Nutrient concentration of inner bark tissue in pine trees in Mpumalanga in relation to baboon damage.

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Declaration

I declare that this dissertation is my own, unaided work. It is submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

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Abstract

Pine saw timber plantation forestry on the Eastern Escarpment of South Africa contributes significantly to the economy of the country. Losses to plantation value through fire, insects and disease, and particularly over the last decade, losses due to baboon damage are of serious concern. Anecdotal evidence indicated that baboons damage pine trees shortly following pruning operations and at certain times of the year. A perception existed that damage has increased dramatically, yet no documented evidence to this effect is available. As a result two physiological studies were undertaken to investigate whether changes in nutrient concentration of inner bark tissues of pine trees on the Eastern Escarpment of South Africa, act as triggers for baboon damage. A literature review was also undertaken to document the extent of baboon damage, tree volume and associated economic costs. A comparison was made with Zimbabwe, where baboon damage is quoted to be a severe threat to the continued viability of plantation forestry.

The first study investigated changes in nutrient concentration of the soft, inner bark tissue of *Pinus patula*, in response to pruning measured in five year old plantations in the Mpumalanga Province, South Africa. Samples of tissues were collected from pruned and unpruned trees at 2, 7, 14 and 28 days after 26% of the live crown had been removed in the pruning treatment. Results indicated that live pruning of *Pinus patula* did not influence nutrient concentration of inner bark tissues at set intervals post pruning. Treatment differences of aggregate data for sample interval showed that potassium concentration increased by 0.03% whereas magnesium concentration decreased by 0.02% following pruning. Aggregate data for treatment showed that phosphorus, carbohydrates (fructose, glucose, sucrose and starch), boron and nitrogen concentration, and moisture content of inner bark tissues varied during the short time period of the study. Variations are attributed to

the commencement of growth, translocation of nutrients from needles and branches and possibly moisture stress. Results from the study do not support anecdotal evidence that baboon damage to pine plantations which increases shortly after pruning operations is as a direct physiological response to the pruning event. In this study it is much more likely that changes in nutrient concentrations coincided with a remobilization of resources in response to seasonal triggers.

In the second study, nutrient concentrations of the inner bark of *Pinus patula* and *Pinus taeda* growing on the Eastern Escarpment of South Africa were studied over a seasonal cycle in order to investigate the allegations that baboon damage in the plantations was related to the degree of nutrient remobilization. Significant differences were found in phosphorus concentration and moisture content across seasons and between baboon damaged and undamaged trees. Undamaged *Pinus taeda* trees recorded the highest phosphorus levels in April 2003 (0.13%). Moisture content was lowest in damaged *Pinus patula* trees in August 2003 (57%). Anecdotal evidence that baboon damage to pine trees on the Eastern Escarpment of Mpumalanga increases prior to the growing season is supported by the significant changes in inner bark tissue concentration. Nutrient translocation prior to needle fall alters inner bark nutrient concentration, as does moisture stress and demand for nutrients prior to cambial activity. Pine bark is easier to peel during periods of peak cambial activity. These factors are discussed as they may trigger baboon damage. Significantly higher inner bark tissue concentrations of sucrose (4.25 versus 2.61%), starch (4.75 versus 2.84%) and nitrogen (0.61 versus 0.49%) in *Pinus taeda* compared with *Pinus patula,* supports anecdotal evidence that *Pinus taeda* is preferentially damaged by baboons. Baboon damaged trees contained higher concentrations of zinc (30.4 versus 22.3 ppm) and calcium (0.26 versus 0.20%), and lower concentrations of sucrose (2.95 versus 3.91%) and starch (3.21 versus

4.39%) than undamaged trees, which was attributed to resource allocation to wound response and not that baboons selected trees with higher concentrations of zinc or calcium. The variability of inner bark tissue concentration due to a number of factors highlights that baboon damage in pine plantations is not readily answered, and remains a complex problem.

A literature review was undertaken of reported baboon damage occurrence and intensity of damage, following statements that baboon damage to pine plantations is rapidly escalating in the Mpumalanga Province, South Africa. The extent and intensity of baboon damage from the first reported damage (1960's) until current levels are documented. A comparison is made between Zimbabwe and South Africa where the baboon damage is viewed as a serious problem. The extent of baboon damage in Zimbabwe, expressed as the total percentage of area damaged by baboons as a function of the total area planted to pine for the period 2000-2004 has escalated from 10.8 to 13.3% despite harvesting activities removing damaged trees (Fergusson, 2004). The total area with reported baboon damage in Zimbabwe amounted to 5 317 hectares in 2004 (Fergusson, 2004). In South Africa baboon damage has increased markedly from the first reports of 300 hectares in 1980 (Bigalke, 1980) to 7 641 hectares in 2004. The average percentage of trees damaged in affected compartments is 20.4% with the percentage increasing from 17.2 to 23.6% from 2002-2004. *Pinus taeda* appears to be the most severely affected species with *Pinus elliottii* showing increasing levels of damage in many compartments in 2004. Quantifying the value lost by baboon damage to the industry requires reliable assessment methods that are cost effective to implement. Assessment methods need to take into account the position of the damage on the stem, and resultant saw log value that is lost. Assessment methods implemented in South Africa and Zimbabwe are described, and results given by method applied. A standard assessment method is required for comparisons to be made between areas with baboon damage. An investigation in Zimbabwe highlighted significant differences between standing tree volume estimations (4.98 – 7.59 m^3/ha, with various methods), and actual volume losses (50.45 m^3/ha) (Ngorima *et. al.,* 2002). The associated Rand value loss determined by the South African assessment method in 2004 was in excess of 20 million Rand. This estimated loss in revenue does not include losses of incremental growth due to the damage, re-establishment costs, loss of thinning and clearfelling product revenue due to timber wastage, or losses experienced in down line processing at the saw mill. The extent of the baboon damage problem warrants proactive management, continued monitoring and investment into research in order to gain a better understanding of the problem. The increase in the extent of baboon damage from early documented figures is most alarming, showing that the baboon damage problem continues to grow.

Dedication

This manuscript is dedicated to Erin Mary McNamara, who was truly with me from the start to the finish.

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Chapter 1: Introduction

A total of 1.3 million hectares in South Africa are afforested to tree plantations. Of this 705 000 hectares are afforested to pines, 525 000 hectares to eucalypts, 112 500 to wattle and the remainder consists of other species. More than half the pine plantings (325 000 hectares) occurs in the Mpumalanga Province. A total area of 480 600 hectares in South Africa is dedicated to pine sawlog production, the majority of which occurs in Mpumalanga (Forestry South Africa, 2003).

Pine plantation forestry companies on the Eastern Escarpment of South Africa and the Eastern Highlands of Zimbabwe have been concerned with the extent and intensity of damage to pine plantations by baboons (*Papio ursinus*). The management of pests in large tracts of land with uniformly grown species is a serious concern. In South Africa, the greatest threats to long term sustainability of pine plantations are fire, insect damage and disease, affecting the viability and survival of plantations. However, more recently baboon damage is becoming as serious a threat to plantation sustainability. Damage by baboons has also been reported in Zimbabwe, where damage levels are quoted as being extreme, and a severe threat to the continued viability of plantation forestry in that country (Valintine, 2001). A perception exists in South Africa that the level of damage by baboons in commercial pine plantations is increasing to unacceptable levels. Bark stripping is the main form of damage reported, which leads to tree deformity and reduced wood quality. Trees may also die where bark is stripped around the full circumference of the tree. Baboons remove cones from trees which impacts tree improvement research and results in genetic material being lost from seed orchards. Bark stripping by primates is not an unique occurrence to the pine growing areas of South Africa and Zimbabwe. The Barbary macaque (*Macaca sylvanus*) of the Middle Atlas Mountains in Morocco is reported to strip bark from cedar forests (Ciani *et. al.*, 2001). Blue monkeys

(*Cercopithecus mitis*) are reported to strip bark from *Pinus patula* plantations in Tanzania (Maganga and Wright, 1991), and chimpanzees are reported to strip bark from 21 species of trees, shrubs and wood vines in Tanzania (Nishida, 1976). Samango monkeys (*Cercopithecus (mitis) albogularus*) have also been reported to strip bark from commercial plantations in South Africa (von dem Bussche and van der Zee, 1985). Other vertebrate species such as black bears (*Ursus thibetanus*) (Yoshimura and Fukui, 1982), squirrels (*Sciurus aberti)* (Pederson and Welch, 1985), moose (*Alces alces L.*,) (Faber, 1996) and sambar deer (*Cervus unicolor*) (Stafford, 1997) and sika deer (*Cervus nippon*) (Ando *et. al.,* 2003), are among some of the species reported to damage forest trees to access the bark tissues.

On the Eastern Escarpment of Mpumalanga, South Africa, baboons have been observed sitting in the canopy of pine trees. They bite on the stem of the tree and pull the bark loose from the tree with their front paws. They then proceed to use their teeth to scrape the succulent, moist, inner bark layer from the main stem, and use the stripped pieces of bark to scrape over the teeth of the lower jaw. It appears that the soft, inner, tissue is sought after and not the outer bark. The cork cambium of the bark may also be chewed on for short periods, however this is not swallowed, but spat out onto the ground (Dyer, 2002, *pers. comm.*). Damage occurs throughout the year but intensity of damage decreases during winter and increases prior to the start of the growing season in Mpumalanga, South Africa. It has however been reported to increase during winter in Zimbabwe (Valintine, 2002, *pers. comm.*).

It has been noted by foresters in Mpumalanga that baboon damage is more prevalent shortly after pruning operations. Some research studies have focused on the possible links between baboon behaviour and damage in the Western Cape and Limpopo Provinces. However, these studies do not clearly define the sections of tissue sampled, and have been confounded with little attention being paid to rigorous experimental design. Much of the evidence has been anecdotal with emphasis being placed on baboon social behaviour. This MSc focuses on tree physiological responses, is based in the Province where most of the damage occurs, and specifically addresses the extent of baboon damage and economic implications to pine saw timber plantations on the Eastern Escarpment of South Africa.

The following key questions have been posed:

1.1 Key questions

a. How does the composition of inner bark tissue of *Pinus patula* vary following a pruning lift, as determined at specified intervals post-pruning?
b. How does the composition of inner bark tissue of *Pinus patula* and *Pinus taeda* vary between seasons?
c. How does the moisture content of inner bark tissue vary between *Pinus patula* and *Pinus taeda*?
d. How much do trees damaged by baboons differ in zinc content compared with undamaged trees?
e. What is the current estimate of the level of damage in pine saw timber plantations in Mpumalanga?

The thesis is written in such a manner as to allow for the rapid publication of results. There is a degree of repetition which is necessary to facilitate publication. Chapter 1 gives an introduction to the rationale for the study. Chapter 2 consists of a detailed literature review, focusing on three main areas, namely the background to the study area (pines, afforestation history, pine growth habits, and baboons), tree physiological responses with special emphasis on the effect seasonality and pruning, and a record of economic assessment of baboon damage. Chapter 3 encompasses the materials and methods used in the study and includes a detailed site description. Chapter 4 which is written as a manuscript contains the details and results of the effect of pruning on nutrient concentrations. Chapter 5 which is also written as a manuscript details the effect of season and species differences in nutrient concentrations following mechanical damage to the stem. Chapter 6 records the economic assessment of damage levels in pine plantations and follows the format of a manuscript for publication. Chapter 7 contains a general discussion on the research conducted, and the last chapter (8) contains conclusions of the work.

Chapter 2: Literature review

2.1 Pines

Nearly a hundred taxonomically distinct species comprise the genus *Pinus,* with many additional hybrids, varieties, forms and cultivars (Poynton, 1979). Pines are evergreen trees ranging from tall forest trees to dwarfed or semi-prostrate shrubs. The different species produce resin to varying degrees, however all make use of resin for primary defense to insect attack and wounding. In forests or plantations most *Pinus* species form tall, cylindrical trunks and compact crowns. The lower branches die off progressively from below due to shading. Bark of young trees are thin and smooth, with dry scales forming as the tree matures resulting in a thick protection layer in older trees (Poynton, 1979).

The genus *Pinus* is of great economic importance due to the utilizable wood yielded by the various species. Wood produced by pines is characteristically resinous, of low to medium density with long fibers but fairly soft which lends itself well to being worked. Use of pine timber includes building and bridge construction, the interior finish of buildings, joinery, mouldings, utility furniture, patternmaking, carving and crating. Due to the resin content it also makes good fire wood and some species such as *Pinus pinaster* have been tapped for resin from which turpentine is produced by distillation (Poynton, 1979).

Pines can be grown successfully under a wide range of soil conditions, provided root penetration is sufficient and drainage adequate. Most species of pine withstand severe frost and exposure to cold winds. The principle pine species grown in South Africa are *Pinus pinaster* and *Pinus radiata* (in the winter rainfall areas of the country) and *Pinus patula*, *Pinus elliottii*, *Pinus taeda* and more recently the *Pinus caribaea* x *Pinus elliottii* hybrid in the summer rainfall areas of the country. The species focused on for the study were *Pinus taeda* and *Pinus patula.*

2.1.1 Origin of *Pinus taeda*

Pinus taeda is the principal commercial pine species of the south-eastern United States. It is a vigorous, medium to large sized tree (30-45 meters tall). The climate where it naturally occurs is temperate and humid, with long warm summers and mild to cool winters. Temperatures range between extremes of -23 °C to 38 °C. The mean annual rainfall varies from about 1000 mm to 1500 mm. The climatic factors which restrict the range of the species are low temperatures or snow damage and drought risk. Variations do exist in the ease of establishment, hardiness to drought and frost, rate of growth and susceptibility to disease of this species within the provenance or clinal gradients of its origin (Poynton, 1979).

2.1.2 Origin of *Pinus patula*

Pinus patula is a medium sized tree (up to 30 m) that has a restricted and discontinuous distribution in the temperate, humid regions of south-central Mexico. In its natural habitat the climate is temperate to cooler-temperate and humid. Mean annual temperatures vary between about 10 °C and 19 °C. Frost at the higher elevations is fairly severe. The rainfall averages from 1000 to 1350 mm per year, the majority of which falls during the summer months, when the humidity is high. Mists are frequent at most times of the year, though the winters are otherwise comparatively dry (Poynton, 1979).

In South Africa, *Pinus patula* is more heavily branched (both in number of whorls per stem and number of branches per whorl) than *Pinus taeda*. *Pinus patula* displays a greater growth rate over *Pinus taeda* and is not as subject to compression wood as *Pinus taeda*, making it the preferred species for plantation forestry on the Eastern Escarpment. *Pinus patula* does however have a greater effective rooting depth limitation than *Pinus taeda.* A full description of the growing conditions for the study area of the Eastern Escarpment is given in Chapter 3.

2.2 Brief history of afforestation in South Africa

Afforestation of exotic plantations began in the Union of South Africa during the second half of the 19^{th} century when indigenous forests were placed under protection following a period of severe destruction of these forests (Grut, 1965). The first plantation was established by the Department of Forestry in 1876 consisting of 30 hectares of eucalypts near Worcester in the Cape Province with the intention of supplying firewood to the railways. Exotic tree species were preferred to indigenous trees species, due to the faster rate of growth and consequent higher yield of useful timber. Afforestation continued in 1883 and 1884 with conifers in the region of Cape Town and Knysna (Cape Province). Following the Anglo-Boer war, the Cape forest service sent some of their forest experts to the Transvaal (now Mpumalanga), Orange Free State and Natal (now Kwa-Zulu Natal) to serve as advisors in forestry related matters. One advisor, Sir David Hutchins commented on the similarity in climate between the Transvaal and certain parts of Mexico, and on his advice seeds were obtained from Mexico and introduced to the country in 1907. The oldest state plantation in the area of the study was established with *Pinus patula* around Graskop in 1906 (Grut, 1965).

The reduction of trading opportunity, resulting from restricted movement of the first world war emphasized the need for a more energetic afforestation policy in South Africa, as timber imports fell dramatically. Timber prices were impressive and this encouraged afforestation by private land owners and increased the drive to afforest plantations. Social motives were behind the government’s interest in afforestation, as work could be provided for many unemployed persons who were severely influenced by the depression which hit the country after the second world war. Tables 1 and 2 below, show the rate of afforestation on state and private land respectively from the late 1800’s to 1960 (Grut, 1965). Table 3 shows the rate afforestation post 1960 (Anon[a], 1972, Anon[b], 1977 and Anon[c], 1982, Forestry South Africa, 2003).

Table 1. Rate of afforestation on state land from 1876-1960 (Grut, 1965).

Period	Hectares afforested per annum
1876-1917	733
1918-1920	2 073
1921-1923	3 370
1924-1938	6 255
1939-1945	2 348
1945-1949	5 085
1950-1960	6 895

Table 2. Rate of afforestation on private land from 1890-1960 (Grut, 1965).

Period	Hectares afforested per annum
1890-1921	4 308
1922-1930	21 000
1931-1936	5 300
1937-1946	7 215
1946-1955	20 688
1955-1960	22 462

Table 3. Rate of afforestation on private land and public land post 1960 (Anon[a], 1972, Anon[b], 1977 and Anon[c], 1982, Forestry South Africa, 2003).

Period	Hectares Afforested Private	Hectares Afforested Public	Total Afforested hectares in South Africa	Reference
1970-1971	683 348	282 933	966 281	Anon[a], 1972
1975-1976	761259	302 714	1 063 973	Anon[b], 1977
1980-1981	777 883	317 274	1 095 157	Anon[c], 1982
1985-1986	799 448	333 776	1 133 224	Forestry South Africa, 2003
1990-1991	952 370	343 161	1 295 531	Forestry South Africa, 2003
1995-1996	1 050 012	436 911	1 486 923	Forestry South Africa, 2003

Currently in South Africa 1 351 000 hectares are established to plantations made up of pine (705 000 hectares, primarily *Pinus patula*), eucalypts (525 000 hectares), wattle (112 500 hectares) and other species (8 500 hectares), according to Forestry South Africa (2003). The decrease in afforested area from 1995-1996 levels was due to withdrawal of trees from environmentally sensitive areas.

2.3 Description of growth habits of pines on the Eastern Escarpment

The growth habits of *Pinus patula* and *Pinus taeda* on the Eastern Escarpment of Mpumalanga, based on measurements of shoot elongations on a limited number of trees of different ages over a period of two years, was described by Norskov-Lauritsen (1963). The species are multi-nodal (interval between whorls of branches), but older trees have mostly only one elongation period per year and one to four short internodes growing successively but continuously. Spring growth starts during August for both species and the first flush is usually terminated during the period October-November. Subsequent internodes are produced during the summer more or less continuously without having specified growth periods. Elongation takes place in periods of fast and slow growth. Active growth has been recorded as late as in July, and some elongation has been observed through the winter. Trees stay dormant or at least semi-dormant for some time in winter, ranging from about one month to six months, depending on the number of internodes produced in the previous season. In general *Pinus patula* rests for about two months during June-August, while *Pinus taeda* stops growth a month or two earlier, staying dormant for about four months until mid August. Sometimes there is no period of complete cessation of growth, and data tend to show that under South African conditions the growth stoppage in winter is a temporary slow down rather than real winter dormancy (Norskov-Lauritsen, 1963).

The observations by Norskov-Lauritsen (1963) that elongation takes place in periods of fast and slow growth, were verified by Wilcox (1962) who documented cambial growth characteristics. Growth of shoots, roots and cambium (including xylem and phloem) occurred in recurrent cycles, alternating with periods of dormancy or relative inactivity in temperate areas. These cycles were regulated by physiological conditions, primarily the genetic systems within the plant, and were influenced by factors of the environment such as photoperiod, day-night temperature variation during the growing season, soil factors and among others the provenance (origin) of the tree. Natural periodicity may also be subject to the influence of age as well as the environment, as youthful vigor was displayed in longer growing seasons, as compared with mature individuals. A correlation exists between vegetative growth, such as shoot elongation, and cambial activity (Coster, 1928). This is supported by the observation of leaf renewal in deciduous trees being accompanied by a burst of cambial activity. The activity of cambium first came to the attention of early botanists and foresters through the recognition of so-called sap-peeling season, a period during which the bark can be easily removed from the tree. Forestry practice resulted in rules of thumb being developed for determining the best time to remove bark based on phenological observations of foliar development. In the “early sap-peeling stage”, changes occur in the cambium prior to cell division in the spring. Cells expand radially, the radial walls become thinner, and the cytoplasm takes up a parietal position about a large central vacuole (Bannan, 1955). It is at this time that the bark first starts to peel. An important feature of the early awakening of the cambium and the consequent bark slippage is that these changes first occur below the buds and move down the branches and stem. Bark peels easier while cambial activity occurs (Wilcox, 1962).

There is an internal balance between times of maximum development of needles, cambium and roots, determined by internal competition for carbon, water and possibly mineral nutrients (Richardson, 1968). Growing trees require a wide variety of substances to maintain metabolic activities. These substances circulate within the tree through specialized transport tissues. Xylem is the tissue most involved with the upward movement of water and mineral ions, influenced by the rate of foliar transpiration. The dead xylem cells of which the central cavities contain no cytoplasm, allows for rapid and efficient translocation of large quantities of solution (Richardson, 1968). The living xylem parenchyma cells main function is the storage of starch built up during the growing season which is utilized during cambial activity the following season. Analyses of xylem sap reveal that most essential mineral elements (nitrogen, phosphorus, potassium, sulphur, magnesium, iron, calcium, copper, zinc, molybdenum, manganese and boron) are detected at all times but with marked seasonal variations (Richardson, 1968). Sugars and other organic constituents such as amino acids and alkaloids are frequently but not always detected. The dead cells of the xylem are separated from the phloem by a layer of living cells known as the vascular cambium. The primary function of meristematic cells of the cambium is the continued production of new cells of xylem and phloem by successive divisions. It is the most recently produced xylem lying adjacent to the cambium which carries the main stream of nutrient salts upwards. Rapid lateral transfer of solutes can occur between the xylem and phloem (Richardson, 1968).

Phloem tissue is composed of a number of morphologically different cells. The main cells are the sieve elements, companion cells and the phloem parenchyma, but in addition fibres, schlereids and albuminous cells also occur. Phloem is the conducting tissue for substances produced in leaves. It was proven in 1917 by Mangham, that sieve tubes of phloem are rich in carbohydrates, and that the carbohydrate content varied in relation to the environmental conditions. Carbohydrate content of phloem sieve tubes increased when conditions favoured rapid rates of photosynthesis in leaves (Richardson, 1968). The use of isotopic isomers substantiated findings that lateral movement between xylem and phloem occurs. Sucrose is the major transport substance of higher plants and can be viewed as a protective derivative of glucose. Sucrose is a non-reducing but easily hydrolysed derivative of glucose (Richardson, 1968).

2.4 Baboons

Modern baboons (*Papio hamadryas)* emerged in Southern Africa approximately two million years ago and subsequently diverged into five nominal subspecies, of which the Chacma baboon (*Papio ursinus)* is one (Newman *et. al.,* 2004). Baboons are highly intelligent and ecologically flexible animals able to exploit diverse habitats from subtropical woodland to mountainous grasslands (Henzi and Barrett, 2003). Baboons forage on a wide range of plants, insects, reptiles and at times small mammals. Baboons have been documented as being the most important biological control agent in limiting the numbers of pine emperor moth (*Nudaurelia cytherea clarki*), an important forest pest to *Pinus patula* (van den Berg, 1974). Baboons utilize specific vegetation types within their home range differentially throughout the year (Marais, 2005). They are highly selective both in their choice of particular food species eaten and in the part of these species eaten, allowing them to feed on the most nutritious plant parts available in their habitat at various times during the year. The adaptability displayed by baboons enable them to exploit artificial human habitats, such as pine plantations, and as a result cause conflict with humans, categorizing them as “problem animals”.

Baboons are highly mobile within individual home ranges, which vary in size between baboon troops, depending on the food available within the various plant communities occurring in that area. These home ranges may overlap with neighbouring troops (Marais, 2005). The baboon troop is a complex structure in which intricate social organization occurs. The baboon's greatest assets are its extreme adaptiveness, vigilance and the close social structure of the troop (Moss, 1975).

Damage in pine plantations of South Africa by baboons, was first documented in the early 1960's (Anon[d], 1969). Tree deformity, reduced wood quality and tree mortality when bark is stripped around the full circumference, are the main forms of damage reported from bark stripping. Cone removal from trees has also been observed which has serious consequences for tree improvement research, and genetic value is lost from seed orchards. Baboon damage was first recorded on the Eastern Escarpment of Mpumalanga, South Africa in the mid 1970's (Internal Memo, South African Forest Investments, 1975). Damage by baboons has also been reported in Zimbabwe, with the first instances of damage being recorded in the early 1940's, and damage levels in Zimbabwe are stated to be excessive, and a severe threat to the continued viability of plantation forestry in that country (Valintine, 2001).

Baboons are not the only primates to strip bark from forest trees. The Barbary macaque (*Macaca sylvanus*) of the Middle Atlas Mountains in Morocco is reported to strip bark from cedar forests (Ciani *et. al.*, 2001). Blue monkeys (*Cercopithecus mitis*) are reported to strip bark from *Pinus patula* plantations in Tanzania (Maganga and Wright, 1991), and chimpanzees are reported to strip bark from a variety of trees, shrubs and wood vines in Tanzania (Nishida, 1976). Samango monkeys (*Cercopithecus (mitis) albogularus*) have also been reported to strip bark from commercial plantations in South Africa (von dem Bussche and van der Zee, 1985).

Baboons strip bark from trees by first biting on the stem to loosen the bark, and then pulling sections of bark loose from the trees with their paws. They do this while sitting in the live crown of the tree. They use their teeth to scrape the succulent, moist, inner bark layer from the main stem, and scrape the stripped pieces of bark over the teeth of the lower jaw. It appears that the soft, inner tissue is sought after and not the outer bark. The cork cambium of the bark may also be chewed on for periods of time, however this is not swallowed, but spat out onto the ground, (Dyer, 2002, *pers. comm.*). Damage intensity in the Mpumalanga Province of South Africa is lowest during winter and increases prior to the growing season. However, damage is reported to increase during winter in Zimbabwe (Valintine, 2002, *pers comm.*) and the southern Cape of South Africa (Erasmus, 1993), and during spring in the Western Cape (Erasmus, 1993). In terms of pine species preference by primates, *Pinus patula* is preferred by blue monkeys in Tanzania (Maganga and Wright, 1991), *Pinus taeda* by baboons in Mpumalanga (Viljoen and Pienaar, 1997) and Zimbabwe (Valintine, 2001), and *Pinus radiata* and *Pinus pinaster* by baboons in the Cape Provinces (Erasmus, 1993). The species preference however more likely reflects the availability of the various species in the home range of the damaging troops. It is however confirmed that the softer bark species are more readily stripped than others (for example *Pinus patula* over *Pinus elliottii*).

In terms of bark stripping by baboon in pine plantations, anecdotal evidence by foresters in Mpumalanga, and recorded comments in Bigalke and van Hensbergen (1990), is that damage appears to occur shortly after a pruning operation has taken place. The removal of live branches during the pruning operation is suggested to change the photosynthetic dynamics of the tree, resulting in a change in sap flow composition, which may yield higher concentrations of nutrients that are more appealing to baboons.

There are other reports that the bark stripping behaviour of baboons is due to the following assumptions and that nutrition does not play a role:

- "they may just enjoy the taste and thus find it worthwhile to expend energy and time to access the soft inner bark tissue layers of pine trees",
- "it is merely a boredom habit",
- "the terpentine component of the pine resin has become addictive to the baboons",
- "they are merely searching for insects underneath the bark",
- "the terpenes in the resin may act as an antihelminthic agent",
- "it has become a response to looking for food hidden by workers in the plantation – reason being that during pruning and thinning operations workers hide their lunch boxes away as they were regularly raided by troops",
- "the moisture content of inner bark tissue provides a source of liquid refreshment", or
- "the super-abundance of identical food items (pine trees) act as super-normal stimulus to the baboons, leading to excessive stripping (Beesen, 1985)".

2.5 Tree physiological responses

Anecdotal evidence in South Africa indicates that damage to pine trees by baboons increases just prior to the start of the growing season (late August, early September). Reports from Zimbabwe state that damage increases during the winter period (Valintine, 2002, *pers.comm.)* which coincides with reports on damage to pine plantations by blue monkeys (*Cercopithecus mitis*) in Tanzania, where tree damage was generally low during the wet season and peaked during the dry season (Mananga and Wright, 1991). Further anecdotal evidence from foresters in Mpumalanga indicates that bark stripping by baboons occurs shortly after pruning live branches.

