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Water Use and Socio-Economic Benefit of the Biomass of Indigenous Trees
Volume 1: Research Report

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This report forms part of a series of two reports. The other report is *Water Use and Socio-Economic Benefit of the Biomass of Indigenous Trees. Volume 2: Site-Specific Technical Report* (WRC Report No 1876/2/15).

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EXECUTIVE SUMMARY

REPORT STRUCTURE

This report is structured in two volumes. Volume 1 (Research Report) covers background information on indigenous trees and forests, project details, research methods, economic and financial viability assessments, market and product potential information, rapid screening techniques for estimating water use efficiencies, and general conclusions and recommendations. Volume 2 (Site-Specific Technical Report) provides details on the respective field measurement sites/species, specific measurement methods employed, results and conclusions/recommendations.

MOTIVATION

South Africa is very reliant on its plantations of introduced tree species to meet its pulp and timber needs and the benefits of this industry in terms of production, income generation and job provision are undisputed (Chamberlain *et al*., 2005). The downside is that these benefits come at some environmental cost, not least the impact of the industry on water resources (Dye & Versfeld, 2007; Dye, 2012). Many catchment areas are consequently now closed to further afforestation, but economic growth and development continue unabated. Imports and improved productivity are potential solutions to continue meeting the demand for timber and forest products, but further consideration of the feasibility of expanding indigenous tree resources is also warranted. With over 1000 species of indigenous trees in the country, South Africa is extremely rich in natural arboreal diversity (von Breitenbach, 1990). The numerous benefits of indigenous trees and forests, in terms of the goods and services that they offer, are widely recognised (Lawes *et al*., 2004; Shackleton *et al*., 2007). There are also widespread perceptions that indigenous tree species use less water than introduced tree plantations. While data from previous studies are available on the water-use efficiency (WUE) of common introduced plantation species in South Africa (Olbrich *et al*.. 1996; Dye *et al*., 2001), information on the water-use of indigenous trees and forests is scarce and indirect and relationships between growth and water-use within indigenous forests have only started to be investigated in South Africa within the last 10 years (Dye *et al*., 2008).

Information on the water-use, growth and economic value of indigenous trees is required in order to facilitate sustainable land-use planning from hydrological, ecological and socio-economic perspectives. New and innovative techniques to quantify the water-use (transpiration and total evaporation) of a range of tree species and forest types are available

(Jarmain *et al*., 2008), and these may be used to broaden our understanding of forest hydrological processes and their associated effects on water resources in this country. The overall efficiency of water-use for biomass production and the net benefit of the water used are important criteria that need to be understood to permit the evaluation of different land use scenarios.

PROJECT OBJECTIVE AND AIMS

The overall objective of this project was:
To measure and model the water use and growth of indigenous trees in different types of tree systems, and to quantify the economic benefits and costs of the biomass production under a range of bio-climatic conditions in South Africa.

The specific aims of this project were:

1. To screen, shortlist and select indigenous tree species that are most promising for natural forest and indigenous plantation tree production systems with particular attention to single species/even aged and mixed species/mixed aged tree systems.
2. To improve knowledge of the water use efficiency (WUE) of indigenous trees under natural forest and indigenous plantation systems through growth and water use measurements and modelling, using proven methods and techniques.
3. To analyse the economic viability and market potential of biomass products from natural indigenous forests and indigenous plantation tree systems (in different social contexts) and in comparison with exotic commercial plantations.
4. To develop and test a rapid screening technique to identify indigenous tree species-site combinations based on water use, economic viability and eco-system adaptability, thereby optimizing WUE and socio-economic potential.

METHODS

The project conducted intensive measurements of tree and forest water use, stem growth, weather variables, soil water dynamics and tree attributes, as well as economic and financial assessments within indigenous and introduced tree systems. Research work focussed on priority individual indigenous tree species and forest types, through 6 phases of field measurements and data collection exercises. The studies started on indigenous *Podocarpus henkelii* (Henkel's Yellowwood) trees, growing in a single species/even aged stand in the KZN midlands, and compared growth, water-use and a financial analysis for a comparative Yellowwood plantation against an introduced *Pinus patula* plantation. Phase 2 measurements were conducted over a year in an indigenous Scarp (Transkei Coastal) forest at Manubi (Eastern Cape), and included sap flow and stem growth monitoring on indigenous *Millettia grandis* (Umzimbeet) and *Ptaeroxylon obliquum* (Sneezewood) trees, as well as on a commercially grown coppicing Eucalyptus species in the area, for comparative purposes. Additional water use measurements in the mixed species/mixed age indigenous Scarp forest at Manubi were collected by means of eddy covariance measurements of total evaporation above the forest canopy. This site also formed the basis for an economic assessment of the resource use of selected indigenous species occurring in that forest. Data collected through a field survey of approximately 120 surveys/questionnaires conducted amongst rural inhabitants in the Manubi area, was analysed and interpreted.

Phase 3 measurements consisted of the collection of primary data on tree and forest water-use and growth rates in indigenous *Prunus africana* (Red Stinkwood), *Celtis africana* (White Stinkwood) and *Rapanea melanophloeos* (Cape Beech) trees growing within Southern Mistbelt forest at Ingeli State Forest in southern KZN. Additional water use measurements in the mixed species/mixed age indigenous Southern Mistbelt forest at Ingeli were collected by means of eddy covariance measurements of Total evaporation above the forest canopy. A subsequent modelling exercise to calibrate models against seasonally observed total evaporation rates, and extrapolate to a full year of total evaporation estimates was carried out. A phase 4 study site (Richards Bay Minerals) was then established in northern KZN, where measurements took place on indigenous *Vachellia kosiensis* (Dune Sweet Thorn, previously *Acacia karroo*) trees growing on rehabilitated dunes, as well as on introduced *Casuarina equisetifolia* and *Eucalyptus grandis* species for comparative purposes.

Phase 5 measurements consisted of the establishment of a research site in the southern Cape, where water use and growth data were collected and compared between indigenous *Ocotea bullata* (Black Stinkwood), *Ilex mitis* (Cape Holly) and *Podocarpus latifolius* (Real Yellowwood) trees, in contrast to simultaneous measurements on introduced *Pinus radiata* trees growing in a plantation environment in the same area. A test of the ability of the MAESPA tree water use model to replicate the transpiration trends and volumes observed in the *Ilex mitis* tree at this site was carried out. Finally, Phase 6 water use and growth measurements on additional *Millettia grandis* (Umzimbeet) and *Ptaeroxylon obliquum* (Sneezewood) trees were taken at a site in Pietermaritzburg.

Research was also conducted on the more formal/recognised markets where indigenous timber products are traded, and information on potential products, processes and values associated with those markets was collected.

RESULTS

Results showed that the range and average of observed 1-year water-use totals (transpiration component) was noticeably less for indigenous tree species compared to introduced plantation tree species. Maximum water-use was also lower in the indigenous species studied compared to introduced plantation species, despite growing conditions that could be considered ideal for most of the indigenous species sampled (readily available water, energy and nutrients, and limited competition). The indigenous tree annual cumulative sap flows were all less than 8100 L tree^{-1} year^{-1}, irrespective of tree size, whereas sap flows in the more productive introduced plantation trees exceeded 20 000 L tree^{-1} year^{-1} in some cases. This suggests that there is a genetically determined maximum threshold to water-use by indigenous tree species that is substantially lower than that for introduced plantation species.

Evidence suggests that indigenous forests cannot compete with plantations of introduced tree species for wood production, and this was confirmed through a comparison of the growth rates observed in respective indigenous and introduced tree species in this study. Certain instances of relatively high 1-year stem growth rates in indigenous species were observed in the study, with *Millettia grandis* (Umzimbeet), *Prunus africana* (Red Stinkwood) and *Celtis african*a (White Stinkwood) being the best performing species. However, it should be borne in mind that the conditions under which these particular indigenous trees were growing were more favourable than the average plantation environment. These trees were free-standing, unshaded trees with little competition for resources, growing in riparian zones with readily available water.

In terms of growth and water-use it was found that while biomass production was much lower for the indigenous tree species, they also used much less water than introduced plantation species. Resultant WUE estimates showed substantial variation, even within a particular species, but on average results indicated that indigenous tree species appear to exhibit similar water use efficiencies to introduced plantation tree species. This supports the argument of a general correlation between growth and water use.

The MAESPA model was found to be well suited to predict long-term water use of individual indigenous trees with well-defined canopies. An important application of this finding is the rapid screening of WUE of trees, where growth increments measured on the stems of sample trees can be matched to water use over the same period. In this way, a wide range of sample trees of varying species, of different ages and growing on different sites can be assessed with relative ease, and ranked according to their WUE.

The economic viability of specific indigenous tree species could not be judged in a fully inclusive fashion in this project due to the number of unknown variables. Additional field trial data is required to account for this limitation. However, the value of indigenous forests in the upkeep and maintenance of rural livelihoods appeared to be substantial, particularly if the opportunity cost of this function was accounted for. Regarding the financial viability of a Yellowwood plantation, it was noted that the direct production costs were comparatively small relative to the opportunity cost of the extremely long rotation cycle when compared to an introduced plantation. However, the extremely long rotation period required rendered it uncompetitive against introduced species such as pine, unless it was possible to shorten growing periods (via breeding and selection programmes). Additional challenges associated with the more formal indigenous wood market were found to be numerous. These included unpredictable and variable supply, widely ranging shape, size and quality of logs, high harvesting and extraction costs, and unpredictable market demand. Consequently, this study represents an important descriptive presentation of the dynamics associated with the formal and informal indigenous tree product markets.

CONCLUSIONS

The relatively low water-use characteristics of indigenous tree species suggests that they are promising for expanding natural and plantation tree production systems in South Africa, maximising benefits (goods and services) while minimising resource impacts (water-use). Apart from the importance of accurate site/species matching, appropriate species for establishment need to be considered from environmental, social and economic perspectives. Potential benefits include suppression of alien invasive plants, biodiversity conservation, provision of ecosystem services, supporting rural livelihoods, ecotourism and urban greening. Given the increasing pressure on water resources and a growing demand for timber and non-timber forest products, further exploration of the numerous multiple-use indigenous tree species that are found in this country, matched to the wide range of existing climatic and site conditions, is merited. There is surely potential for managed, productive and sustainable indigenous forest and woodland systems. Considering that further afforestation with commercial forest species is now restricted due to limitations in available land and concerns about reductions in catchment water yields, the possibility of expanding low water-use forms of forestry with indigenous trees deserves to be explored further.

From a wood production point of view, it appears unlikely that indigenous species will be competitive in terms of volume production, and their economic viability appears to be limited, apart from certain scenarios. However, much depends upon the growth or demand of markets for indigenous timber products, and whether supply can be enhanced to meet that demand. Furthermore, with appropriate recognition of the “non-tangible” benefits (eco-system services) of indigenous trees, their value could be increasingly recognized. By virtue of their low water-use impacts, this study has confirmed the important role of indigenous trees from an ecohydrological perspective, and the findings have wider scale applicability in fields such as forest restoration, erosion control, replacement of invasive alien species and multiple-use indigenous tree wood-lots, particularly where water-conservation is a priority.

The link between growth rates and water use suggests that easily obtained growth rates of trees (e.g. 1-yr stem biomass increments) may be used to provide a rough estimate of corresponding water use, without the need for expensive and technically demanding water use monitoring equipment. Alternatively, modelling approaches, particularly with the MAESPA model were shown to have promise in predicting water use of trees and forests, and combined with less technically demanding growth measurements, could provide useful estimates of water-use efficiency.

EXTENT TO WHICH CONTRACT OBJECTIVES HAVE BEEN MET

The terms of reference for this project were similar to the aim and objectives stated above. The general requirement was “*To measure and model the water use and growth of indigenous trees in different types of tree systems, and to quantify the economic benefits and costs of the biomass production under a range of bio-climatic conditions in South Africa.”* The extent to which contract objectives have been met may be assessed in relation to the specific objectives of the project:

1. *To screen, shortlist and select indigenous tree species that are most promising for natural and plantation tree production systems with particular attention to single species/even aged and mixed species/mixed aged tree systems.*

This objective was addressed through the stakeholder workshop and subsequent short-listing and selection of priority indigenous tree species and forest types for measurement in the project. The main findings that illustrate how this objective was met include:

a) The drafting of a short-list of indigenous tree species considered to be the most promising for natural and plantation tree production systems, and the subsequent identification of the top 10 indigenous tree species considered to be the most beneficial from environmental, social and economic perspectives.

b) The compilation of a database of planted indigenous tree stands in South Africa, based on data collected during an awareness campaign and appeals for relevant information, conducted through a range of media and publicity channels. These incorporated television, internet, publications and presentations.

c) The identification of appropriate tree species and suitable sites for water use measurements and modeling with particular attention to single species/even aged and mixed species/mixed aged tree systems.

2. *To improve knowledge of the water use efficiency (WUE) of indigenous trees under natural and plantation systems through growth and water use measurements and modelling, using proven methods and techniques.*

This objective was addressed by means of six phases of field work, conducted for a minimum duration of 12-months each, and located in a diverse range of bio-climatic environments. At each of these sites, detailed measurements were taken of tree/forest water-use, above-ground stem biomass increments, weather variables, soil water fluctuations and tree/forest attributes. The data facilitated the calculation of Water Use Efficiency (WUE) for the respective indigenous tree species and forest types, as well as an understanding of the driving variables (weather, water availability, tree/forest attributes). Parameterisation and testing of the MAESPA and Penman-Monteith ("Big-Leaf"-type) models at a selection of these sites, investigated their ability to replicate the field observations of tree and forest water-use. The main findings that illustrate how this objective was met include:

a) The generation of detailed and quality-checked data on tree water use (transpiration), utilizable stem growth (biomass increment) and resultant water use efficiency (e.g. wood produced per Litre water transpired) for a wide range of priority indigenous tree species, observed in different bio-climatic regions, over a minimum time period of one year for each species.

b) A growing body of evidence that suggests that indigenous tree species tend to use less water than similarly-sized introduced tree species, but also grow substantially slower than they do, with the net result of similar biophysical water use efficiency tendencies.

c) The resultant conclusion is that there appears to be a trade-off between growth rates and water use of trees.
d) Confirmation of the important role of indigenous trees from an ecohydrological perspective, and their wider scale applicability in fields such as forest restoration, erosion control, replacement of invasive alien species and multiple-use indigenous tree wood-lots, particularly where water-conservation is a priority.

3. *To analyse the economic viability and market potential of biomass products from indigenous natural and plantation tree systems (in different social contexts) and in comparison with exotic commercial plantations.*

This objective was addressed by means of economic and financial assessments conducted on informal indigenous tree product markets (resource use in Manubi forest), as well as more formal/recognised indigenous wood markets (indigenous tree plantations, SANParks auctions, indigenous wood sales and potential products). Information on potential products, supply and demand processes, trading and values associated with those markets was collected. The main findings that illustrate how this objective was met include:

a) Improved understanding of the economic viability and market potential of biomass products from indigenous natural and plantation tree systems (in different social contexts) and in comparison with exotic commercial plantations.
b) The conclusion that the informal indigenous tree product industry is heterogeneous, amorphous and unregulated; yet economically significant at local scales, and the quantification of the economic value of some products in this industry through a case study.
c) The conclusion that the more formal indigenous tree product industry is currently a small, high-value, niche market, with potential for growth, but with considerable challenges in terms of sourcing, availability and reliability of supply, quality variation, transportation and milling.
d) Indications that the financial viability of Yellowwood plantations may be favourable over a 45-yr rotation period, given certain assumptions and a long-term perspective.

4. *To develop and test a rapid screening technique to identify indigenous tree species-site combinations based on water use, economic viability and eco-system adaptability, thereby optimizing WUE and socio-economic potential.*"

This objective was addressed through consideration of the necessary data and information required to assess WUE and site-species optimality, taking into account the economic/financial value of preferred indigenous tree species. Based on experience gained from field measurements it took into account practicalities associated with obtaining the requisite data, compared to a modelling approach. The main findings that illustrate how this objective was met include:

a) The impression, gained from a review of literature and information, that there is not yet the necessary understanding to identify complex attributes like cumulative growth and transpiration from one or more easily measured attributes.
b) The conclusion that growth increments, using a series of measurements of stem and branch diameters of various sizes, taken at the start and end of a 12-month period can yield accurate annual growth rates to compare among different species.
c) The identification of the MAESPA model as a potentially suitable model for transpiration simulation and subsequent WUE ranking.
d) Recommendations on a procedure for ranking tree species in terms of their water use efficiency, which is practical and avoids the difficulties of measuring transpiration.

Additional over-arching objectives of the project, including capacity building, timely progress reporting and production of project-related conference papers/posters, popular articles and scientific articles, were met, as detailed in the following integrated final report.

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Roman Symbols

c_p	specific heat capacity of air at constant pressure (approximately 1040 J kg^{-1} K^{-1})
D	deep drainage (mm)
E_s	soil evaporation (mm day^{-1})
ET	total evaporation (mm)
ET_{EC}	total evaporation (mm) from eddy covariance measurements
ET_o	FAO-56 reference total evaporation (mm)
ET_{sz}	ASCE-EWRI short grass (0.12 m) reference evaporation (mm)
g_c	canopy conductance (m s^{-1}) = (1/r$_s$)
g_{cmax}	maximum conductance (m s^{-1})
G	soil heat flux (W m^{-2})
H	sensible heat flux (W m^{-2})
LE	latent heat flux (W m^{-2})
P	precipitation (mm)
Q	streamflow (mm)
r_b	leaf boundary layer resistance (s m^{-1})
r_s	stomatal resistance (s m^{-1})
R	surface runoff (mm)
R_n	net irradiance (W m^{-2})
spha	stems per hectare
T	transpiration (mm or L)
T_a	temperature of the air (°C)
T_{sonic}	air temperature using sonic temperature (°C)
V_h	Heat Pulse Velocity (cm hr^{-1})
w	vertical wind velocity (m s^{-1})
W	contribution from water table upward (mm)

Greek symbols

Δ	slope of saturated vapour pressure vs air (*kPa* $^oC^{-1}$)
ΔS	change in soil water storage (mm)
γ	psychrometric constant (*kPa* $^oC^{-1}$)
θ	actual volumetric water content (m^3 m^{-3})
ρ_a	density of air (approximately 1.12 kg m^{-3})
ρ_s	bulk density of soil (kg m^{-3})
ρ_w	density of water (kg m^{-3})
λ	latent heat of vaporisation of water (J kg^{-1})

Abbreviations

ASCE	American Society of Civil engineers
AWS	Automatic weather station
CSIR	Council for Scientific and Industrial Research
DAFF/DOA	Department of Agriculture, Forestry and Fisheries
DWS/DWAF	Department of Water Affairs & Sanitation
FAO-56	Food and Agriculture Organisation, paper no. 56
GDP	Gross Domestic Product
HPV	Heat Pulse Velocity
HRM	Heat Ratio Method
LAI	Leaf Area Index
MAP	Mean Annual Precipitation
PAR	Photosynthetically Active Radiation
PAW	Plant Available Water
SWB	Soil Water Balance
TDR	Time Domain Reflectometry
VPD	Vapour Pressure Deficit
WUE	Water Use Efficiency

1 INTRODUCTION

1.1 Background

Specific findings, recommendations and gaps in knowledge regarding the Water Use Efficiency (WUE) and economic potential of indigenous tree systems were identified in a previous WRC report (TT 361/08) which was published in December 2008 (Dye *et al*., 2008). These included the need for improved understanding of the water-use efficiency of a wider selection of indigenous tree species growing under a range of bio-climatic conditions in South Africa. This information is needed to further explore the possibility of expanding and growing the local forestry industry using indigenous tree species. Potential benefits of this expansion include the expected lower water-use rates of indigenous species (evidence for which was obtained in the initial project), and the high economic value of biomass products. Furthermore, it is important to place the water-use of introduced commercial plantations in perspective, through comparisons with indigenous tree production systems. There is also a need to establish a baseline water-use by indigenous trees under natural conditions to facilitate the evaluation of likely water resource changes associated with a change in land use. Improved knowledge in these aspects will contribute to improving or enhancing rural livelihoods through the use of indigenous tree production systems. In addition, possibilities exist to provide alternative wood production systems to replace alien invasive plants, as the process of alien plant eradication continues.

Research was required on WUE, site-species matching and economic viability (primarily biomass production but taking consideration of traditional medicinal products, carbon sequestration and potential for use in Payment for Ecosystem Services (PES) schemes) of indigenous tree systems, to support sustainable rural development and the expansion of the existing forestry industry. Recommendations were required which needed to take cognizance of additional aspects necessary for the successful expansion of indigenous forests including their potential ecological affects, population dynamics, successional state and social acceptance.

This project, under the directed call in response to the published terms of reference, set out to achieve the following: Improved understanding of the WUE characteristics, bio-climatic requirements and economic potential of a wide range of indigenous tree species. This was to allow more meaningful decisions to be made regarding site-species matching with indigenous trees, and to facilitate the promotion of alternative (indigenous) forms of forestry in South Africa.

1.2 Rationale

There are approximately 1000 tree species indigenous to South Africa, which display a very wide variety of structure, growth form, growth rate, ecological requirement and useful products. In the past, use of indigenous tree species for timber production was widely considered by foresters to be pointless, since their growth is substantially less than that of the fast growing commercial forestry species. This is why the bulk of South Africa's needs for timber are met by plantations of eucalypts, pine and wattle. A few stands of indigenous tree species were established in several localities, but were not seriously considered as an alternative to fast-growing introduced species, as the focus was almost entirely on the production of useful timber. However, the forestry situation is now changing rapidly in response to the following drivers.

