing, China.

Shiver, B. D. and Borders, B. D. (1996). *Sampling Techniques for Forest Resource Inventory*. John Wiley and Sons Publishers, USA. 356pp.

Spanos, K., Gaitanis, D. and Spanos, I. (2010). Resin production in natural Aleppo pine stands in northern Evia, Greece. *Web Ecology* 10: 38 – 43.

TEITI (2014). *Scoping Study of the Forestry Sector for the Purpose of Including the Industry in Revenue Disclosure through the Tanzania Extractive Industries Transparency Initiative*. Green Advocated International Inc., Liberia. 83pp.

TFS (2019). *Report on the Separation of Water and Impurities in Resin Test Conducted on 30/09/2019*. Sao Hill Forest Plantation Mafinga, Tanzania. 5pp.

Tiarks, A., Nambia, E. K. S. and Cossalter, C. (1998). *Site Management and Productivity in Tropical Forest Plantations*. Occasional Paper No. 16. Center for International Forestry Research, Bogor, Indonesia. 118pp.

Tsoumis, G. (1992). *Harvesting Wood Products.* Stobart Davis Ltd., Hertford, Herts. England. 57pp.

URT (2018). *Gross Domestic Product 2017*. National Bureau of Statistics. Ministry of Finance and Planning, Dar es Salaam. 10pp.

URT (1998). *National Forest Policy of Tanzania*. Ministry of Natural Resources and Tourism, Dar es Salaam, Tanzania. 69pp.

URT (2001). *National Forest Programme of Tanzania 2001-2010*. Ministry of Natural Resources and Tourism, Dar es Salaam, Tanzania. 132pp.

V. M. Kelkar. (2005). How to recover more value from small pine trees: Essential oils and resins. *Biomass and Bioenergy* 30: 316 – 320.

Wang, Z., Calderon, M. M. and Caradang, M. G. (2006). Effects of resin tapping on optimal rotation age of pine plantation. *Journal of Forest Economics* 11: 245–260.

Werker, E. and Fahn, A. (1969). Resin ducts of Pinus halepensis Mill. – Their structure, development and pattern of arrangement. *Botanical Journal of the Linnean Society* 62: 379 – 411.

Wu, H. and Hu, Z. (1997). Comparative anatomy of resin ducts of the Pinaceae. *Trees* 11: 135 – 143.

Xu, B. and Liu, X. (1992). World main resin tapping tree species and development tendency of rosin production. *Chemistry and Industry of Forest Products* 12(4): 333 – 339.

Zanski, E. (1970). The effect of microclimatic conditions on resin duct formation and resin secretion in *Pinus halepensis* Mill. For. Abstr. 1390/1971.

APPENDICES

Appendix 1: Distribution of Plots in Divisions within the Study Area

S/N	RANGE	SPECIES	AGE (Years)	PLOTS	DIVISION
1	RUAHA	*P.patula*	15	3T, 3C	DIV I – IRUNDI
2	IRUNDI	*P.patula*	20	3T, 3C	DIV I – IRUNDI
3	NUNDWE	*P.elliottii*	10	3T, 3C	DIV III- IHALIMBA
4	IRUNDI	*P.elliottii*	25	3T, C3	DIV I – IRUNDI
5	MAKALALA	*P.patula*	5	3T, 3C	DIV II – IHEFU
6	SAOHILL	*P.elliottii*	12	3T, 3C	DIV II – IHEFU
7	MATANANA	*P.patula*	10	3T, 3C	DIV II – IHEFU

Key: T - Treatment, C - Control

Appendix 2: Tools and Equipment for resin tapping

S/N	Tools/Equipment	Required	Comments
1	GPS receiver (Geographic Positioning System)	1	With extra batteries
2	Measuring tape, 50m	2	Metric units
3	Caliper	2	Mm scale
4	Combined Suunto hypsometer	1	
5	Colored flagging ribbon and /or spray	Severalrolls/cans	Marking plots and trees.
6	Field forms		For each sampling unit
7	Compass (360°)		In degrees-water proof model
8	Hook knife	4	For grooving
9	Bamboo nails	300	
10	Guap knife	2	
11	Field data sheet – Ht, DBh, Wt, temp, Ppt,		
12	Spring balance		
13	Bucket		
14	Hummer		
15	Chiesl		
16	PVC slice		
17	Oil bag		
18	Hook knife		
19	Helmets		
20	Gloves		
21	Panga/matchet		
22	Goggles / spectacles		Needed during shaving the stem
23	Sulphuric acid (40%)		

Appendix 3: Field Form for Inventory Data

PLOT FORM
Gps point (MIS………………Lat…………...Long…………)

Name of Plantation………………………… Species……………………… Compartment No ……………………...

Year planted…………………Age……………...Original planting spacing …….x……. m. Thinning history: Thinned (1) Unthinned (2).