Literature was reviewed for relationships between growth, season and wound response (such as with pruning) on the nutrient concentration of inner bark tissues (cambium, phloem and xylem). A study conducted by Erasmus (1993) in the Western Cape Province of South Africa in *Pinus radiata* trees investigating mineral concentrations, nitrogen and moisture content is referred to, as well as a previous investigation (Bigalke *et. al.,* 1981) of carbohydrate levels of *Pinus patula, Pinus elliottii* and *Pinus taeda* in the Limpopo Province of South Africa. Other than these studies focused on baboon damage, very few cited values from literature could be obtained for concentrations of nutrients in the inner bark tissues. However the effect of season (including drought stress) and growth, and response to wounding and defense mechanisms have been discussed, as these may play a role in understanding the changed tree physiological responses that may lead to baboon damage. The majority of information available was from studies in the USA on bark beetle interactions with *Pinus taeda* (Blanche *et. al.,* 1992, Dunn and Lorio, 1991 and Hodges and Lorio, 1969), fertilizer and water stress studies in the USA (Warren *et. al.,* 1999), moose damage (Faber, 1996), squirrel damage (Pederson and Welch, 1985), and the effects of pruning on tree growth conducted in New Zealand and Australia (Pinkard and Beadle, 2000 and 1998, Pinkard *et. al.*, 1999, and Proe *et. al.*, 2000).

2.5.1 Tree physiological responses to seasonality

Partitioning of biomass is dependent on the functional balance between plant parts, and the relative requirement of the areas for carbon utilization. Roots supply water to the needles and the needles in turn supply nutrients to the roots. Where good water availability is present on sites, partitioning to roots is less than where water availability is poor (Cannell, 1985). Where pines experience a shortage of carbohydrates caused by a loss of foliage (i.e., with pruning), the tree response is to allocate more carbon to the growth of shoots and foliage. In *Pinus taeda* under drought stress, increased carbon allocation went to the root systems at the expense of shoot and foliage (Dewar *et. al.*, 1994). This highlights the ability of trees to respond to changes during a growing cycle.

Pines begin each phenological year with a reserve of stored carbohydrates (Dewar *et. al.*, 1994). These stores are mobilized through the phloem to support early season growth. However most of the growth that occurs in pines within a year is dependent on the amount of carbon fixed within that year. Carbon fixation is a function of leaf area, rate of carbon fixed per unit leaf area and site resource limitations of photosynthesis. Internal and external factors influence carbon allocation for growth and photosynthesis. Internal factors include tree phenology, where some species show fixed growth in which the number of needle primordial is determined in the autumn. Therefore the conditions experienced in the previous autumn determine the spring reserves. External factors that alter carbon allocation patterns of pines include light, temperature, moisture, nutrient availability and competition. A balance in carbon utilization and mineral nutrients for growth must be obtained from the assimilates of the needles and absorption of mineral nutrients by fine roots (Dewar *et. al.*, 1994).

Rate of nutrient accumulation by a plantation, is a function of the rate of growth, the development stage and the availability of soil nutrients. It is reasonable to suggest that the rate of needle fall throughout the rotation is broadly proportional to the rate of production of new foliage (Miller, 1984). Nutrient concentrations vary greatly between component parts of trees. Nutrient rich foliage and lateral roots reach their maximum development rather early in the rotation, whereas biomass of nutrient poor, woody, structural organs accumulate progressively. The difference is more apparent in concentrations between deciduous and evergreen species. Appreciable differences in nutrient concentrations occur even within species, planted on different sites due to soil supply having a greater influence than genetic factors on the concentration of nutrients in tree tissues (Miller, 1984). Nutrient ions taken up by a tree may be translocated into and out of a variety of tissues, where they may become involved in a range of growth processes or stored, before being either immobilizied in accumulating structural tissues or released through litter fall, root death or crown leaching (Miller, 1984). As tissues mature nutrient ions, other than those irretrievably bound in structural tissues are liable to be withdrawn back into the living tissues. As foliage ages many nutrients are translocated back into living tissues, a process that accelerates during the weeks prior to needle fall. From 60-85% of the major nutrients can be conserved in this way, an exception being calcium, which accumulates with age and is present in high concentrations in litter fall (Miller, 1984). After uptake, long distance transport of mineral nutrients takes place primarily in the xylem where they are carried in the transpiration stream. The composition of xylem sap is not constant as it flows through the tree and amino acids may be differentially accumulated and metabolized in the xylem tissue. Phloem sap is more concentrated than xylem sap and 80-90% of the solids in the sap are carbohydrates, with sucrose being the most abundant. Retranslocation from senescing tissue takes place through the phloem. Substantial amounts of nutrients have been shown to be withdrawn from young *Pinus radiata* needles to support seasonal growth of new shoots (Fife and Nambiar, 1982). A reported estimate on a tree basis is that 86, 48 and 39% of phosphorus, nitrogen and potassium respectively, in summer shoots could have come from retranslocation from 4-5 month old needles formed during the preceding spring. Recovery to spring needle nutrient levels coincided with autumn rain (Fife and Nambiar, 1982). Seasonal variations in nutrient levels of *Pinus patula* foliage recorded by Morris (1984) showed that nutrient levels drop at about the same time that *Pinus patula* starts its first flush of growth in early spring. The spring internode is generally the longest formed during the growing season, and the rapid elongation and formation of new needles requires a high rate of supply of nutrients. In August (start of spring in Southern Hemisphere) summer rains have yet to commence and the soil profile remains dry, preventing supply of nutrients from the topsoil. Nutrient supply for this early growth depends largely upon retranslocation of nutrients from older needles and branches into the new growth. The increase shown in nutrient levels in needles during the late spring/summer period corresponds with more frequent rainfall, when topsoil becomes moist and increased nutrient supply comes from the soil (Morris, 1984). As all retranslocations are transported through the inner bark tissues, there may be certain times of the year or certain management practices that alter nutrient concentrations of inner bark tissue, possibly making it more worthwhile to baboons to damage pine trees.

Knowledge of relationships between tree growth and development, including inner bark characterization, in response to environmental conditions is necessary to understand bark beetle/tree interactions (specifically Southern Pine Beetle and *Pinus taeda*), as studied in the USA (Blanche *et. al.,* 1992). Marked seasonal changes occurred in carbohydrate and nitrogen fractions in the phloem, which coincided with beetle infestations, and influenced subsequent alterations in resin flow, the primary defense of pine trees to bark beetle attack. Total levels of sugars increased from May (spring in northern hemisphere) to a maximum in August (summer), followed by a sharp decline for 2 weeks, a subsequent increase to a high level for an extended period and then a gradual decline to a low constant level. Starch content generally declined from May until year end with intermittent trivial increases. Decline toward year end is stated to be closely associated with a general decline in air temperature during the winter period. Clear seasonal changes also occurred in amino nitrogen and total nitrogen. Amino nitrogen levels peaked distinctly in May and June, and again in late November, early December, and were at the lowest levels in April and August. Total nitrogen first peaked in June, then late September-early October, and finally in December. The pattern of change again concurs with findings of other authors working on the same species as documented in Blanche *et. al.,* (1992). The peaks of amino and total nitrogen coincided with initiation of late wood cells and in a sharp decline with oleoresin yield. The second peak in September was attributed to the major translocation of nitrogen from needles prior to needle fall, and the third peak was reported to be a response to cold winter temperatures (Blanche *et. al.*, 1992).

In water stress treatments that were applied to simulate seasonal fluctuations, the chemical composition of inner bark tissues of *Pinus taeda* in Louisiana, USA, was significantly affected. Water stress conditions included both deficiency and excess moisture (Hodges and Lorio, 1969). An increase occurred in carbohydrates, primarily the simple sugars, in stressed trees. In the carbohydrate analysis for control trees (standard conditions), there was a marked decrease in values from the summer months, and values remained low until the start of autumn when recovery began. Drought conditions markedly altered this pattern. Accumulation of carbohydrates began in summer and peaked during mid-summer. The increase occurred at a time when trees showed initial signs of severe moisture stress. Low values for total carbohydrates during the summer were due entirely to a decrease in starch. There was a general decrease in starch from early summer to the beginning of autumn, and the pattern was the same for all trees until mid summer, at which time the decrease became slightly more pronounced in stressed trees. In contrast to starch, total sugars increased markedly. For control trees the increase was in the form of sucrose. In stressed trees, particularly those subjected to drought, much of the increase was in the reducing forms (glucose and fructose). Hexose sugars resulting from photosynthesis, and sucrose constitute most of the sugar pool in *Pinus taeda*, although other sugar compounds are present on a transitory or permanent basis. Compounds from the pool are either used directly for growth of cells or are polymerised to form starch. When starch in turn is hydrolysed, the products are used in growth or accumulate in the sugar pool where they are available for synthesis of starch (Hodges and Lorio, 1969). In research, especially dealing with herbaceous plants, an increase in sugars (particularly reducing sugars) has been accompanied by a reduction in starch (Hodges and Lorio, 1969). Two phases of moisture stress have been identified. The first phase is an initial reaction that breaks down starch, followed by the second phase where starch synthesis again takes place. The results of the above study, showed a decrease in starch in control trees while sucrose increased and reducing sugars (glucose and fructose) showed little change. In stressed trees, the reducing sugars, sucrose, and total carbohydrates accumulated, while starch hydrolysis occurred at about the same rate as for controls (Hodges and Lorio, 1969). Thus the increase in sugars cannot be accounted for on the basis of starch hydolysis alone. It has been suggested that reduced growth under stress results in accumulation of sugars (Iljin, 1957). Since starch hydrolysis was about equal in stressed and control trees it would appear that in control trees the product (reducing sugars) was rapidly used for cell growth, perhaps in preference to the transport sugar (sucrose), whereas in stressed trees at least part of it accumulated in the sugar pool (Hodges and Lorio, 1969).

Nitrogen analyses did not give as clear results as those for carbohydrates. In the early part of the study discussed above, stressed trees and especially those subjected to drought showed less accumulation of insoluble nitrogen than control trees. Total nitrogen accumulation was lower in stressed trees than in controls. Therefore observed differences in insoluble nitrogen could not have resulted from hydrolysis of protein and incorporation of the products into compounds other than amino acids. In the drought treatment, the rate of increase in both total and alcohol-insoluble nitrogen was slow in early spring, and the amount of increase during the entire study period was much less than for the controls. Deficient soil moisture apparently had little effect on amino (soluble) nitrogen (Hodges and Lorio, 1969). Although stress may result in less total nitrogen, at least initially it does not affect amino nitrogen. Hodges and Lorio (1969) state that no universal agreement could be found as to the influence of moisture stress on the various nitrogen fractions.

Plant organs with high turnover rates (such as flowers, fruits, seeds, needles and cambial tissue), rapid growth and decay cycles have higher concentrations of nitrogen than the more structural tissues. The nitrogen content of phloem and xylem sap of plants exhibits marked seasonal and between-plant variation. Phloem sap contains at least 10 times more nitrogen than xylem sap. Phloem sugar content is around 1000 times more concentrated than xylem sap. Nitrogen content and other nutrient concentrations decline at least slightly with age (Mattson, 1980). Genetically programmed rhythms such as diurnal and seasonal changes influence the concentration of nutrients in tissues, but other random factors such as temperature-moisture stresses and tissue damage by abiotic and biotic agents also play a role. Effects vary by plant species, tissue type and duration of the stress factor. Stress may further affect a plant by changes in production of secondary compounds such as alkaloids and allelochemicals, however the extent of these are not well understood (Mattson 1980).

2.5.2 Tree physiological responses to fertilizer

During investigations into mineral nutrition, resin flow and phloem phytochemistry in *Pinus taeda* in relation to Southern Pine Beetle attack in South Eastern USA, it was found that mineral nutrient additions (fertilizer) affect tissue chemistry of conifers (Warren *et al.*, 1999). Although pines in the Eastern Escarpment of South Africa are generally not fertilized, the results bear consideration as fertilized trees had a reduced ability to produce resin. Carbon is used for growth only when sufficient resources exist to support the structural development and physiological activity of additional tissue otherwise the carbon is stored or allocated to secondary metabolism. Compared with unfertilized trees, fertilized trees have larger growth sinks and more available carbon can be used for growth, resulting in less carbon available for production of secondary metabolites (Warren *et. al.*, 1999). Phloem carbohydrate concentrations were reported to vary over time with the fertilized and control trees following similar seasonal trends. When growth became limited by moderate water stress in late summer, photosynthesis continued and excess carbohydrates were allocated to alternative carbon pools such as defensive mechanisms. The result of the study showed that fertilized trees had reduced rates of resin flow by up to 50% (Warren *et al.,* 1999).

2.5.3 Tree physiological responses to damage

The outer bark of pine trees is the defensive barrier to invading organisms, and protects the wood and living cells. The primary defense mechanism of pine trees to damage is the oleoresin secretory system (Tisdale and Nebeker, 1992). When pine trees are damaged, the tree secretes oleoresin to the wound to seal the exposed wood. Ray and epithelial cells start to proliferate to form a callus pad. New cambium is formed which produces phloem to the outside and xylem to the inside. Where wounds are exposed to air and dry out prior to a callus pad forming, healing is accomplished by the growth of tissue from the edges of the wound (Lewis, 1980). Secondary compounds such as phenolics and proanthocyanidins play a role in neutralizing pathogens at the wound site, and preventing fungal development (Warren *et. al.*, 1999). Monoterpenoids, such as alpha-pinene and beta-pinene occur in the bark of pine trees. Pedersen and Welch (1985) suggested that high concentrations of monoterpenoids made bark less attractive to squirrels. The terpenoid content of pine bark has been suggested as an addictive substance to baboons consuming inner bark tissue (Pepler, 2001, *pers. comm.*).

2.5.3.1 Moose

Damage to forests in Sweden by moose (*Alces alces L.*) has been documented since the end of the 19^{th} century, where the main form of damage consists of browsing young pine shoots (Faber, 1996). Stem breakage and bark stripping occurs to a lesser degree but it has been suggested that bark stripping occurs due to a deficiency of sodium in leaves and twigs. In general it has been agreed that bark stripping in winter is indicative of browse shortage, but it appears in spring that moose actively select bark. A study was undertaken to investigate seasonality of bark stripping in the Grimso Wildlife Research Area in south-central Sweden, and to examine the qualitative value of pine bark (Faber, 1996). It must be noted that in the study only bark down to but not including the stem cambium layer was sampled. The results showed that bark was significantly more actively stripped during the spring and summer months, than at other times of the year. This coincided with the highest concentrations of starch and total carbohydrates in the bark tissue. Although levels of mineral elements (phosphorus, calcium, magnesium and potassium) showed significant variation throughout the year, sodium levels did not vary significantly. The cause of bark stripping did not appear to be selection for high mineral levels, as values in pine bark were lower than in leaves and twigs of two other commonly used species browsed by moose. The total amount of pine bark consumed by moose was too limited to be of any major importance from an energetic standpoint (Faber, 1996). A relationship between bark stripping and an age related change in bark structure was identified. Bark on pines over the height of 4 m was rough, scaly and seemingly less palatable. Bark stripping by moose to trees over this height was notably less. It remains difficult to determine any definitive cause for moose bark stripping in pine (Faber, 1996).

2.5.3.2 Baboons

It is reported in South Africa that significant differences occur between carbohydrate levels of inner bark and outer bark tissues (Bigalke and van Hensbergen, 1990). The result was consistent over the three pine species tested, namely *Pinus elliottii, Pinus patula* and *Pinus taeda* in the Limpopo Province of South Africa. Outer bark tissue concentration of starch and sugars was significantly lower than inner bark tissue. Seasonal differences occurred in the carbohydrate concentration, where higher levels occurred during spring and summer than in winter. The energy yielded by consumption by baboons, of the inner bark tissues was very low (0.2 MJ per 100g inner bark tissue). It is not likely that bark tissue contributes significantly to baboon dietary requirements, (Bigalke *et al*., 1981). In a further study conducted by Erasmus (1993) on inner bark tissues of *Pinus radiata* trees in the Western Cape Province of South Africa, macro and micro nutrients, crude protein, and water content were evaluated. Zinc levels were higher in baboon damaged trees as compared to undamaged trees. The author concluded that there appears to be a selection based on the higher zinc content of damaged trees, inferring that baboons selected trees based on zinc content. Moisture content coincided with the spring growth, following the winter rainfall period. Nitrogen levels (0.3% dry matter or 1.6% crude protein) were comparable to levels found in many of the other plants commonly consumed by baboons (Erasmus, 1993).

2.5.3.3 Squirrels

It is documented that Abert squirrels (*Sciurus aberti)* make use of *Pinus ponderosa* trees to meet their dietary requirements. Specifically pine seeds, inner bark (phloem, cambium and trace amounts of xylem), terminal buds and fruiting bodies of fungi and mistletoe berries are used as food items. Abert squirrels are totally dependent on terminal buds and inner bark tissue during winters with heavy snow. The purpose of the study by Pederson and Welch (1985) was to determine the role monoterpenoids and crude protein content play in the selection of trees as food sources. Squirrels first peel off the outer bark of twigs before proceeding to chew the inner bark tissue. The mean crude protein value of inner bark was 2.4% of dry matter. In bark peeling studies conducted on twigs sampled, pine trees used by squirrels were distinctly easier to peel than pine trees not used by squirrels for food requirements. Pedersen and Welch (1985) suggested that high concentration of monoterpenoids made bark less attractive to squirrels.

2.5.3.4 Monkeys

In work conducted on pine tree damage by blue monkeys (*Cercopithecus mitis*) in Tanzania, (Mananga and Wright, 1991), the greatest recorded damage to pine trees was to trees of intermediate size (neither the largest nor the smallest diameters at breast height). The reason was related to the chemical and physical characteristics of the bark. The bark of dominant pine trees was tougher than that of intermediate trees. In addition, dominant trees were thought to have higher concentrations of secondary chemical compounds such as tannins than the intermediate trees, and suppressed trees were thought not to be preferred due to the thin layer of the phloem. Damage occurred on the middle and top sections of the trunk possibly due to the higher concentrations of carbohydrates in the phloem of the aerial tissues. Nishida (1976) reported that chimpanzees feed on bark during specific times of the year, often coinciding with periods of low fruit availability. Seasonality in debarking might also be related to the ease with which the bark can be peeled. According to Wilcox (1962) this is usually just before the leaf-growing season (vegetative growth) during the period of high cambial activity.

2.5.3.5 People

The ease of bark peeling in spring/early summer has been documented in work done to understand the usage of Scots pine (*Pinus sylvestris L.*) inner bark by the traditional Saami people in Northern Sweden (Niklasson *et al*., 1994). The Saami are reported to have used pine inner bark as a thickening agent and/or to mix it with fish, meat and reindeer milk. The native inhabitants of Northern America are reported to have used inner bark from the stems of several trees, preferably pines (White, 1954).

2.5.4 Tree physiological responses to pruning

Removal of live branches during pruning operations results in tree physiological responses. Pruning promotes stem growth in eucalypts and pines, as lower branches that drain tree resources are pruned, more resources are made available for greater stem growth (Pinkard and Beadle, 2000). Pruning severity increases the response up to the limitation of the maximum rate of biochemical reactions involved in photosynthesis. Therefore there is a level of pruning above which the rate can no longer increase. Increased pruning frequency may increase the magnitude and duration of the response. The increased photosynthetic rate with pruning results in plants that have capacity to increase biomass production of the remaining crown. A study with *Eucalyptus nitens* estimated that photosynthetic responses to 50 or 70% live crown removal increased biomass production by 20 and 25% respectively (Pinkard *et. al.,* 1999). Partitioning of biomass is dependent on the functional balance between plant parts. Boosts in foliage production following green pruning operations have been reported, whereby foliage removed by pruning is replaced by regrowth (Leverenz, 1995). This indicates that biomass is allocated to the shoots over the roots to restore the balance in plant parts. Many species have photosynthetic rates below the potential maximum (Harbinson, 1994) and pruning requires photosynthesis in remaining leaves to occur at optimal levels. The instantaneous rate of light saturated photosynthesis of certain species increases, and the response occurs throughout the crown, irrespective of foliage age, but the magnitude and duration of the response is species specific. Increased photosynthetic rates result in increased foliar concentrations of nitrogen, phosphorus, potassium and chlorophyll (Lavigne *et. al.*, 2001). Most pruning investigations report on needle nutrient concentration, which is not comparable with the tissues sampled from the inner bark. However, nutrient concentration in inner bark tissues would be influenced by the pruning as these tissues are responsible for nutrient transport resulting in differences in needle nutrient concentration.

Other factors which influence growth of trees at time of pruning include stand spacing, tree dominance, timing of pruning (as with canopy closure) and site conditions. Tree dominance affects biomass production when pruned trees can no longer compete with unpruned trees. As biomass production is a function of total leaf area, and leaf distribution, tree size, age, vigour and environmental constraints (Cannell, 1985), physiological responses following defoliation have shown to increase biomass production of the remaining crown in the short term. Thus responses to pruning are expected to be short lived. Trees under stress allocate more resources to resin production than biomass production (Warren *et. al.,* 1999). Green pruning of pines results in open wounds on stems of pruned trees, requiring increased levels of resin production. Removal of live crown requires adjustment in nutrient allocation for new foliage production or accelerated rates of photosynthesis. Thus pruning must be conducted within restricted levels of live crown reduction (not more than 33% of live crown), and the response to wounding in biomass allocation must be considered in stipulating management practices. The improvement in wood quality from pruning justifies pruning in pine saw log plantations.

Green pruning has been shown to induce increased foliar boron concentrations in Scots pine (*Pinus sylvestris*) (Nuorteva, 2002). Pruning 50% or more of the live crown increased concentrations of foliar boron markedly for three years. Slightly higher boron concentrations in the needles of *Pinus sylvestris* saplings after moose browsing have been reported, and on Norway spruce (*Picea abies*) there are reports of a positive correlation between foliar boron and crown defoliation (Nuorteva, 2002). It seems that if the crown condition is disturbed enough by rapid loss of needles, foliar boron analysis of the affected trees reflect increased boron concentrations.

2.6 Economic assessment of the baboon damage problem

Pinus species are grown over 705 000 hectares in South Africa as an exotic timber species mostly for the pulp and sawmilling industry. Half of the total area (325 000 hectares) is concentrated on the Eastern Escarpment of the Mpumalanga Province. In 2003 the Gross Domestic Product (GDP) for South Africa was 1 251 468 million Rand (Statistics South Africa, 2004). Of this, the agriculture, forestry and fishing sector contributed 3.4% to the GDP. The forest industry plays an important role towards employment and job creation, specifically in rural areas. Collectively in the timber growing and wood processing industries, an estimated 140 000 people are directly employed (Edwards, 2000). This does not take into account people employed in downstream or upstream activities of the core jobs, nor the dependents supported by the 140 000 people employed. The average round wood sales for the period 2002-2004 amounted to 15.93 million tons per annum. This includes all pine, eucalypt and wattle sold during the period irrespective of product. Of the 15.93 million tons, 8% constituted pine saw log sales or 1.21 million tons on average per annum for the period 2002-2004 (Godsmark, 2004).

Baboon damage in *Pinus* species has been observed since the 1960's in the Western Cape (Anon[d], 1969) and since the mid 1970's in Mpumalanga (Internal Memo, South African Forest Investments, 1975). Pine plantation forestry companies on the Eastern Escarpment of South Africa and the Eastern Highlands of Zimbabwe have been concerned with the extent and intensity of damage to pine plantations by baboons. A perception exists in South Africa that the level of damage by baboons in commercial pine plantations is increasing to unacceptable levels. Bark stripping causes tree deformity, reduced wood quality, and tree mortality. Tree improvement research and genetic value is negatively affected when cones are removed from research trees. Estimates of damage in 1980 were 450 hectares in the Western Cape, 200 hectares at Tsitsikamma, and 300 hectares in Eastern Transvaal (now Mpumalanga), (Bigalke, 1980). In 1997 (Viljoen and Pienaar, 1997) damage levels in Mpumalanga were estimated to be 2 506 hectares.

The age of trees damaged and the position of the damage impacts the value lost to the saw timber industry. Most assessments of damage include the extent of the problem in hectares, and the average percentage of trees affected. This value is then extrapolated to an average volume (growth increment in meters cubed per annum) that is lost. In saw timber the mature tree is divided into a series of logs each with an inherent value depending on the extent of the pruning conducted, and any other defects which may detract from the value. The bottom section of the tree is used for veneer or high grade sawn board used in furniture and other household commodities. These logs fetch a higher value than the subsequent logs. It is therefore important to evaluate not only the volume lost to forestry companies but also the value by log class that is lost through baboon damage. In reviewing damage reports from Zimbabwe and South Africa, no consistent method is applied in determining the value of baboon damage (Erasmus, 1993, Ngorima *et. al.,* 2002 and Viljoen and Pienaar, 1997). Furthermore, the value lost from damaged trees, does not include loss of incremental growth from the damage, re-establishment costs, loss of thinning and clearfelling product revenue due to timber wastage, or losses experienced in down line processing such as at the saw mill. Frequently timber deterioration occurs beyond the visible scar length, as fungal infections discolour and decrease timber quality. This is only determined once the log has been cut into boards at the sawmill. The reports do not clearly indicate year on year variation, as damaged trees removed during thinning or clearfelling activities are not concisely quantified. There is a need to standardize on the method used for baboon damage assessments, so that damage reports and value losses may be compared between areas with baboon damage.

Chapter 3: Materials and Methods

3.1 Study area

3.1.1 Location and topography:

The general study area lies approximately between latitudes 24°46″03′ and 24°47″57′ South, and longitudes 30°51″41′ and 30°51″19′ East. It occurs on part of the eastern Drakensberg escarpment range. The study sites are located on a plantation situated about 20 kilometers from the town of Graskop, Mpumalanga, and 6 kilometers west of the Drakensberg escarpment. Compartments J06, H04C and J12A were selected for the pruning study and compartments J06 and J02B were chosen for the seasonal study. Table 4 provides details of the compartments.

Table 4. Description of compartments selected for the pruning and seasonal studies.

Compartment	Species	Geology	Date Planted	Pruning history	Stems per hectare	Altitude	Midpoint coordinates
H04C	*Pinus patula*	Dolomite	1996/04	2.5 m	1027	1600	24° 46″ 03′ S 30° 51″ 19′ E
J12A	*Pinus patula*	Dolomite	1996/04	2.5 m	1027	1540	24° 47″ 57′ S 30° 51″ 47′ E
J06	*Pinus patula*	Dolomite	1995/06	2.5 m	1027	1620	24° 47″ 24′ S 30° 51″ 41′ E
J02B	*Pinus taeda*	Dolomite	1996/04	2.5 m	1027	1600	24° 46″ 36′ S 30° 51″ 30′ E

The chosen compartments were previously pruned in 2001 to 2.5 m above ground level. The stems per hectare are estimate values, allowing a 93% survival of initial planting density of 1111 stems per hectare, at four years of age. All of the above compartments had trees damaged by baboons.

3.1.2 Climate

3.1.2.1 Precipitation

The Eastern Escarpment lies within the afro-temperate climatic zone with rainfall predominantly in summer. Reliable precipitation records available from a forestry company for eight sites across the region indicate an annual average of 1250 mm of rain. The mean monthly long term variation from all rainfall stations is shown in Figure 1 (McNamara, 2004). Actual mean monthly rainfall for the region is indicated in Figure 1 by the dashed line. Rain falls in the form of heavy downpours to light penetrating showers. An appreciable amount of rain falls in the form of gentle drizzle and mist giving rise to the name, “the mist-belt area”. During the rainy season, precipitation exceeds evaporation, however in winter (dry season) there is little rain and soil dries out, which is accelerated by strong winds.

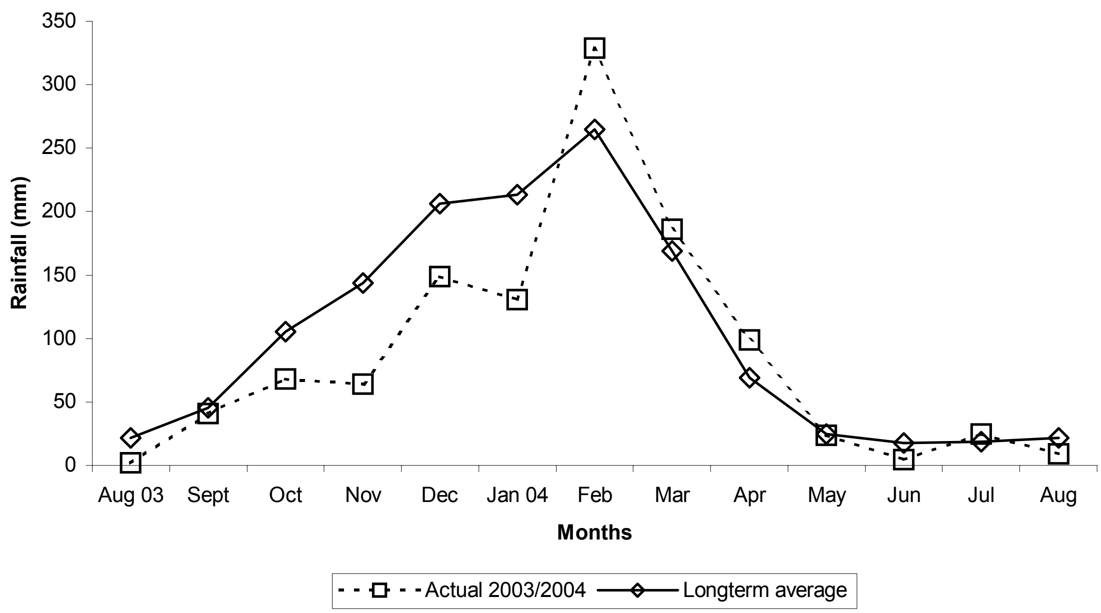

Figure 1. Long term mean monthly and actual mean monthly rainfall for the region (McNamara, 2004).