1) Further afforestation with commercial forest species is now severely restricted by legislation, to guard against further reductions in catchment water yields. South Africa's water resources will soon be fully utilized. There is renewed interest in the possibility of low water-use forms of forestry. It is estimated that at least 7% of the country is potentially suitable for forest growth on the basis of climate and substrate, (Geldenhuys and Mucina, 2006), but current indigenous forests cover just 0.1% (around 4 000 km^2) of the land area (Mucina and Rutherford, 2006).
2) Demand for high quality wood from indigenous timber species such as Yellowwood and Stinkwood remains high, and demand substantially exceeds supply. Results from the first phase of this project suggest that profitable sustainable forest systems may be possible if management costs can be kept low.
3) Appreciation of the aesthetic value of indigenous trees and forests is growing, and the recreational value of indigenous forests can greatly increase their economic value.
4) Progress in reducing levels of poverty in South Africa has been disappointing, and poverty remains a huge problem. The rural poor continue to rely heavily on available natural resources, often over-exploiting limited forest resources.
5) There is growing appreciation of non-timber forest products and ecosystem services provided by indigenous forests.

It is an appropriate time in the development of South Africa to reconsider whether indigenous tree species can form the basis of new, viable kinds of "**Indigenous Forestry**" to supplement existing introduced plantation forests, and assist in improving the lives of the poor.

1.3 Research Objectives

The overall objective of this project was:

To measure and model the water use and growth of indigenous trees in different types of tree systems, and to quantify the economic benefits and costs of the biomass production under a range of bio-climatic conditions in South Africa.

The specific aims of this project were:

1. To screen, shortlist and select indigenous tree species that are most promising for natural forest and indigenous plantation tree production systems with particular attention to single species/even aged and mixed species/mixed aged tree systems.
2. To improve knowledge of the water use efficiency (WUE) of indigenous trees under natural forest and indigenous plantation systems through growth and water use measurements and modelling, using proven methods and techniques.
3. To analyse the economic viability and market potential of biomass products from natural indigenous forests and indigenous plantation tree systems (in different social contexts) and in comparison with exotic commercial plantations.
4. To develop and test a rapid screening technique to identify indigenous tree species-site combinations based on water use, economic viability and eco-system adaptability, thereby optimizing WUE and socio-economic potential.

1.4 Approach

Indigenous tree systems that were studied in this project included mixed-species/mixed aged natural forests, single-species/even-aged indigenous plantations, stands and individual trees. An initial screening exercise short-listed the most promising indigenous tree species in South Africa with regard to value of utilizable wood and other goods and services, growth rates, geographical distribution, climatic preferences and adaptability. This was done through a knowledge review that included a literature search, interviews with appropriate people (forestry representatives, community members, researchers) and site visits to gather relevant information. This guided the initial selection of individual tree species for measurements, modelling and economic analysis. The population of a database on existing indigenous tree trials and plots also provided a basis for selecting sites and species to focus on. Finalisation of sites and species for monitoring took place following a workshop with interested and affected parties (IAPs) at the start of the project.

Field-work consisted of measurements of water-use, growth and ancillary variables (weather, physiological attributes of the trees and soil characteristics/water) according to the methods refined in the previous and related WRC project (K5/1462 – Water use in relation to biomass of indigenous tree species in woodland, forest and/or plantation conditions) (Dye *et al*., 2008). The respective phases of monitoring different sites/species were carried out for a minimum period of 12-months each in order to incorporate a full year of climatic/seasonal variation. The field-work phases of the project focused on different sampling regions representing a range of bio-climatic zones with differing site quality characteristics. The study areas were selected to best represent the major forest groups and forest types belonging to them. Measurements of water-use and growth were subsequently carried out in a selection of the most promising and available species, at different bio-climatic locations, using the techniques refined in the previous WRC project K5/1462. State-of-the-art micrometeorological techniques such as Heat Pulse Velocity (HPV) and eddy covariance were used to obtain estimates of transpiration and total evaporation (ET_{EC}) respectively, from stands of indigenous trees. The focus was on individual species most representative of each bio-climatic zone and which showed the greatest potential for more wide-scale establishment.

Water use modelling and economic analysis exercises were undertaken following the field monitoring. The modelling tested the ability of appropriate models to adequately replicate the observed water-use of the measured species, while economic analyses explored the financial and economic viability of selected indigenous tree species in plantation rotation production systems, informal natural forest resource utilisation, and the more formal market potential of indigenous tree products. In addition to the field measurements, water use modelling and economic analyses, a rapid screening technique to identify the most promising site/species combinations from a WUE perspective was tested and refined. Overall findings from these various project components were integrated into this final report.

1.5 Report Structure

This report is structured in two volumes. Volume 1 (Research Report) covers background information on indigenous trees and forests, project details, research methods employed, economic and financial viability assessments, market and product potential information, rapid screening techniques for estimating water use efficiencies, and general conclusions based on the results of field measurements. Volume 2 (Site-Specific Technical Report) provides details on the respective field measurement sites/species, specific measurement methods employed, results and conclusions.

2 CLASSIFICATION, DISTRIBUTION AND SELECTION OF INDIGENOUS TREE SPECIES AND SITES[1]

Indigenous trees in South Africa occur predominantly in natural forests and savanna woodlands; however limited areas of planted indigenous stands do exist. This section provides an overview of these indigenous tree systems, citing relevant definitions and summarising their classification, distribution, and suitability for a range of tree production systems. The definition of what constitutes an indigenous forest in South Africa has changed over the years, and at the outset it is important to distinguish between **forest** and **natural forest**. The National Forest Act (NFA) of 1998 broadly defines **forest** as:

"including a natural forest, a woodland and a plantation, the forest produce in it, and the ecosystems which it makes up."

However, the definition of a natural forest needs to consider the development stages of that forest (different ecosystems which make up a particular forest) because this may be disputed amongst different stakeholders. Consequently, the legal definition of a **natural forest** in the NFA (1998) is:

"a group of indigenous trees, which a) in the undisturbed state have overlapping crowns (>75% crown cover of their combined tree strata); b) in the disturbed state may be open-grown, or not present at all, but the associated remnant indigenous plant species of all life forms are generally associated with natural forest; c) forms part, or had formed part in the last 50 years, of the stages of a mature forest, whether in degradation or recovery; and d) is not a woodland or a plantation or another woody vegetation unit; or e) have been declared by the Minister to be a natural forest under Section 7(2)."

Definitions also need to provide for planted stands of indigenous tree species, and also plantation and invader plant stands which may eventually incorporate the establishment of many and diverse indigenous tree species to become a regrowth or secondary forest. This applies even to sites that may not have had natural forest cover before, because of the exclusion of fire from the

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[1] When making reference to this section, please cite as follows:

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landscape through agriculture, plantation forestry, urban development and settlements, or strict nature conservation practices. In the NFA (1998) a **plantation** is simply defined as:

“a group of trees cultivated for exploitation of the wood, bark, leaves or essential oils in the trees.”

All plantations are, somewhat controversially, classified as **forest** under the current NFA (1998), however no formal distinction appears to have been made between plantations of indigenous species as opposed to those of introduced species. For the purposes of this discussion the definition of a plantation follows that drafted by the Global Forest Resources Assessment (FAO 2001), namely:

“a collection of trees of one or more species, planted at the same time, in regular rows of known spacing, and managed with the objective of maximizing the production of utilizable above-ground biomass.”

This distinguishes plantations of indigenous tree species from regenerated/natural forests of mixed species and mixed ages of trees, and excludes trees planted in gardens or cities.

Shackleton *et al*. (1999) defined the term **woodland** (or savanna) as:

“a suite of tropical and subtropical vegetation types in which fire-adapted, co-dominant, continuous or discontinuous herbaceous and largely deciduous woody strata experience markedly seasonal growth patterns and processes in relation to the seasonal delivery of precipitation, which occurs during hot summers, followed by cooler, but warm, dry winters. Generally the herbaceous stratum is dominated by C4 grasses and sedges, but this, and the overall cover of the woody and herbaceous strata, may be temporarily altered by a range of disturbance phenomena.”

Woodlands constitute all those vegetation types in South Africa commonly referred to as bush, bushland, bushveld, thicket, thornveld and scrub. The NFA (1998) defines **woodland** on the basis of canopy cover as:

"a group of trees which are not a natural forest, but whose crowns cover more than five percent of the area bounded by the trees forming the perimeter of "the group".

2.1 Classification and Production Systems

South African indigenous forests were formerly classified into two principal types, namely Afromontane Inland Forests and Coastal Subtropical Forests (White, 1978), and then into just one Forest Biome (Low and Rebelo, 1998). A national forest type classification conducted by von Maltitz *et al.* (2003) subdivided the biome into twenty natural forest types in 7 groups, with an additional 4 azonal forest types (Table 1 and Figure 1).

Table 1. National Forest Type groupings as used on the map of the national vegetation types of South Africa (Mucina and Rutherford, 2006) based on Von Maltitz *et al.,* 2003).

Forest Group	Forest Type
I: Southern Afrotemperate Forests	I1: Western Cape Talus I2: Western Cape Afrotemperate I3: Southern Cape Afrotemperate
II: Northern Afrotemperate Forests	II1: Marekele Afromontane II2: Northern Highveld II3: Drakensberg Montane Forests II4: Northern KwaZulu-Natal Mistbelt
III: Northern Mistbelt Forests	III1: Limpopo Mistbelt III2: Mpumalanga Mistbelt
IV: Southern Mistbelt Forests	IV1: Eastern Mistbelt IV2: Transkei Mistbelt IV3: Amatole Mistbelt
V: Scarp Forests	V1: Eastern Scarp V2: Pondoland Scarp V3: Transkei Coastal
VI: Northern Coastal Forests	VI1: KwaZulu-Natal Coastal VI2: KwaZulu-Natal Dune
VII: Southern Coastal Forests	VII1: Eastern Cape Dune VII2: Albany Coastal VII3: Western Cape Milkwood
Azonal Forest Types	A1: Lowveld Riverine A2: Swamp A3: Mangrove A4: Licuati Sand

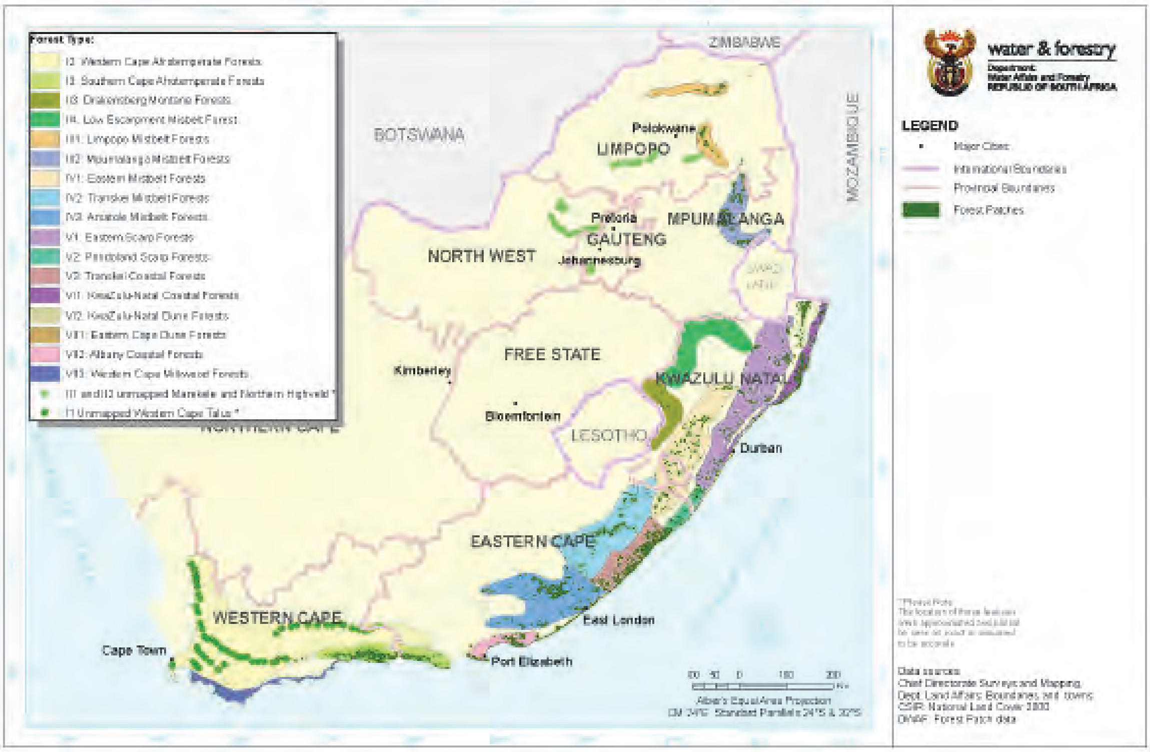

Figure 1. Forest extent and fragmentation by the different national groupings and types of natural forest in South Africa (Von Maltitz *et al.,* 2003; Mucina and Rutherford 2006). Source: DWAF State of Forests Report, (2008).

The same forest groupings have largely been retained in the most recent natural vegetation mapping exercise for South Africa (Mucina and Rutherford, 2006), with the addition of Sand Forest and Ironwood Dry Forest as new groups, and the removal of Licuati Sand Forest as an azonal forest type. Defining the forest types to be included in this project was guided by the actual areas and relative proportions of the different forest groups and azonal forest types now considered by Mucina and Rutherford, (2006) to make up the forest biome (Table 2).

Table 2. Areas represented by the various natural forest groups in South Africa (from Mucina and Rutherford, 2006), and their respective proportions of the entire forest biome.

Forest Group	Area (km²)	Percentage of Biome
Southern Mistbelt Forest	1100.15	23.34%
Scarp Forest	867.18	18.39%
Southern Afrotemperate Forest	799.8	16.96%
Northern Mistbelt Forest	613.38	13.01%
Northern Coastal Forest	467.05	9.91%
Sand Forest	242.75	5.15%
Northern Afrotemperate Forest	169.74	3.60%

Forest Group	Area (km²)	Percentage of Biome
Southern Coastal Forest	165.45	3.51%
Lowveld Riverine Forest	158.4	3.36%
Ironwood dry Forest	59.19	1.26%
Swamp Forest	38.03	0.81%
Mangrove Forest	33.4	0.71%
Total	**4714.52**	**100.00%**

A great number of woodland (savanna) types have also been classified for South Africa (Acocks, 1988: Low and Rebelo, 1998). This is attributable to the tremendous diversity and geographical range of this biome. In the most recent vegetation assessment for South Africa, Mucina and Rutherford (2006) now classify the savanna biome into 87 different vegetation types within six groups or bio-regions.

2.2 Distribution of Indigenous Forests

The natural indigenous forests of South Africa, although limited in extent, occur scattered over a wide latitudinal gradient along the eastern and southern margins (escarpment, mountain ranges and coastal lowlands) of the country (Figure 2). Their distribution ranges from the Soutpansberg in the north of Limpopo province, through Mpumalanga to Maputaland in the east, in the eastern Free State and along the Drakensberg Mountains of KwaZulu-Natal, discontinuously through the midlands of KwaZulu-Natal and the Eastern Cape to the coast, down through the Outeniqua and Tsitsikamma Mountains of the southern Cape to the Cape Peninsula in the south-west (Mucina and Geldenhuys, 2006).

Typically, indigenous forests occur as a series of scattered small to very small patches (<10 ha), and most forests are smaller than 100 ha in size (Cooper, 1985). While at least 7% of the country is a potential habitat for indigenous forests owing to the favourable combination of climate and substrate suitable for forest growth, only approximately 4700km² (0.1%) of the land surface of South Africa is actually covered by natural forests (Mucina and Geldenhuys, 2006). Woodlands on the other hand are estimated to cover approximately 290 000 km² (6.2 %) of South Africa (Mucina and Rutherford, 2006), and are distributed over a substantially wider land area (Figure 3).

Figure 2. Map showing the extent and distribution of natural forests in South Africa (DAFF, 2009).

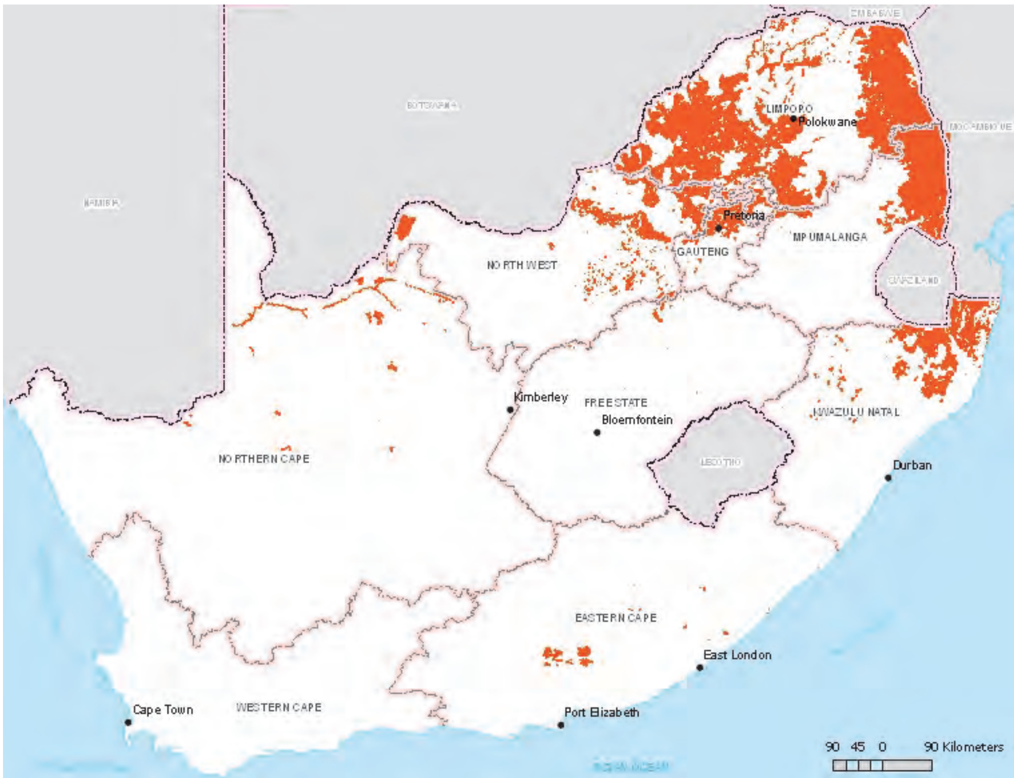

Figure 3. Map showing the extent and distribution of savanna woodlands in South Africa (DAFF, 2009).

2.3 Taxonomical Changes

A number of indigenous tree taxonomical changes took place during the course of the project, which are important to note. The first refers to the species originally known as *Acacia karroo* (Sweet Thorn). A retypification of African species of the genus Acacia into two distinct genera, namely Vachellia and Sengalia, was somewhat controversially approved in 2011 (Boatwright *et al*. 2014; Dyer, 2014), and henceforth the species *Acacia karroo* was renamed *Vachellia karroo*. Subsequent to this decision, the *Vachellia karroo* complex was subdivided into six separate species, one of which was the newly named *Vachellia kosiensis* (Dune Sweet Thorn) (see: http://www.acacia-world.net/index.php/africa-me/south-africa/the-vachellia-karroo-complex). It has been allocated the South African National Tree No. 172.2.

The second noteworthy taxonomical change concerns the species *Podocarpus falcatus* (Outeniqua Yellowwood). Some schools of thought now regard this particular species as *Afrocarpus falcatus* (Leistner *et al*., 1995; Barker *et al*., 2004). Names of the three other Podocarpus species occurring in South Africa, i.e. *Podocarpus latifolius* (Real yellowwood), *Podocarpus elongatus* (Breede River Yellowwood) and *Podocarpus henkelii* (Henkel's yellowwood), remain unchanged.

2.4 Distribution of Indigenous Tree Plantations

In terms of indigenous tree plantations in South Africa, there is very little information available on their current extent and distribution. Nevertheless, there has long been a desire to establish viable indigenous tree production systems in South Africa (van Wyk, 1982), some of which can be traced back over 100 years. One of the earliest efforts were experimental plantings of *Ocotea bullata* (Black Stinkwood), *Curtisia dentata* (Assegaai), *Apodytes dimidiata* (White Pear) and both local Yellowwoods, *Podocarpus latifolius* (Real Yellowwood) and *Afrocarpus falcatus* (Outeniqua Yellowwood) at Concordia (Knysna) between 1897 and 1900 (Stapleton, 1955).

Additional trial plantings of indigenous yellowwood trees are known to have been established at sites in the southern Cape (Witfontein), Mpumalanga (Frankfort) and Limpopo provinces (De Hoek) of South Africa in the early 1980s (Geldenhuys and von dem Bussche, 1997). Some experimental plantings of *Khaya anthotheca* (East African Mahogany) took place on Frankfort State Forest near Sabie, Mpumalanga and at Entabeni State Forest, Limpopo province (von dem Bussche and Ellis, 1987). While this species is not indigenous to South Africa, it does occur naturally in eastern Zimbabwe.

Also in Limpopo Province, experimental plantings of *Trema orientalis* (Pigeonwood) were initiated at the Westfalia Estate near Tzaneen (Keet, 1962). In addition to these controlled plantings, observations of indigenous species (e.g. *Podocarpus spp.*) regenerating beneath pioneer indigenous trees as well as beneath plantations of introduced tree species have been noted over the years by Wicht (1949), Taylor (1962), van der Schyff (1963), Seagrief (1965) and Geldenhuys (1997).

Most of these early experimental plantings are no longer in existence, having been felled and replaced with alternative crops. For the purposes of this project it was therefore important to establish an up-to-date inventory of indigenous tree trials and plots which currently exist in South Africa. A database of indigenous tree plantations (Table 3) was compiled, incorporating details gathered from existing literature sources (e.g. Geldenhuys, 1975a; Geldenhuys, 1975b;Geldenhuys *et al.*, 1986; Lübbe and Geldenhuys, 1991; Geldenhuys and von dem Bussche, 1997) and additional information gathered during the project.