Plot No……………… Name of Group leader……………………………………………

Date:

Tree No	dbh (cm)	HT (m)	SH (m)	CrD (m)	Date	Resin (g)	Dat e	Resin (g)	Dat e	Resin (g)	Date	Resin (g)	Date	Resin (g)
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														

Key: SH- Height to the first live branch; CrD Crown diameter

Appendix 4: Technical Order No. 1 of 2003

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

SPECIES	AGE (YEARS)	STEMS per HA. (SPH)
Pinus caribaea	0	1111 (3.0 x 3.0 m)
Pinus elliottii	10	650
Pinus patula	15	400
Pinus tecunumanii	25 – 30	0
Cupressus lusitanica		
Tectona grandis	0	1600 (2.5 x 2.5m)
	5	800
	10	400
	15	300
	30 – 40	0

Appendix 5: Multiple regression output of factors with resin yield

(a) *P. elliottii*

Regression Statistics	
Multiple R	0.98903282
R Square	0.978185919
Adjusted R Square	0.941829118
Standard Error	14.22180641
Observations	9

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	27209.16836	5441.833672	26.90516986	0.01072524
Residual	3	606.7793328	202.2597776		
Total	8	27815.94769			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	138.7490617	49.08591561	2.826657301	0.06637246	-17.46422902	294.9623525	-17.46422902	294.9623525
Age	-16.23351348	3.443261726	-4.714574368	0.018068531	-27.19150903	-5.275517917	-27.19150903	-5.275517917
Height (m)	10.21568692	3.998457313	2.554907086	0.083584306	-2.50918878	22.94056263	-2.50918878	22.94056263
N	0.137379992	0.223580778	0.614453502	0.582374992	-0.574153829	0.848913813	-0.574153829	0.848913813
G	-15.96223436	35.25015443	-0.45282736	0.68141636	-128.1439581	96.21948937	-128.1439581	96.21948937
V	1.756122285	2.491989971	0.704706803	0.531775202	-6.174501992	9.686746562	-6.174501992	9.686746562

Y = 138.7491 + 10.2157*Ht + 0.1374N + 1.7561V - 16.2335 Age - 15.9622G

Residual Output

Observation	*Predicted Resin yield/ha (Kg/ha)*	*Residuals*	***(O-E) ^2***
1	230.8542866	1.55312085	2.412184374
2	189.3887463	7.625142595	58.14279959
3	186.446782	-9.178263445	84.24051986
4	79.4191527	-12.79878233	163.808829
5	95.29632696	-0.250030668	0.062515335
6	59.17340923	13.04881299	170.2715205
7	100.6647901	-9.021271598	81.38334124
8	103.9234082	2.812702899	7.911297601
9	127.657172	6.208568698	38.54632528
Summation of Squared Residuals			**606.779333**
Summ of squared residuals divided by n			**67.419926**
RMSE			**8.210964**

(b) *P. patula*

Regression Statistics	
Multiple R	0.986570043
R Square	0.97332045
Adjusted R Square	0.951087492
Standard Error	6.726016938
Observations	12

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	5	9902.492325	1980.498465	43.77827014	0.000120904
Residual	6	271.4358231	45.23930386		
Total	11	10173.92815			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*

Intercept
-31.98239956
37.46112555
-0.853749029
0.426009846
-123.6464716
59.68167251
-123.6464716
59.68167251
Age
2.135016012
1.601187821
1.333395111
0.230790342
-1.782949442
6.052981466
-1.782949442
6.052981466
Height (m)
0.233076187
1.658498122
0.14053449
0.892836976
-3.825122522
4.291274896
-3.825122522
4.291274896
N
0.075663787
0.088586549
0.85412275
0.425818363
-0.141099689
0.292427262
-0.141099689
0.292427262
G
0.746010844
10.65720595
0.070000603
0.946467948
-25.33123271
26.82325439
-25.33123271
26.82325439
V
0.486477942
0.849608905
0.572590446
0.587720214
-1.592440157

2.565396041
-1.592440157
2.565396041

Y = 2.1350*Age + 0.2331*Ht + 0.0757*N + 0.7460*G + 0.4865*V - 31.9824

Residual Output

Observation
Predicted Resin yield/ha (Kg/ha)
Residuals
(O-E) ^2

1
68.4944708
-3.864841173
14.93699729

14.93699729

2
44.36231669
10.12842405
102.5849738
102.5849738

3
53.21186151
-1.684083729
2.836138005
2.836138005

4
90.15146125
-8.531090881
72.77951162
72.77951162

5
87.54970298
-0.026554829
0.000705159
0.000705159

6
69.1943286
-0.143402676
0.020564327
0.020564327

7
125.7731427
2.467598018
6.089039977

6.089039977

8
101.4346087
2.384835709
5.687441358
5.687441358

9
112.0779007
1.787840041
3.196372014
3.196372014

10
36.9397894
-7.032381989
49.45439644
49.45439644

11
42.36204
3.610182223
13.03341568
13.03341568

12
44.8835618
0.903475233
0.816267497
0.816267497

Summation of Squared Residuals

	271.4358231
Sum of squared residuals divided by n	
	22.61965193
RMSE	
	4.756012188