3.1.2.2 Temperature

The nearest temperature recording station for the study area is located at the town of Graskop. The long term maximum, mean and minimum temperatures for the station are given in Table 5 (Herbert, 1998). The mean monthly annual temperature for Graskop is 14.4 °C. The mean monthly temperature data indicates that the warmest months are December, January and February (17.5 °C, 17.7 °C and 17.5 °C, respectively), and coolest is between June and July (10.9 °C and 10.7 °C, respectively).

Table 5. Temperature data for Graskop (Herbert, 1998).

Station	Altitude masl	Criteria	Jan °C	Feb °C	Mar °C	Apr °C	May °C	Jun °C	Jul °C	Aug °C	Sep °C	Oct °C	Nov °C	Dec °C	Annual °C
Graskop	1478	Max	22.4	22.0	21.1	20.4	18.5	17.2	17.0	18.5	20.7	22.4	22.4	22.7	20.8
		Mean	17.7	17.5	16.6	15.2	12.6	10.9	10.7	12.0	14.2	16.3	16.9	17.5	14.4
		Min	13.0	13.0	12.1	10.0	6.7	4.5	4.3	5.5	7.7	10.1	11.3	12.3	8.0

3.1.2.3 Geology and soil

The geology of the study area consists primarily of dolomite and chert of the Malmani subgroup, Chuniespoort Group, Tansvaal sequence (Idema, 1989). Soils originating from this geology are red apedal dystrophic soils, with high clay and organic matter content, and with fine sand clay loam textures (Soil Survey of London, Mondi Forests, Eastern Escarpment Region, Driekop WPU, 1989-1994).

3.1.2.4 Vegetation and land use

According to Low and Rebelo (1996), the natural vegetation of the area is classed as North-eastern mountain grassland or more commonly as the North-eastern mountain Sourveld. Around 7.4% of this biome is conserved and around 45% has been transformed. Economic uses of the veld type are forestry, grazing and ecotourism. The study area has been established to timber plantations since the mid 1960’s (Malloch-Brown, 2005, *pers. comm.*). It is estimated that the sites are under their second to third rotation of pines (each rotation being around 26 years).

The main usuage of the pine plantations along the Eastern Escarpment area is the production of pine saw logs and veneer lumber. In general, plantations are established to 1111 stems per hectare from seedlings grown from selected seed produced in carefully managed seed orchards. The seed has been improved for tree form, branch angle, and growth (yield). Fertilizer may be applied at re-establishment of pine plantations, but is not a general practice throughout the Eastern Escarpment area. Certain areas are more prone to insect related establishment failures, and under these conditions insecticides are applied in the planting water during establishment. No further applications of insecticides or fertilizer are currently applied during the rotation period.

Generally at least two thinning operations are conducted during the average growing cycle of 26 years. The thinning operations are carried out at 10 and 15 years, whereby selected stems are removed based on poor growth, stem form and to ensure adequate space is created for the remaining trees, reducing competition for light, nutrients and moisture. The major product produced from the trees at first thinning is pulpwood, and second thinning consists of small dimension saw logs and pulpwood. Weeding operations are carried out at various intervals during the rotation period (26 years) but most intensively during the first four years while the trees are still small. Pruning is conducted to specific heights on at least four intervals during the rotation period, but in general all pruning is completed by ten years of age. Pruning is aimed at reducing dead knots in the lumber, and where trees are grown for a long enough period of time, clear lumber is also produced.

Fire is seen as a major risk to plantations and active management is undertaken to reduce the fire risk, such as burning harvested residue prior to re-establishment in strategic areas under specific conditions (temperature, moisture, wind speed, organic carbon content of top soil). Burns are also conducted in natural areas to act as fire breaks, and this is conducted prior to the winter period (end of July).

3.2 Material and methods

Two manipulative studies were conducted in the field namely a pruning study, conducted over a short time period to investigate the effects of pruning on inner bark nutrient concentration in *Pinus patula*, and a seasonal study conducted over a longer period to investigate changes in nutrient concentration of inner bark tissue at different times of the year, between different species of pine (*Pinus patula* and *Pinus taeda*) and between baboon damaged and undamaged trees.

3.2.1 Experimental design: pruning study

The pruning study was designed to investigate what the changes are in inner bark tissue concentration in *Pinus patula* at certain time intervals following pruning. Three compartments were used to obtain sample trees for the study. Sampling of inner bark tissue was carried out at time zero, before pruning was conducted and again at 2, 7, 14 and 28 days after pruning trees to 5.0 m above ground level. Comparative samples were taken on “unpruned trees” at the same time intervals as the pruned treatment. A definition of “unpruned trees” is given below.

Trees in commercial plantation compartments may be selectively pruned. In other words while the crop is still young all trees are pruned, generally until five years of age to a height of 2.5 m above ground level. However, with a saw timber rotation two thinning operations are traditionally conducted, and the main product from the first thinning around ten years of age is for pulpwood. The product does not require pruning. Therefore, trees that are to be removed at the first thinning operation are marked and receive no further pruning activities. The unmarked trees will still receive a pruning lift to 5.0 m at age seven. In this study, unpruned tree refers to marked trees which had a pruned height of 2.5 m, but will not receive further pruning lifts. Although in general it is the trees with poorer form and growth which are marked for removal, the first thinning reduction is in the region of 55% which is greater than the percentage of trees with poor form. The marked trees selected in this study were of comparative size and condition to the unmarked trees.

Due to the size of the wound to the tree in order to obtain an adequate sample of inner bark tissue the same tree was not re-sampled. Instead undamaged trees were sampled at each sample interval. A total of 90 individual trees were sampled during the pruning study. All sample trees were measured for diameter at breast height (DBH) in centimeters with a standard DBH tape, and height in meters using a Vertex Hypsometer prior to the commencement of the study. The method of sampling is described below and treatments are summarized in Table 6.

Table 6. Treatment by species and interval of sampling for the pruning study.

Pruning study			
Compartment	Species	**Treatment**	**Sampling interval**
J06	*Pinus patula*	Prune to 5.0 m	Sample 3 trees by treatment: before pruning (11 August 2003), 2 days (13 August 2003), 7 days (18 August 2003), 14 days (25 August 2003 and 28 days (1September 2003) after pruning
H04C	*Pinus patula*	Prune to 5.0 m	
J12A	*Pinus patula*	Prune to 5.0 m	
J06	*Pinus patula*	No pruning	
H04C	*Pinus patula*	No pruning	
J12A	*Pinus patula*	No pruning	

3.2.2 Experimental design: seasonal study

The study investigated differences in concentration of inner bark tissues between *Pinus patula* and *Pinus taeda,* across seasons, and between baboon damaged and undamaged trees. The study did not cover all age groups that are currently damaged by baboons, but focused in the 5-7 year age class where most intensive pruning is conducted, and where it appeared that the most extensive damage occurred.

Three trees were sampled per site and damage category, i.e., baboon damaged trees and undamaged trees. Trees showing the freshest signs of baboon damage were selected prior to the start of the study. It was intended that if further damage occurred during the sampling period, that trees showing freshest damage would be sampled in place of the pre-selected trees. However no baboon activity occurred during the sampling period. Trees sampled as damaged trees were selected for the type of wound on the tree, with selection against trees severely girdled with dead tops. Sampling was conducted at approximately the same height on all trees, in the live crown where the bark is softest – which generally coincides with the position chosen by baboons. Four samples of inner bark tissue were taken at three monthly intervals to cover seasonal effects. All sample trees were measured for diameter at breast height (DBH) in centimeters with a standard DBH tape, and height in meters using a Vertex Hypsometer prior to the commencement of the study. The sampling intervals are summarized in Table 7.

Due to the size of the wound to the tree in order to obtain an adequate sample of inner bark tissue the same tree could not be re-sampled at each sample interval. Instead trees of similar condition were used at each sample interval. A total of 48 individual trees were sampled during the seasonal study. The method of sampling is described below and treatments are summarized in Table 7.

Table 7. Treatment by species and interval of sampling for the seasonal study.

Seasonal study			
Compartment	**Species**	**Treatment**	**Sampling interval**
J02B	*Pinus taeda*	Baboon damaged	Sample 3 trees by treatment interval: 11 August 2003, 3 December 2003, 12 April 2004, and 2 August 2004.
J06	*Pinus patula*	Undamaged	
J02B	*Pinus taeda*	Baboon damaged	
J06	*Pinus patula*	Undamaged	

3.2.3 Sampling methodology

Inner bark tissue was sampled in the same manner for both studies. The rough, dry outer bark was scraped away with a sharp axe to reveal the corky cambial layer. The size of the area prepared in this way was rectangular (in the region of 10 cm by 30 cm). After the rough bark was removed, a sharp chisel was used to scrape away the soft inner bark tissue, taking care to scrape away all the soft tissue closest to the woody stem. It is the most recently produced xylem lying adjacent to the cambium which carries the main stream of nutrient salts upwards (Richardson, 1968), and this tissue layer was included in the sample. Tissue sampled was analyzed for anatomy and a sketch of the sample is shown in Figure 2. The sample of inner bark tissue was placed in re-sealable plastic bags, marked and sealed, and placed on ice in a cooler box. At least 100 g wet mass of sample was required for the analyses and this was coarsely measured in the field with a light weight scale. The samples were first frozen overnight and then couriered to the Institute for Commercial Forestry Research (ICFR) in Pietermaritzburg, in small polystyrene cooler boxes.

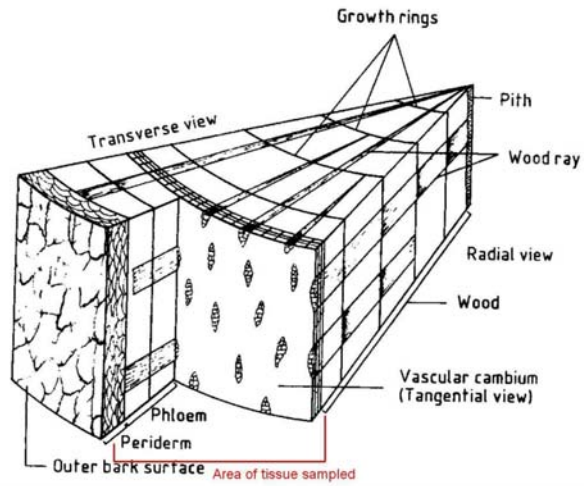

Figure 2. Sketch indicating inner bark tissue zone that was sampled (adapted from Iqbal, 1995).

3.2.4 Methods of chemical analyses

The ICFR conducted the percentage moisture content analyses by taking a sub sample for drying at 105 ºC. The remaining bulk sample was air dried and ground to pass through a one millimeter sieve. Sub samples were analysed by the ICFR for nitrogen, macro nutrients (calcium, magnesium phosphorus and potassium) and micro nutrients (boron, copper, iron, manganese, sodium and zinc), by Cedara for starch analysis and by the Sugar Milling Research Institute (SMRI) for the sugar analyses (glucose, sucrose and fructose).

The ICFR conducted the analyses for macro and micro nutrients and total nitrogen (adapted from methods described in Heffernan, 1985, Kalra and Maynard, 1991 and Nicholson, 1984) as follows:

- calcium, magnesium, copper, iron, zinc and manganese were determined using atomic absorption spectroscopy;
- potassium and sodium were determined using flame emission spectroscopy;
- total nitrogen was assessed using the Kjeldahl method;

- phosphorus was determined by the colour of the reduced complex of antimony phoshomolybdate complex by ascorbic acid at 880 nm; and
- boron was determined by absorption at 420 nm of the yellow colour complex when boron is treated with Azomethine H.

Starch analysis was carried out at the Cedara laboratories through enzymic procedures (Rasmussen and Henry, 1990 and Marais *et al.,* 1966).

The SMRI conducted analysis on the sugars using High Pressure Liquid Chromatography (HPLC), with anion exchange separation and through amperometric detection (Schäffler *et. al.,* 1997 and Day-Lewis and Schäffler, 1992).

3.2.5 Method of statistical analysis

Various statistical tests were used to interrogate the data, using the statistics package Genstat® for Windows™ (Lane and Payne, 1996). Significance of results was determined at the 95% confidence interval. Data were first graphed in histograms to identify if any outliers occurred in the data set. Histograms gave a useful visual impression of the distribution of the data. All data were graphed in this way according to treatment and element. A few outliers were removed through this process following requests to the laboratories to verify the results. The results of the re-analysis were then included into the data set where applicable, and in other circumstances the outliers were removed permanently from the data sets. Graphs were generated from the statistical software package Statistica (StatSoft Inc., 1999). With assistance from a statistician, the most robust test for the data was multi-factorial analysis of variance (MANOVA). Three compartments were used for the pruning study. However as no site differences could be detected as influencing the results, compartments were used as a blocking function in the MANOVA test and data were then pooled.

Chapter 4: The short term response of pruning on the soft inner bark nutrient concentration in Pinus patula.

Abstract

Changes in nutrient concentration of the soft, inner bark tissue of *Pinus patula*, in response to pruning were measured in five year old plantations in the Mpumalanga Province, South Africa. This study was conducted to investigate the claim that baboons were stripping bark from the trees following pruning possibly due to increased translocation of nutrients. Samples of tissues were collected from pruned and unpruned trees at 2, 7, 14 and 28 days after 26% of the live crown had been removed in the pruning treatment. Results indicated that live pruning of *Pinus patula* did not influence nutrient concentration of inner bark tissues at set intervals post pruning. Treatment differences of aggregate data for sample interval showed that potassium concentration increased by 0.03% whereas magnesium concentration decreased by 0.02% following pruning. Aggregate data for treatment showed that phosphorus, carbohydrates (fructose, glucose, sucrose and starch), boron and nitrogen concentration, and moisture content of inner bark tissues varied during the short time period of the study. Variations are attributed to the commencement of growth, translocation of nutrients from needles and branches and possibly moisture stress. Results from the study do not support anecdotal evidence that baboon damage to pine plantations which increases shortly after pruning operations is as a direct physiological response to the pruning event. In this study it is much more likely that changes in nutrient concentrations coincided with a remobilization of resources in response to seasonal triggers.

4.1 Introduction

Pinus species are grown over 705 000 hectares in South Africa as an exotic timber species mostly for the pulp and sawmilling industry. Half of the total area (325 000 hectares) is concentrated on the Eastern Escarpment of the Mpumalanga Province, which lies contiguously with sub tropical fruit orchards and extensive ecotourism areas. *Pinus patula* is the preferred pine species for the South African forestry industry constituting the highest percentage of planted area in the Eastern Escarpment. It has the softest bark of all species planted, which lends itself to severe damage by baboons through bark stripping. It is also a more heavily branched species, with a greater number of branches per whorl, and a greater number of whorls per tree length, than the other two species typically planted in the area, namely *Pinus elliottii* and *Pinus taeda*. It is the species most sensitive to re-establishment, but gives the highest mean annual increment (MAI) in m^3/ha/year and has the best wood properties for both saw milling and pulp. Baboon damage in *Pinus* species has been observed since the 1960's (Anon[d], 1969) and anecdotal evidence from foresters in Mpumalanga indicates that bark stripping by baboons occurs shortly after pruning live branches. Suggestions as to why this damage takes place has been linked to changes in nutrient concentration of inner bark tissue, increased baboon numbers, reduction in natural habitat or to increased zinc availability in pine tree tissue (Erasmus, 1993). Much of the evidence is anecdotal with little knowledge available as to why the baboons damage the trees.

Removal of live branches during pruning operations results in tree physiological responses. Pruning promotes stem growth in eucalypts and pines, as lower branches that drain tree resources are pruned, more resources are made available for greater stem growth (Pinkard and Beadle, 2000). Pruning severity increases the response of stem growth, up to the limitation of the maximum rate of biochemical reactions involved in photosynthesis. Therefore there is a level of pruning above which the rate can no longer increase. Increased pruning frequency may increase the magnitude and duration of the response. The increased photosynthetic rate caused by pruning, results in plants that have capacity to increase biomass production of the remaining crown (Pinkard *et. al.,* 1999). Pruning of pines on the Eastern Escarpment of South Africa is conducted during ages of 3 to 10 years. On average four pruning lifts are done during this time, and guidelines state that at least 33% of live crown must remain after each pruning operation.

Partitioning of biomass is dependent on the functional balance between plant parts. Boosts in foliage production following green pruning operations have been reported, whereby foliage removed by pruning is replaced by regrowth (Leverenz, 1995 and Pinkard and Beadle, 1998). This indicates that biomass is allocated to the shoots over the roots to restore the balance in plant parts. Many species have photosynthetic rates below the potential maximum (Harbinson, 1994) and pruning requires photosynthesis in remaining leaves to occur at optimal levels. Increased photosynthetic rates result in increased foliar concentrations of nitrogen, phosphorus, potassium and chlorophyll (Lavigne *et al*, 2001). Foliar boron concentrations in *Pinus sylvestris* were increased by removing 50% or more of the live crown through pruning (Nuorteva 2002). Allocation of carbon to the apex is higher than the stem in most trees, which explains why height growth is less influenced by pruning than diameter growth. The effect is less evident however, where environmental stresses are present, or nitrogen availability is low (Pinkard and Beadle, 2000).

If live pruning results in stress to the tree it may possibly be compared to other forms of stress experienced by trees. Limitation of growth in late summer due to moderate water stress results in excess carbohydrates not used for photosynthesis being allocated to alternative carbon pools such as defensive mechanisms. Trees under stress allocate more resources to resin production than biomass production (Warren *et al*., 1999). Green pruning of pines results in open wounds on stems of pruned trees, requiring increased levels of resin production. Removal of live crown requires adjustment in nutrient allocation for new foliage production or accelerated rates of photosynthesis. Thus pruning must be conducted within restricted levels of live crown reduction (not more than 33% of live crown), and the response to wounding in biomass allocation must be considered in stipulating management practices. The improvement in wood quality from pruning justifies pruning in pine saw log plantations.

Pruning of trees and other stressors impact on the rate of transportation of solutes and the concentration of elements in the inner bark tissues. The response to pruning is short lived, although the magnitude and duration of the response may be increase with more frequent pruning. The change therefore in nutrient concentration in inner bark tissue is expected to occur shortly following the pruning operation. Together with the anecdotal information on baboon damage and the potential for severe economic implications an experiment was conducted to investigate what the changes are in inner bark tissue concentration in *Pinus patula* at certain time intervals following pruning. The time intervals chosen were 2, 7, 14 and 28 days post pruning, as the response to pruning in nutrient allocation is short lived (Pinkard and Beadle, 2000). Thus, the selected time intervals in this study were deemed adequate to measure if a response occurred in nutrient concentration of inner bark tissue following the pruning treatment.

4.2 Materials and methods

The sites for the pruning study were located on a plantation situated about 20 kilometers from the town of Graskop, Mpumalanga, and 6 kilometers west of the Drakensberg escarpment. The general study area lies approximately between latitudes 24°46″03′ and 24°47″57′ South, and longitudes 30°51″41′ and 30°51″19′ East. It occurs in the summer rainfall area, with most rain falling between October and March. Reliable precipitation records available from a forestry company for eight sites across the region indicate an annual average of 1250 mm of rain. The mean monthly long term variation from all rainfall stations is shown in Figure 3 (McNamara, 2004). Actual mean monthly rainfall for the region is indicated in Figure 3 by the dashed line. Winters are normally dry and cold, with frost commonly occurring in the lower valleys. The mean annual temperature for Graskop is 14.4 °C (Herbert, 1998). The mean monthly average temperature data indicate that the warmest months are December, January and February (17.5 ºC, 17.7 ºC and 17.5 ºC, respectively) and coolest months are June and July (10.9 ºC and 10.7 ºC, respectively). The geology underlying the plantation consists of Dolomite, Quartzite and Shale. Compartments J06, H04C and J12A were selected for the study as they all occur on dolomite geology, are at similar altitude, and receive similar rainfall. Table 8 provides details of the compartments.

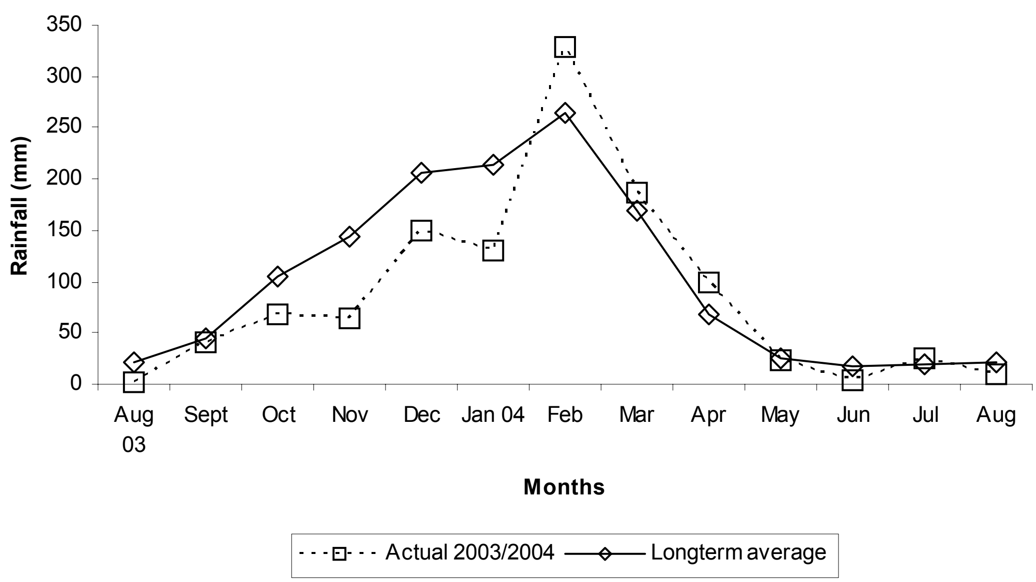

Figure 3. Long term mean monthly and actual mean monthly rainfall for the region (McNamara, 2004).

Table 8. Description of compartments selected for the pruning study.

Compartment	Species	Geology	Date Planted	Pruning history	Stems per hectare	Altitude	Midpoint coordinates
H04C	*Pinus patula*	Dolomite	1996/04	2.5 m	1027	1600	24°46″03′ S 30°51″19′ E
J12A	*Pinus patula*	Dolomite	1996/04	2.5 m	1027	1540	24°47″57′ S 30°51″47′ E
J06	*Pinus patula*	Dolomite	1995/06	2.5 m	1027	1620	24°47″24′ S 30°51″41′ E

The chosen compartments were previously pruned in 2001 to 2.5 m above ground level. The pruning treatment administered in the study increased the pruning height to 5.0 m above ground level on selected trees in August-September 2003. Sampling of inner bark tissue was carried out at time zero, before pruning was conducted and again at 2, 7, 14 and 28 days after pruning trees to 5.0 m above ground level. Comparative samples were taken on “unpruned trees” at the same time intervals as the pruned treatment. A definition of “unpruned trees” is given below.

Trees in commercial plantation compartments may be selectively pruned. In other words while the crop is still young all trees are pruned, generally until five years of age to a height of 2.5 m above ground level. However, with a saw timber rotation, two thinning operations are traditionally conducted, and the main product from the first thinning around ten years of age is for pulpwood. The product does not require pruning. Therefore, trees that are to be removed at the first thinning operation are marked and receive no further pruning activities. The unmarked trees will still receive a pruning lift to 5.0 m at age seven. In this study, unpruned tree refers to marked trees which had a pruned height of 2.5 m, but would not receive further pruning lifts. Although in general it is the trees with poorer form and growth which are marked for removal, the first thinning reduction is in the region of 55% which is greater than the percentage of trees with poor form. The marked trees selected in this study were of comparative size and condition to the unmarked trees.

Due to the size of the wound to the tree in order to obtain an adequate sample of inner bark tissue (100 g wet mass), the same tree was not re-sampled. Instead undamaged trees were sampled at each sample interval. A total of 90 individual trees were sampled during the pruning study. Tissue sampled was analyzed for anatomy and a sketch of the sample is shown in Figure 4.

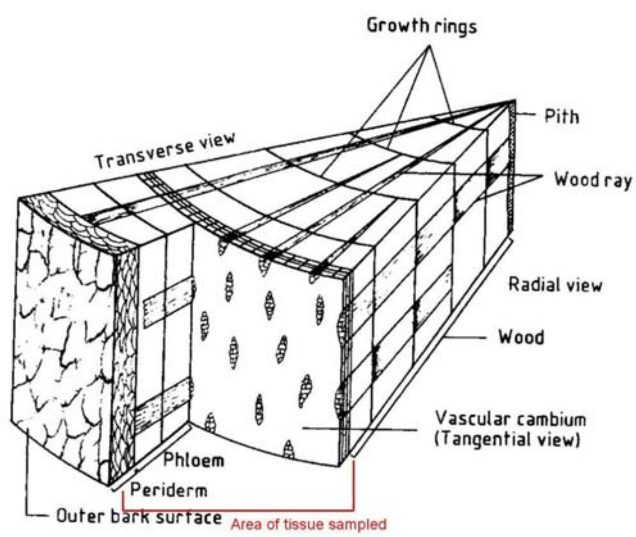

Figure 4. Sketch indicating inner bark tissue zone that was sampled (adapted from Iqbal, 1995).

All sample trees were measured for Diameter at Breast Height (DBH) in centimeters with a standard DBH tape, and height in meters using a Vertex Hypsometer prior to the commencement of the study. The method of sampling is described below and treatments are summarized in Table 9.

Table 9. Treatment by species and interval of sampling for the pruning study.

Pruning study			
Compartment	**Species**	**Treatment**	**Sampling interval**
J06	*Pinus patula*	Prune to 5.0 m	Sample 3 trees by treatment: before pruning (11 August 2003), 2 days (13 August 2003), 7 days (18 August 2003), 14 days (25 August 2003 and 28 days (1 September 2003) after pruning
H04C	*Pinus patula*	Prune to 5.0 m	
J12A	*Pinus patula*	Prune to 5.0 m	
J06	*Pinus patula*	No pruning	
H04C	*Pinus patula*	No pruning	
J12A	*Pinus patula*	No pruning	

The rough, dry outer bark was scraped away with a sharp axe to reveal the corky cambial layer. The size of the area prepared in this way was rectangular (in the region of 10 cm by 30 cm). After the rough bark was removed, a sharp chisel was used to scrape away the soft inner bark tissue, taking care to scrape away all the soft tissue closest to the woody stem. It is the most recently produced xylem lying adjacent to the cambium which carries the main stream of nutrient salts upwards (Richardson, 1968), and this tissue layer was included in the sample. The sample of inner bark tissue was then placed in a resealable plastic bag, marked and sealed, and placed on ice in a cooler box. At least 100 g wet mass of sample was required for the analyses and this was coarsely measured in the field with a light weight scale. The samples where first frozen overnight and then couriered to the Institute for Commercial Forestry Research (ICFR) in Pietermaritzburg, in small polystyrene cooler boxes. The ICFR prepared the sub samples for distribution to the various laboratories conducting specific nutrient analyses.

The ICFR conducted the percentage moisture content analyses by taking a sub sample for drying at 105 ºC. The remaining bulk sample was air dried and ground to pass through a one millimeter sieve. Sub samples were analyzed by the ICFR for nitrogen, macro nutrients (calcium, magnesium phosphorus and potassium) and micro nutrients (boron, copper, iron, manganese, sodium and zinc), by Cedara for starch analysis and by the Sugar Milling Research Institute (SMRI) for the sugar analyses (glucose, sucrose and fructose).

The ICFR conducted the analyses for macro and micro nutrients and total nitrogen (adapted from methods described in Heffernan, 1985, Kalra and Maynard, 1991 and Nicholson, 1984) as follows:

- calcium, magnesium, copper, iron, zinc and manganese were determined using atomic absorption spectroscopy;
- potassium and sodium were determined using flame emission spectroscopy;
- total nitrogen was assessed using the Kjeldahl method;
- phosphorus was determined by the colour of the reduced complex of antimony phoshomolybdate complex by ascorbic acid at 880 nm; and
- boron was determined by absorption at 420 nm of the yellow colour complex when boron is treated with Azomethine H.

Starch analysis was carried out at the Cedara laboratories through enzymic procedures (Rasmussen and Henry, 1990 and Marais *et al.,* 1966).

The SMRI conducted analysis on the sugars using High Pressure Liquid Chromatography (HPLC), with anion exchange separation and through amperometric detection (Schäffler *et. al.,* 1997 and Day-Lewis and Schäffler, 1992).

The data collected were analysed using multi-factor Analysis of Variance (MANOVA) from the statistical package Genstat® for Windows™ (Lane and Payne, 1996). As samples were taken from different compartments, blocking by compartment was applied to the data in the MANOVA. The units of analysis for the micro nutrients are in parts per million, whereas the other categories are shown as percentage of dry mass. Significant differences were determined at the 95% confidence interval. Graphs were generated from the statistical software package Statistica (StatSoft Inc., 1999).