Table 3. Database of known single-species/single-age indigenous tree plantations in South Africa

Name	Location	Lat.	Long.	Species	Area (ha)	Spacing	Stems per ha	Planting date	Contacts/Info
De Hoek	Magoebaskloof, Tzaneen, Limpopo	23° 49' 50.4" S	30° 02' 31.2" E	*Afrocarpus falcatus*	2.5	3m X 3m	1111	1983	Willem Hollenstein (KLF) 015-3053203. Geldenhuys and von dem Bussche (1997)
De Magtenburg	Karkloof, KZN	29° 21' 25.2" S	30° 11' 49.3" E	*Podocarpus henkelii*	0.12	3m X 3m	1111	unknown	Doug Burden (Mondi) (033-8974034/0828258425)
Symes Farm	Windy Hill, KZN	29° 29' 29.3" S	30° 33' 48.2" E	*Afrocarpus falcatus, Podocarpus henkelii & P. latifolius*	0.45	3m X 3m	1111	2002	Craig Symes 033-5031753/0765057701
Benvie Farm	Karkloof, KZN	29° 16' 48.1" S	30° 23' 43.5" E	*Afrocarpus falcatus, Podocarpus henkelii & P. latifolius*	0.4	3m X 3m	1111	unknown	
Diepwalle Arboretum	Diepwalle, Knysna	33° 57' 03.9" S	23° 09' 36.3" E	Several species (pure & mixed stands)	2.63 & 1.23	1m x 1m to 1.3m x 1.3m		1927/32	Lübbe and Geldenhuys (1991)
Reid se Draai Taungya planting	Diepwalle, Knysna	33° 56' 59.4" S	23° 08' 56.2" E	Several species (mixed stand)	0.15	1m x 1m		1927/32	Geldenhuys (1975)
Concordia Arboretum	Concordia, Knysna	34° 01' 20.0" S	22° 27' 38.7" E	Several species (pure & mixed stands)		1m x 1m		1897/1900	Stapleton (1955)

Name	Location	Lat.	Long.	Species	Area (ha)	Spacing	Stems per ha	Planting date	Contacts/Info
Assegaai plantation	Witfontein, George	33° 56' 14.5" S	22° 27' 38.7" E	Pure stand of *Curtisia dentata*	1.8		1020	1899	Geldenhuys, Le Roux, & Cooper (1986)
Moodies Farm	Grabouw	34° 09' 35.1" S	19° 07' 16.8" E	Mixed stand				1952	In Fynbos, above apple orchards
Zingcuka plantings	Hogsback, Keiskammahoek	32° 40' 06.3" S	27° 00' 46.1" E	*Afrocarpus falcatus* & *Podocarpus latifolius* under Oak					Geldenhuys (1975)
Sneezewood plantings	Kentani near Butterworth	32° 30' 37.6" S	28° 18' 29.6" E	*Ptaeroxylon obliquum* & *Pinus halepensis*	2.8			1989	
Fort Donald plantings	near Brooks Nek, Kokstad	30° 41' 28.8" S	29° 31' 20.9" E	*Podocarpus hekelii* pure stand	1.5?			1899/00	
NCT Byrne	Richmond KZN near Byrne			*Afrocarpus falcatus*	0.4			1992	Lance Bartlett – 082-806 6961 or Jacob Kotze, NCT Cell: 083 642 9044/Tel: 033 8978500
Breezy Brae	Creighton/Donnybrook	29°58'40.75"S	29°50'19.31"E	*Afrocarpus falcatus & Ptaeroxylon obliquum*	1				Peter Nixon Tel: 039 8339015, Cell 0828022826, email peter.rfm@futurenet.co.za

2.5 Suitability of Indigenous Tree Species for Tree Production Systems

Indigenous forests and woodlands in South Africa provide numerous goods for the benefit of society, primarily valuable timber for building and craft materials, fuel-wood and non-timber forest products (Mckenzie, 1988; Everard and Hardy, 1993; Shackleton and Shackleton, 2000; van Wyk *et al*., 2003; Lawes *et al.*, 2004). They also provide ecosystem services such as carbon sequestration, nutrient cycling and watershed protection, and are important cultural and recreational sites, supporting high levels of biodiversity (Geldenhuys, 1999; Shackleton *et al.*, 1999). They are home to approximately a quarter of all South Africans (Shackleton *et al.*, 1999), and as such are heavily relied upon in rural areas and have the potential to make a marked contribution to the economy of the country (Shackleton *et al.,* 2007). The southern Cape indigenous forests have been extensively utilized for timber almost continuously since their discovery by the Dutch in 1711. The history of this exploitation has been well documented in the literature and, through gradual advancement of policy from 1778 onwards, a formal system of multiple-use with close monitoring to ensure sustainability has been developed (Phillips, 1931; Laughton, 1937; Phillips, 1963; von Breitenbach, 1968; Geldenhuys, 1980, McKenzie, 1988; Seydack *et al.*, 1990; Geldenhuys 1994b; Seydack, 1995; Seydack *et al*., 1995; Geldenhuys, 1996; Vermeulen, 2000).

Why is there a need to better understand the water-use and economic value of indigenous trees systems? One potential application is in reforestation programmes, where indigenous tree species are used for restoration of ecosystem services, biodiversity conservation, wood production and carbon sequestration. The potentially high water-use rates associated with reforestation will however require that a balance is found between environmental, social and economic benefits such as wood production or carbon sequestration, and the use of water resources. To achieve this potential indigenous tree species could be considered from environmental, social and economic perspectives. An environmental perspective would be likely to focus on hydrological aspects (Dye *et al.*, 2008), the potential for suppression of alien invasive plants (Geldenhuys, 2004), biodiversity conservation (Armstrong and van Hensbergen, 1996; Ratsirarson *et al*, 2002) and the provision of ecosystem services (Turpie *et al*., 2008). A social perspective might focus primarily on rural livelihoods (Lawes *et al.*, 2004; Shackleton and Shackleton, 2004; Shackleton *et al.*, 2007), but may also consider ecotourism and the use of street trees for urban greening (Stoffberg *et al.*, 2008). An economic perspective would need to consider appropriate means of valuing forests and the goods and services they provide, and then assess markets, product values and total economic value (Hassan and Haveman, 1997). Recommendations could be made as to the species considered to be the most beneficial from these individual perspectives.

2.5.1 Environmental considerations

In this section, we look at the environmental aspects to be considered when selecting a short-list of possible indigenous tree species for evaluation.

Hydrological influences

The establishment of forestry plantations in high-rainfall areas previously dominated by water-conservative grasslands and Fynbos has brought about reductions in catchment water yields that have been well proven and documented (Scott *et al*., 2000; Scott and Prinsloo, 2008). These forest hydrological influences have also been shown to be consistent with global trends (Zhang *et al*., 1999). As a result of these influences, legislation exists in South Africa which restricts further afforestation in catchments where water is largely allocated already. This situation pertains in most of the catchments where forestry is potentially possible, and so opportunities for expansion of the national forestry estate are increasingly scarce. Meanwhile, the demand for wood products continues to grow as the human population continues to rise and standards of living increase.

There is a widespread perception that indigenous tree species are low water users because of their relatively slow growth rates and presumed better adaption to low and variable rainfall in South Africa. A link between transpiration and growth rate is expected under certain conditions, since both processes depend on gas exchange (CO_2 and water vapour) regulated by stomatal openings in the leaves. However, this ratio is known to be greatly affected by air humidity, which suppresses transpiration, but has minimal effect on CO_2 diffusion and carbon assimilation. Other factors such as carbon allocation strategies, respiration, canopy rainfall interception, competition effects, age effects, etc. may all influence the ratio of evapotranspiration to above-ground biomass accumulation in stands of trees. It is therefore very difficult to separate environmental from genetic influences on transpiration and evapotranspiration rates.

Some leaf-scale evidence from the southern Cape (Saasveld campus of NMMU, George) and the Natal Midlands (Karkloof) suggests that indigenous tree species may show lower leaf conductance rates than introduced, fast-growing timber species. These results were obtained with a leaf porometer and photosynthesis meter, and are described in phase one of this project (Dye *et al*., 2008). However, direct measurement of ET above the Groenkop forest adjacent to the Saasveld campus revealed high rates of ET under conditions of high atmospheric demand, showing that lower stomatal conductances do not necessarily translate into lower ET rates at the whole-forest scale. The Groenkop forest is characterized by a high total leaf area index which may easily compensate for lower stomatal conductances to permit high ET rates. Also, a wet climate promotes high rainfall interception losses, which in the case of this forest, was estimated to be 27 % of gross rainfall (Lubbe and Versfeld, 1991).

Despite the strong environmental influences on ET, there is a clear case of genotypically determined low water-use in a group of indigenous tree species. A study of whole year sap flow in a stand of *Afrocarpus falcatus* at Duiwelskloof confirmed earlier leaf-based studies and showed that sap flow and water-use are low in this species. *Podocarpus* spp. are gymnosperms, and it is thought that low water-use rates may be a result of the tracheid-dominated xylem, which is less efficient than vessel xylem at transporting water. Low sap flow rates were confirmed in a study of an *A. falcatus* tree in the Karkloof district (Dye *et al*., 2008).

Results to date are insufficient to offer conclusive evidence of low water-use by indigenous tree species as a group, and further ET measurements are required over a range of forests and site types. Previous experience has emphasized the importance of measuring or estimating total ET at the stand or forest scale, so that comparisons can be made across different kinds of forests. This ensures that the effects of competition from surrounding trees and understorey are taken into account. Planted stands of indigenous tree species are scarce, but advertisements were placed in a variety of relevant publications to seek assistance in locating as many as possible. Availability of these will largely determine the species selected for further ground-based water-use studies of plantation stands.

Forest water-use is greatly affected by recent rainfall occurrence and the current evaporative demand of the air, which underlines the importance of comparing total ET across stands of trees or forests under comparable climatic and site conditions. This needs to happen simultaneously to obtain a true comparison of alternative land-use covers. Micrometeorological systems have permitted direct measurement of ET above forest canopies, but such equipment is expensive and seldom sufficient to monitor ET from more than one site. Spatial comparisons of ET have been impossible to undertake with available methods to date, but new methodologies based on remote sensing estimates of the surface energy balance offer a means of mapping spatial ET at different times of the annual growth cycle, and gaining much more insight into comparative spatial ET. The use of this methodology was planned for the current project, and shed much light on ET patterns from indigenous forests.

Species selection for plantation systems at this stage of inadequate understanding of water-use differences should be guided primarily by high growth rates and quality of timber. A list of useful, fast-growing tree species associated with the main forest types in South Africa has been extracted from the National forest Type Classification (Von Maltitz *et al*., 2003), and is shown in Appendix D. The vegetation map of South Africa (Mucina and Rutherford, 2006) includes lists of common tree species for each vegetation type, and should be used as a guide to selecting appropriate species from this list to match particular localities.

Suppression of weeds

There are very many examples of sites where a forestry cover would be useful to provide a stable land-use to control the development of weeds. Two examples are given below.

1) In the commercial forestry plantations of the wetter parts of the country, trees are excluded from the upper riparian zones, which are rapidly colonized by invasive weeds, following disturbance. Foresters incur repeated high costs in controlling these weeds, but are unable to attain long-term control. Establishment of indigenous tree species adapted to wet riparian soils and characterised by low transpiration rates would provide a more sensible strategy for managing these highly disturbed zones. *Afrocarpus falcatus*, *Podocarpus latifolius* and *Podocarpus henkellii* meet these requirements. They may be planted in dense stands, provide deep shade, suppress understorey plants, and require minimal maintenance. Their water-use is low, and impact on streamflow is therefore also considered to be low. They may be harvested over the course of time to provide an income from timber. Other species that could be considered for wet riparian soils include *Ilex mitis*, *Sideroxylon inerme*, *Syzygium cordatum* and *Ocotea bullata*.

2) Areas recently cleared of alien invasive plants are often subject to a rapid reinvasion, necessitating expensive and repeated follow-up spraying and other control measures. Establishment of a quick stabilizing tree cover to suppress the re-establishment of weeds would be an ecologically appropriate control strategy on sites where forests are ecologically feasible. Fast-growing tree species, tolerant of high density planting and capable of rapid canopy development and high leaf areas to shade out newly invading plants and regrowth could be effective for this purpose. Possible tree species could be *Trema orientalis, Virgilia oroboides, Afrocarpus falcatus, Millettia grandis, Ptaeroxylon obliquum, Prunus africana, Rapanea melanophloeos, Vepris lanceolata* and *Dais cotinifolia*. Regeneration of indigenous tree species within

nursery stands of introduced plantations (e.g. *Pinus patula*) has been documented (Geldenhuys, 1997), and the reported benefits of rapid height growth and reduced competition from weeds are worth considering in this regard.

Trees for biodiversity protection

Several studies of the utilization of indigenous forests have revealed very high levels of utilization (e.g. Hassan and Haveman, 1997; Geldenhuys, 1999). Many such forests are degraded and not managed in a sustainable way. In most cases, the primary need is for fuel wood (Basson, 1987), and degradation may be severe where no alternative sources of fuel wood exist. The strong market for traditional medicines is also leading to over-exploitation of certain highly valuable species (e.g. *Ocotea bullata*, *Warburgia salutaris*, *Curtisia dentata*) (Lawes *et al*., 2000) and threatening the biodiversity of indigenous forests. The scale of utilization is reflected by the size of this industry. According to Mander (1998), there are an estimated 27 million traditional medicine consumers in South Africa, approximately 100 000 practicing traditional healers using indigenous plants, and a turnover of R270 million per annum involving approximately 19 500 tonnes of plant products. Furthermore, the most valued traditional medicines come from forests (Cunningham *et al*., 1988). This scale of utilization represents a substantial threat to the biodiversity of indigenous forests (Mucina and Rutherford, 2006). Establishment of plantations of indigenous tree species, or re-planting of valuable tree species in over-utilized forests could do much to meet demands for forest products, reduced utilization of natural forests, and permit their recovery. Species to consider would be those in greatest demand that are ecologically matched to the available sites. Lists of such species are available for different regions (e.g. Lawes *et al*., 2000 for KwaZulu-Natal). A degree of site-species matching can be achieved for a given site by looking up the natural vegetation type expected in the area, and determining the trees that are particularly characteristic of that type (Mucina and Rutherford. 2006).

Many of the rural poor of South Africa are situated in relatively dry regions where a high demand for fuel wood results in over-utilization of woodlands and riparian forests. A different suite of tree species needs to be considered for such climatic regions. Fire resistance, drought resistance, ability to coppice, and the ability to co-exist with a grass cover are likely to be important attributes. Candidate species could include such species as *Acacia karroo*, *Albizia versicolor/adianthifolia*, *Combretum krausii*, *Croton sylvaticus*, *Combretum erythrophyllum, Searsia lancea and S. pendulina*[2].

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[2] Formerly *Rhus lancea* and *Rhus pendulina*

Other ecosystem services
Forests are likely to be useful in providing a range of other ecosystem services, which are relatively poorly quantified at present. These include high rates of nutrient cycling and organic matter addition to the soil, which may be substantial on nutrient-poor soils and permit relatively high biomass accumulation. Soil stabilization by plant roots may be an important benefit in certain forest sites. The Raphia palm was considered by the conservationist Ian Garland to be excellent in stabilizing eroding stream channels in the Mtunzini district because of its extensive near-surface root system which is able to hold soil in place. Carbon sequestration is an increasingly important topic, and indigenous forests and plantations may play a small but useful role in this regard. Devastating forest fires in introduced plantations appear to be on the increase in South Africa and abroad (e.g. Australia), possibly linked to climate change. There is potential for indigenous forests or plantations of indigenous trees, with inherently low flammability to provide effective fire breaks in the vicinity of introduced plantations, and this aspect requires further study

2.5.2 Social considerations

In this section we consider indigenous tree species that show the greatest potential to provide social benefits. While this is an extremely broad subject, encompassing a wide range of potential benefits, for the purposes of this report (linked to the objectives of the project) attention has been focused primarily on rural livelihoods and how they may benefit from biomass products derived from indigenous tree species. Only indirect economic benefits (i.e. use of naturally grown products that would otherwise have had to be purchased) and/or the intrinsic value of certain indigenous tree species are discussed, because the following section deals specifically with direct economic benefits.

Rural livelihoods
Natural forests in South Africa have always been, and still are, traditional resources supporting the daily livelihoods of people. They play a role in the welfare of society which is disproportionately greater than their small extent and low potential for commercial exploitation (McKenzie, 1988; Geldenhuys, 1999b; Lawes *et al*., 2004; Cawe and Geldenhuys, 2007). As such, concentrations of rural people living in the vicinity of the natural forests in the Eastern Cape, KwaZulu-Natal, eastern Mpumalanga and north-eastern Limpopo Provinces benefit directly from those forests in numerous ways.

Recognition of the potential uses and value of natural forests is crucial when evaluating their importance in the landscape, and resolving conflicts with respect to alternative land use options (e.g. forests vs. farmland). For example, McKenzie (1988) recognized many direct uses and the indirect value of products from South African forests, while Geldenhuys (1999b) used the list of tree and shrub species for 14 forests and forest complexes in South Africa (Geldenhuys, 1992b) to summarise their uses in South Africa as recorded by Palmer and Pitman (1972). Generally formal statistics only provide data on the commercial use and value of a few species, and usually only include timber species. However, ethno-botanical surveys show that many forest species are used for a wide range of traditional and contemporary needs, particularly subsistence needs.

In a survey of 21 villages in the Eastern Cape Province, Hassan and Havemann (unpublished report, 1997) listed 140 tree and shrub species favoured for informal commercial and subsistence use from the forests in that region. The uses included construction (a variety of poles), firewood, crafts (from timber and non-timber species), binding and weaving, food sources (vegetables, fruits, and meat), and traditional medicine (bark, roots and other sources). In another study Cawe and Geldenhuys (2007) sampled one household in each of four forest/village complexes in each of three Forest Management Units (FMUs) in the Port St Johns Forestry Estate in the Eastern Cape. The household study showed that the main species used for house construction, fencing and firewood (i.e. biomass use only), were (in order of importance) *Millettia grandis*, *Ptaeroxylon obliquum*, *Brachylaena discolor*, *Margaritaria discoidea*, *Buxus macowanii* and *B. natalensis*, *Englerophytum natalense*, *Strychnos usambarensis, Duvernoia adhatodioides*, *Combretum kraussi* and two *Tricalysia species*, as well as introduced *Eucalyptus* and *Pinus* species and *Cestrum laevigatum* (an invader species).

Cawe and Geldenhuys (2007) found that the average hut (rondavel) used 28.5 poles of 2.6 m length and 6 to 8 cm diameter in the wall and 27.4 poles of 3.3 m length and about 6 cm diameter in the roof. The average total fence length per household was 281 m with 214 poles of 2.2 m length and 8.1 cm diameter per fence line. Cattle pens had on average 40 m long pole fences using 28 poles of 2.2 m length and 9.6 cm diameter. The average dimensions of a firewood pile at a household were: 2.7 m long by 1.4 m wide and 0.8 m high (volume of 3 m^3). Women collected up to two head loads per day with average dimension of a head load 2.0 m long, 0.3 m wide and 0.3 m high (volume of 0.2 m^3). *Millettia grandis* was used in all 12 households and *Ptaeroxylon obliquum* in 11 of the households (it was not present in all the sampled forests). The survey in the forest closest to a sampled household showed that various tree and shrub species were cut to provide poles and laths for hut construction, garden poles or craftwork. The main species harvested were *Millettia grandis, Strychnos usambarensis, Buxus natalensis, Tricalysia lanceolata, Teclea natalensis,* and *Ptaeroxylon obliquum*. Other important species were *Cussonia spherocephala, Combretum kraussii, Drypetes gerrardii, Duvernoia adhatodoides, Acalypha glabrata, Brachyleana discolor* and *Englerophytum natalense*. In most cases stems less than 20 cm in diameter were cut, but for *Millettia grandis* and *Ptaeroxylon obliquum* a much wider range of stem sizes were cut (Figure 4). Most cut stems showed signs of vegetative regrowth (coppicing). Some species were debarked for traditional medicine, and bark of particularly *Millettia grandis* and *Dalbergia obovata* were used for fibre for binding and construction.

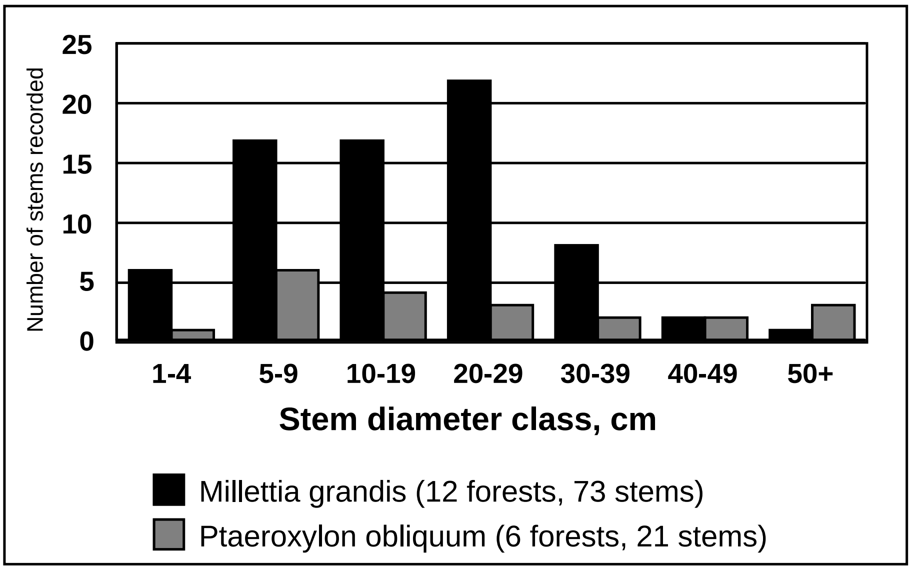

Figure 4. Stem diameter range of *Millettia grandis* and *Ptaeroxylon obliquum*, the two species most commonly cut from the Port St Johns forests for use in house and fence construction, as recorded during a random walk in each of the natural forests closest to the sampled households (Cawe and Geldenhuys, 2007).

The harvested trees of both *Millettia grandis* and *Ptaeroxylon obliquum* showed strong vegetative regrowth, and both showed abundant regeneration on the edge of the forests where they were present (Figure 5 and Figure 6). *Acacia karroo*, frequently harvested for poles, firewood and fibre, rapidly establishes on abandoned agricultural fields on the area of the Transkei Coastal Forest (Figure 6b). Other forest species become established underneath these trees to eventually develop into regrowth forest if the area is not cleared for crops.