4.3 Results

The main purpose of the experiment was to investigate what the changes are in the nutrient concentration of inner bark tissue of *Pinus patula* following live pruning, in order to determine possible reasons for increased baboon damage shortly after pruning operations, as observed by foresters from the area. The pattern of change in nutrient concentration was of greater interest than the absolute values of nutrients sampled. The major finding of this experiment was that nutrient concentrations of inner bark tissue of *Pinus patula* measured at set intervals post pruning were not significantly influenced by the pruning treatment. Through pooling data in various combinations, patterns of significant change during the sampling interval were obtained for a number of nutrients. The results of the experiment are reported for the main factors investigated (treatment and sample interval), and for the aggregate combinations of treatment or sample interval only. Results are reported under groupings of nutrients, namely macro nutrients, micro nutrients, carbohydrates, nitrogen and moisture content.

4.3.1 Macro nutrients

Macro nutrient concentration of inner bark tissue measured at set intervals post pruning were not influenced by the pruning treatment, the results of which are shown in Tables 10 and 11 below.

Table 10. Values for macro nutrients of the pruned treatment by sample interval.

Element	Treatment	Sample Interval	Mean (%)	Std Dev	Minimum	Maximum	Number
Calcium	Pruned	0 days	0.27	0.13	0.11	0.55	9.00
Calcium	Pruned	2 days	0.29	0.14	0.13	0.61	9.00
Calcium	Pruned	7 days	0.20	0.11	0.08	0.43	9.00
Calcium	Pruned	14 days	0.24	0.15	0.06	0.51	9.00
Calcium	Pruned	28 days	0.20	0.08	0.11	0.34	9.00
Magnesium	Pruned	0 days	0.11	0.03	0.06	0.16	9.00
Magnesium	Pruned	2 days	0.13	0.04	0.09	0.22	9.00
Magnesium	Pruned	7 days	0.10	0.01	0.08	0.11	9.00
Magnesium	Pruned	14 days	0.11	0.03	0.07	0.15	9.00
Magnesium	Pruned	28 days	0.11	0.03	0.07	0.17	9.00
Phosphorus	Pruned	0 days	0.05	0.01	0.03	0.08	9.00
Phosphorus	Pruned	2 days	0.06	0.01	0.05	0.08	9.00
Phosphorus	Pruned	7 days	0.06	0.01	0.05	0.08	9.00
Phosphorus	Pruned	14 days	0.07	0.01	0.05	0.10	9.00
Phosphorus	Pruned	28 days	0.06	0.01	0.05	0.08	9.00
Potassium	Pruned	0 days	0.26	0.13	0.11	0.53	9.00
Potassium	Pruned	2 days	0.26	0.12	0.06	0.42	9.00
Potassium	Pruned	7 days	0.27	0.13	0.12	0.57	9.00
Potassium	Pruned	14 days	0.24	0.08	0.13	0.38	9.00
Potassium	Pruned	28 days	0.23	0.08	0.12	0.34	9.00

Table 11. Values for macro nutrients of the unpruned treatment by sample interval.

Element	Treatment	Sample Interval	Mean (%)	Std Dev	Minimum	Maximum	Number
Calcium	Unpruned	0 days	0.29	0.14	0.12	0.51	9.00
Calcium	Unpruned	2 days	0.28	0.16	0.14	0.70	9.00
Calcium	Unpruned	7 days	0.28	0.12	0.11	0.43	9.00
Calcium	Unpruned	14 days	0.24	0.11	0.10	0.38	9.00
Calcium	Unpruned	28 days	0.27	0.13	0.11	0.49	9.00
Magnesium	Unpruned	0 days	0.12	0.03	0.08	0.17	9.00
Magnesium	Unpruned	2 days	0.13	0.05	0.09	0.24	9.00
Magnesium	Unpruned	7 days	0.12	0.03	0.07	0.16	9.00
Magnesium	Unpruned	14 days	0.11	0.03	0.07	0.17	9.00
Magnesium	Unpruned	28 days	0.14	0.02	0.11	0.19	9.00
Phosphorus	Unpruned	0 days	0.05	0.00	0.05	0.06	9.00
Phosphorus	Unpruned	2 days	0.06	0.02	0.05	0.12	9.00
Phosphorus	Unpruned	7 days	0.06	0.01	0.05	0.08	8.00
Phosphorus	Unpruned	14 days	0.06	0.00	0.05	0.06	9.00
Phosphorus	Unpruned	28 days	0.06	0.01	0.05	0.08	9.00
Potassium	Unpruned	0 days	0.22	0.08	0.12	0.35	9.00
Potassium	Unpruned	2 days	0.22	0.20	0.11	0.77	9.00
Potassium	Unpruned	7 days	0.25	0.07	0.12	0.36	9.00
Potassium	Unpruned	14 days	0.20	0.06	0.12	0.29	9.00
Potassium	Unpruned	28 days	0.21	0.12	0.12	0.50	9.00

If the time component data of the study are pooled, then the concentration of potassium and magnesium in inner bark tissue varies significantly by pruning treatment. Potassium concentration of the inner bark tissue varied significantly (p=0.039) between pruned and unpruned trees, with the pruned trees having higher concentrations of potassium (0.25% compared to 0.22% for the unpruned trees shown in Figure 5). The concentration of magnesium in the inner bark tissue was significantly (p=0.016) lower in pruned trees when compared with unpruned trees (0.11 and 0.13% respectively shown in Figure 6).

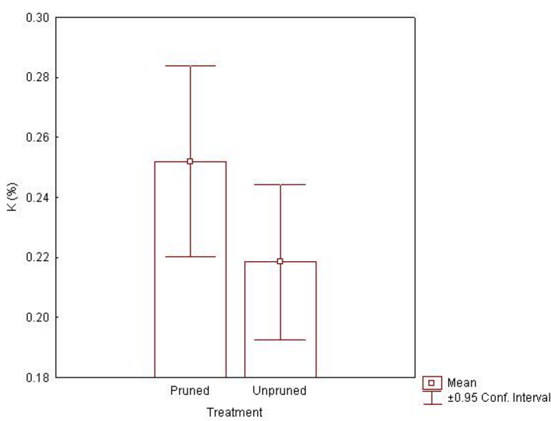

Figure 5. Aggregate sample interval data for potassium concentration of inner bark tissue by treatment.

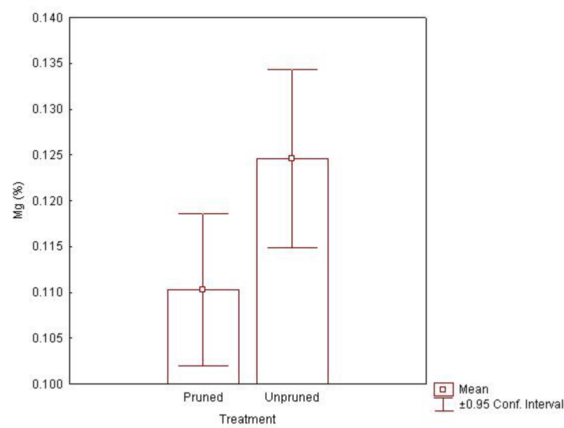

Figure 6. Aggregate sample interval data for magnesium concentration of inner bark tissue by treatment.

When the treatment data were aggregated, statistically significant differences (p=0.018) occurred at different sample intervals in the phosphorus concentration of inner bark tissue. Figure 7 below shows the mean values of phosphorus by sample interval.

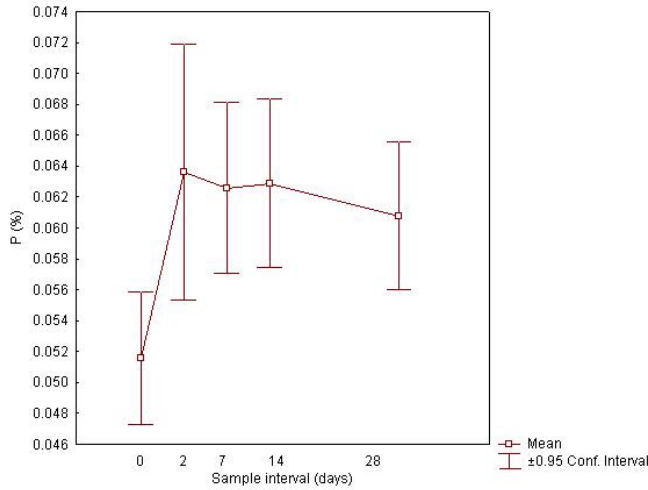

Figure 7. Aggregate treatment data for phosphorus concentration of inner bark tissue by sample interval.

4.3.2 Carbohydrates

Carbohydrate concentrations of inner bark tissue measured at set intervals post pruning were not influenced by the pruning treatment, the results of which are shown in Tables 12 and 13 below.

Table 12. Values for carbohydrates of the pruned treatment by sample interval.

Element	Treatment	Sample Interval	Mean (%)	Std Dev	Minimum	Maximum	Number
Fructose	Pruned	0 days	5.59	1.06	3.90	7.50	9.00
Fructose	Pruned	2 days	5.37	0.95	4.30	6.70	9.00
Fructose	Pruned	7 days	4.29	0.44	3.70	4.90	9.00
Fructose	Pruned	14 days	5.90	1.53	4.60	9.70	9.00
Fructose	Pruned	28 days	5.30	0.64	4.40	6.30	9.00
Glucose	Pruned	0 days	4.57	1.62	2.30	7.20	9.00
Glucose	Pruned	2 days	4.41	0.87	3.40	6.10	9.00
Glucose	Pruned	7 days	3.73	0.59	3.00	4.70	9.00
Glucose	Pruned	14 days	5.07	1.49	3.70	8.70	9.00
Glucose	Pruned	28 days	4.23	0.99	2.00	5.20	9.00
Starch	Pruned	0 days	3.80	2.57	1.56	9.47	9.00
Starch	Pruned	2 days	5.48	3.80	0.01	10.17	9.00
Starch	Pruned	7 days	2.85	2.71	0.01	8.68	9.00
Starch	Pruned	14 days	3.24	3.13	0.01	7.13	9.00
Starch	Pruned	28 days	3.31	3.14	0.64	10.33	9.00
Sucrose	Pruned	0 days	1.81	0.69	0.80	3.00	9.00
Sucrose	Pruned	2 days	2.50	1.13	1.20	4.10	9.00
Sucrose	Pruned	7 days	5.06	1.44	3.20	6.90	9.00
Sucrose	Pruned	14 days	3.37	1.95	1.30	7.90	9.00
Sucrose	Pruned	28 days	2.77	1.48	1.00	4.90	9.00

Table 13. Values for carbohydrates of the unpruned treatment by sample interval.

Element	Treatment	Sample Interval	Mean (%)	Std Dev	Minimum	Maximum	Number
Fructose	Unpruned	0 days	5.92	1.28	3.50	7.80	9.00
Fructose	Unpruned	2 days	5.81	0.96	4.20	7.80	9.00
Fructose	Unpruned	7 days	4.43	0.73	2.70	5.30	9.00
Fructose	Unpruned	14 days	5.51	0.82	4.30	6.60	9.00
Fructose	Unpruned	28 days	5.84	0.60	5.10	7.10	9.00
Glucose	Unpruned	0 days	4.84	1.77	2.10	7.00	9.00
Glucose	Unpruned	2 days	4.97	1.02	3.90	7.10	9.00
Glucose	Unpruned	7 days	3.82	0.64	2.40	4.50	9.00
Glucose	Unpruned	14 days	4.97	0.89	3.70	6.40	9.00
Glucose	Unpruned	28 days	4.58	0.45	3.60	5.10	9.00
Starch	Unpruned	0 days	5.20	2.10	2.05	8.03	9.00
Starch	Unpruned	2 days	4.50	2.71	0.01	9.19	9.00
Starch	Unpruned	7 days	1.75	2.56	0.01	6.72	8.00
Starch	Unpruned	14 days	4.06	4.00	0.01	9.55	9.00
Starch	Unpruned	28 days	3.97	2.56	0.26	8.34	9.00
Sucrose	Unpruned	0 days	2.32	0.96	1.10	3.50	9.00
Sucrose	Unpruned	2 days	2.84	1.03	1.40	4.30	9.00
Sucrose	Unpruned	7 days	5.66	2.69	1.70	9.20	9.00
Sucrose	Unpruned	14 days	4.80	1.97	2.00	8.10	9.00
Sucrose	Unpruned	28 days	2.60	2.08	0.00	7.50	9.00

When the treatment data were aggregated, statistically significant differences occurred at different sample intervals in the concentrations of inner bark tissue of fructose, glucose and sucrose. Fructose concentration was lowest 7 days into the study (Figure 8). Glucose concentrations of inner bark tissue followed the same trend as fructose, with lowest values being realised 7 days into the study (Figure 8). Sucrose concentration of inner bark tissue followed an inverse pattern to the reducing sugars. Maximum levels (5.4%) were reached 7 days into the study. Although starch concentration in inner bark tissue did not show significant differences ($p=0.091$) with sample interval as per the sugars, it did follow a similar trend. Starch concentration was the lowest (2.3%) at 7 days into the study (Figure 8).

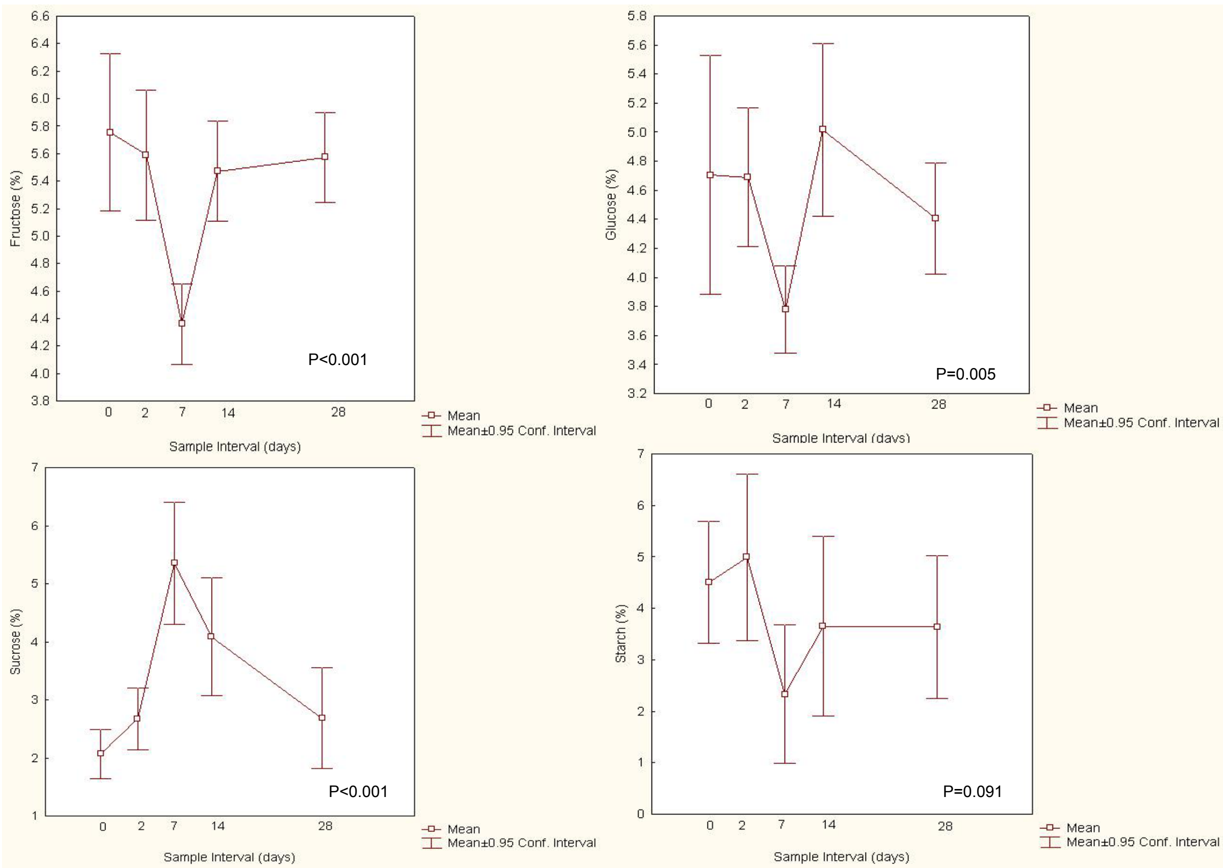

Figure 8. Aggregate treatment data for carbohydrate concentration of inner bark tissue by sample interval.

4.3.3 Micro nutrients

Micro nutrient concentrations of inner bark tissue measured at set intervals post pruning were not influenced by the pruning treatment, the results of which are shown in Tables 14 and 15 below.

Table 14. Values for micro nutrients of the pruned treatment by sample interval.

Element	Treatment	Sample Interval	Mean (ppm)	Std Dev	Minimum	Maximum	Number
Boron	Pruned	0 days	14.28	3.38	9.65	19.00	9.00
Boron	Pruned	2 days	16.46	2.43	11.30	19.34	9.00
Boron	Pruned	7 days	19.84	3.38	14.49	24.65	8.00
Boron	Pruned	14 days	25.39	9.92	13.84	42.00	8.00
Boron	Pruned	28 days	17.50	3.24	10.20	20.63	9.00
Copper	Pruned	0 days	2.39	0.49	1.77	3.29	9.00
Copper	Pruned	2 days	2.31	0.59	1.68	3.60	9.00
Copper	Pruned	7 days	2.19	0.50	1.66	3.33	9.00
Copper	Pruned	14 days	2.46	0.93	1.30	4.37	9.00
Copper	Pruned	28 days	2.09	0.46	1.54	2.82	9.00
Iron	Pruned	0 days	22.06	6.24	12.18	31.88	9.00
Iron	Pruned	2 days	24.37	4.18	18.06	32.18	9.00
Iron	Pruned	7 days	22.88	4.28	16.64	28.78	9.00
Iron	Pruned	14 days	21.16	3.57	15.78	25.44	9.00
Iron	Pruned	28 days	20.27	3.19	16.27	25.16	8.00
Manganese	Pruned	0 days	827.78	204.34	509.00	1134.00	9.00
Manganese	Pruned	2 days	773.67	167.46	507.00	1065.00	9.00
Manganese	Pruned	7 days	774.19	219.14	427.16	1106.00	9.00
Manganese	Pruned	14 days	867.72	242.61	521.95	1398.00	9.00
Manganese	Pruned	28 days	763.37	219.01	444.05	1115.78	9.00
Sodium	Pruned	0 days	450.00	359.06	80.00	1300.00	9.00
Sodium	Pruned	2 days	394.44	195.20	90.00	650.00	9.00
Sodium	Pruned	7 days	343.33	291.16	80.00	970.00	9.00
Sodium	Pruned	14 days	525.56	471.70	90.00	1450.00	9.00
Sodium	Pruned	28 days	316.67	311.05	50.00	990.00	9.00
Zinc	Pruned	0 days	29.59	13.14	17.53	52.47	9.00
Zinc	Pruned	2 days	33.60	13.39	16.47	54.54	9.00
Zinc	Pruned	7 days	31.69	14.41	19.11	53.91	9.00
Zinc	Pruned	14 days	27.31	11.72	10.80	46.71	9.00
Zinc	Pruned	28 days	27.64	10.82	19.34	52.77	9.00

Table 15. Values for micro nutrients of the unpruned treatment by sample interval.

Element	Treatment	Sample Interval	Mean (ppm)	Std Dev	Minimum	Maximum	Number
Boron	Unpruned	0 days	17.33	5.76	11.24	27.18	9.00
Boron	Unpruned	2 days	14.84	2.46	10.92	18.94	9.00
Boron	Unpruned	7 days	19.76	9.15	10.03	39.78	9.00
Boron	Unpruned	14 days	29.22	7.11	20.02	42.00	9.00
Boron	Unpruned	28 days	20.39	9.17	13.31	42.67	9.00
Copper	Unpruned	0 days	2.56	0.71	1.45	4.01	9.00
Copper	Unpruned	2 days	2.18	0.42	1.63	2.84	9.00
Copper	Unpruned	7 days	2.20	0.41	1.36	2.74	9.00
Copper	Unpruned	14 days	2.27	0.37	1.73	2.82	9.00
Copper	Unpruned	28 days	2.50	0.85	1.40	4.34	9.00
Iron	Unpruned	0 days	28.17	11.19	18.47	55.77	9.00
Iron	Unpruned	2 days	24.53	8.33	17.05	45.51	9.00
Iron	Unpruned	7 days	24.93	7.51	16.17	40.42	9.00
Iron	Unpruned	14 days	22.06	5.10	15.13	28.88	9.00
Iron	Unpruned	28 days	22.59	12.63	9.54	53.49	9.00
Manganese	Unpruned	0 days	908.67	235.32	628.00	1399.00	9.00
Manganese	Unpruned	2 days	862.44	224.28	538.00	1128.00	9.00
Manganese	Unpruned	7 days	706.67	340.13	202.78	1255.00	9.00
Manganese	Unpruned	14 days	725.07	179.21	501.26	1043.53	9.00
Manganese	Unpruned	28 days	754.71	226.14	359.12	1143.12	9.00
Sodium	Unpruned	0 days	355.56	248.55	70.00	720.00	9.00
Sodium	Unpruned	2 days	410.00	271.39	70.00	960.00	9.00
Sodium	Unpruned	7 days	471.11	377.14	140.00	1250.00	9.00
Sodium	Unpruned	14 days	411.11	381.39	90.00	1350.00	9.00
Sodium	Unpruned	28 days	538.89	357.02	50.00	910.00	9.00
Zinc	Unpruned	0 days	36.09	19.11	14.83	70.91	9.00
Zinc	Unpruned	2 days	28.80	13.66	17.73	62.88	9.00
Zinc	Unpruned	7 days	33.37	10.01	21.61	46.28	9.00
Zinc	Unpruned	14 days	24.34	7.16	11.54	33.21	9.00
Zinc	Unpruned	28 days	31.58	9.59	22.86	50.89	9.00

When the treatment data were aggregated, statistically significant differences occurred at different sample intervals in boron concentration of inner bark tissue, with levels reaching a maximum value 14 days (27.5 ppm) into the study period (Figure 9).

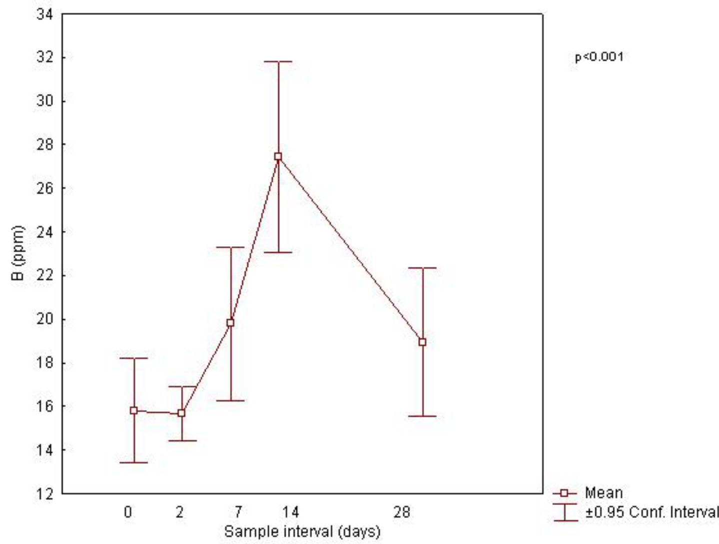

Figure 9. Aggregate treatment data for boron concentration of inner bark tissue with sample interval.

4.3.4 Nitrogen and moisture content

Nitrogen concentration and moisture content of inner bark tissue measured at set intervals post pruning were not influenced by the pruning treatment, the results of which are shown in Tables 16 and 17 below.

Table 16. Values for nitrogen and moisture content of the pruned treatment by sample interval.

Element	Treatment	Sample Interval	Mean (%)	Std Dev	Minimum	Maximum	Number
Moisture content	Pruned	0 days	63.08	2.77	57.80	66.20	9.00
Moisture content	Pruned	2 days	61.19	2.44	56.40	63.90	9.00
Moisture content	Pruned	7 days	63.61	1.67	60.10	65.70	9.00
Moisture content	Pruned	14 days	63.48	2.81	58.90	67.20	9.00
Moisture content	Pruned	28 days	57.26	3.82	51.90	62.10	9.00
Nitrogen	Pruned	0 days	0.44	0.08	0.36	0.62	9.00
Nitrogen	Pruned	2 days	0.51	0.11	0.31	0.67	9.00
Nitrogen	Pruned	7 days	0.47	0.08	0.34	0.60	9.00
Nitrogen	Pruned	14 days	0.53	0.11	0.40	0.75	9.00
Nitrogen	Pruned	28 days	0.48	0.10	0.40	0.68	9.00

Table 17. Values for nitrogen and moisture content of the unpruned treatment by sample interval.

Element	Treatment	Sample Interval	Mean (%)	Std Dev	Minimum	Maximum	Number
Moisture content	Unpruned	0 days	63.41	1.69	60.30	65.60	9.00
Moisture content	Unpruned	2 days	62.48	2.67	58.50	67.60	9.00
Moisture content	Unpruned	7 days	63.78	2.38	60.50	66.80	9.00
Moisture content	Unpruned	14 days	61.66	2.15	58.60	65.80	9.00
Moisture content	Unpruned	28 days	60.52	4.60	53.40	66.00	9.00
Nitrogen	Unpruned	0 days	0.47	0.09	0.38	0.69	9.00
Nitrogen	Unpruned	2 days	0.46	0.09	0.36	0.58	9.00
Nitrogen	Unpruned	7 days	0.49	0.09	0.37	0.64	9.00
Nitrogen	Unpruned	14 days	0.57	0.06	0.45	0.66	9.00
Nitrogen	Unpruned	28 days	0.49	0.11	0.32	0.68	9.00

When the treatment data were aggregated, statistically significant differences occurred at different sample intervals in nitrogen concentrations ($p=0.034$) and moisture content ($p<0.001$) of inner bark tissue. Nitrogen concentrations peaked (0.55%) 14 days into the study (Figure 10). Moisture content of the inner bark tissue became much drier at the end of the study (59% as compared with 63% at the start of the study) as shown in Figure 11.

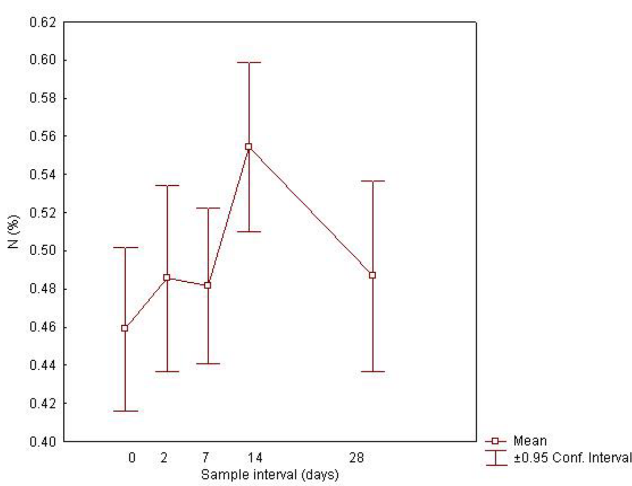

Figure 10. Aggregate treatment data for nitrogen concentration of inner bark tissue by sample interval.

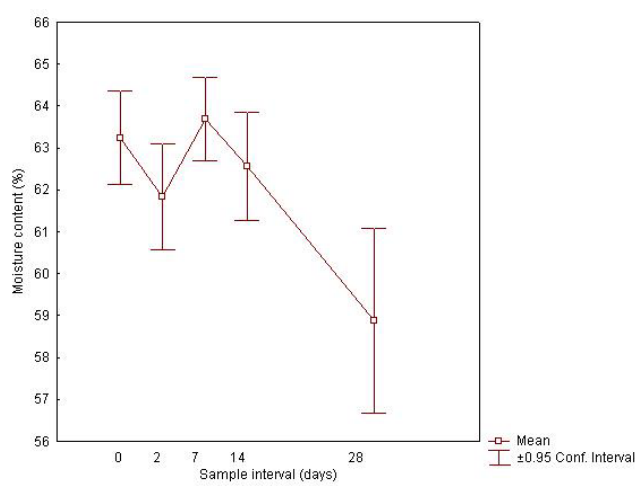

Figure 11. Aggregate treatment data for moisture content of inner bark tissue by sample interval.

4.4 Discussion of results

Nutrient concentration of inner bark tissue measured at set intervals post pruning were not influenced by the pruning treatment. It has been reported in literature that boron concentrations in needles increased under live pruning in excess of 50% of the live crown (Nuorteva, 2002). The response to pruning in reallocating nutrients for increased foliage production or increased rates of photosynthesis is short lived (Pinkard and Beadle, 2000) although the magnitude and duration of the response may be increased by the frequency of pruning. It is reasonable that sampling at 2, 7, 14 and 28 days post pruning would identify a response in nutrient concentration of inner bark tissue to the pruning treatment. It is possible that the pruning lift was not of a magnitude to influence the concentrations of nutrients in the inner bark tissue at the intervals measured. The live crown percentage removed in the treatment was in the region of 26%, calculated from mean tree height measurements.

By aggregating sample interval data for potassium, the pruned treatment showed significantly higher levels of potassium as compared with the unpruned treatment. Potassium is largely involved in maintaining the charge balance across cell membranes but is not incorporated into any structural tissues of plants (Landsberg and Gower, 1997). Potassium stabilizes pH in cells and plays an important role in osmoregulation, it is highly mobile within cells, tissues and in long distance transport via the xylem and phloem. High concentrations of potassium occur in the sieve tubes of phloem tissue contributing to total osmotic pressure and flow of photosynthates from source to sink (Marschner, 1986). Some enzymes are dependant on or are activated by potassium, it is required for protein synthesis and plays a key role in photosynthesis. Following pruning in certain species, the instantaneous rate of light saturated photosynthesis increases, and the response occurs throughout the crown (Lavigne *et. al.,* 2001). Potassium foliar concentration has been shown to increase following increased photosynthetic rates (Lavigne *et. al.,* 2001). It may be possible that potassium concentration of inner bark tissue was elevated in the pruned trees in order to increase the rate of photosynthesis, and compensate for the loss of live crown, although peak demand for potassium was not indicated at any particular time post pruning.

Magnesium concentration in the unpruned trees was higher than the pruned trees. Many enzyme reactions require or are promoted by magnesium, and a key enzyme with a high magnesium requirement is that which regulates assimilate partitioning for starch synthesis and regulates ammonia assimilation within chloroplasts. High levels of potassium affect magnesium function, particularly in protein synthesis (Marschner, 1986). Low magnesium concentration in the pruned trees may be related to higher concentrations of potassium.

Sampling commenced on the 11th of August 2003 and ended at the beginning of September 2003. Growth of *Pinus patula* on the Eastern Escarpment of Mpumalanga, initiates during August (Norskov-Lauritsen, 1963). Furthermore, during August (start of spring in Southern Hemisphere) summer rains have yet to commence and the soil profile remains dry, preventing supply of nutrients from the topsoil. Nutrient supply for this early growth depends largely upon retranslocation of nutrients from older needles and branches into the new growth (Morris, 1984). Pines begin each phenological year with a reserve of stored carbohydrates (Dewar *et. al.*, 1994). These stores are mobilized through the phloem to support early season growth. Xylem is the tissue most involved with the upward movement of water and mineral ions, the rate of which is influenced by transpiration. The living xylem parenchyma cells main function is the storage of starch built up during the growing season, and utilized during cambial activity the following season (Richardson, 1968).

During August, the photoperiod begins increasing and rains have not yet commenced, and were noticeably later than the norm reported for long term averages. Dryness and demand for growth places stress on trees, causing starch to be hydrolysed into sugars. The increased photoperiod also increases time available for photosynthesis by needles. Carbohydrate content of phloem sieve tubes has been shown to increase under conditions favouring rapid rates of photosynthesis in needles. Sucrose is the major transport substance of higher plants. It is a non-reducing but easily hydrolysed derivative of glucose (Richardson, 1968). The noticeable drop in aggregate treatment data for glucose and fructose levels 7 days into the study, could indicate a period of high demand for sugars, potentially for the spring growth. Aggregate treatment data for starch levels were lower at this time, potentially indicating starch hydrolysis to make additional reducing sugars available. The sucrose levels were the highest at 7 days into the study, possibly due to greater demand for growth, and elevated levels may indicate relocation of sucrose through the inner bark tissues. Hexose sugars resulting from photosynthesis, and sucrose, constitute most of the sugar pool in *Pinus taeda* (Hodges and Lorio, 1969). Compounds from the pool are either used directly for growth of cells or are polymerised to form starch. When starch in turn is hydrolysed, the products are used in growth or accumulate in the sugar pool where they are available for synthesis of starch.

The inner bark tissue concentration of phosphorus in the aggregated data for treatment was the lowest at the commencement of the study. Phosphorus has a structural role in plants in RNA, DNA, and phospholipids. It has a key role in energy transfer where in particular phosphate esters are intermediates in metabolic pathways of biosynthesis and degradation. Phosphorus plays a role in regulating release of photosynthates, and influences the carbohydrate metabolism in needles, and sucrose translocation (Marschner, 1986). With the possible increased demand for carbohydrates as discussed above, it may be that phosphorus levels were increased in order to regulate or influence carbohydrate metabolism and sucrose translocation.

Aggregated data for moisture content of inner bark tissues decreased significantly with sample interval indicating continued water stress in the trees. Water stress has been shown to increase carbohydrates, primarily the simple sugars, glucose and fructose (Hodges and Lorio, 1969). At the end of the sampling interval when moisture content is the lowest, fructose levels show a slight increase.

Levels of aggregate treatment data for nitrogen in inner bark tissue peaked 14 days into the study. Plant organs with higher turnover rates (such as flowers, fruits, seeds, needles and cambial tissue) and rapid growth and decay cycles have higher concentrations of nitrogen than the more structural tissues (Mattson, 1980). If the sampling interval coincided with the initiation of spring growth, it could explain the increased demand for nitrogen by cambial activity, and further growth of tissues. The nitrogen content of phloem and xylem sap of plants exhibits marked seasonal and between-plant variation (Mattson, 1980). Genetically programmed rhythms such as diurnal and seasonal changes influence the concentration of nutrients in tissues, but other variations occur due to random factors such as temperature-moisture stresses and tissue damage by abiotic and biotic agents. The extended moisture stress could have contributed to elevated nitrogen concentration.

Aggregated treatment data for boron indicate a similar peak to nitrogen at 14 days into the study. The function of boron in plants is not well understood (Marschner, 1986). A deficiency in boron inhibits or stops primary and lateral root elongation. Interactions have been described between auxins and boron in the differentiation of xylem vessels, although the interaction between auxin level, differentiation and lignification is not well understood. Boron has also been shown to have an effect on membrane permeability, and requirement for boron is higher during seed and grain production than for vegetative growth alone (Marschner, 1986). The peak in nitrogen could coincide with increased cambial acitivity, which may be the cause for increased boron concentration at this time.

The results of this experiment do not support anecdotal evidence that baboons damage pine trees shortly after pruning due to changes in composition of the inner bark tissue as a result of the pruning operation. The change in concentration of certain nutrients in the inner bark tissue over the sampling interval in this study, were interesting in terms of describing the variability that occurs in nutrient concentration over a short time period, irrespective of pruning. There are many other factors that influence inner bark tissue nutrient concentration such as water stress, photoperiod, rate of photosynthesis, relocation of nutrients prior to senescence and mobilization of reserves prior to the commencement of the growing season. The sampling methodology followed in this experiment resulted in large wounds to the trees that did not allow for repeat measures to be taken from the same trees. This may have contributed to the degree of variability in the data which may have masked treatment responses. Improved sampling techniques where the wound caused to the tree is minimal, such as with the USA studies (Blanche *et. al.,* 1992 and Hodges and Lorio, 1969), may allow for repeat samples taken from the same trees. Such equipment and facilities were not available during this study, but would be viewed as an improvement to the method should it be repeated. A further component which has not been investigated in baboon damage studies, particularly following pruning operations, is the response of baboons to an olfactory stimulus with the release of volatile substances following the pruning. This would support anecdotal evidence that damage occurs shortly following pruning operations.

4.5 Conclusions

Nutrient concentration of inner bark tissue measured at set intervals post pruning were not influenced by the pruning treatment. It may be possible that the pruning treatment applied in the experiment was not severe enough to influence nutrient concentration in the inner bark tissue of pines at set intervals post pruning. The frequency of sampling would have been adequate to determine a response. The results from aggregation of data could be describing events occurring in the resumption of spring growth. The anecdotal evidence that baboons damage pine trees shortly following pruning due to a change in nutrient concentration cannot be supported, but additional studies should be undertaken into a possible olfactory stimulus that attracts baboons to freshly pruned compartments.

4.6 References

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Chapter 5: A seasonal study of soft inner bark nutrient concentration in *Pinus patula* and *Pinus taeda* following bark stripping by baboons.

Abstract

Nutrient concentrations of the inner bark of *Pinus patula* and *Pinus taeda* growing on the Eastern Escarpment of South Africa were studied over a seasonal cycle in order to investigate the allegations that baboon damage in the plantations was related to the degree of nutrient remobilization. Significant differences were found in phosphorus concentration and moisture content across seasons and between baboon damaged and undamaged trees. Undamaged *Pinus taeda* trees recorded the highest phosphorus levels in April 2003 (0.13%). Moisture content was lowest in damaged *Pinus patula* trees in August 2003 (57%). Anecdotal evidence that baboon damage to pine trees on the Eastern Escarpment of Mpumalanga increases prior to the growing season is supported by the significant changes in inner bark tissue concentration. Nutrient translocation prior to needle fall alters inner bark nutrient concentration, as does moisture stress and demand for nutrients prior to cambial activity. Pine bark is easier to peel during periods of peak cambial activity. These factors are discussed as they may trigger baboon damage. Significantly higher inner bark tissue concentrations of sucrose (4.25 versus 2.61%), starch (4.75 versus 2.84%) and nitrogen (0.61 versus 0.49%) in *Pinus taeda* compared with *Pinus patula,* supports anecdotal evidence that *Pinus taeda* is preferentially damaged by baboons. Baboon damaged trees contained higher concentrations of zinc (30.4 versus 22.3 ppm) and calcium (0.26 versus 0.20%), and lower concentrations of sucrose (2.95 versus 3.91%) and starch (3.21 versus 4.39%) than undamaged trees, which was attributed to resource allocation to wound response and not that baboons selected trees with higher concentrations of zinc or calcium. The variability of inner bark tissue concentration due to a number of factors highlights that the

reason for baboon damage in pine plantations is not readily answered, and remains a complex problem.

5.1 Introduction

Exotic timber plantations of *Pinus* species occur on 705 000 hectares in South Africa, grown for the pulp and saw milling industries. Half of the total area (325 000 hectares) is concentrated on the Eastern Escarpment of the Mpumalanga Province, which lies contiguously with sub tropical fruit orchards and extensive ecotourism areas. Baboon damage in *Pinus* species has been observed since the 1960's in the Western Cape (Anon[d], 1969) and since the mid 1970's in Mpumalanga (Internal Memo, South African Forest Investments, 1975). Pine plantation forestry companies on the Eastern Escarpment of South Africa and the Eastern Highlands of Zimbabwe have been concerned with the extent and intensity of damage to pine plantations by baboons. A perception exists in South Africa that the level of damage by baboons in commercial pine plantations is increasing to unacceptable levels. The main form of damage reported is bark stripping which leads to tree deformity, reduced wood quality, and tree mortality when bark is stripped around the full circumference of the tree. Cones are removed from trees which impacts tree improvement research and genetic material is lost from seed orchards.

Bark stripping by primates is not an unique occurrence to the pine growing areas of South Africa and Zimbabwe. The Barbary macaque (*Macaca sylvanus*) of the Middle Atlas Mountains in Morocco is reported to strip bark from cedar forests (Ciani *et. al.*, 2001) primarily during periods of water scarcity. Blue monkeys (*Cercopithecus mitis*) are reported to strip bark from *Pinus patula* plantations in Tanzania, (Maganga and Wright, 1991) primarily during the dry season, and chimpanzees are reported to strip bark from 21 species of trees, shrubs and wood vines in Tanzania (Nishida, 1976).

Samango monkeys (*Cercopithecus (mitis) albogularus*) have also been reported to strip bark from commercial plantations in South Africa (von dem Bussche and van der Zee, 1985). Other vertebrate species such as black bears (Yoshimura and Fukui, 1982), squirrels (*Sciurus aberti)* (Pederson and Welch, 1985), moose (*Alces alces L.*) (Faber, 1996), sambar deer (*Cervus unicolor*) (Stafford, 1997) and sika deer (*Cervus nippon*) (Ando *et. al.,* 2003), among other animals are also reported to damage forest trees to access the bark tissues. On the Eastern Escarpment of Mpumalanga, South Africa damage occurs throughout the year but intensity of damage does decrease during winter and then increases prior to the growing season. It has however been reported to increase during winter in Zimbabwe (Valintine, 2002, *pers. comm.*), as it does in the Southern Cape of South Africa (Erasmus, 1993). Damage in the Western Cape however is reported to increase during spring (Erasmus, 1993).

Spring growth of *Pinus patula* and *Pinus taeda* on the Eastern Escarpment starts during August and the first flush is usually terminated during the period October-November (Norskov-Lauritsen, 1963). Pines begin each phenological year with a reserve of stored carbohydrates (Dewar *et. al.,* 1994), which are mobilized through the phloem to support early season growth. Growth is dependent on the amount of carbon fixed within a phenological year. External factors that alter carbon allocation patterns of pines include light, temperature, moisture, nutrient availability and competition (Dewar *et. al.,* 1994). Pine growth in Mpumalanga is multinodal, where subsequent internodes to the first flush are produced during the summer more or less continuously without having specified growth periods. Active growth has been recorded as late as in July, and some elongation has been observed through the winter (Norskov-Lauritsen, 1963). Trees stay dormant or at least semi-dormant for some time in winter. In general *Pinus patula* rests for about two months during June-August, while *Pinus taeda* stops growth a month or two earlier, staying dormant for about four months until mid August. Sometimes there is no period of complete cessation of growth, and data tend to show that under South African conditions the growth stoppage in winter is a temporary slow down rather than real winter dormancy (Norskov-Lauritsen, 1963).

Growth is achieved by a balance of carbon assimilation and nutrient uptake. Water stress conditions that occur during winter months and the relocation of nutrients particularly prior to needle fall influence nutrient concentration and sap flow. Investigations with *Pinus taeda* in the USA (Blanche *et. al.,* 1992) showed total levels of sugars increased in spring to a summer maximum and then declined to a constant level at the onset of winter. Starch content generally declined from May (spring in Northern Hemisphere) until year end with intermittent, trivial increases. Decline towards year end is associated with a general decline in air temperature during the winter period. Clear seasonal changes also occurred in amino nitrogen and total nitrogen. Amino nitrogen levels peaked distinctly in spring, and again in late autumn but were at the lowest levels in April and August. Total nitrogen first peaked in summer and then late in autumn. The peaks of amino and total nitrogen coincided with initiation of late wood cells and in a sharp decline with oleoresin yield. The second peak was attributed to the major translocation of nitrogen from needles prior to needle fall, and the third peak in response to cold winter temperatures (Blanche *et. al.,* 1992). In water stress experiments in the USA with *Pinus taeda,* to simulate seasonal dryness, an increase occurred in carbohydrates, primarily the simple sugars (Hodges and Lorio, 1969). Drought conditions led to an accumulation of carbohydrates in summer, which peaked during mid-summer. The increase occurred at a time when trees showed initial signs of severe moisture stress. Low values for total carbohydrates during the summer were due entirely to a decrease in starch. Total nitrogen accumulation, was lower in stressed trees than in control trees, but the general pattern was the same for treated and control trees (Hodges and Lorio, 1969). Translocation of nutrients accelerates just prior to needle fall in *Pinus nigra* var. *maritima* allowing for 60-85% of the major nutrients to be conserved (Miller, 1984). All relocations are transported through the inner bark tissues, indicating that at certain times of the year nutrient concentrations of inner bark tissue will be altered. These natural tree response patterns may trigger increased baboon activity.

Anecdotal evidence in South Africa indicates that damage by baboons to pine trees increases prior to the start of the growing season. Reports from Zimbabwe state that damage increases during the winter period (Valintine, 2002, *pers. comm.).* Damage to pine plantations by blue monkeys in Tanzania was generally low during the wet season and peaked during the dry season (Mananga and Wright, 1991). Seasonality in debarking might also be related to the ease with which the bark can be peeled. According to Wilcox (1962) this is usually just before the leaf-growing season (vegetative growth), the period when trees have much sap and cambial activity is high. Bark peels more easily during periods of high cambial activity (Wilcox, 1962).

Since 1995, *Pinus taeda* is being planted on a larger scale due to its seedling survival rate and disease resistance for *Diplodia pinea* especially in areas that experience hail, than *Pinus patula*. *Pinus taeda* is reported as the preferred species damaged by baboons in Zimbabwe (Fergusson, 2004). *Pinus patula* however, remains the most economically important pine species grown in South Africa. An investigation was conducted to determine what the seasonal influence is on the nutrient concentrations of inner bark tissue of *Pinus patula* and *Pinus taeda* and between baboon damaged and undamaged trees.

5.2 Materials and Methods

The sites for the seasonal study were located on a plantation situated about 20 kilometers from the town of Graskop, Mpumalanga, and 6 kilometers west of the Drakensberg escarpment. The general study area lies approximately between latitudes 24°46″03′ and 24°47″57′ South, and longitudes 30°51″41′ and 30°51″19′ East. The study area occurs in the summer rainfall area, with most rain falling between October and March. Reliable precipitation records available from a forestry company for eight sites across the region indicate an annual average of 1250 mm of rain. The mean monthly long term variation is shown in Figure 12 (McNamara, 2004). Actual mean monthly rainfall of the region for the study period is indicated in Figure 12 by the dashed line. Winters are normally dry and cold, with frost commonly occurring in the lower valleys. The mean annual temperature for Graskop is 14.4 °C (Herbert, 1998). The mean monthly average temperature data indicate that the warmest months are December, January and February (17.5 ºC, 17.7 ºC and 17.5 ºC, respectively) and coolest months are June and July (10.9 ºC and 10.7 ºC, respectively). The geology underlying the plantation consists of Dolomite, Quartzite and Shale, however compartments J06 and J02B selected for the study both occurred on dolomitic geology. The compartments were at the same altitude, received similar rainfall and had baboon damaged trees. Table 18 provides details of the compartments.

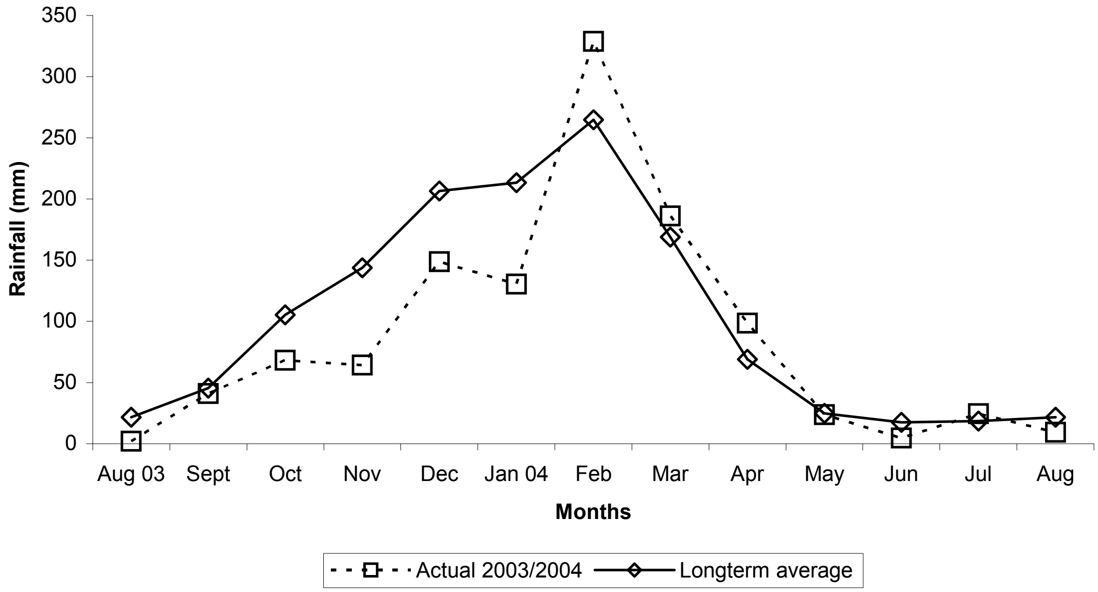

Figure 12. Long term mean monthly and actual mean monthly rainfall for region (McNamara, 2004).

Table 18. Description of compartments selected for the seasonal study.

Compartment	Species	Geology	Date Planted	Pruning history	Stems per hectare	Altitude	Midpoint coordinates
J06	*Pinus patula*	Dolomite	1995/06	2.5 m	1027	1620	24°47″24′ S 30° 51″41′ E
J02B	*Pinus taeda*	Dolomite	1996/04	2.5 m	1027	1600	24° 46″36′ S 30° 51″30′ E

The study investigated the difference in concentration of inner bark tissues between *Pinus patula* and *Pinus taeda,* and between baboon damaged and undamaged trees, across seasons. The study did not cover all age groups that are currently damaged by baboons, but focused in the 5-7 year age class where most intensive pruning is conducted, and where it appeared that the most extensive damage occurred.

Three trees were sampled per site and damage category. Trees showing the freshest signs of baboon damage were selected prior to the start of the study. It was intended that if further damage occurred during the sampling period, that trees showing freshest damage would be sampled in place of the pre-selected trees. However no baboon activity occurred during the sampling period. Trees sampled as damaged trees were selected for the type of wound on the tree, with selection against trees severely girdled with dead tops. Sampling was conducted at approximately the same height on all trees, in the live crown where the bark is softest – which generally coincides with the position chosen by baboons. Four samples of inner bark tissue were taken at three monthly intervals to cover seasonal effects. All sample trees were measured for Diameter at Breast Height (DBH) in centimeters with a standard DBH tape, and height in meters using a Vertex Hypsometer prior to the commencement of the study. The treatment and sampling intervals are summarized in Table 19.

Table 19. Treatment by species and interval of sampling for the seasonal study

Seasonal study			
Compartment	**Species**	**Treatment**	**Sampling interval**
J02B	*Pinus taeda*	Baboon damaged	Sample 3 trees by treatment interval: 11 August 2003, 3 December 2003, 12 April 2004, and 2 August 2004.
J06	*Pinus patula*	Undamaged	
J02B	*Pinus taeda*	Baboon damaged	
J06	*Pinus patula*	Undamaged	

Due to the size of the wound to the tree in order to obtain an adequate sample of inner bark tissue, the same tree could not be re-sampled at each sample interval. Instead trees of similar condition were used at each sample interval. A total of 48 individual trees were sampled during the seasonal study. Tissue sampled was analyzed for anatomy and a sketch of the sample is shown in Figure 13.

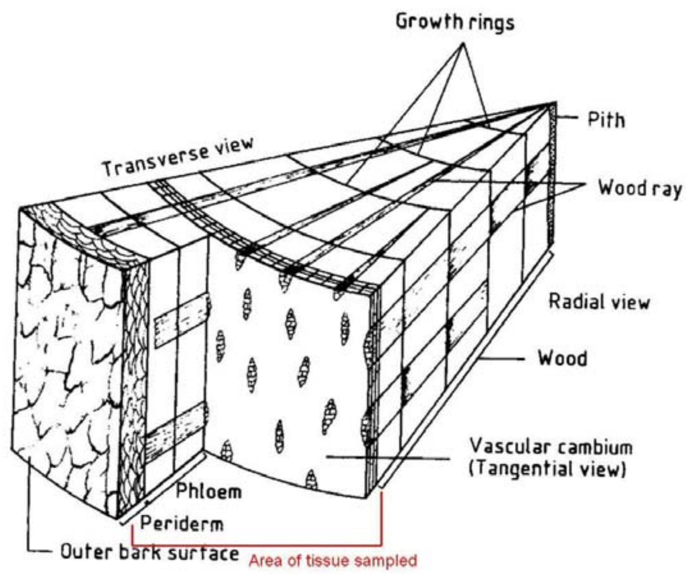

Figure 13. Sketch indicating inner bark tissue zone that was sampled (adapted from Iqbal, 1995).

The rough, dry outer bark was scraped away with a sharp axe to reveal the corky cambial layer. The size of the area prepared in this way was rectangular (in the region of 10 cm by 30 cm). After the rough bark was removed, a sharp chisel was used to scrape away the soft inner bark tissue, taking care to scrape away all the soft tissue closest to the woody stem. It is the most recently produced xylem lying adjacent to the cambium which carries the main stream of nutrient salts upwards (Richardson, 1968), and this tissue layer was included in the sample. The sample of inner bark tissue was then placed in a re-sealable plastic bag, marked and sealed, and placed on ice in a cooler box. At least 100 g wet mass of sample was required for the analyses and this was coarsely measured in the field with a light weight scale. The samples where first frozen overnight and then couriered to the Institute for Commercial Forestry Research (ICFR) in Pietermaritzburg, in small polystyrene cooler boxes. The ICFR prepared the sub samples for distribution to the various laboratories conducting specific nutrient analyses.

The ICFR conducted the percentage moisture content analyses by taking a sub sample for drying at 105 ºC. The remaining bulk sample was air dried and ground to pass through a one millimeter sieve. Sub samples were analysed by the ICFR for nitrogen, macro nutrients (calcium, magnesium phosphorus and potassium) and micro nutrients (boron, copper, iron, manganese, sodium and zinc), by Cedara for starch analysis and by the Sugar Milling Research Institute (SMRI) for the sugar analyses (glucose, sucrose and fructose).

The ICFR conducted the analyses for macro and micro nutrients and total nitrogen (adapted from methods described in Heffernan, 1985, Kalra and Maynard, 1991 and Nicholson, 1984) as follows:

- calcium, magnesium, copper, iron, zinc and manganese were determined using atomic absorption spectroscopy;
- potassium and sodium were determined using flame emission spectroscopy;
- total nitrogen was assessed using the Kjeldahl method;
- phosphorus was determined by the colour of the reduced complex of antimony phoshomolybdate complex by ascorbic acid at 880 nm; and
- boron was determined by absorption at 420 nm of the yellow colour complex when boron is treated with Azomethine H.

Starch analysis was carried out at the Cedara laboratories through enzymic procedures (Rasmussen and Henry, 1990 and Marais *et al.,* 1966).

The SMRI conducted analysis on the sugars using High Pressure Liquid Chromatography (HPLC), with anion exchange separation and through amperometric detection (Schäffler *et. al.,* 1997 and Day-Lewis and Schäffler, 1992).

The data collected were analysed using multi-factorial Analysis of Variance (MANOVA) from the statistical package Genstat® for Windows™ (Lane and Payne, 1996). Statistical significance was determined at the 95% confidence interval. The units of analysis for the micro nutrients are in parts per million, whereas the other nutrients are shown as percentage of dry mass. Graphs were generated from the statistical software package Statistica (StatSoft Inc., 1999).

5.3 Results

The main purpose of the experiment was to investigate changes in the nutrient concentration of inner bark tissue of pine trees with season, in order to determine possible reasons for increased baboon damage at certain times of the year. The pattern of change in nutrient concentration was of greater interest than the absolute values of nutrients sampled. It was identified that moisture content and phosphorus concentration of inner bark tissue varied significantly between seasons, damage category (baboon damaged and undamaged trees) and tree species. Through pooling data in various combinations, patterns of significant change through the year were obtained for a number of other elements, and species specific differences were also identified. The results of the experiment are reported for the main factors investigated (season, treatment and species), and then the aggregate combinations of seasonal, treatment or species effects.

5.3.1 Season x treatment x species

The concentration of phosphorus in April 2004, in undamaged *Pinus taeda* trees was significantly greater than all other variables tested ($p=0.039$) (Figure 14).

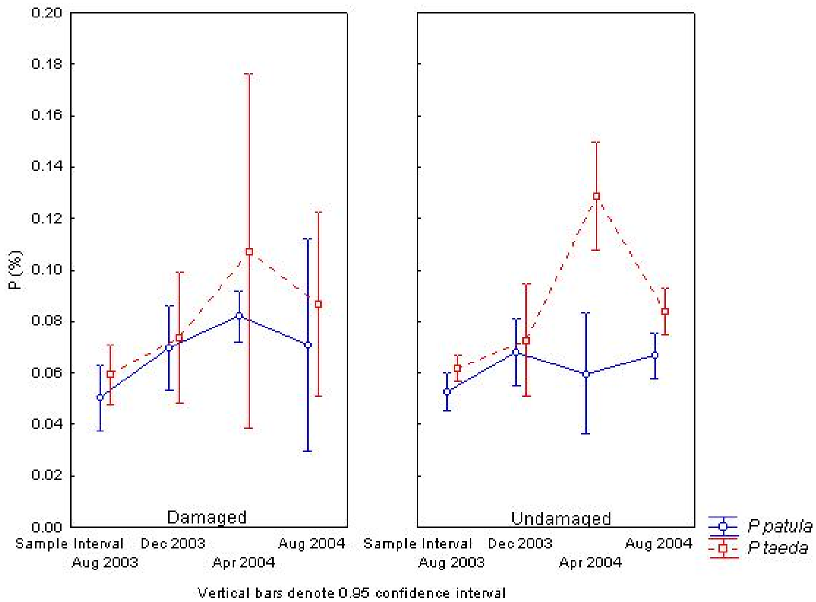

Figure 14. Phosphorus concentration of inner bark tissue for *Pinus patula* and *Pinus taeda*, by season and damage category.

Moisture content varied significantly for damaged *Pinus patula* trees in August 2003, and damaged *Pinus taeda* trees in December 2003 and April 2004, compared with the other variables (p=0.008) (Figure 15).