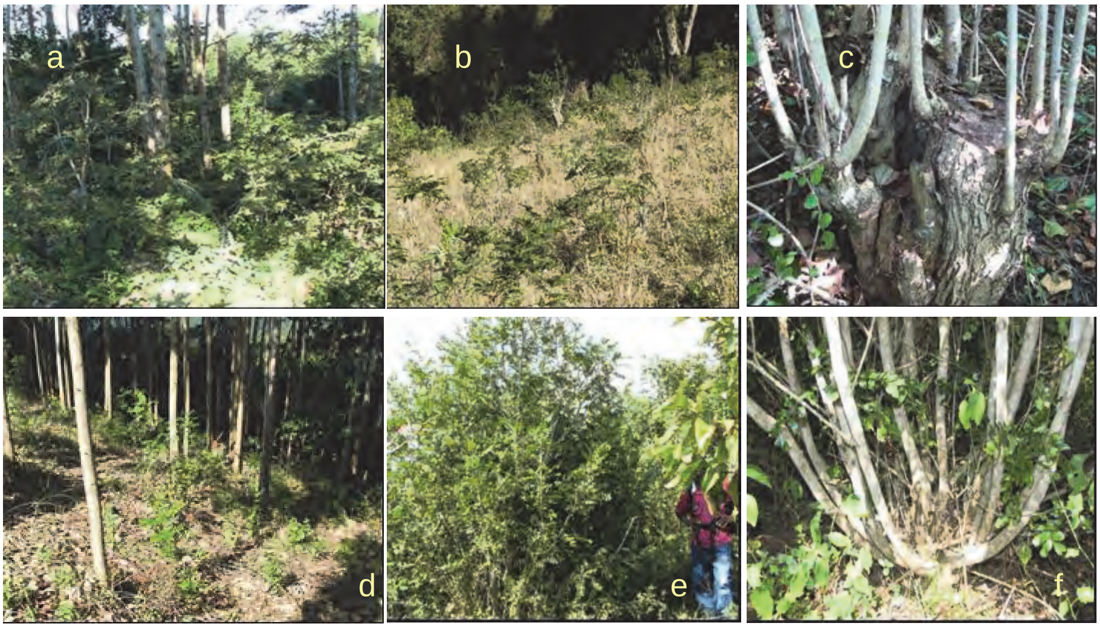

Figure 5. Regeneration strategies of *Millettia grandis* (top row) and *Ptaeroxylon obliquum* (bottom row) in the Transkei Coastal Forest in the Port St Johns Forestry Estate (Cawe and Geldenhuys, 2007): a) Top left: Seedling regeneration under a Eucalypt belt; b) Top middle: Seedling regeneration on forest margin in field of abandoned crop cultivation; c) Top right: Vegetative regrowth shoots on cut stump; d) Bottom left: Regeneration from seed in a Eucalypt belt along the upper edge of the forest; e) Bottom middle: Bushy multi-stemmed plants of previously cut trees in cleared forest; f) Bottom right: Vegetative regrowth of multiple stems from the cut base of a tree, showing the potential for thinning to produce laths and eventually poles and timber (Photos: C J Geldenhuys).

Figure 6. Forest regrowth of pioneer tree species in the Port St Johns area during July 2004: a) Left: Typical regrowth stand of *Millettia grandis* on the edge of a natural forest; b) Right: Extensive regrowth of *Acacia karroo* on abandoned cultivated land with other forest species becoming established underneath the pioneer stands.

Tree bark is used for fibre, particularly *Millettia grandis* and *Acacia karroo* in the Eastern Cape, but bark is mainly used for traditional medicine (Cunningham and Gwala, 1986; Geldenhuys, 2004b). Traditional medicines are important to rural communities for medical, psychosomatic and economic reasons (McKenzie, 1988). The dependence on species used for traditional medicine of urbanised people who migrate from the rural areas generated a local and countrywide multimillion Rand annual trade between rural source areas and urban markets and shops (Mander, 1998; Williams *et al*., 1997). This trade increased the pressure on the forests in the rural areas. In a forest inventory in the Umzimkulu forests, 7281 stems of 95 tree species were recorded of which 6.1% and 36 species were harvested for their bark for traditional medicine for sale mostly at the Durban market for traditional medicine (Geldenhuys, 2004b). The most targeted species were *Ocotea bullata* (359 stems recorded, 57.4% harvested), *Rapanea melanophloeos* (124, 38.7%), *Curtisia dentata* (50, 60.0%), *Pterocelastrus rostratus* (29, 86.2%), *Prunus africana* (10, 70.0%), *Chionanthus peglerae* (11, 36.4%), *Casearia gladiiformis* (6, 50.0%) and *Pittosporum viridiflorum* (2, 100.0%). The intensity of use over different stem diameter classes for some of these species is shown in Figure 7. *O. bullata, C. dentata* and *R. melanophloeos* are also regularly targeted in forests around Cape Town, in the southern Cape and other areas where they occur. *P. africana* is harvested all over Africa and Madagascar for an internationally marketed pharmaceutical product used for treatment of prostate cancer (Cunningham and Mbenkum, 1993). Of the other species listed in Appendix D, the following species are also sometimes harvested for their bark in Umzinkulu and other forest areas: *Apodytes dimidiata, Celtis africana, Ekebergia capensis, Ilex mitis, Kiggelaria africana, Olea capensis subsp macrocarpa, Afrocarpus falcatus* and *Ptaeroxylon obliquum* (Du Toit, 2000; Geldenhuys, 2004b). It has been shown for several bark-harvested species that the leaves contain the same chemical compounds that occur in the bark and are associated with healing (Drewes *et al*., 2006), and this information has been used to suggest that many of the bark-harvested species could be grown in production systems for the use of their leaves instead of their bark, in a similar way to which tea leaves are harvested (Geldenhuys, 2004b; Mander and Le Breton, 2006).

The stem diameter distributions of *O. bullata, C. dentata, P. africana* and *R. melanophloeos* show a bell-shaped curve (**Figure 7**), which is typical of light-demanding species in natural forest, so when artificially establishing these species there is a need to grow them in large gaps inside the forest or on the forest margin. Good seedling establishment of most of these species has been recorded in the understorey of *Pinus patula* stands growing adjacent to indigenous forests that provided seed sources (Geldenhuys and Delvaux, 2007).

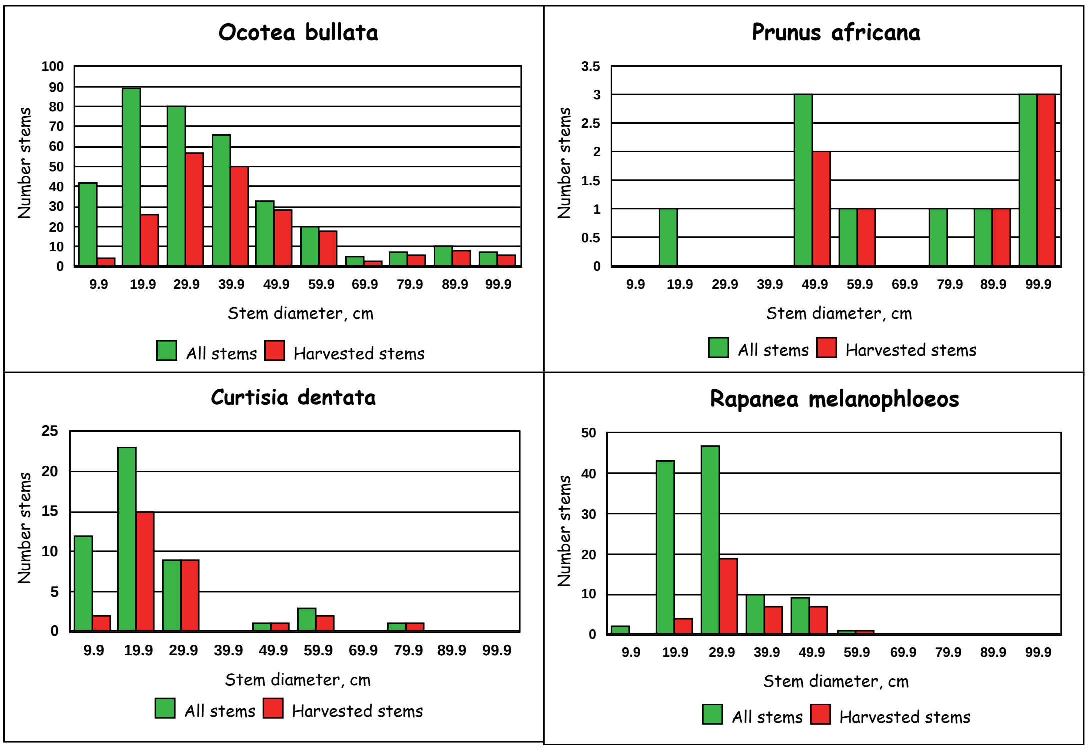

Figure 7. Stem diameter distribution of four bark-harvested species in the Umzimkulu forests showing the intensity of harvesting of the species and the potential future impact of bark harvesting (Geldenhuys, 2004b). *Ocotea bullata* and *Curtisia dentata* show good vegetative regrowth whereas the other two species show poor vegetative regrowth.

Edible tree fruits from forest species, particularly *Englerophytum natalense* and *Harpephyllum caffrum*, provide important dietary supplements to rural people in less developed areas, providing nutrients that are deficient in a starchy staple diet. Fruits are primarily a source of vitamin C but are poor sources of Ca and nicotinic acid (Cunningham, 1985). This role increases in importance during drought periods, particularly in marginal agricultural areas (Grivetti, 1979).

Several home crafts use resources from indigenous forests (McKenzie, 1988). Forest hardwoods are used for sticks (particularly *Millettia grandis* in the Port St Johns area), grinding mortars and domestic items such as meat dishes. The commercial sale of wooden items probably accounts for higher localized use of wood than minor use for utilitarian purposes. Around Port St Johns along the Wild Coast over 100 people were at one stage directly employed in craft work, earning a cumulative annual income of over one million Rand (Obiri and Lawes, 1997). Shackleton (1996) recorded a small but thriving wood carving and furniture making industry in the Mpumalanga region that made use of indigenous tree species. *Pterocarpus angolensis, Olea europaea* subsp. *africana, Spirostachys africana* and *Dalbergia melanoxylon* were found to be the most commonly utilized species. According to Desmet *et al.* (1996), *Pterocarpus angolensis* (Kiaat) is a common tree of savannah woodlands throughout southern Africa where annual rainfall exceeds 500 mm. It is used extensively as a medicinal plant (Coates-Palgrave, 1984) as well as being sought after for its timber (Vermeulen, 1990).

Many of the preferred species discussed above have become over-exploited and indigenous forests utilised in these cases have been severely degraded. Extreme poverty in many of the adjacent communities leads to increased pressure on the forests, and even forest clearing. At least in the short to medium term there is a real need for commercialisation and domestication of indigenous forest products to assist in rural socio-economic development and environmental conservation. Van Eck *et al*. (1997) are of the opinion that the indigenous forests of South Africa are not going to be saved from destruction by legislation and law enforcement alone, and that alternatives will have to be found. They carried out a study on indigenous tree uses and preferences in the Eastern Cape province (Port St. Johns and Lusikisiki areas). Through informal interviews a list was compiled of the 25 most popular indigenous trees being used for their fruit and timber by the local people[3]. They emphasize that it is important to establish relationships between people and the resources provided by the forest. They suggest that this may be implemented by adding monetary value to forest products through the development of small-scale industries based on the sustainable utilization of natural forests. Local knowledge will play a vital role in this process, and projects such as the establishment of appropriate indigenous woodlots and the domestication of indigenous fruit trees can be undertaken in collaboration with rural people. Many of the used tree species have the potential to be grown outside forests to supplement the limited resources available from the forest, which can also be used to form nurse stands in forest restoration practices (Geldenhuys 2000b).

Ecotourism

Ecotourism is intensively practised in the natural forests for the recreation and aesthetics of an increasingly urbanized and industrialized society in southern Africa. Activities include picnicking and camping, forest walks, hikes and

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[3] Potential target species (in decreasing order of importance):: *Englerophytum natalense, Harpephyllum caffrum, Milletia grandis, Ficus sur, Ptaeroxylon obliquum, Duvernoia adhatodoides, Acacia karoo, Vepris lanceolata, Cestrum laevigatum* (introduced)*, Grewia lasiocarpa, Vangueria infausta, Ficus natalensis, Dalbergia obovata, Uvaria caffra, Tricalysia lanceolata, Phoenix reclinata, Dalbergia armata, Cussonia spicata, Dovyalis caffra, Syzygium cordatum, Celtis Africana, Rubus pinnatus, Monanthotaxis caffra, Mimusops caffra and Trichilia dregeana*.

views from vantage points, all of which have the rich biodiversity and aesthetics of the forest as the basic attraction (Vermeulen, 1993). In several areas, *Afrocarpus falcatus*, the South African national tree, a nationally protected tree and the Big Tree of the natural forests, is often used as a focal point for picnic sites and short forest walks, such as in the southern Cape, Amatole Mountain Complex and other forest areas. In 1994/95 the income from visitor use of some of these facilities in the southern Cape (two sites with big trees and two forest walks) was 0.56 million Rand (US$0.112 million) (Geldenhuys, 1999b). Several local private tour operators are almost totally dependent on the forest for their small industries. Sale of indigenous plants from the forest nurseries amounted to 0.029 million Rand (US$0.006 million) for the same period, but many other private nurseries in the area also sell plants of indigenous forest species.

Street Trees and Urban Forestry

Various indigenous tree species are actively planted in urban areas by municipalities for the provision of shade (carparks, streets & parks), green-belts, visual screens, sound- or wind-breaks and aesthetic benefits. The preferred species are usually related to geographical location, but also often have specific requirements in terms of physical attractiveness, deciduousness, growth rates, canopy size, tree dimensions, etc. Stoffberg *et al*. (2008) conducted a study on the relationships between tree age and canopy and height growth of *Combretum erythrophyllum*, *Searsia lancea* and *Searsia pendulina* trees, being commonly planted street trees in the city of Tshwane.

Recognition of the numerous social, aesthetic, health, environmental and economic benefits of greening urban environments is possibly most clearly demonstrated in the widespread planting of trees in private gardens. This phenomenon, often termed ‘urban forestry’, was recognised and defined in the National Forestry Action Programme (NFAP, 1997) as “an integrated approach to the planting, care and management of trees in urban and peri-urban areas to secure economic, environmental and social benefits of urban dwellers”. Considering that the city of Johannesburg is estimated to now contain approximately 10million trees in a region where the natural/original vegetation type (Highveld grassland) was one practically devoid of trees, the importance of determining the relative benefits and costs of introduced and indigenous forests and trees in urban forestry has not gone unnoticed (Shackleton, 2006).

2.5.3 Economic considerations

The consideration of economic and financial aspects associated with indigenous tree uses, products and markets is addressed in Chapter 5 of this report.

2.6 Final Selection Process

2.6.1 Indigenous trees

The initial screening exercise short-listed the most promising indigenous tree species in South Africa from environmental, social and economic perspectives. The database of existing indigenous tree trials and plots in South Africa also provided a basis for the selection of sites and species to focus on in terms of water-use and growth measurements, and economic analyses. However, final determination of sites and species for field monitoring was decided upon in a workshop with interested and affected parties, held on the 17th February 2010. Invitations were extended to a wide range of stakeholders having extensive knowledge of the distribution and use of indigenous trees and forests in South Africa, as well as to representatives of the public and private sectors having a vested interest in this area, and were experts in their field. Fourteen participants attended the workshop, which comprised an initial information sharing session, where workshop participants were brought up-to-date on the history, rationale and current status of the project by means of a series of presentations by the project team. This was followed by periods of open discussion where delegates had an opportunity to clarify any issues of uncertainty and discuss aspects raised in the presentations.

Individual break-away groups were then tasked to discuss and agree upon a priority list of the top 5 indigenous tree species (drawn from a short-list of 47 high-potential species) that they felt should be the focus of specific water-use and growth measurements. After re-convening, each spokesperson presented and motivated their choice of species, and the lists were combined. With this knowledge in mind each of the fourteen participants individually ranked their top 10 priority indigenous tree species from most important (score of 10) to least important (score of 1). All results were collated and scores were summed for each species based on the number of times it achieved a particular ranking (Table 4).

Table 4. Results of the ranking exercise, by experts in the field, to determine priority indigenous tree species for detailed measurements.

Ranking	Rank 1	Rank 2	Rank 3	Rank 4	Rank 5	Rank 6	Rank 7	Rank 8	Rank 9	Rank 10	
Species/Points	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**Final Score**
Ptaeroxylon obliquum	1	5	2								71
Millettia grandis	2	1	2	1							52
Ocotea bullata	1			4	1						44
Afrocarpus falcatus	2		1		1	2					44
Prunus africana	1				2	1	2				35
Curtisia dentata			1	1	1			2		1	28
Acacia (Vachellia) karroo			2		1					2	24
Podocarpus henkelii	1	1									19
Ilex mitis				1				1	2	1	15
Rapanea melanophloeos							2	2		1	15
Olinia ventosa		1					1				13
Olea europaea africana						1	1				9
Warburgia salutaris						1		1			8
Celtis africana						1			1		7
Cunonia capensis				1							7
Apodytes dimidiata					1						6
Podocarpus latifolius					1						6
Combretum kraussii							1			1	5
Harpephyllum caffrum						1					5
Olea capensis macrocarpa								1			3
Albizia adianthifolia									1		2
Kiggelaria africana									1		2
Syzygium cordatum									1		2
Vepris lanceolata									1		2
Cryptocarya spp										1	1

Based on the results of the ranking exercise, a list of the 10 top priority species was compiled (**Table 5**) catering for potential tree production systems involving single species/even aged stands and mixed species/mixed age stands.

Table 5. Top 10 priority indigenous tree species identified for monitoring.

Rank	Scientific Name	Common Name	Production System*
1	*Ptaeroxylon obliquum*	Sneezewood	MS/MA
2	*Millettia grandis*	Umzimbeet	MS/MA
3	*Ocotea bullata*	Black Stinkwood	MS/MA
4	*Afrocarpus falcatus*	Outeniqua Yellowwood	SS/EA
5	*Prunus africana*	Red Stinkwood	MS/MA
6	*Curtisia dentata*	Assegaai	MS/MA
7	*Acacia (Vachellia) karroo*	Sweet Thorn	MS/MA
8	*Podocarpus henkelii*	Henkel's Yellowwood	SS/EA
9	*Ilex mitis*	Cape Holly	MS/MA
10	*Rapanea melanophloeos*	Cape Beech	SS/EA

* SS/EA = Single species/even aged
MS/MA = Mixed species/mixed age

A subsequent session was dedicated to discussing appropriate sites for measurement. Based on the distribution and classification of indigenous forest groups in South Africa, it was noted that mist-belt forest and scarp forest regions covered the majority of potential forestry land in SA including regions with large populations, and would consequently be highly representative. The specific study sites within these forest types were agreed to be positioned in proximity to the long-term growth plots running in these forest, in order to supply useful growth data for WUE calculations.

2.6.2 Introduced trees

While the focus of the project was on indigenous trees, the project team and workshop participants also recognised the importance of simultaneous and directly comparable water use, growth and WUE measurements on introduced tree species. Consequently, it was decided that where budget, equipment availability and logistics allowed, additional measurements would be conducted on introduced tree species co-occurring at the selected sites. These were largely opportunistic, but an effort was made to sample as wide a range of introduced trees species as possible.

3 RESEARCH APPROACH AND METHODS[4]

Individual studies were conducted to determine the water-use, growth rates and resultant WUE of indigenous tree species. The primary objectives were:

1. To determine whether indigenous tree species use less water than introduced tree species, and
2. To determine whether indigenous tree species use water more efficiently than introduced tree species.

In addressing these questions two methods were applied. In the first method, estimates of water-use and water-use efficiency (WUE) for an entire forest (trees and undergrowth) were obtained using above-canopy total evaporation (ET) data from scintillometry and eddy covariance measurements, combined with long-term growth data (utilisable above-ground woody biomass increments) obtained from Permanent Sample Plots (PSPs). In the second method estimates of water-use and WUE for individual trees only were determined using measurements of transpiration (sap flow) and above-ground woody biomass increments.

3.1 Water-use Measurements

In terms of water-use measurements, two approaches were applied where possible, namely eddy covariance for total evaporation (ET_{EC}) measurements, and sap flow studies for single-tree water-use measurements (transpiration only). These two approaches were both necessary for a number of reasons. In terms of total ET measurements, results obtained using this method are directly comparable to other vegetation types which have historically been measured in this way. This type of measurement technique is also well-suited to use over mixed-species forests where there is a need to integrate the water-use and rainfall interception (canopy and litter) of all the species represented in the forest. This is most relevant to studies of catchment water balance and land use impacts on streamflows. It also lends itself to

[4] When making reference to this section, please cite as follows:

Gush, M.B., Dye. P.J. de Lange, W.J. and Naiken, V. 2015. Research approach and methods. In: Gush, M.B., de Lange, W.J., Dye, P.J. and Geldenhuys C.J. (Eds). 2015. Water Use and Socio-Economic Benefit of the Biomass of Indigenous Trees: Volume 1 (Research Report). Water Research Commission, Pretoria, RSA, WRC Report 1876/1/15, Section 3.

comparison with the integrated growth rates of the forest obtained through the sampling of all species represented in the sample plots.

On the other hand, single tree sap flow studies (e.g. heat pulse velocity) are an accurate means of determining the water-use rates of specific indigenous (and introduced) tree species. The latter technique quantifies transpiration only; however this is the major water loss process. The Heat Ratio method (Burgess *et al*., 2001), and the Thermal Dissipation Probe (TDP) method (Granier, 1985; 1987) were utilised for this purpose. The water-use measurements done in this way are also readily combined with individual tree stem growth increments carried out over a year, to derive WUE. Past WUE studies carried out on introduced (exotic) tree species (e.g. Pines and Eucalypts) were done in this way, making the data for indigenous tree species directly comparable. Where instrumentation and capacity allowed, additional measurements were conducted on certain introduced tree species at the study sites (e.g. Pines at Karkloof, and Eucalypts at Manubi) for comparative purposes.

The eddy covariance ET_{EC} measurements to determine total evaporation were deployed for "window periods" (1-2 week periods in different seasons). However, the HPV technique was deployed continually to determine transpiration over the entire monitoring period (at least 1 year to account for seasonal variation). Combining these techniques required the extrapolation ("in-filling") of the total evaporation measurements to the rest of the un-monitored period. This was achieved through a modelling exercise (e.g. Penman Monteith equation), facilitated by the availability of detailed weather data (from weather stations deployed at the sites) and species-specific data (e.g. leaf area index and soil water measurements).

3.2 Biomass Increment Measurements

Above-ground stem biomass increments were quantified for all single-tree studies at the various monitoring sites. Surveys were undertaken at the inception of the monitoring period and subsequently a year later, sometimes with interim assessments as well, in order to include all seasons in one year. Stem circumferences were generally measured at 1 m intervals up the tree, and subsequently converted into volume by assuming that the stem consisted of a series of truncated cones with a complete cone on the top (Gush *et al*. 2011). The volume (V; m^3) of the individual cones was calculated using Equation 1:

$$V = (\pi r^2 h)/3 \qquad \text{(Eq. 1.)}$$

where r is radius of the base of the cone (m), and h is height of the cone (m). The volumes of the truncated cones were calculated using (Eq. 2):

$$V = (\pi\, h\, (r_1^2 + r_1\, r_2 + r_2^2))/3 \qquad \text{(Eq. 2.)}$$

where r_1 is radius of the base of the truncated cone (m), r_2 is radius of the top of the truncated cone (m), and h is height of the truncated cone (m). The individual stem section volumes were totalled for each tree, which allowed for the calculation of stem volume increase in the year. The stem volume increments were converted to dry mass using the wood densities determined from samples collected for each species in this study. In conjunction with the sap flow (water-use) results this allowed the calculation of WUE, defined as mass of woody biomass produced (g) per unit of water transpired (L), and results were compared against existing data for indigenous and introduced tree species available from previous studies (Olbrich *et al*., 1996; Dye *et al*., 2001; Gush and Dye, 2009).

3.3 Economic Data Assimilation

The financial and economic viability of selected indigenous tree species were assessed for plantation rotation production systems and informal natural forest resource utilisation, as well as the more formal market potential of indigenous tree products. One of the objectives was to incorporate different socio-economic contexts in the assessment, to facilitate comparisons between the financial and economic viability of indigenous species and commercial plantations of introduced tree species. The focus of this component was on biophysical products harvested from the trees (in different study areas around South Africa) excluding non-timber forest products. Further detail is supplied in the specific chapter below relating to this component of the study (Chapter 5).

3.4 Modelling

Modelling ET/transpiration at the whole stand/forest scale and at the individual tree scale was undertaken for most sites and species. At the forest scale, continuous measurements of ET_{EC} with eddy covariance systems could not be sustained over periods of a year or longer, due to the need to use the instrumentation at other sites and for different projects. In addition, the valuable equipment could not be left unattended in the field due to the risk of theft or vandalism. Short windows of field measurements were available in different seasons of the year, but a model was required to fill in the ET gaps to provide a total water use estimate to compare to the tree/forest growth estimates. Several different models were used for this purpose.

- FAO 56 ET_0 Reference Evaporation model. This is an ET modelling approach that is commonly used for crop water use determination and which is comprehensively described in the FAO 56 report (Allen *et al*., 1998). It is based on calculation of the reference evapotranspiration from, most commonly, a short green grass cover, although other reference crops such as lucerne are sometimes chosen. The Penman-Monteith equation is the basis of these calculations of daily ET, and standard parameter values for describing the plant influences on daily ET such as canopy conductance and boundary layer conductance are employed. ET at any particular stage of the growth cycle of a crop is largely determined by the amount of green transpiring leaf that is present, as well as the availability of soil water and the rate of evaporation from the soil surface that is affected by the amount of plant cover. These typically vary in a predictable way over the course of the growth cycle, especially in irrigated fields, and are captured by using a ratio which is the fraction of actual ET to the potential ET rate (ET_0) occurring at a given time.

  ET from trees and forests require different parameter values since the physics of water vapour diffusion from taller plants is different from short uniform plant cover. Non transpiration evaporative losses such as canopy rainfall interception and soil surface evaporation are also likely to be different for trees and forests. Despite these differences, transpiration/ET from trees and forests can often be usefully correlated to reference evaporation. Since reference ET is easily programmed in data loggers and calculated as a weather station output, it represents a potentially useful and simple model which is worth evaluating before more complex models are resorted to. It is also useful to examine the consistency of ET measurements taken in different "window" periods of field measurements in different seasons of the year, to assess whether soil water deficits have reduced ET rates during dry seasons and drought periods.
- Another relatively simple model described by Granier (Granier *et al*., 2000) is more specifically designed for use in predicting forest ET. It uses simple functions of suitable form to describe the influence of solar radiation, vapour pressure deficit, leaf area and soil water availability to predict the canopy conductance from forests. This is a measure of the potential total water vapour diffusion from the forest canopy. Total evapotranspiration can then be calculated from the Penman-Monteith equation or simplified derivative of this equation.
- The Pitman model is a monthly time-step, conceptual, rainfall-runoff model that was developed in 1973 (Pitman, 1973) and has seen a number of

modifications since then (Hughes, 2004). A detailed description of the model is available in Hughes *et al*. (2006). In this project, the same (or similar) main water balance algorithms were implemented in a daily version of the model so that the outputs could be more directly compared to the available field data. The model was used to estimate the annual water balance of the Manubi forest, predicting processes such as surface runoff, evapotranspiration, groundwater recharge and soil water outflow. Further details are provided by Hughes *et al.* (2014) (see section 3.3.6 in Volume 2).

- The MAESPA model is the most detailed model used in this project and incorporates much physiological and structural detail in estimating ET. The MAESPA tree/forest model was used to model hourly ET from Ingeli forest. It is a flexible soil-plant-atmosphere continuum (SPAC) process-based model combining parts of the MAESTRA canopy model (Medlyn, 2004) and the SPA model (Williams *et al*., 1996). A very comprehensive description of MAESPA is available on the internet (http://maespa.github.io/manual.html) and further details are available in Duursma and Medlyn (2012). It can be used to predict water use by individual trees as well as from plots and forests from a detailed consideration of soil plant and atmospheric conditions at daily or sub-daily time steps. This higher level of detail was particularly valued in addressing two issues not well covered by the simpler models:

  i. The magnitude of forest-scale canopy rainfall interception and the subsequent evaporation of this free water back to the atmosphere require additional investigation. Recent research in South Africa suggests that it can comprise a substantial proportion of total ET, especially in forest environments with much mist and frequent rainfall (Bulcock, 2011; Bulcock and Jewitt, 2012), whereas some other studies reported in the literature suggest much lower interception losses. Some doubt over the required sampling intensity for rainfall interception measurements suggests that further field research and modelling is required. Measurements of eddy covariance evaporation from wet canopies in misty weather and under low-flux night-time conditions is subject to errors and so cannot be viewed as entirely definitive in measuring the magnitude of rainfall interception losses. MAESPA uses the Rutter model (Rutter *et al*., 1972; Rutter *et al*., 1975; Rutter and Morton, 1977) to calculate rainfall interception losses. Parameter estimates are based on forest structure and hydrological processes (e.g. canopy rainfall storage, throughfall, stem flow, leaf drying rates) which may be measured in the field.
  ii. The MAESPA model allows for a detailed description of the structure and physiology of leaves and canopies and is therefore suited to estimating ET from the great diversity of tree species, leaf types and leaf distribution found in South African indigenous trees. Factors such

as different canopy shapes, leaf inclination and leaf distribution within the canopy, leaf flushes, senescence in older leaf cohorts, seasonal changes in LAI, differences in photosynthesis and transpiration rates in different leaf cohorts, varying stomatal presence on abaxial and adaxial leaf surfaces, shading effects from own leaves and neighbouring trees, rainfall interception and evaporation, understorey transpiration, soil evaporation, boundary layer resistances may all be taken into account. Our present state of knowledge of the physiology of indigenous trees is poor and much further study is required to improve our ability to parameterize this model. Nevertheless, MAESPA appears to be fairly "forgiving" and can be run with limited parameterization, using default values for many of the parameters. The level of required model input is not over-whelming and parameters may, in some cases, be estimated from relatively simple surrugate leaf measurements. It has been shown to successfully scale up from leaf-level to canopy-level processes (Medlyn *et al*., 2007). MAESPA was used to simulate individual tree sap flow (*Ilex mitis*) within Groenkop forest (southern Cape). Further details are provided in sections 4.2.3, 6.2.3 and Appendix A of Volume 2 of this report. Input files showing parameter values for this study are included in that appendix.

After exploring the possibility of using various wood characteristics as rapidly measured indicators of WUE (see chapter 6), it was concluded that the best techniques for ranking indigenous tree species according to their WUE were through direct measurement of stem increments as performed in this study, and through modelling annual transpiration or ET using the MAESPA model. This is described further in sections 6.3 and 6.4 of this volume.

4 WATER-USE, GROWTH AND WATER USE EFFICIENCY[5]

4.1 Background, Definition and Units

Estimates of Water-Use Efficiency (WUE) are useful in evaluating different land-use scenarios with the objective of maximising returns (socio-economic and environmental) from the landscape in the face of finite water supplies (Hubbard *et al*., 2010). This is of particular relevance in high water-using or water-constrained environments, such as those associated with commercial afforestation in South Africa (Dye, 2000). Consequently, a need for WUE information is expected to develop as Catchment Management Agencies in South Africa are constituted to manage water resource allocations in the various Water Management Areas of the country (Nomquphu *et al*., 2007). The volume or value of product generated per unit of water utilized by a crop, orchard or forest is anticipated to become an important criterion in deciding on competing land-use scenarios (Calder, 2005). However, the necessary scientific information required for this purpose is currently inadequate, and requires a combination of bio-physical data (e.g. yields produced or growth observed per volume of water used) and economic data (e.g. value or profit of yield per unit of water used). The majority of bio-physical WUE studies in South Africa have been conducted on introduced commercially grown tree species (Olbrich *et al*., 1993; Olbrich and Olbrich, 1995; Le Roux *et al*., 1996; Olbrich *et al*., 1996; Dye *et al*., 1997b; Dye *et al*., 2001; Wise *et al*., 2011). Limited WUE information is available for indigenous trees native to South Africa, and addressing this knowledge gap was the primary motivation for this study.

Many different definitions of WUE exist in the literature, consequently it is important to clarify the specific definition of WUE being referred to at any particular time, as well as the methods used to determine it and the units employed. The bio-physical water-use efficiency (WUE) of a plant or vegetation type relates some measure of growth (e.g. carbon assimilation or gross primary production), to some measure of water-use (e.g. transpiration or total evaporation), over a particular time period. The links and trade-offs

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[5] When making reference to this section, please cite as follows:

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between carbon uptake and water loss that take place through photosynthesis and stomatal control have been well researched (Jarvis, 1981; Whitehead, 1998; Law *et al.*, 2002). However, the estimation of WUE may be conducted at vastly different scales, which requires different measurement approaches (Lindroth and Cienciala, 1996), and occasional application of differing measurement techniques across a range of scales in a single study (Tu *et al*., 2008).

At the molecular level stable carbon isotope ratios, when combined with an estimate of the leaf-to-air vapour pressure difference, provide a measure of the efficiency of water-use in photosynthesis (Farquhar *et al*., 1982; Marshall and Zhang, 1994; Dawson *et al*., 2002). As Whitehead and Beadle (2004) explain, the trade-off between photosynthesis and transpiration in leaves of C_3 plants, regulated by stomatal conductance, determines the ratio of the intercellular to ambient partial pressures of carbon dioxide and determines the degree of discrimination against the heavier ^{13}C isotope relative to the lighter ^{12}C isotope during photosynthesis. The ratios of $^{13}C/^{12}C$ relative to a standard or $\delta^{13}C$ ratios of plant material may be used as a determination of intrinsic water-use efficiency (Farquhar and Richards, 1984). More negative $\delta^{13}C$ values denote higher efficiencies of water-use (Farquhar *et al*., 1982).

In leaf-level studies instantaneous WUE may be determined through a combination of gas-exchange measurement techniques consisting of CO_2 and H_20 measurements using instruments such as porometers and Infra-red gas analysers (IRGAs). These describe a plant's demand for water relative to its photosynthetic production (Cernusak *et al.*, 2007).

At the single-tree or stand scale, water-use and growth measurements are usually conducted on a number of individual trees over a certain period, typically using heat dissipation/sap flow measurement techniques (Gyenge *et al.*, 2008), and are scaled up according to the planting density (Hatton and Wu, 1995; Wullschleger *et al*., 1998).

At a canopy scale, estimates of WUE are possible using micrometeorological measurements of carbon and water fluxes (Lamaud *et al*., 1997; Law *et al.*, 2002). For example, Krishnan *et al*. (2006) describe WUE at this scale as a measure of the amount of Carbon taken up during photosynthesis (*P*) relative to the water lost by the ecosystem (*E*) (WUE = P/E). Similarly, Lamaud *et al*. (1997) define WUE as the ratio of photosynthesis over canopy transpiration, representing the loss in water associated with the gain of carbon. In the absence of specific measurements of photosynthesis and transpiration rates, they suggest the use of carbon uptake (net CO_2 flux) and water loss (ET) by the vegetation as surrogates.

At wider regional scales, estimates of WUE are possible using remotely sensed data from which values of total evaporation (ET) and biomass production (e.g. Gross Primary Production) may be derived (Lu and Zhuang, 2010). At all scales the period of measurement is ideally a year or longer, to incorporate seasonal variation, however this may not always be practically feasible, and instantaneous or short term estimates of WUE may be resorted to. The slope between changes in biomass accumulation (growth) and water-use represents a measure of WUE. It is thus a ratio that can be altered through changes in growth rate and/or changes in water use.

In describing bio-physical WUE, units applicable to the variables of interest, namely growth/yield and water-use, need to be employed. In terms of growth increment this could be described as total growth both above and below the ground. However, since it is difficult to estimate below-ground root growth accurately, and since it is mostly the above-ground biomass that provides the economic benefit, it is common when referring to trees for WUE to be defined as above-ground biomass increment per unit of water consumed (Dye, 2000). In a forestry environment, productivity is most often described in terms of utilizable stem volume increments and yields, however in published WUE studies, it is the convention to express growth in units of mass (dry matter) rather than volume (Jones, 2004). This is advantageous where wood density varies in the trees under study. In a forestry environment it is consequently pragmatic to define growth increment as the dry mass increment of utilizable stem, in which case WUE could be expressed as tons of yield per m^3 (or tons) of water utilized. However, as this usually equates to a very small number because of the small numerator and large denominator, grams may be used to describe mass of yield produced, while kilograms may be used to describe the water transpired or evaporated by the crop, at whatever scale is practical (single tree, m^2, ha; km^2).

Regarding the water use component of WUE, this is sometimes taken to be equal to rainfall (plus irrigation in some cases) received by a stand of trees (Dye, 2000). However, with the increasing application of heat dissipation and micro-meteorological techniques to measure vegetation water-use, actual plant water-use data are able to be used (Asbjornsen *et al*., 2011). Distinction needs to be made between whole plantation/forest total evaporation rates (i.e. water-use of the land-use as a whole, including trees, undergrowth and soil evaporation), as opposed to single-tree transpiration rates (i.e. water-use of the trees alone). This requires two different measurement techniques, the former measuring total evaporation (ET) above the forest canopy, and the latter measuring transpiration only (sap flow) through the stems of individual trees (Er-Raki *et al*., 2009). The quantity of water in each case may be expressed in units of mass or volume, or as mm equivalent depth, where

1 mm of water is equivalent to 1litre or kg of water per square metre of ground. The preferred definitions of WUE applicable to this project are the mass increment of utilizable stem (g) per unit of water transpired or evaporated by the tree (kg).

4.2 Determinants of Water Use Efficiency

The water-use efficiency of plants is influenced by numerous internal and external variables, but these may be grouped into three broad categories. Firstly there are the effects of the numerous physiological processes plants undertake (e.g. water and nutrient uptake and gas exchange), secondly the influence of the environmental conditions that they exist in (e.g. site and weather conditions) and thirdly the genetic and physical attributes that they exhibit (e.g. plant type, size and growth rates). The processes of growth and water-use that are influenced by these variables, and which ultimately determine WUE, occur across wide-ranging spatial and temporal scales, from instantaneous leaf-level changes in water vapour and carbon exchange by means of stomatal control, through to decadal patterns of growth and water-use within a forest. Understanding the linkages in space and time between all the processes and drivers associated with water-use, growth and the resultant WUE presents a formidable challenge. Physiological processes include photosynthesis; stomatal control and carbon allocation patterns. Environmental drivers include water, nutrient and light availability; climatic conditions; water, soil and air quality; fire and herbivory. Physical attributes include plant species/type; plant size; leaf area and canopy characteristics; albedo; hydraulic architecture and rooting characteristics. Nearly all of the above may be influenced anthropogenically, through human-induced effects such as climate change, pollution, genetic modification, landscape alteration and management practices (e.g. site preparation, weed control, fertilisation, pruning, thinning and irrigation).

Leaf-level mechanisms of optimal stomatal control that balance water lost through transpiration against carbon taken up through assimilation, in response to environmental drivers, have been well studied (Cowan, 1977; Farquhar and Sharkey, 1982; Law *et al*., 2002; Nogueira *et al.,* 2004). Determinations of gas exchange suggested that annual productivity increases with mean annual temperature and precipitation (Lieth, 1972; O'Neill and DeAngelis, 1981). More recently however, attention has shifted from gas exchange to how effectively plants intercept and utilise light (Law *et al*., 2002; Hutyra *et al*., 2007). In a review of the physiological processes associated with observed rates of growth and water use in Eucalyptus forests Whitehead and Beadle (2004) adopted a process-based approach which focussed on intercepted irradiance as the determinant of growth. This was linked to leaf area distribution and radiation transfer in canopies and physiological processes regulating photosynthesis, transpiration and carbon allocation. They concluded that high rates of productivity occurred at sites well supplied with water and nutrients, where there was high interception of solar radiation and high light-use efficiency. They classified the most productive species as those with high values for leaf area index, stomatal conductance and photosynthetic rate. In this way, WUE was deemed to be a function of Light-use Efficiency (LUE) (Whitehead and Beadle, 2004).

The effects of physiological mechanisms on WUE are also highly dependent upon environmental conditions prevailing at the time, particularly the availability of light, nutrients and water. Early work on single tree WUE by Webb *et al.* (1978) found that above-ground nett primary production (NPP) was independent of water-use in forest systems which were not water-stressed. For the forests they studied (hardwood forests dominated by *Quercus* and *Acer* spp.) NPP was found to be consistent while water-use varied considerably, which resulted in a wide range of WUE. Measurements conducted at the canopy scale have detected increases in WUE with increasing drought stress and an associated reduction in surface conductance (Baldocchi, 1997; Williams *et al.*, 1998; Krishnan *et al.*, 2006). Krishnan *et al*. (2006) found that although WUE is reported to be sensitive to both vapour pressure deficit (*VPD*) and cloud cover (Williams *et al.*, 1998 and Rocha *et al.*, 2004), the existence of a relationship between growing season WUE and *VPD* was not apparent in their study – a result consistent with observations made in deciduous forests by Law *et al*. (2002). They note that increasing atmospheric CO_2 levels could also improve WUE through an increase in stomatal resistance and resultant reduction in water-use, but a very long data record is required to detect the presence of this effect. To this end tree-ring studies have been used to investigate long-term changes in growth rates relative to climatic conditions (February and Stock, 1999).

Whitehead and Beadle, (2004) suggest that the consequence of the marked sensitivity of decreasing stomatal conductance to increasing vapour pressure deficit, VPD, is that, in well-watered conditions, transpiration from Eucalyptus forests can be explained largely by leaf area index and VPD. They concluded that higher growth rates in trees were attributable to higher hydraulic conductance and an increase in the ratio of leaf area to sapwood cross-sectional area in larger trees. Evidence is emerging that physical attributes such as these and the associated growth rates of plants are linked to WUE. Using case studies from Eucalyptus plantations, Binkley *et al*. (2004) and Stape *et al.* (2004) have both demonstrated that more productive sites tend to have higher efficiencies of resource use than less productive sites, and silvicultural treatments such as thinning and pruning may increase both resource supply and efficiencies of resource use. This is consistent with results from other studies, which have also shown that WUE is often positively correlated with growth rate (Almeida *et al.*, 2007, Forrester *et al.*, 2010). Stape *et al.* (2004) go so far as to suggest that high productivity Eucalyptus stands in Brazil could produce wood in shorter (6-yr) rotations on half the land area required for low productivity stands, using only half as much water. In South Africa, long-term tree breeding programmes for increased growth rates (Verryn, 2000) together with improvements in silvicultural practices have vastly increased the productivity of commercial plantations of introduced tree species (Pallet and Sale, 2004). Based on the findings of Binkley *et al*. (2004) and Stape *et al.* (2004) this suggests that these interventions may already have inadvertently improved WUE in introduced tree plantations in South Africa.

4.3 General Findings and Synthesis

Prior to this study, all South African tree-related WUE studies had been conducted on introduced plantation species, particularly eucalypts (Olbrich *et al*., 1993; Olbrich and Olbrich, 1995; Le Roux *et al*., 1996; Olbrich *et al*., 1996; Dye *et al*., 1997a; Dye *et al*., 2001). The work developed out of the very successful tree improvement programme, in which genetic improvement of plant material focused primarily on increasing productivity within plantations, but also addressed aspects such as wood quality, tree form and resistance to pests and diseases (Verryn, 2000). With the success of this programme as a foundation, together with increasing attention on the water-use impacts associated with commercial plantations, it was hypothesized that improvements in the WUE of introduced tree species were possible through tree improvement programmes (Dye, 2000).