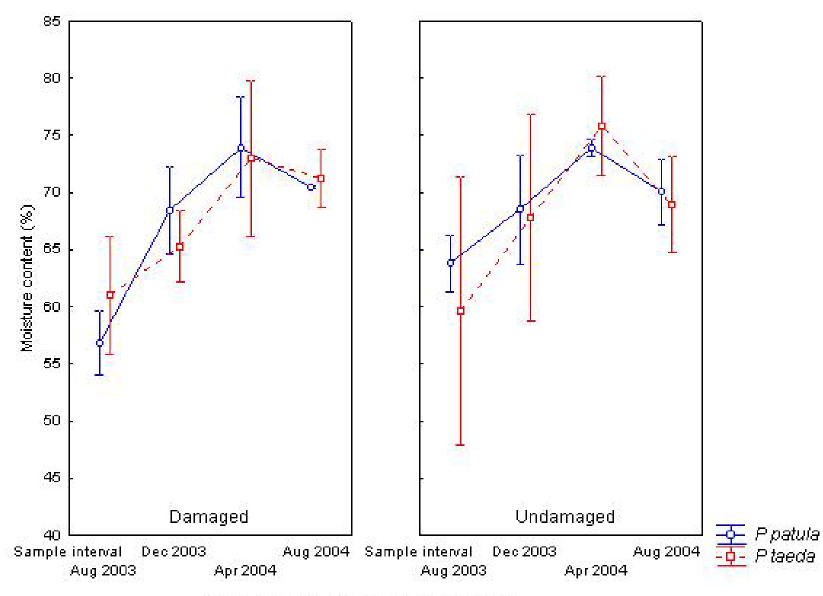

Figure 15. Moisture content of inner bark tissue for *Pinus patula* and *Pinus taeda*, by season and damage category.

5.3.2 Season

By aggregating the data for species and damage category, significant differences across the seasonal measurements were obtained. Inner bark tissue concentration of nitrogen, moisture content and concentration of carbohydrates influenced by season are graphed below in Figures 16 to 21. Peak moisture content occurred in April 2004, whereas sucrose concentration was the lowest at the same sample interval. Fructose and glucose concentrations both followed the same trend of increase and decrease through the year. Starch concentration decreased throughout the duration of the experiment.

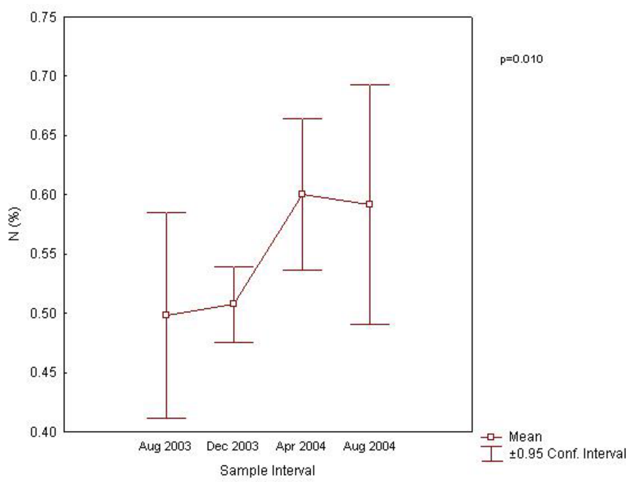

Figure 16. Aggregate species and damage category data for nitrogen concentration of inner bark tissue across seasons.

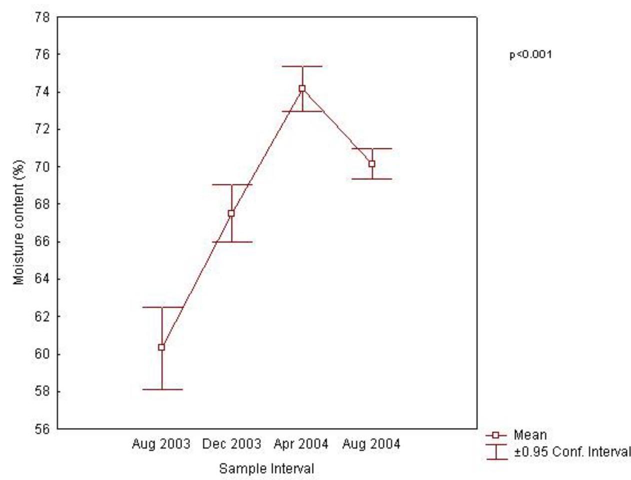

Figure 17. Aggregate species and damage category data for moisture content of inner bark tissue across seasons.

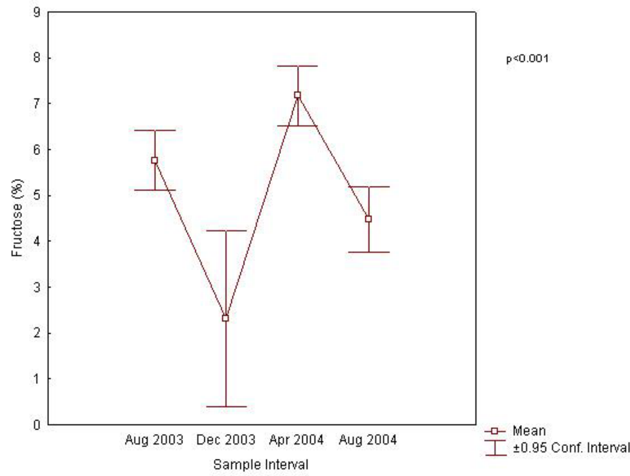

Figure 18. Aggregate species and damage category data for fructose concentration of inner bark tissue across seasons.

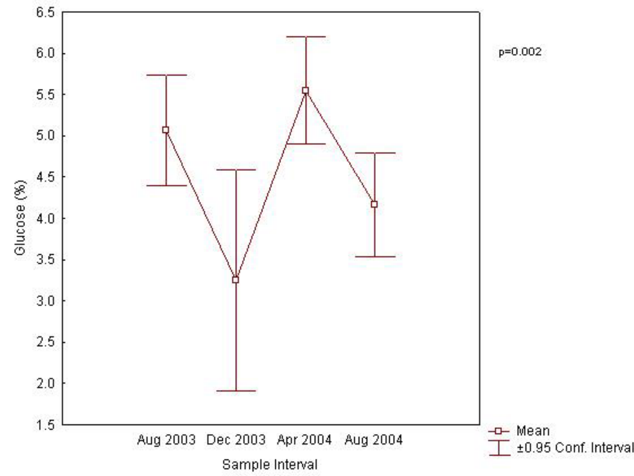

Figure 19. Aggregate species and damage category data for glucose concentration of inner bark tissue across seasons.

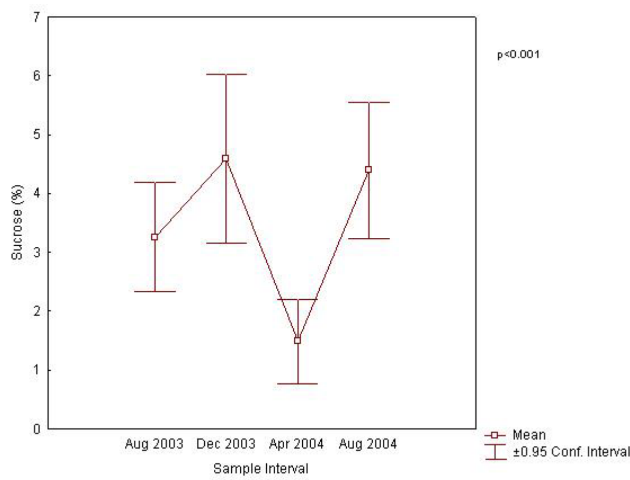

Figure 20. Aggregate species and damage category data for sucrose concentration of inner bark tissue across seasons.

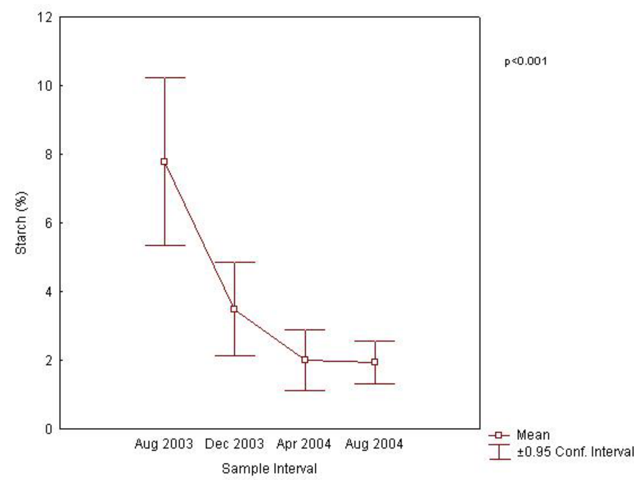

Figure 21. Aggregate species and damage category data for starch concentration of inner bark tissue across seasons.

Significant variations in inner bark tissue concentration for aggregated data for treatment and species also occurred in the following mineral nutrients across the seasons; calcium, phosphorus, magnesium, potassium, boron, copper, iron and manganese. The seasonal variations for the nutrients are shown in Figures 22 to 29 below. Phosphorus, magnesium and boron reached peak concentrations during April 2004. Copper increased consistently over the study period to reach peak concentration in August 2004. Iron and manganese both showed the same pattern of increase to reach peak levels in August 2004.

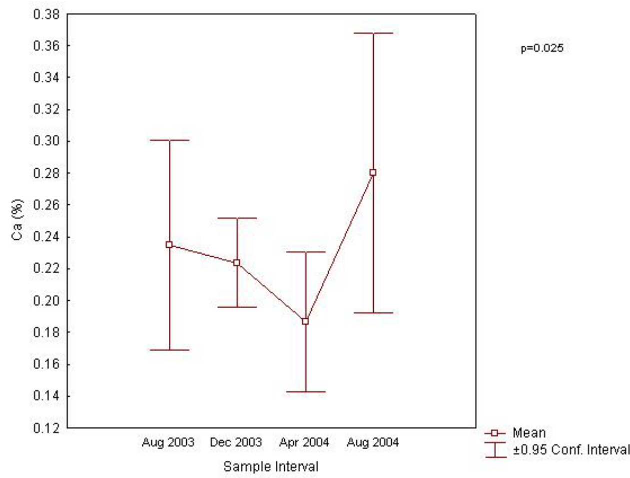

Figure 22. Aggregate species and damage category data for calcium concentration of inner bark tissue across seasons.

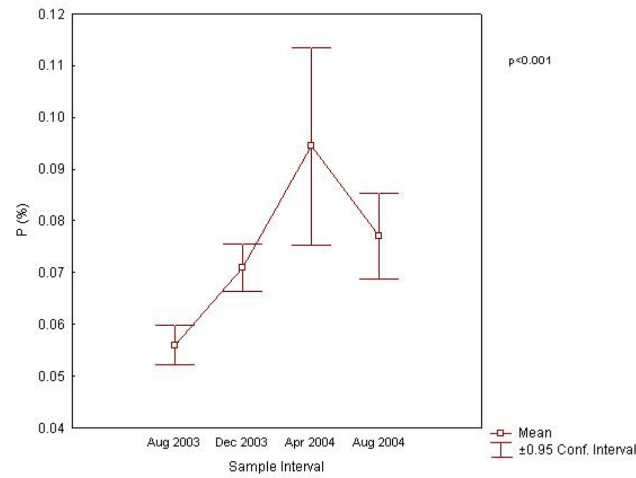

Figure 23. Aggregate species and damage category data for phosphorus concentration of inner bark tissue across seasons.

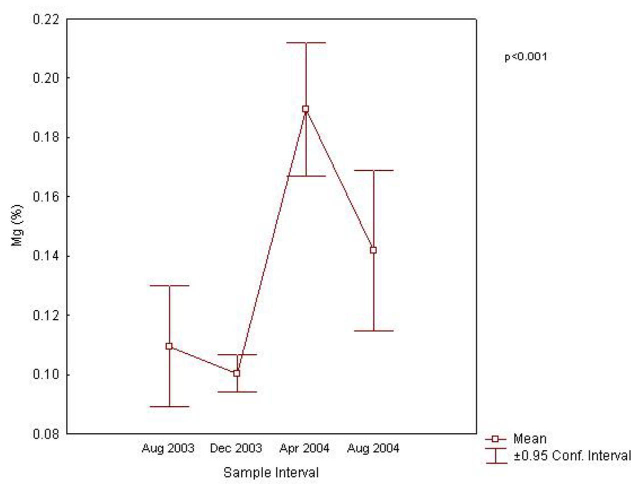

Figure 24. Aggregate species and damage category data for magnesium concentration of inner bark tissue across seasons.

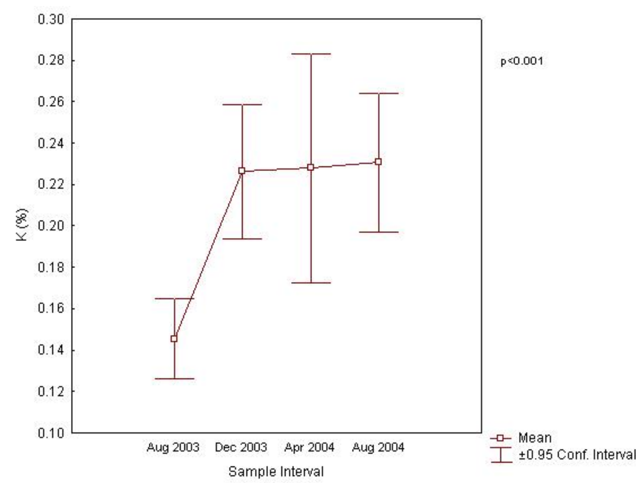

Figure 25. Aggregate species and damage category data for potassium concentration of inner bark tissue across seasons.

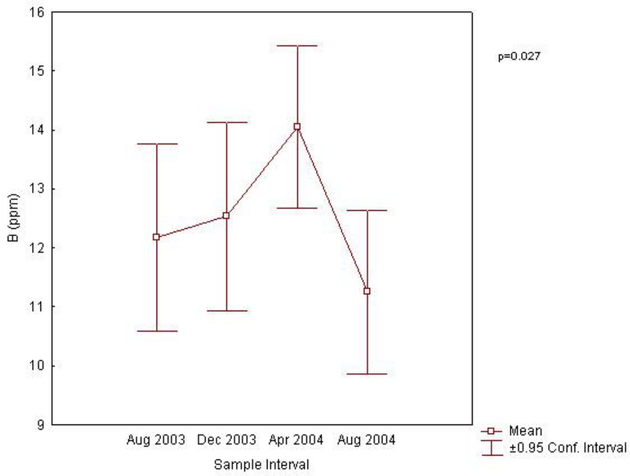

Figure 26. Aggregate species and damage category data for boron concentration of inner bark tissue across seasons.

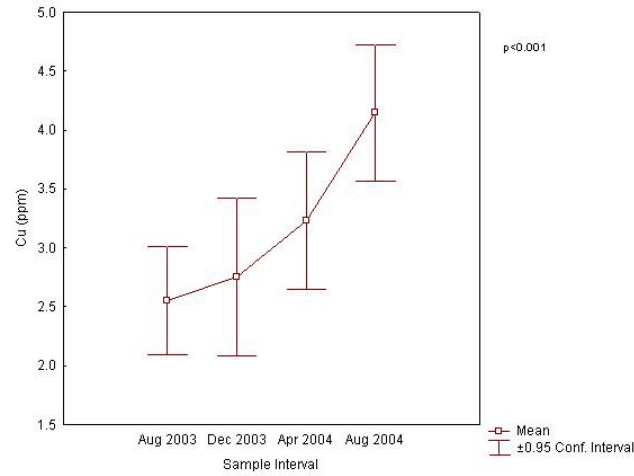

Figure 27. Aggregate species and damage category data for copper concentration of inner bark tissue across seasons.

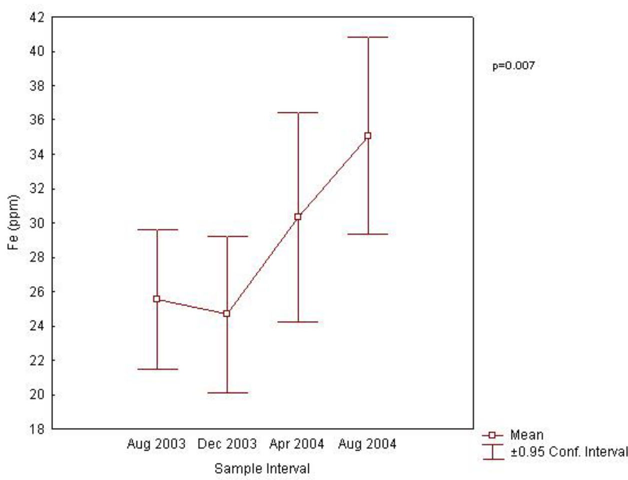

Figure 28. Aggregate species and damage category data for iron concentration of inner bark tissue across seasons.

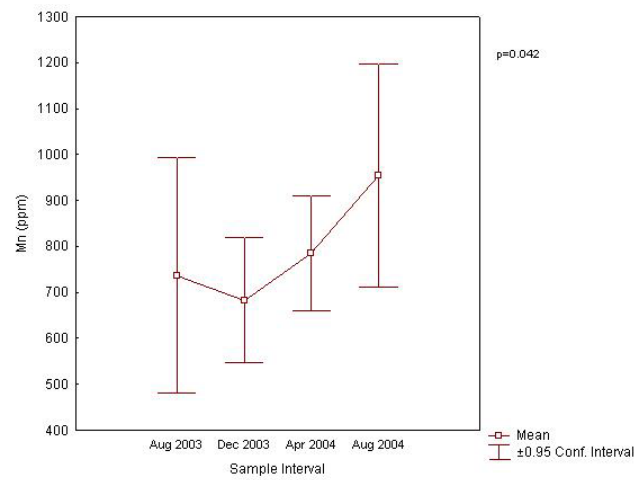

Figure 29. Aggregate species and damage category data for manganese concentration of inner bark tissue across seasons.

5.3.3 Treatment

By aggregating the data for sample interval and species, trees damaged by baboons had significantly higher concentrations of calcium and zinc than undamaged trees (Figures 30 and 31 respectively), and significantly lower concentrations of sucrose and starch, shown in Figures 32 and 33.

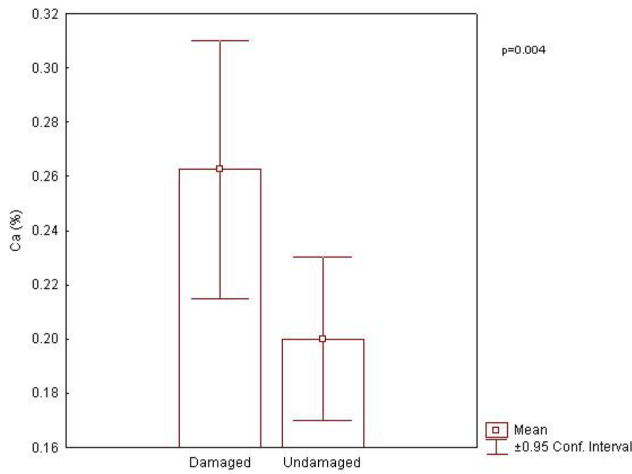

Figure 30. Aggregate species and sample interval data for calcium concentration of inner bark tissue between damaged and undamaged trees.

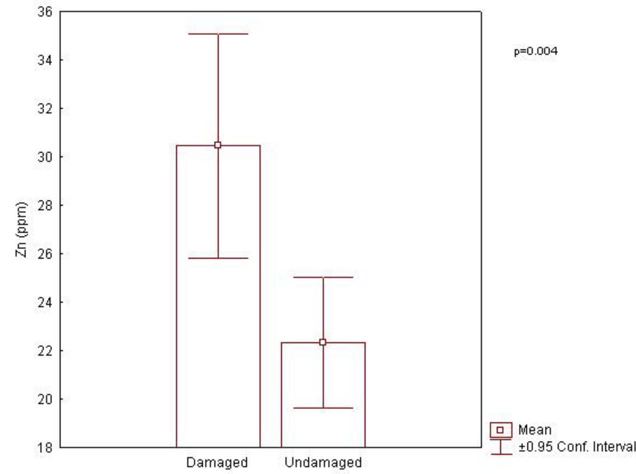

Figure 31. Aggregate species and sample interval data for zinc concentration of inner bark tissue between damaged and undamaged trees.

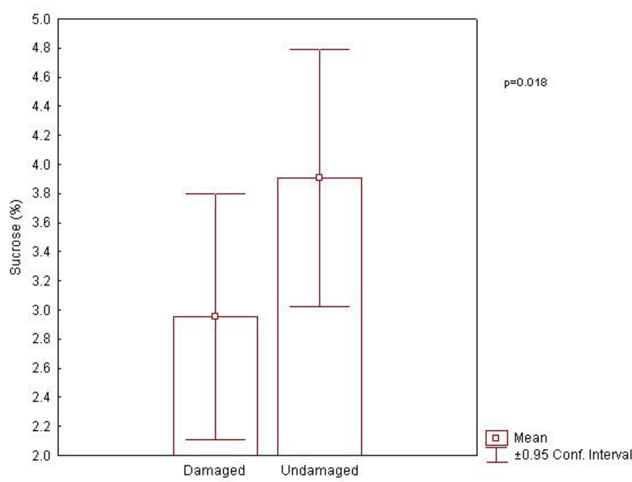

Figure 32. Aggregate species and sample interval data for sucrose concentration of inner bark tissue between damaged and undamaged trees.

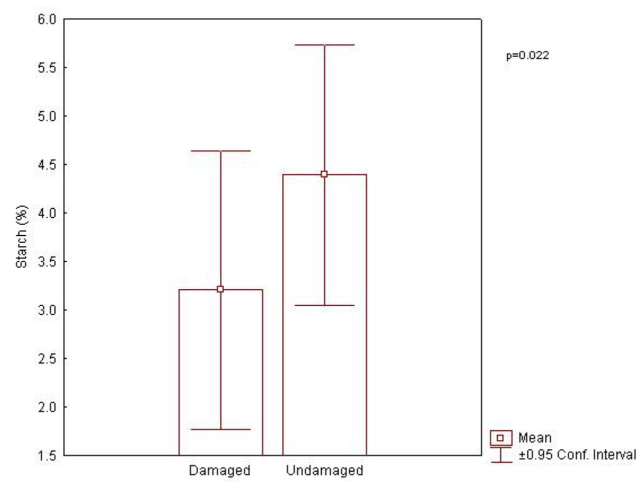

Figure 33. Aggregate species and sample interval data for starch concentration of inner bark tissue between damaged and undamaged trees.

5.3.4 Species

By aggregating the data for sample interval and damage category, *Pinus patula* contained significantly higher inner bark tissue concentrations of calcium, boron, sodium and manganese than *Pinus taeda.* The aggregate data also showed that *Pinus taeda* contained significantly higher inner bark tissue concentrations of phosphorus, potassium, nitrogen, copper, sucrose and starch than *Pinus patula*. Results are shown in Figures 34 to 43 below.

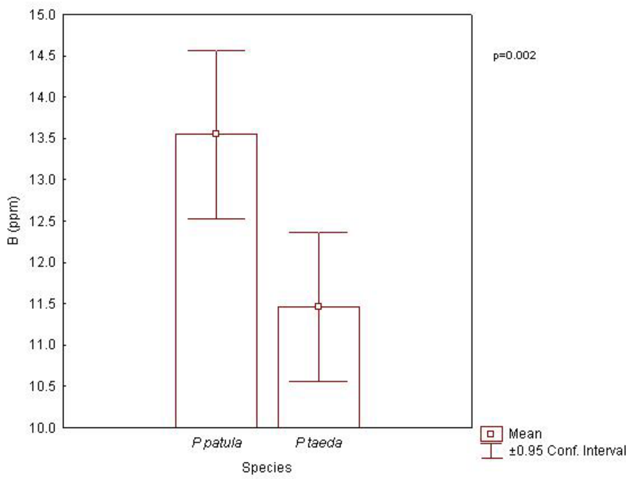

Figure 34. Aggregate sample interval and damage category data for boron concentration of inner bark tissue of *Pinus patula* and *Pinus taeda*.

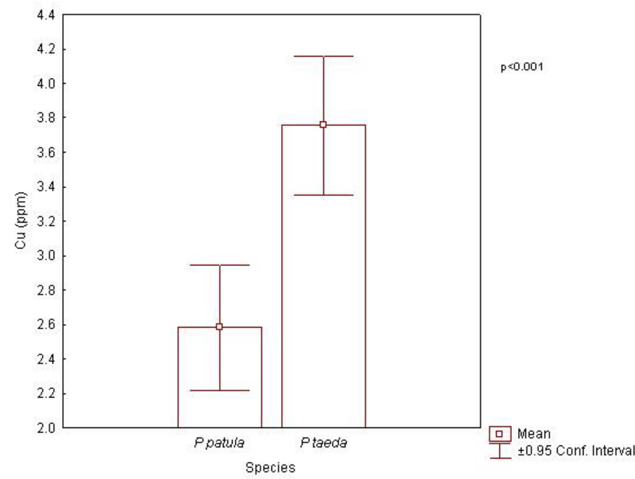

Figure 35. Aggregate sample interval and damage category data for copper concentration of inner bark tissue of *Pinus patula* and *Pinus taeda*.

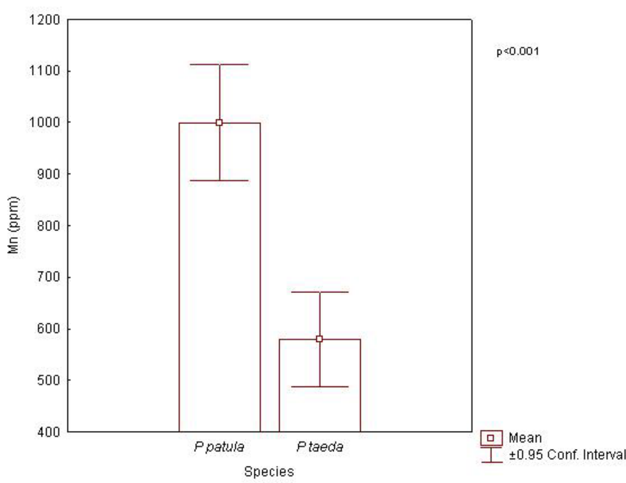

Figure 36. Aggregate sample interval and damage category data for manganese concentration of inner bark tissue of *Pinus patula* and *Pinus taeda*.

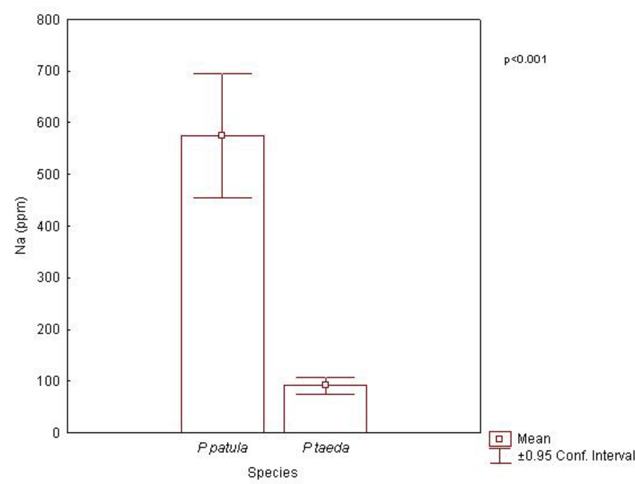

Figure 37. Aggregate sample interval and damage category data for sodium concentration of inner bark tissue of *Pinus patula* and *Pinus taeda*.

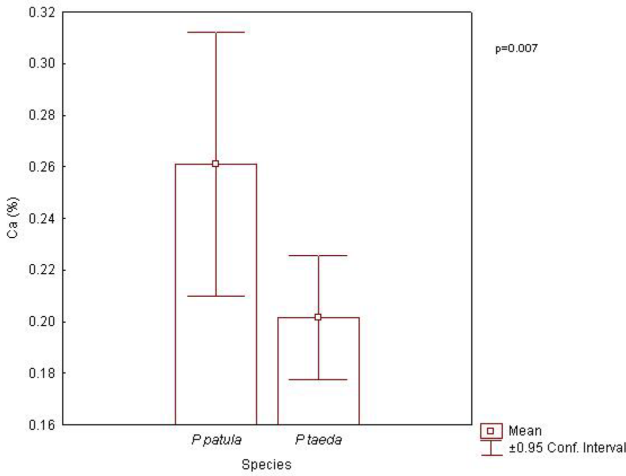

Figure 38. Aggregate sample interval and damage category data for calcium concentration of inner bark tissue of *Pinus patula* and *Pinus taeda*.

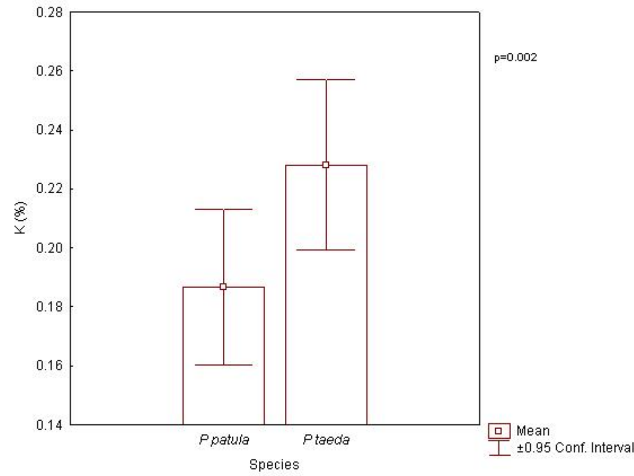

Figure 39. Aggregate sample interval and damage category data for potassium concentration of inner bark tissue of *Pinus patula* and *Pinus taeda*.