The exploratory studies cited above evaluated the range of WUE possible within existing genetic material. Results showed that differences in WUE (defined as water transpired per unit of utilizable stem produced) exist in a range of tree species and clones, suggesting that improvements in WUE could be made through tree improvement programmes. From these studies it was also concluded that WUE could vary over time and from site to site, especially in response to changes in Vapour Pressure Deficit (VPD), as well as to changes in carbon partitioning (above vs. below ground) brought about by soil water and nutrient availability. There was also evidence that WUE declined with increasing water deficits. Olbrich *et al.* (1993) found that variable growth rates were more influential than transpiration in determining WUE, illustrating the importance of a minimum measurement period of 12 months to cover all seasonal growth cycles in the year. The potential to improve yields and optimise WUE within introduced and indigenous tree species in South Africa requires a thorough understanding of key physiological processes underlying how trees function (Dye, 2000).

Water use

Results from Dye *et al.* (2008) showed that mixed species/mixed age indigenous forests of the southern Cape, and mixed species/mixed age savanna woodlands of Mpumalanga were not particularly conservative in terms of their overall water-use, generally utilising all the water supplied by rainfall at their respective study sites. However, a single species/even-aged plantation of indigenous *Afrocarpus falcatus* trees used less than half of the available water supplied by rainfall. By combining the use of above- and below-canopy methods for determining water-use in this indigenous plantation it was possible to distinguish between tree-only water-use (transpiration) and plantation total evaporation (evaporation from trees, soil and understorey vegetation). The resultant water-use of the undergrowth or understorey vegetation, determined by subtraction, was substantial, accounting for up to 66% of the water used by this indigenous tree system. This highlighted the importance of rigorous management of the understorey vegetation under plantation conditions, to minimise water-use.

From results of individual tree water use studies in this project (see Volume 2) the overall water-use of the indigenous trees studied has averaged 3343 ± 1242 L tree^{-1} year^{-1}; which is substantially lower than for introduced plantation species, which averaged 10300 ± 2890 L tree^{-1} year^{-1} for Eucalyptus clonal trees, 7994 ± 5995 L tree^{-1} year^{-1} for *Eucalyptus grandis* trees and 7488 ± 4473 L tree^{-1} year^{-1} for *Pinus* species (Figure 8, Table 6). Maximum water-use has been lower in the indigenous species studied compared to introduced plantation species, despite growing conditions that could be considered ideal for most of the indigenous species sampled (readily available water, energy and nutrients, and limited competition). The indigenous tree annual cumulative sap flows were all less than 8500 L tree^{-1} year^{-1}, whereas sap flows in the more productive introduced plantation trees exceeded 20 000 L tree^{-1} year^{-1}. This suggests that there is a genetically determined maximum threshold to water-use by indigenous tree species that is substantially lower than that for introduced plantation species. Similar findings have been reported by Kagawa *et al.* (2009) and Little *et al*. (2009), who found that the water-use of native tree species, in Hawaii and Chile respectively, was considerably lower than that of introduced timber species. Measurements of water-use in several indigenous *Afrocarpus falcatus* trees growing in a single species/even aged plantation (Dye *et al*., 2008) also showed that the water-use (transpiration component) of these trees was low compared to data for introduced plantation tree species (Olbrich *et al.*, 1996; Dye *et al*., 2001).

<u>Growth</u>

Rates of stem growth in the indigenous trees studied so far has averaged 6090 ± 4762 g $tree^{-1}$ $year^{-1}$; substantially less than the average of 20345 ± 6118 g $tree^{-1}$ $year^{-1}$ for Eucalyptus clonal trees, 20874 ± 14361 g $tree^{-1}$ $year^{-1}$ for *Eucalyptus grandis* trees and 14877 ± 7357 g $tree^{-1}$ $year^{-1}$ for *Pinus* species (Figure 9, Table 6). As has been the experience with introduced plantation species, genetic breeding for fast growth rates and the application of silvicultural practices employed in commercial plantations (e.g. pruning and thinning) could increase growth rates and influence the efficiencies of resource use among indigenous tree species. While some preliminary studies have been conducted in this regard (Geldenhuys and von dem Bussche, 1997), this remains to be more thoroughly tested.

Evidence suggests that indigenous forests cannot compete with plantations of introduced tree species for wood production, and this is confirmed through a comparison of the growth rates observed in respective indigenous and introduced tree species in this study Certain instances of high 1-year stem growth rates in indigenous species were observed in the study, with *Millettia grandis* (Umzimbeet), *Prunus africana* (Red Stinkwood) and *Celtis african*a (White Stinkwood) being the best performing species. However, it should be borne in mind that the conditions under which these particular indigenous trees were growing were far more favourable than the average plantation environment. These trees were free-standing, unshaded trees with little competition for resources and readily available water (the *Celtis* and *Prunus* trees were in a riparian zone). Plantations of several indigenous species of trees have been established over the years to evaluate growth rates and wood properties against existing commercial forest plantations, but these have generally shown slow growth rates. From a wood production point of view, it appears unlikely that indigenous species will be competitive in terms of volume production, and their economic viability appears to be limited, apart from certain scenarios.

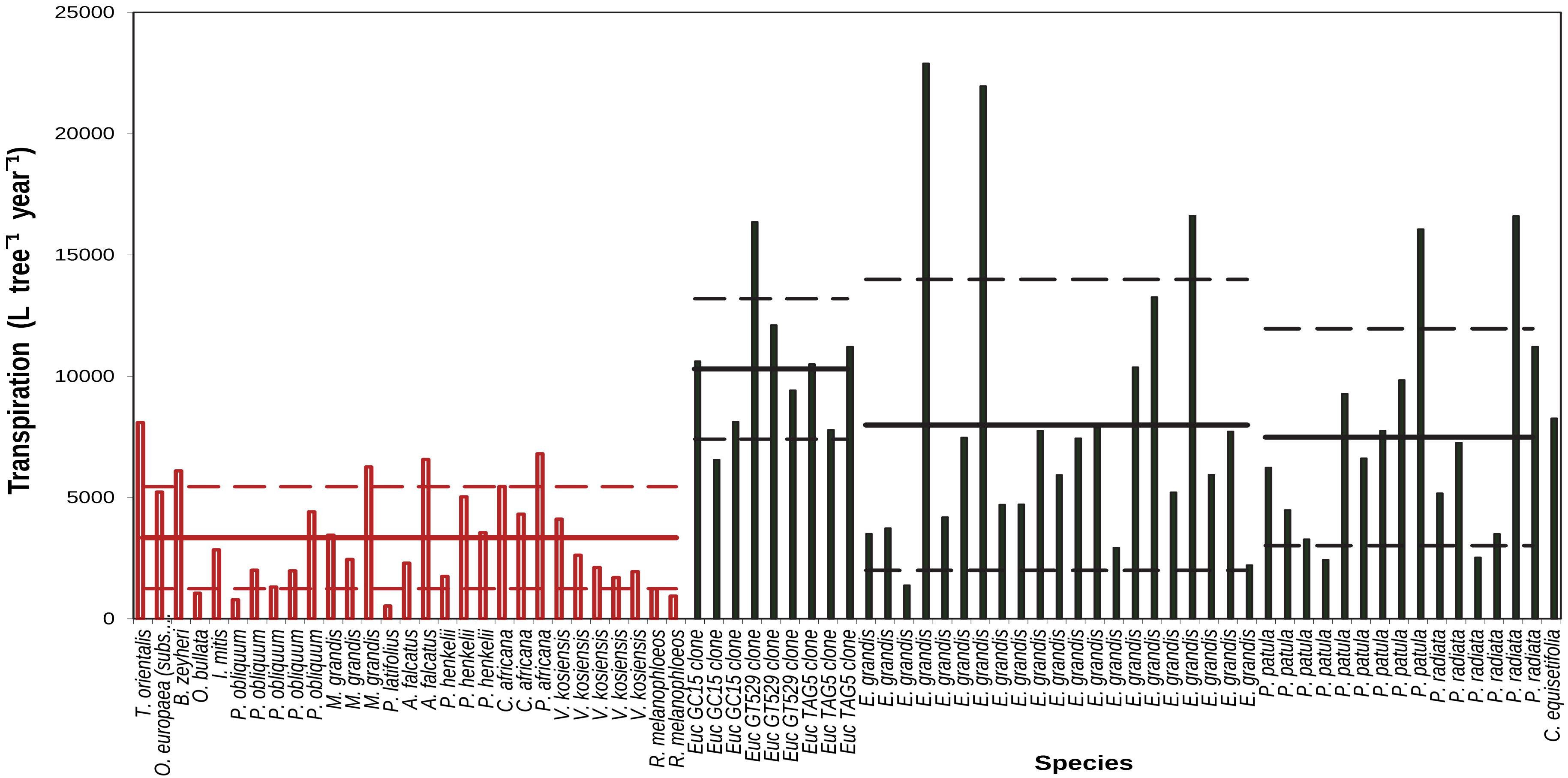

Figure 8. A comparison of 1-year sap flow (transpiration) volumes for selected South African indigenous tree species (open bars – this study) and introduced plantation tree species and clones (solid bars – Olbrich *et al*., 1996; Dye *et al*., 2001; this study). The means (solid lines) and standard deviations (dashed lines) for the data sets are shown.

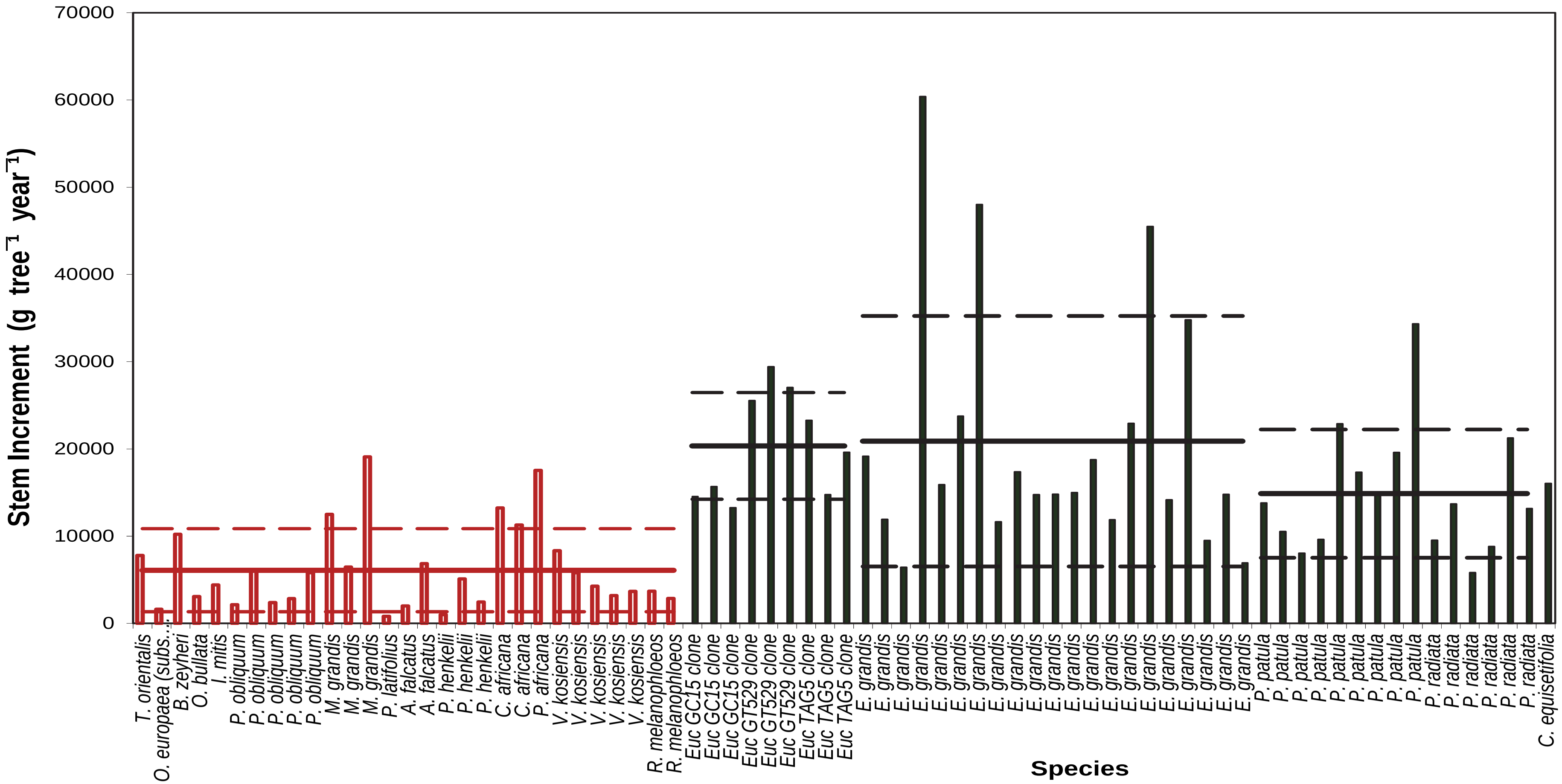

Figure 9. A comparison of 1-year stem growth increments (mass based) for selected South African indigenous tree species (open bars – this study) and introduced plantation tree species and clones (solid bars – Olbrich *et al*., 1996; Dye *et al*., 2001; this study). The means (solid lines) and standard deviations (dashed lines) for the data sets are shown.

Water use efficiency

The question then is, to what extent do growth rates correspond with water-use rates within indigenous and introduced species, and what is the net result in terms of their respective water-use efficiency values? WUE in the indigenous species studied so far has averaged 1.95 ± 0.88 g (stem wood) L^{-1} (water), only slightly lower than for introduced plantation species (Table 6, Figure 10). These averaged 2.01 ± 0.49 g L^{-1} for Eucalyptus clonal trees, 2.91 ± 0.99 g L^{-1} for *Eucalyptus grandis* trees and 2.2 ± 0.64 g L^{-1} for *Pinus* species. The slightly lower WUE of the indigenous species is more a consequence of slow growth rates as opposed to high water-use rates – a finding supported by other studies (Binkley *et al*., 2004; Gyenge *et al*., 2008). Results therefore indicate that on average indigenous tree species appear to exhibit similar water use efficiencies to introduced plantation tree species. This supports the argument of a general correlation between growth and water use. The potential for substantial year-to-year variation in WUE of a particular tree species or even an individual tree is uncertain. WUE in any given year may be dependent upon the climatic conditions experienced, although it is possible that a year of above-average rainfall would result in above-average water-use and growth (similarly with a below-average year), rendering the overall effect on WUE insignificant unless certain thresholds in water-use or growth were reached.

Table 6. Average 1-year transpiration, stem growth and water use efficiency data for grouped South African indigenous tree species (this study), and introduced plantation tree species and clones (Olbrich *et al*., 1996; Dye *et al*., 2001; this study). Standard Deviations of the data sets are represented in brackets.

Tree Species Group	1-yr Water-use (L)	1-yr Stem Mass Increment (g)	WUE (g stem wood/L water transpired)
Indigenous trees	3343 (± 1242)	6090 (± 4762)	1.95 (± 0.88)
Eucalyptus clones	10300 (± 2890)	20345 (± 6118)	2.01 (± 0.49)
Eucalyptus grandis	7994 (± 5995)	20874 (± 14361)	2.91 (± 0.99)
Pinus species	7488 (± 4473)	14877 (± 7357)	2.20 (± 0.64)

Plantations of introduced tree species established in the higher rainfall regions of the country exhibit high water-use rates, but they have also been genetically selected and bred for higher growth rates over a long time (Verryn, 2000). Based on findings by Binkley *et al*. (2004) and Stape *et al.* (2004) this is likely to have improved their WUE. On the other hand, efforts at tree improvement and silvicultural enhancement of growth rates in indigenous tree species have been limited in extent.

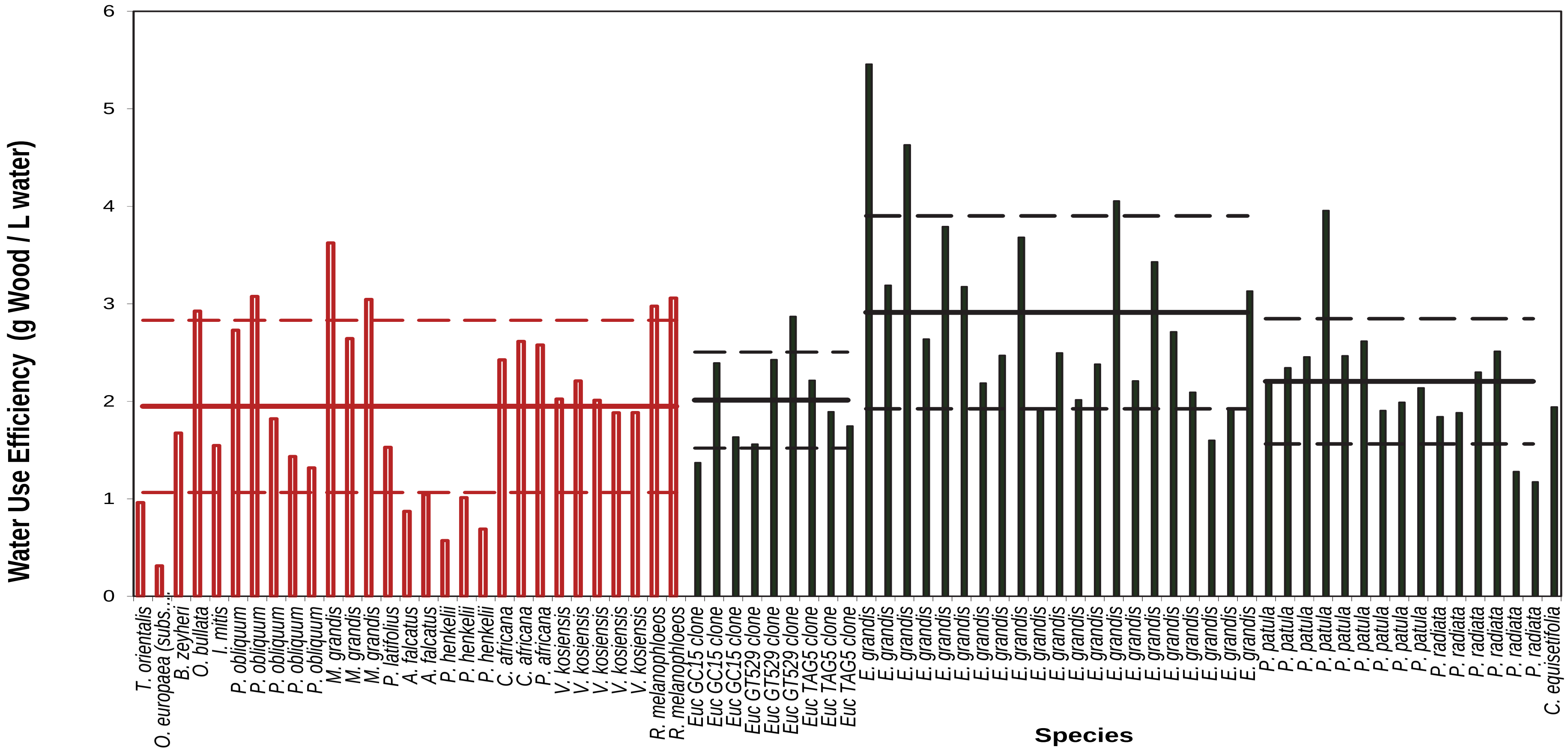

Figure 10. A comparison of water-use efficiency (stem mass increment per volume water transpired) for selected South African indigenous tree species (open bars – this study) and introduced plantation tree species and clones (solid bars – Olbrich *et al*., 1996; Dye *et al*., 2001; this study). The means (solid lines) and standard deviations (dashed lines) for the data sets are shown.

5 ECONOMIC VIABILITY AND MARKET POTENTIAL[6]

5.1 Introduction

The analyses reported on in this section aimed to explore the financial and economic viability of selected indigenous tree species in plantation rotation production systems and informal natural forest resource utilisation, as well as the more formal market potential of indigenous tree products. One of the objectives was to incorporate different socio-economic contexts in the assessment in order to facilitate comparisons between the financial and economic viability of indigenous species and commercial plantations of introduced tree species. The focus of this component was on biophysical products harvested from the trees (in different study areas around South Africa) excluding non-timber forest products.

5.2 Literature Review

5.2.1 History of government policy on the management of indigenous forests

The legacy of government policy on communal lands in South Africa and the associated open access problem had a detrimental impact on natural resources and particularly forests in South Africa (Mogaka *et al*,. 2001). For example, the 1913 Natives Land Act (No 27 of 1913) prohibited Africans from purchasing land, and tenure tended to be based on management under trusteeship of the state; such that little incentive existed to utilise such land on a sustainable basis. However, the Bantu Authorities Act in 1951 (Act 68 of 1951), in effect re-incorporated tribalism into control of the native reserves; establishing tribal, regional and territorial authorities with limited powers of local government. Furthermore, so-called 'betterment schemes' were introduced from 1936 through to the 1960s, which replaced traditional scattered homesteads with nucleated villages surrounded by rigidly

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[6] When making reference to this section, please cite as follows:

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demarcated arable and grazing zones. This resulted in increased pressure on resources around settlements compared to the previous situation where the scattered homesteads had adequate access to natural resources. These schemes also created a landless class, through displacement of rural populations and forced relocations in the 1980s, which involved the resettlement of African people into the homelands and resulted in further overcrowding of the homeland areas. This added enormous pressure to the already over-utilised land (Obiri and Lawes, 2002). This political history, along with a collapse of local institutions responsible for resource management, and high unemployment and poverty, has contributed to the over-utilisation of forests (Neil, 2000). As forests became increasingly threatened, the Forestry Act of 1969 and Nature Conservation Act of 1971 were passed to protect all indigenous forests. Presently over 72 tree species are protected under the current Forests Act (Department of Water Affairs and Forestry, 1998), including three of the four species on which this report focuses.

As a consequence of this legislation, forests have been managed as hands-off protected areas, allowing little, if any, access by surrounding communities to the resources contained therein (Von Maltitz and Shackleton, 2004). The lack of a participatory approach and adequate account of community needs, as well as the loss of precious grazing land without adequate compensation fostered resentment, antagonism and suspicion among communities with regard to government-initiated development initiatives aimed at forestry restoration (Kepe, 1997). This led to a largely negative perception of protected area management among neighbouring communities, but not necessarily to a negative perception towards conservation in itself (Ham, 1999). Nonetheless, compensatory efforts by the previous Department of Water Affairs and Forestry (DWAF) (now the Department of Agriculture, Forestry and Fisheries) focused on the establishment of community nurseries, focusing on indigenous species. However, most of these have failed due to lack of financial viability, inadequate markets, and lack of government staff to provide extension services. Community based forestry efforts in South Africa have therefore failed to reverse the general decline of natural forests or to improve rural livelihoods. The lack of success of community management of forest resources is evident in pervasive fuelwood shortages and local destruction of natural forests, as well as the fact that few communities have incorporated introduced tree-growing into their local development initiatives.

Furthermore, whereas sustainable forest management, offers relatively slow returns (Rogerson, 2000), widespread poverty has forced people to pursue unsustainable practices, offering more immediate cash returns to satisfy basic needs, e.g. harvesting trees which are not yet harvest ready. Thus, although there is little doubt that indigenous forests offer numerous benefits to adjacent communities and to society at large, the scope for an indigenous forest to assist in poverty alleviation remains limited because of a lack of immediate cash benefits. This has led to the under-valuation of natural resources in many rural areas, which has reduced incentives of people to manage the resource in a sustainable fashion (Wunder, 2001).

By the early 1990s it was realised that the needs of neighbouring communities had to be considered if indigenous forests are to be protected. This led to the development of neighbour relations policies by the major conservation agencies (Neil, 2000, Wily, 2000). All of these were based on the belief that pressures on natural forests would only be alleviated if communities benefited from the forest, the initial idea was to allow controlled access and to initiate development projects within the communities. In addition, protected area authorities started to actively recruit staff from neighbouring communities. Thus, communities started enjoying increased benefit from increased access to forests. In most cases, however, the responsibility for the management of these resources largely remained with the conservation authorities. This is because demand for resources, such as thatch grass and fuelwood, generally outstrips the sustainable supply, and without a strict definition of communities' rights and responsibilities, people will behave opportunistically (Williams and Shackleton, 2002), which results in forests being degraded even further.

During the mid-1990s the deterioration of the indigenous forests revealed the knock-on effect of deteriorating rural livelihoods and increased poverty (Ham and Theron, 2001). It was recognised that a more effective approach would be necessary to create incentives aimed at conservation of indigenous forests (Wily, 2000). Unfortunately, the situation has not improved since the democratisation of South Africa in 1994. Community forestry has had limited success, if not neglected entirely, except in parts of the Eastern Cape, where woodlot establishment around indigenous forests has helped to conserve natural forests. The Manubi state forest is one such example where small plantations established around natural forests have provided fuelwood and timber to communities, and have relieved the pressure on natural forests to some extent. However, some tension still exists between policies aimed at protecting forests and policies aimed at supporting livelihoods and decreasing poverty – putting Government in something of a dilemma (Obiri and Lawes, 2002). Being common property, these resources require a particular form of co-management to safeguard sustainable utilisation levels. Such co-management is extremely important, but difficult to achieve. Given that indigenous forests have been managed according to protectionist and exclusionary principles (which in practice denied communities the right and means to benefit from the goods and services derived from such forests), the revised National Forestry Act (Act 84 of 1998) created the opportunity to incorporate community-based approaches to forest management by allowing communities to manage and use forests in close proximity, in order to pursue sustainable development goals. This transition has provided economic incentives for community involvement in sustainable forest management in three distinctive ways: direct benefit sharing, co-development of forest-based markets, and the promotion of substitutes to unsustainable forest activities.

This study incorporates some of these initiatives in three selected study sites and reports on the progress of research focusing on the financial and economic viability of two types of indigenous tree production systems. It is expected that this work will present the benefits of conserving and expanding of area of selected indigenous forestry species in order to inform policy decisions regarding the utilisation of indigenous species for commercial forestry in South Africa.

5.2.2 Significance of forest products for the informal market in South Africa

The indigenous forest biome covers approximately 350 000 ha and is the smallest of all biomes in South Africa. Although small, it contains approximately 568 woody plant species, of which 365 species (64%) are currently utilised in one or more ways (Geldenhuys, 2011, Geldenhuys, 2007) by providing useful products and services, including timber, construction and fencing poles, fuelwood, traditional medicines, foods, craft wood and fibres, household goods, and implements (Bailey *et al*., 1999; Venter and Venter, 2009, Shackleton *et al*., 2007, Cocks and Dold, 2006, Cocks, 2006, Cocks and Moller, 2002, Cocks and Wiersum, 2002, Cocks *et al.,* 2008, Boudreau *et al*., 2005). However, attempts thus far to expand the predictive capacity of the prevalence, magnitude and nature of community dependence on forests and forest products have been thwarted by problems relating to, among other things, data availability and definitions, as well as the variable spatial and temporal dynamics of such use and dependence (Cocks, 2006, Shackleton *et al*., 2007, Mavimbela, 2010).

Whereas comparatively little is known about the subsistence and informal use of forest resources, forests seemingly play a significant role in the upkeep of livelihoods (Cocks, 2006, Cocks and Dold, 2004, Cocks and Wiersum, 2002, Shackleton and Shackleton, 2000, Shackleton *et al*., 2007, Lawes *et al*., 2004a). However, this value has not been quantified in monetary terms (except for specific products in certain localised areas) since only a couple of studies have examined the use of forest resources from a livelihoods perspective. Even fewer studies have estimated the relative income streams to households that can be ascribed to forest goods and services.

It is clear from the literature that the extent to which forests are utilised by local communities depends on a variety of economic, social and ecological factors, including household income, employment status, institutional regulations, accessibility and the availability of substitutes. Poor households tend to use a greater variety and quantity of woodland resources than wealthier ones. Direct-use benefits could be either in the form of supplying basic needs, or in terms of savings in cash expenditure on substitutes, or direct income being generated from selling goods and products from forests. It is estimated that forest resources can contribute up to a quarter of the total value of a livelihood income stream via direct use (replacement values) or from income generation (Shackleton *et al*., 2001), however this has not been calculated in a scientific rigorous way.

A few studies were found reporting on the use of forest resources. Most reports focused on a specific product in a localised area, for example firewood (Cocks, 2006, Ham and Theorn, 2001, Hassan, 2002, Dovie *et al*., 2004, Williams and Shackleton, 2002); edible fruits (Shackleton *et al*., 2000, Emanuel *et al*., 2005, Shackleton *et al*., 2002, Shackleton and Shackleton, 2006, Shackleton and Shackleton, 2004a, Shackleton and Shackleton, 2003, Shackleton, 1999); medicinal plants (Cocks *et al*., 2004, Dold and Cocks, 2002, Geldenhuys, 2007, Shackleton and Shackleton, 2003); or weaving fibres (Cawe and Geldenhuys, 2007a) to name a few. Fewer studies dealt with the use of all resources at a specific site (Vermeulen, 2009, Dovie *et al*., 2002, Lawes *et al*., 2004a, Shackleton and Shackleton, 2004a, Shackleton and Shackleton, 2004b). Hassan (2002) estimated an average local direct use value from harvested plants and animals of R544 per person per year, for resources consumed within the household from forests and woodlands.

Rural communities are still highly dependent on wood as their primary energy source, contributing between 50 and 60% of household energy requirements (Williams and Shackleton, 2002) in rural areas. The value associated with fuelwood can be estimated using the replacement cost method; i.e. based on what it would cost to replace this source of fuel with the next best alternative. In terms of paraffin as alternative sources of fuel, this value has been estimated at about R7.8 billion on a national scale (Hassan, 2002), (however, the calorific value of paraffin and wood still needs to be accounted for in this comparison to fine-tune this finding.) Similarly, the use of medicinal plants by traditional healers in the country is estimated at R500-R1000 million annually (Department of Water Affairs and Forestry, 1997, Cocks *et al*., 2004, Dold and Cocks, 2002). However, tractability of species is a major challenge, as more and more substitutes are presented for essentially the same use. For example both Acacia Karoo and Umzimbeet make excellent fire wood and the relative proportion of the benefit attributable to a specific species becomes extremely challenging when the value attributes are aggregated on species level in order to allow comparisons between species.

Goods and services from forests are important since being able to collect and use products from forests to meet daily needs for maintaining livelihoods allows cash resources to be saved and/or allocated to other expenses, such as education, clothes, etc. For example, if the direct-use value of fuel wood is R2000 per household per year (Dovie *et al*., 2004), the cost savings associated with not having to purchase an alternative source of fuel (e.g. paraffin or electricity) could be used to pay the school fees for a child. These savings could run into several thousand rand per household per year (the relative significance of which would be proportionally larger for poor households as opposed to wealthier households); but remain a function of the local context, which implies that the findings of above-mentioned area-specific studies are not necessarily generalizable.

No official national or regional estimates exist of the value generated from trade of forest goods, since this is often done through an informal or even black/illegal market and because of the difficulties associated with inter-species comparisons as mentioned above. However, estimates are that there are more than 10000 timber small-growers, earning a net income of between R1000 and R5000 per year, who in turn, support small-scale contractors involved in land preparation, harvesting and transport (Shackleton *et al*., 2007), these figures are however not confirmed. Furthermore, it is estimated that approximately 4% of rural households are involved in selling forest products, and that there are approximately 300 000 traditional healers in South Africa, serving an estimated 27 million customers, with two-thirds of their plant medicines coming from forests (Cocks and Moller, 2002, Shackleton *et al*., 2007). It is also estimated that there are at least 800 000 people involved in the craft industry carving craft products from forests (Department of Arts Culture Science and Technology, 1998), generating an estimated R7.37 million in retail value (Hassan, 2002). Disregarding the very low profit margins on woodcarving (not the vendors who are selling in urban areas), which is mostly practised because of a lack of other employment opportunities (Obiri, 1997).

It should be mentioned that although the profit margins in all of these industries are small at the beginning of the value chains (i.e. close to where the products originate) the income derived from these activities prevent the worsening of poverty. One should also remember that alternative income sources are scarce because of low levels of education and skills, poor infrastructure, and remoteness, which obstructs employment opportunities. The probability of being employed in the formal sector is consequently extremely low, which implies that although the returns to labour in small-scale trading of forest products is low in absolute monetary terms, it compares favourably to a situation of unemployment and no income at all.

5.2.3 Significance of forest products for the formal market in South Africa

This section explores potential products from South African indigenous wood that may have formal market potential. It discusses the processes that are needed to achieve those products, as well as the market values that can be realised from them.

In a conventional forestry environment, which feeds into a commercial sawmill, trees are either clones, or similarly aged individuals, grown by means of standard silvicultural management techniques. Managers work according to long time frames and harvesting and sawmilling schedules are planned well in advance. Once logs are felled and brought to the mill, an efficient, repetitive production operation ensues, which consists of cutting large volumes of logs to standard sizes – lengths, thicknesses and widths. Trees from tropical rainforests lend themselves to the same production lines because large numbers of trees are often clearfelled to produce many large and straight logs.

Conversely, most indigenous wood in South Africa in planned harvesting operations is harvested as individual trees within a mosaic of standing trees or as a mixture of species salvaged from an activity that destroys trees in its path. The age, shape and size are completely unpredictable, as is the species mix. This means that harvesting and production schedules cannot be planned in advance and it becomes extremely difficult to market the wood in the absence of predictions about volumes. In terms of supplying the market, no commitments can be made in terms of species, sizes and volumes and the market can, in a sense, only be found once the wood has been harvested and processed. The supply, in this instance, is there without a secure demand. This is effectively “putting the cart before the horse”. Because of these constraints, investing in indigenous wood is an “act of faith” and partly driven by a dislike of waste, a passion for discovery and a search for something unique in each species.

The cost of harvesting also becomes an important issue. In the protected forests, where the goal is not to damage surrounding trees, selected trees have to first be “topped”, which means slowly taking the tree down in sections from the top and only felling the main stem when all of the branches have been removed. Then the logs are dragged out by horses or tractors and winches, to minimise damage by heavy machinery. In the case of salvage operations, it is often not cost-effective to bring heavy machinery in and, in some instances (e.g. the coastal dunes on the Richards Bay Minerals mine path), the terrain is extremely hostile for efficient harvesting.

With regard to marketing South African indigenous woods, the difficulty with pricing the wood and, particularly, a final wood product, such as wood turning blanks, stems from a number of complex issues, namely:

1. The variable shape, size and quality of logs obtained from the field, as discussed earlier.
2. The difficulty in estimating useable volume within those logs, since one cannot predict easily what the centre of the log will look like.
3. The variability in the final percentage recovery obtained from logs.
4. Decisions regarding the most effective mix of product sizes that can be obtained from an individual log and the likelihood of selling those sizes.
5. The cost versus benefits of converting offcuts to smaller and smaller saleable stock and the diminishing returns associated with that.
6. The “wear and tear” on blades and machinery due to the variability in characteristics of different species. This includes issues such as density and abrasiveness.
7. The cost of disposal of offcuts and waste.
8. The variability of the International Exchange Rate.

Despite these challenges, a number of products have been, and continue to be, produced from indigenous wood in South Africa. These, more or less in order of value, include:

1. Firewood.
2. Raw timber and rough slabs.
3. Sawn planks.
4. Wood turning blanks.
5. Knife handles (knife scales)
6. Musical instrument parts.

Firewood

Apart from subsistence firewood collection, the biggest commercial market for firewood in South Africa is Gauteng. The wood is usually chopped into pieces, approximately 300 mm long, and split into chunks of approximately

80 x 80 mm. It is then sold in plastic bags of 8-10 kg, depending on the species of wood. As an interesting case study, there is a firewood supplier who operates off a farm in Gravelotte, in the Limpopo Province. He harvests *Colophospermum mopane* (Mopane) and sells it to the Gauteng market – mainly Pretoria and Johannesburg. Mopane logs for woodturning have also been traded. In the winter months, he sells 20 000-30 000 bags of firewood per month and in the summer months, 10 000-15 000 bags per month. Given that a bag weighs 8-9 kg and the density of Mopane is 1 090 kg m^{-3}, this means that each bag holds roughly 8 dm of wood. The total volume that he sells in the winter months is therefore 160-240 m^3 (170-255 tons) and in the summer months it is 80-120 m^3 (85-128 tons) – and he is only one of many firewood suppliers in the area. The price that he achieves per bag on the farm is R9.00 per bag. It costs R3.30 per bag to truck it to Johannesburg (460 km) and the average retail price in Johannesburg is R14.00 per bag.

On the other hand, *Dichrostachys cinerea* (Sicklebush) sells for R8.00 per bag in Johannesburg. A large quantity of that comes from Warmbaths, where the supplier gets paid R7.00 per bag. It is trucked a shorter distance (107 km) and is lighter in weight (890 kg m^{-3}), thus the lower transport costs. Apparently, although the Sicklebush firewood is cheaper, Mopane is a far superior firewood, and once people have tried both they would rather pay the extra and buy Mopane. A specific characteristic associated with good firewood is the presence of calcium oxalate crystals that give its embers high temperatures and make them long lasting. Mopane is known to have a high concentration of Calcium Oxylate.

In this instance, the preparation of firewood involves cross-cutting logs into shorter sections of about 300 mm, using a home-made circular saw, and then splitting the log sections using an axe. Mopane splits far more easily than other species and thus up to 2 tons of Mopane are able to be processed in this way, per day. On the basis of what has been observed about Mopane, one could safely say that it rates as one of the most desirable firewoods in South Africa and one could use it to make comparisons with other species, with ideal characteristics being:

1. Availability;
2. Proximity to markets;
3. Density (higher density being better);
4. Ease of splitting ("brittleness"); and
5. Presence of Calcium Oxylate crystals in the wood.

Raw Timber and Rough slabs

Information on the demand for specific South African indigenous timbers for either the local or export markets is limited. What is known is that demand exceeds supply so a true reflection of the market potential is not currently possible, but it is clear that there is a market available. There does not appear to be any foreseeable limit to the demand for indigenous timbers, so any increase in supply should be readily swallowed up demand without any real impact on prices at this stage. An indirect indication of the demand for indigenous timber is possible from records of sales and amounts that were supplied by SANParks (southern Cape) (Table 7). This data, collected early in the project, represents trends over an 11-year period. Auctions continued until 2013; however frequency of auctions and sales volumes declined markedly towards the end of this period.

An indication of the value of timber charged by different traders at different points on the value chain for specific indigenous tree species is provided in Table 8. The data show that for raw logs the 6 most valuable species (in order of descending value) are *Berchemia zeyheri* (Red Ivory), *Olea europaea* subsp. *africana* (Wild Olive), *Combretum imberbe* (Leadwood), *Colophospermum mopane* (Mopane), *Ocotea bullata* (Black Stinkwood) and *Olinia ventosa* (Hard Pear). This ranking remains the same for timber values after transport and milling, although prices are substantially (approximately 3 times) higher. The ranking changes somewhat when the selling price of planks is considered, and in this case the 6 most valuable species (in order of descending value) are *Dalbergia melanoxylon* (African Blackwood), *Berchemia zeyheri* (Red Ivory), *Combretum imberbe* (Leadwood), *Olea europaea* subsp. *africana* (Wild Olive), *Ocotea bullata* (Black Stinkwood) and *Spirostachys africana* (Tamboti). At R100 000 m^{-3} and R75 000 m^{-3} respectively, *Dalbergia melanoxylon* (African Blackwood) and *Berchemia zeyheri* (Red Ivory) are considerably more valuable than the next few species in terms of the selling price of planks.

Table 7. Annual volumes (m^3) of timber sold by SANParks between 1998 and 2008, from a range of indigenous tree species.

SPECIES	SANParks TIMBER VOLUMES SOLD (m^3): 1998-2008										
	YEAR										
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Stinkwood/Stinkhout (*Ocotea bullata*)	260.0	72.3	165.3	51.8	180.6	192.9	68.7	88.8	164.9	264.0	105.9
Real Yellowwood/Opregte Geelhout (*Podocarpus latifolius*)	848.0	715.4	385.0	789.9	445.2	456.8	335.3	254.9	446.2	660.9	611.7
Outeniqua Yellowwood/Kalander (*Afrocarpus falcatus*)	32.8	27.7	44.1	25.4	5.4	49.0	84.9	31.5	48.3	64.3	53.2
White Alder/Witels (*Platylophus trifoliatus*)	132.6	87.3	40.7	100.0	119.6	147.0	125.1	130.1	73.6	65.6	49.8
Ironwood/Ysterhout (*Olea capensis* subsp.*macrocarpa*)	313.0	650.2	45.7	205.4	169.2	294.0	197.0	78.4	213.5	202.5	132.6
Hard Pear/Hardepeer (*Olinia ventosa*)	124.2	137.6	108.5	39.4	76.8	136.3	53.8	76.5	41.4	126.3	42.1
Cape Beech/Boekenhout (*Rapanea melanophloeos*)	20.5	40.7	23.1	23.1	15.2	82.1	34.1	30.2	36.9	70.1	14.2
Cape Ash/Essenhout (*Ekebergia capensis*)	0.3	0.5	1.1	0.0	2.5	0.5	1.2	1.3	1.4	2.6	2.6
Cape Holly/Without (*Ilex mitis*)	29.5	31.0	8.3	16.0	11.4	21.7	17.4	4.3	31.4	18.3	1.6
White Pear/Witpeer (*Apodytes dimidiata* subsp.*dimidiata*)	93.9	184.0	23.2	82.1	51.4	88.4	41.9	33.9	45.8	60.7	32.2

SPECIES	SANParks TIMBER VOLUMES SOLD (m^3): 1998-2008										
	YEAR										
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Forest Elder/Bosvlier (*Nuxia floribunda*)	16.8	20.2	6.4	4.5	6.2	12.3	0.0	0.8	7.3	14.3	4.2
Cherrywood/Kershout (*Pterocelastrus tricuspidatus*)	36.1	78.5	35.3	29.9	14.9	51.2	24.2	16.5	40.2	55.6	29.6
Assegai/Assegaai (*Curtisia dentata*)	28.5	26.8	12.7	24.0	17.6	18.3	15.0	12.4	12.4	23.7	13.1
Common Saffron/Gewone Saffraan (*Elaeodendron croceum*)	6.9	3.9	0.2	2.1	0.0	0.3	0.7	1.0	0.2	0.4	0.5
Cape Blackwood/Kaapse Swarthout (*Maytenus peduncularis*)	7.0	3.1	2.1	2.4	0.0	1.0	4.0	0.8	2.6	3.6	0.0
White Silky Bark/Witsybas (*Robsonodendron eucleiforme*)	2.8	3.6	0.6	0.8	0.4	0.3	0.2	0.8	0.4	0.5	0.0
Rock Alder/Klipels (*Canthium mundianum*)	0.8	0.1	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.5
Wild Peach/Vaderlandsrooihout (*Kiggelaria africana*)	2.4	3.8	0.0	0.2	0.0	0.4	2.1	0.0	0.0	1.3	4.4
Blossom Tree/Keurboom (*Virgilia oroboides* subsp.*ferruginea*)	1.7	0.0	0.0	0.6	0.4	1.1	0.0	0.0	0.0	0.3	0.0
Kamassi/Kamassie (*Gonioma kamassi*)	2.8	7.6	1.5	4.3	2.1	1.7	0.5	0.8	0.1	3.5	0.0

SPECIES	SANParks TIMBER VOLUMES SOLD (m^3): 1998-2008										
	YEAR										
	1998	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Red Alder/Rooiels (*Cunonia capensis*)	5.3	6.3	1.4	3.1	0.8	12.7	4.9	6.5	0.0	3.5	0.0
Red Currant/Bostaaibos (*Rhus chirendensis*)	0.5	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quar/Kwar (*Psydrax obovata* subsp.*obovata*)	8.0	26.7	1.9	4.3	2.2	4.5	1.8	0.0	4.8	5.6	5.9
Red Pear/Rooipeer (*Scolopia mundii*)	0.5	0.6	0.0	0.8	0.9	0.0	0.0	0.0	0.0	0.0	2.6
False Cabbage Tree/Basterkiepersol (*Schefflera umbellifera*)	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Knobwood/Perdepram (*Zanthoxylum davyi*)	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0
White Ironwood/Witysterhout (*Vepris lanceolata*)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
Malabar Tree/Malbaar (*Brachylaena glabra*)	12.3	0.0	0.6	0.0	0.5	3.2	0.5	0.7	0.0	1.3	3.5
White Stinkwood/Witstinkhout (*Celtis africana*)	1.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
TOTAL (Indigenous species)	**1988.9**	**2129.3**	**907.4**	**1410.1**	**1123.2**	**1576.1**	**1016.5**	**770.3**	**1171.4**	**1650.7**	**1110.1**

Table 8. Values (R m^{-3}) charged by various traders at different points on the value chain for a range of indigenous tree species.