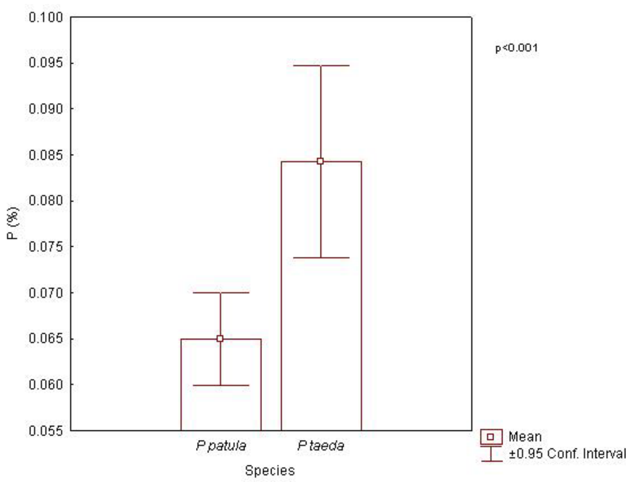

Figure 40. Aggregate sample interval and damage category data for phosphorus concentration of inner bark tissue of *Pinus patula* and *Pinus taeda*.

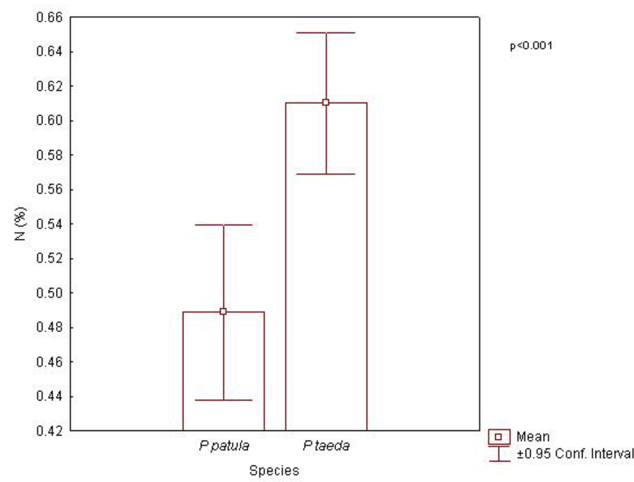

Figure 41. Aggregate sample interval and damage category data for nitrogen concentration of inner bark tissue of *Pinus patula* and *Pinus taeda*.

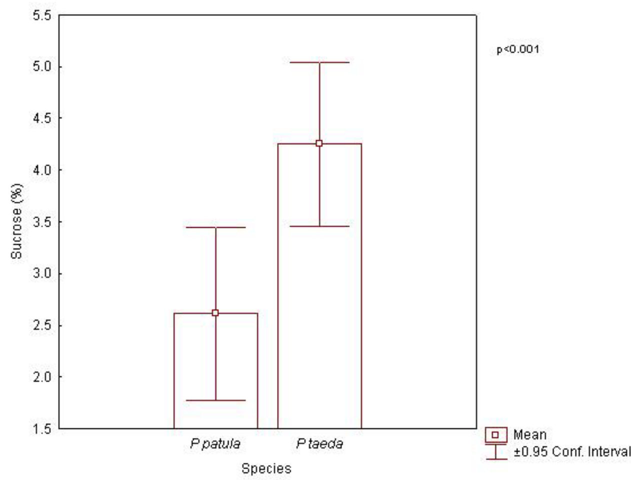

Figure 42. Aggregate sample interval and damage category data for sucrose concentration of inner bark tissue of *Pinus patula* and *Pinus taeda*.

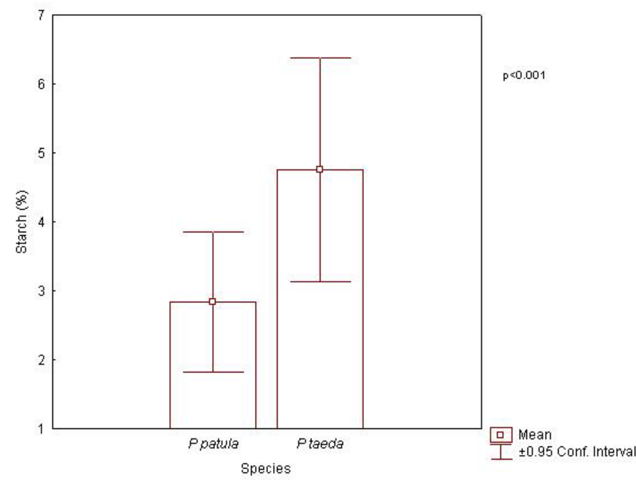

Figure 43. Aggregate sample interval and damage category data for starch concentration of inner bark tissue of *Pinus patula* and *Pinus taeda*.

5.4 Discussion of results

The sampling intervals (11 August 2003, 3 December 2003, 12 April 2004 and 2 August 2004) where chosen to monitor effects of seasonality on the inner bark tissue concentration of pines in the study area. The rainfall pattern for the study period indicated a particularly dry spring and summer when compared with long term averages. The trend from rainfall stations in the area indicated that the autumn and winter periods were noticeably wetter than the long term averages for the area (Figure 12).

5.4.1 Season x treatment x species

Phosphorus is the only mineral element that varied significantly in the inner bark tissue concentration of tree species and damage category across the seasons. Phosphorus concentration was markedly higher in undamaged *Pinus taeda* during April 2004 (0.13%), than all other variables. Erasmus (1993) records phosphorus levels of 0.03% with very little variation across months in undamaged trees, and a maximum value in damaged trees during December (0.05%). The results of the study are from *Pinus radiata* trees in the winter rainfall area of the Western Cape. Phosphorus concentration of xylem tissue only from *Pinus sylvestris* in Scandanavia, has been quoted as being 0.01% in a literature review conducted on mineral nutrient concentration of sapwood and heartwood (Meerts, 2002). Species specific differences seem to occur where in this study phosphorus concentration for aggregated data varied significantly from 0.065% to 0.084% for *Pinus patula* and *Pinus taeda* respectively.

Phosphorus has a structural role in plants in RNA, DNA, and phospholipids. It contributes to energy transfer where in particular phosphate esters are intermediates in metabolic pathways of biosynthesis and degradation. Phosphorus furthermore plays a role in regulating release of photosynthates, and influences the carbohydrate metabolism in needles, and sucrose translocation (Marschner, 1986). *Pinus teada* is reported to rest for about four months of the year, starting around mid-April (Norskov-Lauritsen, 1963). It is possible that phosphorus concentrations were elevated in undamaged *Pinus taeda* during April 2004 prior to the commencement of the resting period.

Moisture content was significantly lower for damaged, *Pinus patula* trees in August 2003 (57%) compared with the other variables. The start of the rainy season was delayed in 2003, and spring and summer mean monthly averages were notably less than the long term mean values. As the season progressed, damaged *Pinus taeda* trees had the lowest moisture content in December 2003 and April 2004. Actual mean rainfall stayed below long term averages until February 2004. In August 2004, damaged *Pinus patula* trees again had the lowest moisture content of inner bark tissue. *Pinus taeda* trees may be more efficient in storing water during the dry season than *Pinus patula*, possibly as a function of reduced transpiration from a smaller canopy, and longer resting periods during the winter season. This could result in

Pinus taeda trees being more vulnerable to baboon damage during times of water stress during the winter season. In the Western Cape, with a winter rainfall pattern (mean annual rainfall of 700 mm), baboon damaged trees were reported to contain 53% moisture content of inner bark tissue in *Pinus radiata* in the month of May, which is just at the beginning of the rainfall season (Erasmus, 1993). The highest reported moisture content in undamaged trees studied in the Western Cape was 67% in the month of December. Moisture content of inner bark tissue in the Western Cape increased from September to December following the peak rainfall month in August. The Eastern Escarpment receives on average 500 mm more rainfall per year than the Western Cape, which may explain the average higher moisture content identified for pines in Mpumalanga as discussed below.

5.4.2 Season

Figure 17 shows the moisture content of inner bark tissue on an aggregated basis for species and treatment. Moisture levels were lowest during August 2003 (60%) but then increased markedly to the April 2004 measurement (74%). The August 2004 levels only dropped by 4% from April 2004 levels. Moisture stress during August and December 2003 could have played a role in inner bark tissue concentration of carbohydrates. Fructose and glucose concentrations of inner bark tissue of all trees sampled during the experiment showed high levels in August 2003. This may be linked to moisture stress, where simple sugars are shown to accumulate during water stress conditions. Drought stressed *Pinus taeda* in the USA recorded peak values of 5% for non-reducing sugars (sucrose) and 4% for reducing sugars (Hodges and Lorio, 1969). Seasonal changes in total sugar concentration of inner bark tissue of *Pinus taeda* in the USA has shown to range from 17 to 11%, and starch from 13 to 8% (Blanche *et. al.,* 1992). Inner bark tissue concentration of total sugars in this study ranged from 14% to 10%, and starch from 8% to 2%. Previous South African research on combined values for *Pinus taeda*, *Pinus patula* and *Pinus elliottii* inner bark tissue concentration, grown in the summer rainfall area of the country (Limpopo Province) report values of 18% (March) to 3% (May) for total sugars, and 6% (August) to 1% (May) for starch (Bigalke and van Hensbergen, 1990).

August is the month during which growth initiates in *Pinus patula* and *Pinus taeda* on the Eastern Escarpment (Norskov-Lauritsen, 1963). Levels of these sugars may also be high to support the initial growth. Starch levels are highest during August 2003 (8%), which correlates with the fact that pines begin each phenological year with a reserve of stored carbohydrates (Dewar *et. al.*, 1994). The living xylem parenchyma cells main function is the storage of starch built up during the growing season which is utilized during cambial activity the following season (Richardson, 1968). Nutrient supply for early growth depends largely upon retranslocation of nutrients from storage, particularly in older needles and branches (Morris, 1984). As the summer rains have yet to commence nutrient supply is not readily accessed from soil, as the soil profile remains dry in the early growth period. Translocation prior to needle fall in *Pinus nigra* var. *maritima* allows for 60-85% of the major nutrients to be conserved (Miller, 1984). An estimate on a tree basis for *Pinus radiata* is that 86, 48 and 39% of phosphorus, nitrogen and potassium respectively, can be withdrawn from young needles to support seasonal growth of new shoots (Fife and Nambiar, 1982). All relocations are transported through the inner bark tissues, indicating that at certain times of the year nutrient concentrations of inner bark tissue will be altered. These natural tree response patterns may trigger increased baboon activity.

Where trees are actively growing in summer (December 2003), fructose and glucose levels are lower possibly indicating the demand for these nutrients by the tree (combined value of 3%). Sucrose levels are high (5%), indicating the growth demand and resultant increased transport of sucrose in the inner bark tissue. Starch levels show a steady decline from the first measurement, possibly indicating that with favourable moisture conditions through the autumn and winter period, growth has continued utilizing the stored starch. The trend in starch decline is similar to that shown for the pines studied in the Limpopo Province (Bigalke and van Hensbergen, 1990). Growth stoppage in winter on the Eastern Escarpment is reported as a temporary slow down rather than real winter dormancy (Norskov-Lauritsen, 1963).

The effect of seasonality and water stress on nitrogen is not as well defined as carbohydrates (Blanche *et. al.,* 1992 and Hodges and Lorio, 1969). Water stress (deficiency) conditions in *Pinus taeda* in the USA, showed peak total nitrogen accumulation of 0.7% (Hodges and Lorio, 1969). Typical nitrogen concentration of *Pinus taeda* in the USA was reported at 0.4% (Hodges and Lorio, 1969), although seasonal variations were reported from 0.6% to 1.2% (Blanche *et. al.,* 1992). Peak total nitrogen values of 0.4% have been reported for baboon damaged *Pinus radiata* trees in December, in the Western Cape (Erasmus, 1993). Peak values of nitrogen (0.6%) recorded in this study occurred in April 2004. The nitrogen content of phloem and xylem sap of plants exhibits marked seasonal and between-plant variation (Mattson, 1980). Genetically programmed rhythms such as diurnal and seasonal changes influence the concentration of nutrients in tissues, but other variations occur due to random factors such as temperature-moisture stresses and tissue damage by abiotic and biotic agents. The significant variation in nitrogen concentration of inner bark tissue as seen across the seasons cannot be readily explained.

Significant variations in inner bark tissue concentration for aggregated data for treatment and species occurred in the following mineral nutrients across the seasons; calcium, phosphorus, magnesium, potassium, boron, copper, iron and manganese. Concentration differences of these minerals across seasons are not easy to explain, but could be linked to stress and/or growth requirements. The main functions of these minerals in higher plants are tabulated below.

Table 20. Main functions of mineral elements calcium, phosphorus, magnesium, potassium, boron, copper, iron and manganese (adapted from Marschner, 1986).

Mineral	Main functions
Calcium	Cell wall stabilization, cell extension, membrane stabilization, enzyme modulation, cation-anion balance and osmoregulation.
Phosphorus	Structural element (RNA, DNA, Phospholipids), energy transfer, and regulation of enzyme reactions.
Magnesium	Chlorophyll synthesis, cellular pH control, protein synthesis, enzyme activation and energy transfer.
Potassium	Enzyme activation, protein synthesis, photosynthesis, osmoregulation, cell extension, stomatal movement, turgor related movement, phloem transport and cation-anion balance.
Boron	Cell elongation, cell division, nucleic acid metabolism, carbohydrate and protein metabolism, tissue differentiation, auxin and phenol metabolism, membrane permeability, pollen germination and pollen tube growth.
Copper	Carbohydrate and nitrogen metabolism, lignification, pollen formation and fertilization.
Iron	Protein synthesis and chloroplast development.
Manganese	Photosynthesis and oxygen evolution, synthesis of proteins, carbohydrates and lipids, cell division and extension.

Documented values for these minerals in inner bark tissue in pines are tabulated below. These values are merely for comparative purposes based on average conditions and are not specific to any season.

Table 21. Documented values for mineral concentration of inner bark tissue in pines.

Element	*Pinus patula*	*Pinus taeda*	*Pinus ponderosa*	*Pinus radiata*	*Pinus sylvestris*
	Results from this study (data aggregated for undamaged trees by sample interval	Results from this study (data aggregated for undamaged trees by sample interval		Undamaged trees only	Xylem only
Boron	10.75	12.17	13.90	13.96	-
Calcium	0.23	0.17	1.86	0.42	0.50
Copper	3.98	3.53	2.70	2.09	-
Iron	28.10	33.80	57.90	40.99	-
Magnesium	0.14	0.13	0.14	0.20	0.15
Manganese	641.00	518.00	49.50	72.58	-
Nitrogen	0.62	0.60	0.36	0.25	0.47
Phosphorus	0.08	0.09	0.04	0.03	0.06
Potassium	0.24	0.23	0.30	0.70	0.30
Sodium	92.00	90.00	94.90	300.00	-
Zinc	35.00	21.70	18.90	18.76	-

Note: Values for boron, iron, manganese, sodium and zinc are in parts per million, whereas other elements are percentage of dry mass. Reference for *Pinus ponderosa* (Linhart *et. al.*, 2001), *Pinus radiata* (Erasmus, 1993) and *Pinus sylvestris* (Meerts, 2002).

The high levels of manganese reported from this study are a function of the geology and soil type on which the trees were established. The high levels of sodium in *Pinus radiata* are attributed to a marine effect, from sea salt spray in the area.

5.4.3 Treatment

By aggregating the data for sample interval and species, trees damaged by baboons have significantly higher concentrations of calcium and zinc than undamaged trees, and significantly lower concentrations of sucrose and starch.

Calcium is located predominantly in cell walls of trees. It has low mobility in the phloem and responds to local changes in environmental conditions through the control mechanism for growth and development processes.

Calcium has essentially structural functions of regulating membrane permeability and related processes, and strengthening of cell walls. In the leaves of plants grown under conditions of high light intensity, a large proportion of the pectic material exists as calcium pectate. The proportion of calcium pectate in cells walls is of importance for determining susceptibility of the tissue to fungal infections. Most parasitic fungi invade cells by releasing pectolytic enzymes which dissolve the middle lamella. The activity of pectolytic enzymes are strongly inhibited by calcium, explaining the close correlation between calcium content of tissues and their resistance to fungal diseases. It has been established that calcium is involved in the regulation of senescence, through selectivity of ion uptake. Mitochondria are rich in calcium and calcium has an important role in the structure and function of mitochondria (Marschner, 1986). Values for calcium content in *Pinus ponderosa* trees in the USA vary from 1.9% to 0.5% (Linhart *et. al.,* 2001), and in *Pinus radiata* trees in the Western Cape South Africa from 0.42% to 0.44% for undamaged and baboon damaged trees respectively (Erasmus, 1993) and for xylem concentration only of *Pinus sylvestris* trees in Scandanavia 0.5% (Meerts, 2002).

Zinc, the long distance transport of which occurs mainly in xylem, acts either as a metal component of enzymes or as a functional, structural or regulatory cofactor of a large number of enzymes. Zinc deficiency through its role in enzyme activation, is associated with an impairment of carbohydrate metabolism and protein synthesis. Zinc affects phosphorus metabolism in roots and increases permeability of the plasma membrane of root cells to phosphorus and chlorine (Marschner, 1986). Zinc stabilizes biomembranes and has been linked to a protective role of enzymes against lipid peroxidation of membranes. Lipid peroxidation of membranes has been closely related to tissue senescence (Marschner, 1986). Values for zinc content in *Pinus ponderosa* trees in the USA vary from 18.9 to 46.0 ppm (Linhart *et. al.,* 2001), and in *Pinus radiata* trees in the Western Cape South Africa, from 18.8 to 22.4 ppm for undamaged and baboon damaged trees respectively (Erasmus, 1993).

Higher concentrations of calcium and zinc in baboon damaged trees could indicate the response of pine trees to wounding. Baboon damaged trees are highly susceptible to infection by blue stain fungus (*Lasiodiplodia spp*.), and thus elevated concentrations of calcium and zinc may be linked to secondary defense response to wound healing. The same can be implied for sucrose and starch, whereby these nutrients would be channeled for secondary defense mechanisms of resin secretion and pathogenic defense. Carbon is used for growth only when sufficient resources exist to support the structural development and physiological activity of additional tissue otherwise the carbon is stored or allocated to secondary metabolism (Warren *et. al.*, 1999). This study did find higher concentrations of zinc in baboon damaged trees, similar to results of a study in the Western Cape in *Pinus radiata*, however the zinc probably accumulated in response to the damage and the trees would not have had high levels of zinc prior to being damaged as was eluded to in the earlier study.

5.4.4 Species

The aggregated data for sample interval and damage category indicate species specific differences for certain elements. The significantly higher inner bark tissue concentrations of nitrogen, sucrose and starch in *Pinus taeda* may indicate that this species provides more nutritional benefit to the baboons consuming the inner bark tissue. It also supports anecdotal evidence that *Pinus taeda* is the preferred pine species damaged by baboons. The significantly higher inner bark tissue concentrations of copper, phosphorus and potassium in *Pinus taeda*, and calcium, boron, sodium and manganese in *Pinus patula*, do not indicate a direct relationship with baboon damage. The differences in crown structure and growth habits of the two species, may result in the significant differences of the above mineral elements in this study.

5.5 Conclusions

Season influences tree growth of pines on the Eastern Escarpment. Winter dormancy is more a period of rest than a true dormancy. Moisture stress at the commencement of spring growth (August) occurs due to increased photoperiods and warmer temperatures, with good rains only falling from September onwards. The moisture stress, resumption of cambial activity, and translocation of nutrients from needles prior to needle fall influence the concentration of nutrients in inner bark tissue of pines during early spring. In particular the reducing sugars and starch concentrations are high during this time. This supports anecdotal evidence that baboon damage on the Eastern Escarpment increases prior to the rainy season. *Pinus patula* and *Pinus taeda* are different in their crown structure and *Pinus taeda* has longer resting periods than *Pinus patula*. The winter season during this study was wetter than the long term average conditions and it is quite possible that tree growth continued for a longer period. The continued decrease in starch concentrations during the study period support this observation. *Pinus taeda* may be more efficient at storing moisture during the dry season, as it has a smaller leaf area than *Pinus patula.* Differences in phosphorus concentration of inner bark tissue between damage category, species and sample interval (particularly April 2004) may be related to changes in carbohydrate metabolism and sucrose translocation at this time.

Significant differences occurred in the concentration of certain nutrients of the inner bark tissue between the two species. Notably sucrose, starch and nitrogen concentration of inner bark tissue is higher in *Pinus taeda* than *Pinus patula*. Anecdotal evidence from Zimbabwe and South Africa indicate that

Pinus taeda is the species preferred by baboons, as determined from assessments of baboon damage in the two countries. The species differences identified in this study, particularly sucrose, starch and nitrogen support the anecdotal evidence. However, all species of pines planted in Mpumalanga, are damaged by baboons and the intensity of species damaged may merely relate to the trees planted within the home range of damaging troops.

The increased levels of zinc and calcium in baboon damaged trees is more likely related to the trees response to wounding, than a preference by baboons to select trees for these nutrients. Tree moisture content could support the baboons' water requirements, as they could avoid trips to permanent water sources while foraging in and around the pine compartments. The reason for baboon damage in pine plantations is not readily answered, and remains a complex problem.

5.6 References

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Chapter 6: Review of baboon damage losses to pine saw timber plantations in South Africa and Zimbabwe.

Abstract

Plantation forestry in South Africa contributed 3.4% together with the agriculture and fishing sector, to the Gross Domestic Product of the country (1 251 468 million Rand in 2003), and is an important source of employment in rural areas. Losses to plantation value through fire, insects and disease and recently baboons, has become a major concern. Following statements that baboon damage is rapidly escalating in the region, a literature review was undertaken of reported baboon damage occurrence and intensity of damage. A comparison was made between Zimbabwe and South Africa where the baboon damage is viewed as a serious problem. The extent of baboon damage in Zimbabwe, expressed as the total percentage of area damaged by baboons as a function of the total area planted to pine for the period 2000-2004 has escalated from 10.8 to 13.3% despite harvesting activities removing damaged trees (Fergusson, 2004). The total area with reported baboon damage in Zimbabwe amounted to 5 317 hectares in 2004 (Fergusson, 2004). In South Africa baboon damage has increased markedly from the first reports of 300 hectares in 1980 (Bigalke, 1980) to 7 641 hectares in 2004. The average percentage of trees damaged in affected compartments is 20.4% with the percentage increasing from 17.2 to 23.6% from 2002-2004. *Pinus taeda* appears to be the most severely affected species with *Pinus elliottii* showing increasing levels of damage in many compartments in 2004. Quantifying the value lost by baboon damage to the industry requires reliable assessment methods that are cost effective to implement. Assessment methods need to take into account the position of the damage on the stem, and resultant saw log value that is lost. Assessment methods implemented in South Africa and Zimbabwe are described, and results given by method applied. A standard assessment

method is required for comparisons to be made between areas with baboon damage. An investigation in Zimbabwe highlighted significant differences between standing tree volume estimations (4.98 – 7.59 m^3/ha, with various methods), and actual volume losses (50.45 m^3/ha) (Ngorima *et. al.,* 2002). The associated Rand value loss determined by the South African assessment method in 2004 was in excess of 20 million Rand. This estimated loss in revenue does not include losses of incremental growth due to the damage, re-establishment costs, loss of thinning and clearfelling product revenue due to timber wastage, or losses experienced in down line processing at the saw mill. The extent of the baboon damage problem warrants proactive management, continued monitoring and investment into research in order to gain a better understanding of the problem. The increase in the extent of baboon damage from early documented figures is most alarming, showing that the baboon damage problem continues to grow.

6.1 Introduction

A total of 1.3 million hectares in South Africa are afforested to exotic tree plantations. In 2003, the Gross Domestic Product (GDP) for South Africa was 1 251 468 million Rand (Statistics South Africa, 2004). Of this, the agriculture, forestry and fishing sector contributed 3.4% to the GDP. The role the forest industry plays towards employment and job creation, specifically in rural areas is most important. Collectively in the timber growing and wood processing industries an estimated 140 000 people are directly employed (Edwards, 2000). This does not take into account people employed in downstream or upstream activities of the core jobs, nor the dependents supported by the 140 000 people employed. The average round wood sales for the period 2002-2004 amounted to 15.93 million tons per annum. This includes all pine, eucalypt and wattle sold during the period irrespective of product. The pine saw log sales constituted 1.21 million tons (8%) of the average round wood sales, per annum for the period 2002-2004 (Godsmark, 2004). Of the 1.3 million hectares of exotic plantation forests, 705 000 hectares are afforested to pines, 525 000 hectares to eucalypts, 112 500 to wattle and the remainder consists of other species. More than half of the pine plantations (325 000 hectares) occur in the Mpumalanga Province, consisting of both saw timber and pulpwood regimes. A total area of 480 600 hectares in South Africa is dedicated to pine sawlog production, the majority of which occurs in Mpumalanga (Forestry South Africa, 2003).

Baboon damage in *Pinus* species has been observed since the 1960's in the Western Cape (Anon[d], 1969) and since the mid 1970's in Mpumalanga (Internal Memo, South African Forest Investments, 1975). Pine plantation forestry companies on the Eastern Escarpment of South Africa and the Eastern Highlands of Zimbabwe have been concerned with the extent and intensity of damage to pine plantations by baboons. A perception exists in South Africa that the level of damage by baboons in commercial pine plantations is increasing to unacceptable levels. Bark stripping is the main form of damage which leads to tree deformity, reduced wood quality and tree mortality where the bark is stripped around the full circumference of the tree. Removal of cones from trees impacts tree improvement research and genetic value is lost from seed orchards.

The age of trees damaged and the position of the damage impacts the value lost to the saw timber industry. Most assessments of damage include the extent of the problem in hectares, and the average percentage of trees affected in these hectares. These data are then extrapolated to an average volume (growth increment in meters cubed per annum) that is lost. In saw timber, the mature tree is divided into a series of logs each with inherent value depending on the extent of the pruning conducted, and any other defects which may detract from the value. The bottom section of the tree is used for veneer or high grade sawn board in the manufacture of furniture and other household commodities. These logs fetch a higher value than the subsequent logs. It is therefore important to evaluate not only the volume lost to forestry companies but also the value by log class that is lost through baboon damage. In reviewing damage reports from Zimbabwe and South Africa, no consistent method is applied in determining the value of baboon damage (Erasmus 1993, Ngorima *et. al.,* 2002 and Viljoen and Pienaar, 1997). A review of South African and Zimbabwean assessment methods was undertaken to record the history of the extent of baboon damage, to identify the value of damage by baboons and to determine if the problem has increased over time.

6.2 History of baboon damaged areas in South Africa

Estimates of damage in 1980 were 450 hectares in the Western Cape, 200 hectares at Tsitsikamma, and 300 hectares in the Eastern Transvaal (now Mpumalanga) (Bigalke, 1980). The estimated 300 hectares of baboon damage in the Mpumalanga Province in 1980 did not include an intensity of damage (% of damaged trees). Summarised reports of baboon damage as documented in the annual reports from the Department of Forestry and Environmental Affairs (1969-1980) and the Department of Water Affairs, Forestry and Environmental Conservation (1980-1986) showed that between 2 and 75% of trees were damaged in the Western Cape (Erasmus, 1993). From 1977 to 1985 the total extent of baboon damage recorded in South Africa amounted to 2 746 hectares (Erasmus, 1993). No intensity of baboon damage was reported. A questionnaire survey conducted in 1991 showed that in the majority of compartments damaged by baboons, less than 25% of the trees were damaged (Erasmus, 1993). Very few plantations had damage in more than 5% of all compartments, and no clear pattern relating to species preference or environmental factors influencing the pattern of damage were identified. In 1997 damage levels in Mpumalanga were estimated to be 2 506 hectares (Viljoen and Pienaar, 1997). Samango monkey damage in the

Limpopo Province was reported to occur on 573 hectares in 1981 (von dem Bussche and van der Zee, 1985), and on 294 hectares on one plantation alone in 1997, in the Limpopo Province (Viljoen and Pienaar, 1997).

Baboon damage reports showed increases in extent and intensity of damage from the 1970's to mid 1980's. The extent of baboon damage increased noticeably between 1980 (300 hectares) (Bigalke, 1980) and 1997 (2 506 hectares) (Viljoen and Pienaar, 1997) in Mpumalanga. The Mpumalanga, Limpopo and Western Cape Provinces are geographically separate areas, and yet damage by baboons and samango monkeys were reported simultaneously. This increase in damage was dramatic and raised many concerns in the industry. Suggestions put forward as to why this increase occurred included that the baboons learned how to utilize exotic trees and that baboon habitat became fragmented and population pressure changed animal behaviour.

6.3 History of baboon damage assessment methods

Baboon damage in Mpumalanga during 1997, was quantified by fixed area plots (250 m^2, circular plots with a radius of 8.92 meters) across 360 hectares (Viljoen and Pienaar, 1997). The number of trees per sample plot, the tree height, pruning height and upper and lower heights of damage scars were recorded for each damaged tree in the sample plot. Damaged trees were classified in two categories:

- live trees with less than 50% of bark removed for any damaged section and ring barked or with broken tops above a live branch whorl, and
- dead or dying trees with more than 50% of bark removed for any damaged section below the lowest branch whorl.

In the first category, it was assumed that the damage or the missing section of tree would be the only volume lost. For each compartment surveyed, volume lost was calculated based on mean tree proportions (height and diameter at breast height). The mean lower scar height and mean upper scar height were used in a taper equation to calculate volume lost for the mean damaged section. In the second category, it was assumed that the whole tree would be lost. Volumes were again calculated from mean tree parameters. The major concern with the assessment method was that it did not take into account where the damaged section occurred on the tree, in relation to log value for that section. The volume loss would have to be multiplied by an average log price to determine the actual value lost to the saw timber industry.

Volume losses due to baboon damage in Zimbabwe in 1998, were determined by random 20 x 20 m plots in compartments with baboon damage (Valintine, 2000). Two sample plots were placed in compartments of less than 5 hectares, three sample plots in compartments between 5 and 9 hectares, and 5 sample plots were placed in compartments in excess of 9 hectares. All trees in the plots were measured for growth parameters (diameter at breast height and tree height) and damaged trees were measured for height to the bottom of the damage, and height at the upper level of the damage. The type of damage was assessed per tree according to the following categories:

- partial damage (damaged but still living and healthy), growth and timber unlikely to be affected,
- half tree diameter damaged, but still living and healthy,
- three quarters of the diameter damaged, still living but sickly, and
- complete damage around diameter, ring barked, dead or tip dead.

Volume of the damaged length of the tree, and full tree volumes were calculated to give an indication of volume lost to baboon damage. The method was expensive, slow and cumbersome due to time required to layout and measure plots. It was difficult to assign actual value losses to the measurement data, leading to concern that results were inaccurate. The sample percentage (around 3%) was unsuitable to make reliable estimates of total damage. A different assessment method was applied in 2000 (Valintine, 2000), where all trees along every 20th row were assessed for damage and categorized according to the classes mentioned in the paragraph above. At each 100th row, full measurements were taken of tree height, diameter at breast height and damage scar lengths. Tree volumes and the volume of the damaged sections were then calculated. This method was further applied, but by assessing every 20th and 21st row, the sample percentage increased to 10%. The major concern with the method was that due to the clustered nature of baboon damage, the sampling method could miss areas of damage.

A model to streamline assessments by avoiding detailed measurements of damage portions and to rather measure compartments more frequently was proposed in 2001 in Zimbabwe (van der Lingen, 2001). The model intended to address more directly, the value lost to the Zimbabwe saw timber industry. The model recorded below, used mean values from measurements of baboon damaged areas to extrapolate results across all damaged areas.

Cost = Mean damage per damaged tree x proportion (%) of trees damaged x standing volume x replacement cost of timber.

Where **mean damage** was the mean proportion of saw log timber lost per damaged tree compared to an undamaged tree, obtained by comparing log yield from samples of damaged and undamaged trees and expressed as a percentage.

Proportion of trees damaged estimated from a sample, is the percentage of damaged trees in the compartment.

Standing volume was the estimate of the saw log yield from a compartment if no baboon damage occurred, obtained from a standard growth model or volume inventory.

Replacement cost of timber was the cost per cubic meter that the same quality timber without baboon damaged could be bought for at roadside. Where this timber was further from the mill than the damaged timber, transport costs were included.

The problem with the above model was that a figure of 25% (mean damage per damaged tree) was obtained from a small sample, and was not a reliable estimate of mean damage. It did not take into account severely damaged young stands that would be cleared before trees yielded merchantable timber, nor were re-establishment costs included in the model. The row survey method was criticized in that it could miss areas of damage and was time consuming to complete. Circular plots (15 m radius) were then implemented representing a 5% sample, whereby every tree within the plots were measured for scar length, height and diameter at breast height. Although it was thought to be a more accurate estimate of damage and volume lost by baboon damage, it was costly and time consuming. A study was commissioned in 2002 to determine the most cost effective and reliable method of baboon damage assessment in Zimbabwe (Ngorima *et. al.,* 2002). The circular sampling plots (15 m radius) and row survey (every 20th row, and every 20th and 21st row) results were compared with a full count covering all trees in the compartment. Three compartments were used to reach conclusions. Results indicated that the assessment of percentage of trees damaged by baboons did not differ significantly ($p<0.05$) between the three methods and the full assessment. In comparing estimates of lost volume from baboon damage between the three assessment methods (the two row survey methods and circular plots) no significant differences were determined. However, comparing the actual volume lost (50.45 m^3/ha) measured during log production, with estimated volume lost from standing trees through the row (4.98 and 5.93 m^3/ha) and circular plot (7.59 m^3/ha) assessments, significant differences occurred (Ngorima *et. al.,* 2002). It was then agreed in Zimbabwe to continue with row surveys that were the most practical to implement, and to acknowledge the underestimation of actual volume losses.

In South Africa during 2001, systematic sampling with fixed area plots (circular plots of which size varied with stocking levels) was initiated. When trees per hectare were greater than 900, plot size equaled 300 m^2, and if trees per hectare were less than 900, plot size equaled 500 m^2. The sampling intensity was approximately 5%. Height and diameter at breast height of 30 trees within the plots were recorded to obtain mean tree proportions. Trees with baboon damage were scored according to the type and location of damage, namely live crown, unpruned (dead knots) and pruned sections. The divisions related to the log values produced from the various tree sections. Assumptions were made on the length of tree that would be lost to log production, based on type and location of damage, as illustrated in Figure 44, and detailed below:

- dead or dying trees - ring barking of a tree lower than live crown height means the tree will die and the whole tree is lost,
- dead top - the top 5 meters of the tree is lost,
- sectional bark stripping in the pruned section where 1 meter of the top of the section is lost,
- sectional bark stripping in the dead knot section where 1 meter of the bottom of the section is lost, and
- sectional bark stripping in the live crown section where 1 meter of the bottom of the section is lost.

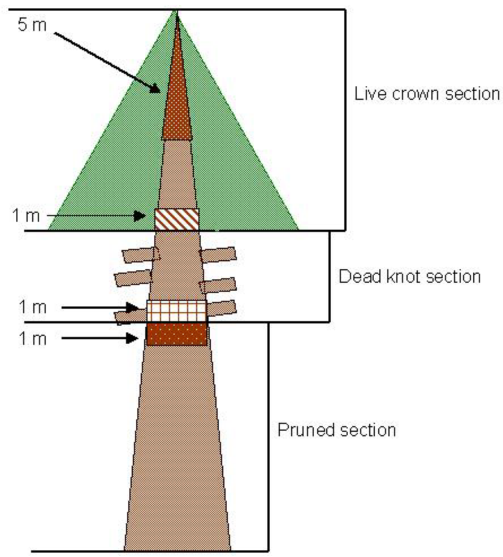

Figure 44. Illustration showing which sections of tree length are deducted as baboon damaged volumes.

The method followed the same sampling approach as thinning controls conducted in saw timber plantations on the Eastern Escarpment, and was easily implemented by the cruising teams. Through the use of a computer program designed specifically to interpret the measurements, relatively quick results could be obtained. Although the method was more costly than the row surveys used in Zimbabwe, it gave more detailed information on the value implications of baboon damage to the South African industry. The method is criticized for potentially underestimating tree length lost by baboon damage, and for the time required to conduct assessments.

6.4 Results from various assessments and discussion

An estimate of the extent of baboon damaged area in 1980 for the Mpumalanga Province was 300 hectares (Bigalke, 1980). Results from compartments assessed during 1997 (Viljoen and Pienaar, 1997) for percentage of trees damaged by species are recorded in Table 22. The results were extrapolated across the plantations affected by baboon damage in the Eastern Escarpment area to indicate that 2 506 hectares were affected by baboon damage in 1997 (Viljoen and Pienaar, 1997). This shows a dramatic increase in area damaged by baboons over the 17 years. The study furthermore indicated that based on mean tree calculations, 9.56% of the total volume was lost per hectare. The estimated value lost due to this damage intensity was not reported. This loss was significant enough for forestry companies to investigate management options to reduce the damage levels.

Table 22. Percentage of damaged trees by species in 1997 (Viljoen and Pienaar, 1997).

Pinus patula	*Pinus elliottii*	*Pinus taeda*	Total average
17.5%	13.6%	20.8%	18.1%

It is important to note that for the above study, stocking levels at the time of measurement were not recorded for compartments surveyed. Some compartments were thinned from initial planting densities, during which baboon damaged trees may have been removed. The tabulated results indicated that *Pinus taeda* was more heavily damaged than the other two pine species. However the report does not indicate the percentage sample of each species used for the study. It could have a bias to sampling *Pinus taeda* over the other species. However, reports from Zimbabwe indicate that *Pinus taeda* is the more heavily damaged pine species in that country (Fergusson, 2004). The average intensity of damage of 18.1% was a concern to the industry, and raised many questions as to why baboons were damaging pine trees on a more intensive scale than before.

Results of assessments in Zimbabwe in 1998 and 1999 are not documented due to concern over inaccurate measurements. The extent of damage (damaged area over planted area) for a portion of Zimbabwe's pine plantation area in 2000 and 2001 was 18.5% and 17.6% respectively (Valintine, 2002). The highest intensity of damage measured during the 2000 assessment with row surveys was 61% of trees damaged (Valintine, 2000). Average volume lost per hectare over the area surveyed in 2000 was quoted to be 12.3 m^3/hectare. The extent of baboon damage in Zimbabwe, expressed as the total percentage of area damaged by baboons as a function of the total area planted to pine for the period 2000-2004 are shown in Table 23 (Fergusson, 2004). The highest percentage of damaged area over the planted area was 44% in 2003 for one estate. The dramatic increase in damage was most alarming and resulted in significant losses of revenue to the Zimbabwean forestry companies and raised questions over how the problem could be effectively managed.

Table 23. Percentage of damaged area in Zimbabwe (Fergusson, 2004).

2000	2001	2002	2003	2004
10.8%	11.4%	11.3%	12.2%	13.3%

A comparison of the extent of damage area through the years 2000 - 2004, indicated that damage increased from 10.8 to 13.3%. This is despite damaged trees being thinned and clearfelled, indicating that damage occurred at a rate faster than the harvesting operations. The total area with reported baboon damage in Zimbabwe amounted to 5 317 hectares in 2004 (Fergusson, 2004). Volume lost due to baboon damage was 3.27% of the total volume produced in 2004, which amounted to a value of 4 006 million Zimbabwean dollars. This level of damage poses a severe threat to the continued viability of the Zimbabwean pine saw timber industry.

Results from compartments assessed during 2002 and 2004 in South Africa, using the fixed area plot method, are recorded in Table 24 below. The table shows the percentage of trees damaged by species in compartments surveyed for the Mpumalanga saw timber area. The same compartments were reassessed in 2002 and 2004, indicating an increase in percentage of trees damaged and value lost over the two year period.

Table 24. Percentage of trees damaged by species in South Africa, during the 2002 and 2004 assessments.

Species	2002	2004	Average
Pinus patula	13.3%	17.8%	15.6%
Pinus elliottii	15.8%	23.2%	19.5%
Pinus taeda	22.5%	29.9%	26.2%
Average	17.2%	23.6%	20.4%

The average percentage of trees damaged increased by 6.4% over the sampling period. *Pinus taeda* was the most severely affected species indicating a possible preference for this species, although the increase in percentage trees damaged between sampling intervals was as dramatic for *Pinus elliottii* (7.4%). Of interest, the mean annual average rainfall in 2003 was 48% lower than the long term average for the region, and may be a possible contributor to increased damage levels. The overall average percentage trees damaged increase by 2.3% in 2004 compared with 18.1% recorded in 1997. Volume and value loss results for the 2002 and 2004 assessments are recorded in Table 25 below.

Table 25. Volume and value lost due to baboon damage in South Africa, during the 2002 and 2004 assessments.

Species	Volume lost 2002 (m^3/ha)	Value lost 2002 (Rand/ha)	Volume lost 2004 (m^3/ha)	Value lost 2004 (Rand/ha)
Pinus patula	2	240	3	379
Pinus elliottii	3	372	3	355
Pinus taeda	7	831	9	1450
Average	4	481	5	728

The market demand for pine saw timber increased markedly since 2002, with prices rising by 25%, and thus the value loss escalated dramatically in 2004. Although more trees are damaged in *Pinus elliottii* in the 2004 assessment compared with the 2002 assessment, the volume and value losses remained similar. What has not been recorded between the assessments are baboon damaged trees removed in thinning operations. What is alarming is the significant increase in volume and value losses in *Pinus taeda*. As the same compartments were reassessed, and the trees grew during the two year interval, it is expected that volume and value losses would have increased by normal growth increment. This however, does not justify the major increase in *Pinus taeda* losses, and is thus attributed to further damage in this species. The overall average of the results from both assessments is that 4.5 m^3/hectare is lost at an estimated average value of R605 per hectare.

It is estimated that 7 641 hectares in Mpumalanga are currently affected by baboon damage. The total Rand loss for the current damaged area of Mpumalanga, using an average of calculated values for the sampling period, amounts to R20 802 622. The value does not include losses of incremental growth due to the damage, re-establishment costs, loss of thinning and clearfelling product revenue due to timber wastage, or losses experienced in down line processing at the saw mill. Frequently timber deterioration occurs beyond the visible scar length, as fungal infections discolour and decrease timber quality. The results do not reflect damaged trees that have been removed during thinning or clearfelling activities. The level of current damage as determined by the South African assessment method significantly affects yield of merchantable timber to the South Africa industry, and is truly alarming. Losses of this nature require active and focused management based on sound scientific principles. Research remains an important component of the baboon damage management recommendations.

6.5 Conclusion

Comparison of baboon damage to plantation forestry across the industry (South Africa and Zimbabwe), has been complicated by different assessment methods and sampling intensities. In terms of financial loss it is essential to determine the position of damage so that higher value logs to the sawmill are given greater value in the damage assessment. However, the method must remain practical and cost effective to implement. Estimates of baboon damage losses are complicated year on year, by removal of damaged trees through clearfelling and thinning operations and as a result the rate of increase in damage is very difficult to quantify. It is currently estimated that baboon damage on the Eastern Escarpment of South Africa covers 7 641 hectares. The intensity of damage (average percentage of trees damaged in affected compartments) is 20.4%. The value effect of this to the industry is estimated to be 4.5 m^3/hectare volume loss, amounting to an average Rand loss of R605/hectare of pine saw timber or R20 802 622 for the damaged hectares. This value however, does not include losses due to reduced growth, re-establishment costs, loss of thinning and clearfelling product revenue, or losses experienced in down line processing. The increase in the extent of baboon damage from early documented figures is most alarming, showing that the baboon damage problem continues to grow.

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Chapter 7: General Discussion

7.1 General

Plantation forestry covers a total of 1.3 million hectares in South Africa, and together with agriculture and fishing, contributed 3.4% to the Gross Domestic Product of 1 251 468 million Rand in 2003 (Statistics South Africa, 2004). The forest industry plays an important role towards employment and job creation, specifically in rural areas. More than half of the pine plantations (325 000 hectares) occur in the Mpumalanga Province of South Africa, (Forestry South Africa, 2003). Pine plantation forestry companies in Mpumalanga have been concerned with the extent and intensity of damage to pine plantations, particularly by baboons (*Papio ursinus*), and a perception exists that the damage levels were escalating rapidly. The principle pine species grown in Mpumalanga are *Pinus patula*, *Pinus elliottii*, *Pinus taeda* and more recently the *Pinus caribaea* x *Pinus elliottii* hybrid. Afforestation with exotic species began in the Union of South Africa during the second half of the 19th century, and the rate of afforestation increased dramatically from 1876-1970 where 966 281 hectares were established. Afforestation continued until the 1990’s to reach a maximum afforested area of 1 486 923 hectares in 1996 (Forestry South Africa, 2003). The decrease in afforested area from 1996 to current levels, was due to withdrawal of trees from environmentally sensitive areas. Baboons were first documented as causing damage in pine plantations of South Africa on the Eastern Escarpment of Mpumalanga, South Africa in the mid 1970’s (Internal Memo, South African Forest Investments, 1975). Bark stripping is the main form of damage, which results in trees with deformities, reduced wood quality and tree mortality when bark is stripped around the full circumference of the tree. Bark stripping of forest trees by animals to access bark tissue is not unique to South Africa. Damage to vegetation by various animals is not well defined or clearly understood in the wide range of studies which have been undertaken (Ando *et. al.,* 2003, Ciani *et. al.*, 2001, Faber, 1996, Maganga and Wright, 1991, Nishida, 1976, Pederson and Welch, 1985, Stafford, 1997, von dem Bussche and van der Zee, 1985 and Yoshimura and Fukui, 1982). Baboons are highly intelligent and ecologically flexible animals able to exploit diverse habitats. This adaptability enables them to exploit artificial human habitats such as pine plantations, which results in conflict with humans and baboons being categorized as “problem animals”.

Very little published data were available on the occurrence and cause of baboon damage in South Africa, and inconsistency in assessment methods makes comparison of damage levels difficult. Anecdotal evidence exists that baboon damage is more prevalent shortly after pruning operations. Further anecdotal evidence states that damage occurs throughout the year but intensity of damage decreases during winter and increases prior to the start of the growing season on the Eastern Escarpment of South Africa. Baboon damage intensity increases during winter in Zimbabwe (Valintine, 2002, *pers. comm.*), as it does in the southern Cape of South Africa (Erasmus, 1993), and increases during spring in the Western Cape (Erasmus, 1993). *Pinus patula* is reported to be the more severely damaged species by blue monkeys in Tanzania (Maganga and Wright, 1991), *Pinus taeda* by baboons in Mpumalanga (Viljoen and Pienaar, 1997) and Zimbabwe (Valintine, 2001), and *Pinus radiata* and *Pinus pinaster* by baboons in the Cape Provinces (Erasmus, 1993). The complexity of the problem, and with mainly anecdotal evidence given for baboon damage, it became important to address the question of which pine species are being targeted on the Eastern Escarpment of Mpumalanga, South Africa. This was addressed in terms of trying to understand if nutrient composition of the inner bark tissue played a major role, following pruning operations and if different times of the year were important. A need was also identified to document the history of the baboon damage problem, and record the current levels of baboon damage and value loss implications to the saw timber industry of South Africa in Mpumalanga, in order to justify the perception that damage was rapidly escalating.

7.2 Pruning

Pruning of trees and other stressors impact on the rate of transportation of solutes and the concentration of elements in the inner bark tissues. It was thought that the physiological response to pruning of pines on the Eastern Escarpment of Mpumalanga, may support suggestions that baboons damage pine trees shortly after pruning operations, due to change in composition of nutrients in the inner bark, making it more attractive to baboons. Most documented values on inner bark tissue nutrient concentration of pines, are from studies conducted in relation with pine bark beetle infestations in the USA. In terms of previous pruning studies, most report nutrient concentration of needles and not inner bark tissue concentrations. It was thus important to quantify inner bark tissue nutrient concentration and the changes in composition that occurs due to pruning. The response to pruning is short lived, thus it was felt that the intervals used in this study to determine nutrient concentration changes were adequate. The results of the experiment reported in this thesis showed that nutrient concentration of inner bark tissue measured at set intervals post pruning was not influenced by the pruning treatment. It may be possible that the pruning treatment applied in the experiment was not severe enough to influence nutrient concentration in the inner bark tissue of pines at the selected intervals post pruning.

The aggregated results for sampling interval, which identified differences between treatment only, showed that significantly higher levels of potassium and significantly lower levels of magnesium occurred in the pruned treatment. It may be possible that potassium concentration of inner bark tissue was elevated in the pruned trees in order to regulate an increased rate of photosynthesis to compensate for the loss of live crown, although peak demand for potassium was not indicated at any particular time post pruning. High levels of potassium affect magnesium function, particularly in protein synthesis (Marschner, 1986). Low magnesium concentration in pruned trees may be related to higher concentrations of potassium.

The results from aggregation of data for treatment could be describing events occurring in the resumption of spring growth, namely mobilization of stored starch, translocation of nutrients from older needles and branches into the new growth and increased activity of cambial tissues. The change in fructose, glucose and sucrose, and starch levels can be explained by the increased demand of carbohydrates for spring growth. The change in phosphorus concentration may be explained by its role in energy transfer, regulation of release of photosynthates, carbohydrate metabolism in needles, and sucrose translocation. The continued decrease in moisture content of inner bark tissues coincides with the lack of rainfall in the area. The relationship between water stress and carbohydrate increases (Hodges and Lorio, 1969) could explain why low moisture content at the end of the sampling interval coincided with high fructose levels. The peak in nitrogen concentration of inner bark tissue could be related to increased demand for nitrogen by cambial activity and growth of tissues. Boron levels peaked at the same time as the nitrogen levels. Interactions have been described between auxins and boron in the differentiation of xylem vessels, although the interaction between auxin level, differentiation and lignification is not well understood (Marschner, 1986). The increased cambial acitivity may be the cause for increased boron concentration.

The results of this experiment do not support anecdotal evidence that baboons damage pine trees shortly after pruning due to changes in composition of the inner bark tissue as a result of the pruning operation. The change in concentration of certain nutrients in the inner bark tissue over the sampling interval in this study, were interesting in terms of describing the variability that occurs in nutrient concentration over a short time period, irrespective of pruning. There are many other factors that influence inner bark tissue nutrient concentration such as water stress, photoperiod, rate of photosynthesis, translocation of nutrients prior to senescence and mobilization of reserves prior to the commencement of the growing season. Improved sampling techniques where the wound caused to the tree is minimal, such as with the USA studies (Blanche *et. al.,* 1992 and Hodges and Lorio, 1969) should be considered for future studies.

A component which has not been investigated in baboon damage studies, particularly following pruning operations, is the response of baboons to an olfactory stimulus with the release of volatile substances following pruning of live branches. This would support anecdotal evidence that damage occurs shortly following pruning operations.

7.3 Season, species and damage category

Growth of pines on the Eastern Escarpment of Mpumalanga is influenced by season. Winter dormancy is more a period of rest than a true dormancy. Anecdotal evidence from foresters in the region state that damage decreases during winter, but increases prior to the commencement of the growing season. Furthermore, foresters in Zimbabwe and South Africa state that *Pinus taeda* is the preferred species damaged by baboons. Previous baboon damage research conducted in the Western Cape state that baboons select trees based on higher zinc content (Erasmus, 1993), and that the carbohydrate content of inner bark tissue in *Pinus patula*, *Pinus elliottii* and *Pinus taeda* was too low to support the energy requirement of baboons (Bigalke and van Hensbergen, 1990) and thus cannot be the reason baboons damage pine trees.

The results of the experiment reported on in this thesis showed that phosphorus is the only mineral element that varied significantly in the inner bark tissue concentration between tree species and damage category across the seasons. It is possible that phosphorus concentrations were elevated in undamaged *Pinus taeda* during April 2004 prior to the commencement of the resting period, where phosphorus plays a role in carbohydrate metabolism and sucrose translocation. Moisture content of inner bark tissues varied significantly between tree species and damage category across the seasons, which reflects species differences in crown structure and growth habits, differences in damage category, and in the seasonal occurrence of rainfall on the Eastern Escarpment.

Moisture stress, resumption of cambial activity, and translocation of nutrients from needles prior to needle fall, influence the concentration of nutrients in inner bark tissue of pines during early spring. In particular the reducing sugars and starch concentrations are high during this time. This supports anecdotal evidence that baboon damage on the Eastern Escarpment increases prior to the start of the growing season. Bark is reported to peel more easily during periods of high cambial activity (Wilcox 1962), which coincides with initiation of growth during August in Mpumalanga, and could furthermore support anecdotal evidence that bark stripping is more severe at the start of the growing season.

The increased levels of zinc and calcium in baboon damaged trees are more likely related to the trees response to wounding, than a preference by baboons to select trees for these nutrients. Furthermore significantly lower concentrations of sucrose and starch in baboon damaged trees could indicate that these nutrients are channeled for secondary defense mechanisms of resin secretion and pathogenic defense.

Copper, phosphorus, potassium, sucrose, starch and nitrogen concentrations of inner bark tissue were significantly higher in *Pinus taeda* than *Pinus patula*, whereas calcium, boron, sodium and manganese were significantly higher in *Pinus patula* than *Pinus taeda*. *Pinus taeda* trees may be more efficient in storing water during the dry season than *Pinus patula*, possibly as a function of reduced transpiration from a smaller canopy, and longer resting periods during the winter season. This could result in *Pinus taeda* trees being more vulnerable to baboon damage during times of water stress during the winter season. The difference in crown structure and growth habits of the two species may result in the significant differences identified in this study. Anecdotal evidence from Zimbabwe and South Africa indicate that *Pinus taeda* is the species preferred by baboons. The species differences identified in this study, particularly sucrose, starch and nitrogen support the anecdotal evidence. It is further possible that the moisture content of inner bark tissues of pine trees could support the baboons' water requirements, as they could avoid trips to permanent water sources while foraging in and around the pine compartments. The results of this study highlight that the reason for baboon damage in pine plantations is not readily answered, and remains a complex problem.

7.4 Baboons

Baboons are highly intelligent and ecologically flexible animals able to exploit diverse habitats. They forage on a wide range of plants, insects (including the pine emperor moth (*Nudaurelia cytherea clarki)* which is an important pest of *Pinus patula*), reptiles and at times small mammals. This adaptability however, enables them to exploit artificial human habitats, such as pine plantations, resulting in conflict with humans, and the label of "problem animals". The need to improve knowledge of the ecological function of baboons (such as seed dispersal of indigenous vegetation) has been highlighted by an investigation into the resource utilization of baboons on the Eastern Escarpment of Mpumalanga (Marais, 2005).

A dramatic increase in extent of baboon damage in Mpumalanga has been shown since the first documented estimates of 300 hectares in 1980. It is currently estimated that baboon damage on the Eastern Escarpment of South Africa covers 7 461 hectares. The intensity of damage (average percentage of trees damaged in affected compartments) in the region has increased from 18% in 1997 to current levels of 20.4%. The value of the intensity of damage to the industry is estimated to be on average 4.5 m^3/hectare volume loss, amounting to an average Rand loss of R605/hectare of pine saw timber or R20 802 622 for the damaged hectares. This value however, does not include losses due to reduced growth, re-establishment costs, loss of thinning and clearfelling product revenue, or losses experienced in down line processing.

Comparison of baboon damage to plantation forestry across the industry (South Africa and Zimbabwe), has been complicated by different assessment methods and sampling intensities. In terms of financial loss it is essential to determine the position of damage so that higher value logs are given greater value in the damage assessment. Estimates of baboon damage from assessments of standing trees, underestimated the true effect of baboon damage (Ngorima *et al.,* 2002). However the method used must remain practical and cost effective to implement. Estimates of baboon damage losses are complicated year on year, by removal of damaged trees through clearfelling and thinning operations and as a result the rate of increase in damage is very difficult to quantify. It remains important to standardize the approach for baboon damage assessments, so that a better comparison can be made between areas. It is also vital that assessments continue on a regular basis to more accurately monitor the problem. The increase in the extent of baboon damage from early documented figures is most alarming, showing that the baboon damage problem continues to grow.

Chapter 8: Conclusions

The pruning treatment investigated in this study did not influence the nutrient composition of inner bark tissue of *Pinus patula* at specified intervals post pruning. It is possible that the pruning treatment applied was not severe enough to induce changes in nutrient concentration similar to those reported in the literature. Investigations into other factors such as a smell stimulus following pruning operations, needs to be investigated to determine if this plays a role and supports anecdotal evidence given by foresters that damage by baboons occurs shortly following a pruning operation.

Seasonality plays a role in pine tree responses to the environment, which is evident through changes in nutrient composition and moisture content of inner bark tissues. Seasonality affects needle senescence and translocation, water stress levels, cambial activity, and demand for and from photosynthesis. Management practices such as pruning, thinning and fertilization further influence nutrient concentration of inner bark tissues. Stress factors have been shown to alter the tree’s resource distribution, particularly when resin secretion is required to protect the tree from insect attack or other forms of damage.

A number of species differences were identified in this study, between *Pinus patula* and *Pinus taeda*, which tends to support anecdotal evidence that *Pinus taeda* is the preferred species of baboons on the Eastern Escarpment of Mpumalanga and Eastern Highlands of Zimbabwe.

Differences identified in a previous study (Erasmus, 1993) on the content of zinc in baboon damaged trees, is thought to be related to the trees response to wounding, and not that baboons are preferentially selecting trees based on a higher zinc content.

Damage levels in saw timber plantations in Mpumalanga have both increased in extent and severity of damage since the first documented reports of baboon damage in 1980. The value lost as a result of baboon damage is most severe and demands improved management practices, continued monitoring of the extent and intensity of damage, improvements in assessment methods - even possibly considering using remote sensing, and for the continued investment into research in order to gain an understanding of the problem from a holistic perspective. The role baboons play in reducing pine emperor moth (*Nudaurelia cytherea clarki*) in pine plantations, and the greater role baboons have to play in the ecology of the area must not be forgotten. Reducing the impact of baboons as a problem animal needs to be the goal, and not eradication of baboons from pine plantations as an attempt to solve the problem.

Chapter 9: References

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