No	Species	Common Name	Log Price		Price after transport & milling		Plank Price		Selling Price – Planks (R m^{-3})	
			SAN-Parks	**Farm**	**SAN-Parks**	**Farm**	**Hodgsen**	**Rare Woods**	**Rare Woods**	**Red Ivory**
1	*Acacia burkei*	Monkey Thorn		1 500		5 000		1 300	7 000	10 000
2	*Acacia kosiensis*	Dune Thorn		1 500		5 000				10 000
3	*Acacia melanoxylon*	Australian Blackwood	1 550		5 100		4 000		9 000	9 000
4	*Acacia nigrescens*	Knob Thorn		1 500		5 000		1 300	7 000	10 000
5	*Acacia robusta*	Robust Acacia		1 500		5 000				10 000
6	*Acacia sieberiana*	Paper Bark Acacia		1 500		5 000				10 000
7	*Acacia tortilis*	Umbrella Thorn		1 500		5 000				10 000
8	*Acacia xanthophloea*	Fever Tree		1 500		5 000				10 000
9	*Afzelia quanzensis*	Pod Mahogany								
10	*Albizia adianthifolia*	Flat Crown		1 500		5 000				8 000
11	*Apodytes dimidiata*	White Pear		1 500		5 000		1 300	7 000	10 000
12	*Berchemia zeyheri*	Red (Pink) Ivory		6 000		14 000			75 000	45 000
13	*Brachylaena glabra*	Malabar	400		2 800		7 000	1 300	7 000	12 000
14	*Breonadia salicina*	Matumi		1 500		5 000				
15	*Bridelia micrantha*	Mitzeeri								
16	*Celtis africana*	White Stinkwood		1 500		5 000				
17	*Cinnamomum camphora*	Camphor		500		3 000			8 500	6 000

No	Species	Common Name	Log Price		Price after transport & milling		Plank Price		Selling Price – Planks (R m^{-3})	
			SAN-Parks	Farm	SAN-Parks	Farm	Hodgsen	Rare Woods	Rare Woods	Red Ivory
18	*Clausena anisata*	Perdipis/Horsewood		500		3 000	5 250			8 500
19	*Colophospermum mopane*	Mopane		2 000		6 000				12 000
20	*Combretum apiculatum*	Red Bushwillow		1 500		5 000				
21	*Combrretum imberbe*	Leadwood		3 000		8 000			26 000	25 000
22	*Commiphora harveyi*	Red Stem Corkwood		1 500		5 000				
23	*Cunonia capensis*	Rooi Els (Red Alder)	450		2 900		8 400			15 000
24	*Curtisia dentata*	Assegai	700		3 400			1 300	7 000	9 000
25	*Dalbergia melanoxylon*	African Blackwood							100 000	
26	*Dovyalis sp*	Sour Berry		1 500		5 000				
27	*Elaeodendron croceum*	Common Saffron	400		2 800		3 500	1 300	7 000	9 750
28	*Ekebergia capensis*	Cape Ash	750		3 500			1 300	7 000	
29	*Euclea divinorum*	Magic Guarri		1 500		5 000				
30	*Euclea racemosa*	Bush Guarri		1 500		5 000				
31	*Ficus stuhlmannii*	Lowveld Fig		1 500		5 000				
32	*Ficus sycomorus*	Sycamore Fig		1 500		5 000				
33	*Grevillea robusta*	Silky Oak		500		3 000				
34	*Guibourtia coleosperma*	African Rosewood								
35	*Halleria lucida*	Tree Fuchsia		1 500		5 000				

No	Species	Common Name	Log Price		Price after transport & milling		Plank Price		Selling Price – Planks (R m^{-3})	
			SAN-Parks	Farm	SAN-Parks	Farm	Hodgsen	Rare Woods	Rare Woods	Red Ivory
36	*Ilex mitis*	Cape Holly	375		2 750			1 300	7 000	
37	*Kiggelaria africana*	Wild Peach	420		2 840					
38	*Maytenus peduncularis*	Bush Blackwood	375		2 750					
39	*Melia azedarach*	Syringa		500		3 000				6 000
40	*Mimusops caffra*	Coastal Red Milkwood		1 500		5 000				12 000
41	*Nuxia floribunda*	Forest Alder	350		2 700			1 300	7 000	
42	*Ochna arborea*	Cape Plane		1 500		5 000				
43	*Ocotea bullata*	Black Stinkwood	1 800		5 600				25 000	9 000
44	*Olea capensis subsp. macrocarpa*	Ironwood	1 450		4 900		7 500		15 000	12 000
45	*Olea europaea subsp africana*	Wild Olive		6 000		14 000			25 000	10 000
46	*Olinia ventosa*	Hard Pear	1 600		5 200		7 000		15 000	12 500
47	*Pericopsis angolensis*	Afrormosia/Muwanga								
48	*Peltophorum africanum*	Weeping Wattle								
49	*Platylophus trifoliatus*	Wit Els (White Alder)	1 320		4 640			1 300	7 000	8 500
50	*Afrocarpus falcatus*	Outeniqua Yellowwood	1 450		4 900				17 000	12 000
51	*Podocarpus latifolius*	Real Yellowwood	1 400		4 800				17 000	12 000
52	*Psydrax obovata*	Quar (Black Alder)	550		3 100		7 500	1 300	7 000	15 000

No	Species	Common Name	Log Price		Price after transport & milling		Plank Price		Selling Price – Planks (R m^{-3})	
			SAN-Parks	Farm	SAN-Parks	Farm	Hodgsen	Rare Woods	Rare Woods	Red Ivory
53	*Ptaeroxylon obliquum*	Sneezewood								
54	*Pterocarpus angolensis*	Kiaat							15 000	
55	*Pterocelastrus tricuspidatus*	Candlewood (Kershout)	1 300		4 600			1 300	7 000	10 000
56	*Rapanea melanophloeos*	Cape Beech	850		3 700			1 300	7 000	
57	*Rhus chirendensis*	Red Current						1 300	7 000	
58	*Rhus lancea*	Karee								
59	*Schotia brachypetala*	Weeping Boer Bean		1 500		5 000				
60	*Sclerocarya birrea*	Marula		1 500		5 000				
61	*Sideroxylon inerme*	White Milkwood		1 500		5 000				12 000
62	*Spirostachys africana*	Tamboti		200		2 400			20 000	20 000
63	*Trichilia emetica*	Natal Mahogany		1 500		5 000				
64	*Vepris carringtoniana*	Coastal White Ironwood		1 500		5 000				
65	*Widdringtonia nodiflora*	Mountain Cypress		1 500		5 000				
66	*Xymalos monospora*	Lemon Wood		1 500		5 000				
67	*Ziziphus mucronata*	Buffalo Thorn		1 500		5 000				9 000

There is also a market for rustic furniture in South Africa, which involves the use of thick slices or slabs of wood with the wavy edge still intact. Usually, the quality of the joinery is fairly crude and the overall price for these items of furniture is at the mid-lower end of the market. Therefore, the manufacturers would generally not use expensive or rare wood species. For the most part, this will exclude indigenous species. However, there is a small market for the more expensive very big slabs (over 500 mm wide and greater than 2 m long) for bar counters and rustic tables. Companies such as Timber Village in Knysna specialise in that market. More upmarket companies, such as Kluyts & Co in Knysna, occasionally use expensive big slabs to create feature tables, such as *Afrocarpus falcatus* (Outeniqua Yellowwood) tables (Figure 11).

Figure 11. Burled *Afrocarpus falcatus* (Outeniqua Yellowwood) slab on metal legs – Kluyts & Co, Knysna.

Sawn planks

Planks sawn to various standard dimensions (unplaned) will be most commonly in the following ranges:

- Thicknesses of 25, 32, 50, 76 and 101 mm, the latter two being less common and more expensive.
- Widths can be random, but planks are often cut to standard widths, such as 100, 150, 200 and 250 mm.
- Lengths can be random, but in SA Pine they would be in 300 mm increments, starting from 1.8 m. SA Pine can be obtained in lengths up to

6.6 m, but indigenous hardwoods are seldom cut to lengths longer than 3 m.

Whilst it may seem attractive to get hold of the widest planks possible for articles such as table tops, the biggest problem with having long and wide planks is that many species twist and warp whilst drying and when one wishes to plane them flat and level, a lot of wood is lost. A more practical strategy if one wants perfectly matched table tops is to use a series of sequentially cut slabs from a log and book-match them, i.e. flip alternate slabs over so that their edges stay together. Then, to avoid planning too much wood away if the planks are warped, to cut them into strips of 100 mm for example, plane those, keeping them in the order in which they were cut, and then glue them back together. With SA Pine and Eucalyptus, large slabs are commonly made up of laminated strips, but there is not the same level of care taken to ensure that the strips are matching and come from the same log.

Rough-sawn Pine and Eucalyptus would be used for structural timber, such as roof trusses, whilst laminated boards and beams would commonly be used for shelving, staircases, beams, etc. Hardwood boards (planks) would be used for cabinet-making, shopfitting (usually in combination with veneered plywood or chipboard, with only facing pieces being solid) and hobby woodworking. Where hardwoods are machined into various profiles (mouldings), they are mostly used for decorative work and facings/edges of plywood and chipboard. The reason why this is important to mention is that when a lot of time can be wasted trying to market indigenous woods to shop-fitters and specialists, such as pub manufacturers. The standard response is often that they would only use wood for which matching, veneered plywood or chipboard was available. Hardwoods are seldom used for picture and mirror frames because synthetic mouldings for framing are usually lighter, cheaper, more stable and easier to cut.

In terms of marketing indigenous woods to cabinet makers and furniture factories, the one-man cabinet-makers are usually more willing to try out new species than the furniture manufacturers and the standard response from furniture manufacturers is that they would be willing to try out new woods only if the colour, characteristics and workability suited their product line and if consistent volumes could be guaranteed for a certain period of time. Decking and flooring are two of the other machined products that are possible, but the same issue of suitability and consistency of supply are the overriding issues with introducing new species into the market. To-date, no South African indigenous species have been shown to have suitable characteristics to compete with any of the commercial exterior decking woods, such as the tropical hardwoods Balau (*Shorea* spp.) and Massaranduba (*Manilkara* *bidentata*). The only really suitable hardwood for exterior decking grown in South Africa is Tallowwood (*Eucalyptus microcorys*). On the other hand, almost any South African indigenous species can be used for flooring, which can consist of strip or parquet in various sizes and patterns. The only real issues in this instance are market resistance and consistency of supply.

The issue of market resistance to new species is important to note. Anecdotal evidence from a USA-based timber dealer suggests that when a new, eminently suitable decking timber was introduced to the USA market, it took more than two years of aggressive marketing before a market for that wood was established.

<u>Wood turning blanks and knife scales</u>

Prior to the 2008 global economic crisis, there seemed to be a growing and consistent market for wood turning blanks for hobby woodturners, but this came to an abrupt halt almost overnight and has yet to recover. Prices for turning blanks sourced in South Africa ranged from R25 000 m^{-3} (Jacaranda, Silky Oak) to R100 000 m^{-3} (Red Ivory, African Blackwood). Pen blanks (19 x 19 x 152 mm) sold for between US$0.75 and US$1.50 each, depending on species, colour and figure. The smaller the dimensions of a turning blank, the more the wastage and the more important it is to have good colour and highly defined figure, so the price goes up disproportionately. Therefore, pen blanks and knife scales (knife handle blanks) need to come from highly attractive or striking wood and the price per cubic metre matches that. Almost any wood is suitable for wood turning, but the characteristics most sought after in turning woods are as follows.

1. Can be machined and sanded to a fine finish and is not “fluffy” or fibrous.
2. Not prone to excessive warping and cracking.
3. Presence of interesting figure or colour variations (Figure 12 and Figure 13).
4. Absence of excessive silica (more an issue with blunting of tools than quality of turning).
5. Blanks cut away from the pith (where cracks are more likely).

Figure 12. *Olea capensis* subsp. *macrocarpa* (Ironwood) – example of desirable figure for wood turning and knife-making.

Figure 13. *Mimusops caffra* (Coastal Red Milkwood) fiddleback figure on back of garden bench

<u>Musical instrument parts</u>

The supply of wood for musical instrument components is probably the most specialised endeavour in the business. Standards are extremely high and the woods need to display a number of characteristics to be suitable, namely:

1. Stability.
2. Absence of checks, cracks or discolouration.
3. Attractiveness.
4. Good tone.
5. Proven suitability for the particular application.
6. Very careful and controlled drying and resting prior to use.

There is only one supplier in South Africa who provides a consistent supply of southern African woods (a select group of seven species) to the International Market, and that is Phillip Montbaron of Prosono (www.prosono.co.za). However, a local Pietermaritzburg-based luthier, by the name of John Soderlund (www.jgsguitars.com), has been experimenting with making electric guitars (Figure 14) with a number of South African woods, including *Ballanites maughammi* (Torchwood), *Berchemia zeyheri* (Red Ivory), *Chaetacme aristata* (Thorny Elm), *Colophospermum mopane* (Mopane), *Dalbergia melanoxylon* (African Blackwood), *Olea capensis* subsp *macrocarpa* (Ironwood), *Olea europaea* subsp. *africana* (Wild Olive), *Olinia* *ventosa* (Hard Pear), *Prunus africana* (Red Stinkwood), *Spirostachys africana* (Tamboti). In addition to Prosono and John Soderlund, a business in Grahamstown, African Musical Instruments (www.kalimba.co.za), specialises in making marimbas out of Sneezewood (*Ptaeroxylon obliquum*), mostly obtained from old fence poles.

Figure 14. *Olea europaea* subsp. *africana* (Wild Olive) and *Colophospermum mopane* (Mopane) guitar (left) made by John Soderlund; Mopane clarinet by Prosono (top right); *Berchemia zeyheri* (Red Ivory) recorder by Sid Jones (bottom right).

5.2.4 Concepts and definitions

Economic definition of water-use efficiency

Water-use efficiency can be broadly defined as the returns derived from a unit volume of water applied in a specific use. The concept is useful to inform water resource management both at the micro and bulk scale, and is used as a performance measure to compare different water management strategies, particularly in the agricultural sector. This study have adopted this concept for the forestry industry (Palmer *et al*. (2010) have done the same for grasslands). The biophysical water-use efficiency (WUE) of a forest may be defined as the quantity of biomass harvested per unit of water used (the total volume transpired by trees, evaporated from the forest canopy and evaporated from the soil) from one hectare of forest over one year. It is calculated as follows:

Biophysical WUE = h/ET

where, h is the amount of biomass harvested per hectare per year (tonnes ha^{-1} $year^{-1}$) and ET is the annual quantity of water used per hectare (m^3 ha^{-1} yr^{-1}). Although the equation is conceptually simple, data limitations often hindered a fully inclusive estimate of the biophysical water-use efficiency and the derived value of relevant products. This project aimed to address some of these data needs. Progress has been made with respect to measuring the water use of trees, however the quantification and valuation of the products from the same study sites where water measurements are done for, has been slow. This report focuses specifically on progress that has been made to date (i.e. quantification of biophysical products from trees themselves, and the monetary valuation of such products). The variables have been estimated for each of the systems under investigation using a combination of direct sampling and simulation modelling techniques. These methods are described in later sections for each tree-production system.

Two factors not accounted for in this study, which will improve the relative inclusiveness of the economic valuation, are the inclusion of the value of indirect and non-use benefits derived from forests (e.g. ecosystem services such as carbon sequestration; as well as existence and bequest values).

Cost benefit analysis

It was originally intended to base the economic assessment on a social cost-benefit framework, which could be used as a decision-support tool for assessing and comparing costs and benefits between different forest utilisation scenarios (Lehtonen, 2005). The reason for this was because such an analysis would provide an objective basis for comparing all of the positive and negative impacts of alternative forest management regimes using a common metric (monetary units tend to be the most convenient metric). However, such an assessment requires that the full range of positive and negative impacts over time (including both private and social costs and benefits) associated with the activity are identified, quantified and valued in monetary terms using an appropriate economic valuation method, and discounted to present value terms using an appropriate social discount rate. A 'decision rule' is then applied in order to decide whether society as a whole would benefit from the proposed activity, or which of a range of alternative activities would be most beneficial. Decision rules that can be applied are as follows:

1. Net present value (NPV): The difference between the benefits and costs (i.e. the net benefit) for each year over the life time of the project is discounted to the present using the social discount rate. The sum of all these net benefits over the economic life of the project is defined as the net present value (NPV), or the present value of net social benefits.
2. Internal rate of return (IRR): Defined as the discount rate at which the present values of costs and benefits are equal. Only projects with an internal rate of return higher than the social discount rate are considered to be viable.
3. Benefit-cost ratio (BCR): Defined as the ratio of the present value of the benefits relative to the present value of the costs.

Since all of the above-mentioned decision rules are based on single numbers, it does not indicate the degree of uncertainty associated with the estimate. Consequently these results are most of the time combined with a sensitivity analysis, which examines the effects of different assumptions about key variables (for example, different discount rates) on the decision rule.

Another important consideration before a cost-benefit analysis (CBA) is undertaken is to state the perspective from which the analysis will be done. For example, costs and benefits to a private investor associated with a particular project could be quite different from the costs and benefits to the relevant municipality, to society at large, or to different communities within society. In cases where externalities are likely to be significant, however, it is best that the analysis be conducted from the perspective of all groups within society who stand to be affected in some way by the proposed activity; hence the need for a social CBA (as opposed to a conventional (private) CBA).

5.2.5 *Approaches to economic valuation of benefits and costs of trees and forests*

Forests, both natural and cultivated, are important for the vast collection of benefits in terms of goods and services they provide. Apart from the direct use value generated from the sale of timber from trees, benefits through other uses, such as a source of food production, tourism and recreation and ecological services can be realised, which can sometimes outperform those realised through timber sales (Secretariat of the Convention on Biological Diversity, 2001, Merlo and Croitoru, 2005). These uses, however, are often interdependent, but can also be mutually exclusive depending on the specific management practices followed. For instance: a forest managed for eco-tourism cannot simultaneously be used for timber mining (Secretariat of the Convention on Biological Diversity, 2001). For this reason the decision of a particular management system is important and has long-term implications.

The monetary valuation of private benefits and costs is relatively straightforward; since these types of benefits and costs tend to have market prices associated with them, which can then be used as proxies of the value derived from benefit, or the extent of the cost. However, external costs and benefits (particularly environmental impacts) tend to be indirect or intangible, and therefore more challenging to value. Since environmental goods and services do not generally enter markets, or do so only imperfectly, market prices for these goods and services either do not exist, or present inaccurate proxies of their value (Dixon and Pagiola, 1998). Thus, the monetary value of these benefits cannot be measured on the basis of an existing market price. In such cases, it will be necessary to conduct an economic valuation exercise using one (or more) of a number of non-market valuation techniques. Economic valuation thus involves placing a monetary value on the (often intangible) costs incurred or benefits derived by society as a result of the environmental or socio-economic impacts associated with an activity. In order to identify these impacts and select an appropriate valuation technique, it is useful to disaggregate any environmental impact into individual components of value. One approach to doing this is called the Total Economic Value (TEV) approach, whereby an impact is decomposed into a number of categories of value (Dixon and Pagiola, 1998: 3).

Total economic value (TEV) is the total value of an environmental resource in so far as it affects human welfare (Edwards-Jones *et al*., 2000). In the first place, it can be decomposed into use and non-use values (Pearce and Turner, 1990, Bateman *et al*., 2003) (see Figure 15). Use value derives from actual or potential use of the resource, and consists of direct use value (derived from harvesting/consuming the outputs of the resource, or from non-consumptive recreational use), indirect use value (i.e. benefits that people derive indirectly from the “ecological functions” performed by the forest, such as watershed protection, fire prevention, water recycling, carbon sequestration, biodiversity conservation, soil fertility and agricultural productivity enhancement), and option value (refers to preserving the possibility of future direct or indirect use of the forest. It represents the insurance premium people are willing to pay today to ensure that the forest, its biodiversity and ecological services are available in the future). By contrast, non-use Values are those benefits totally unrelated to any personal use of the forest. People may value a forest for a number of reasons without ever visiting it. These can be distinguished between 1) Existence Value, which is the perceived value of the forest, unrelated either to current or optional use: its value simply because it exists. It is measured by the willingness to pay (WTP) to secure the survival and well-being of biodiversity, endangered species, habitats and so on; and 2) Bequest Value, which accrues from the desire to conserve forests for future generations. (Mountford and Keppler, 1999, Edwards-Jones *et al*., 2000).

The TEV framework assists with the identification of a ‘fuller’ set of economic values and attempt to capture a broader and more comprehensive range of economic values that individuals and society associate with environmental resources such as forests, but does not claim to encompass all values (Merlo and Croitoru, 2005). Some values cannot be measured in monetary terms (e.g. the cultural value of forests which strengthen cohesion within a community, Cocks and Dold, 2006), while forests might have other values which are intrinsic to its existence (such as an ecological value), even if not used by humans. The framework is depicted in Figure 15.

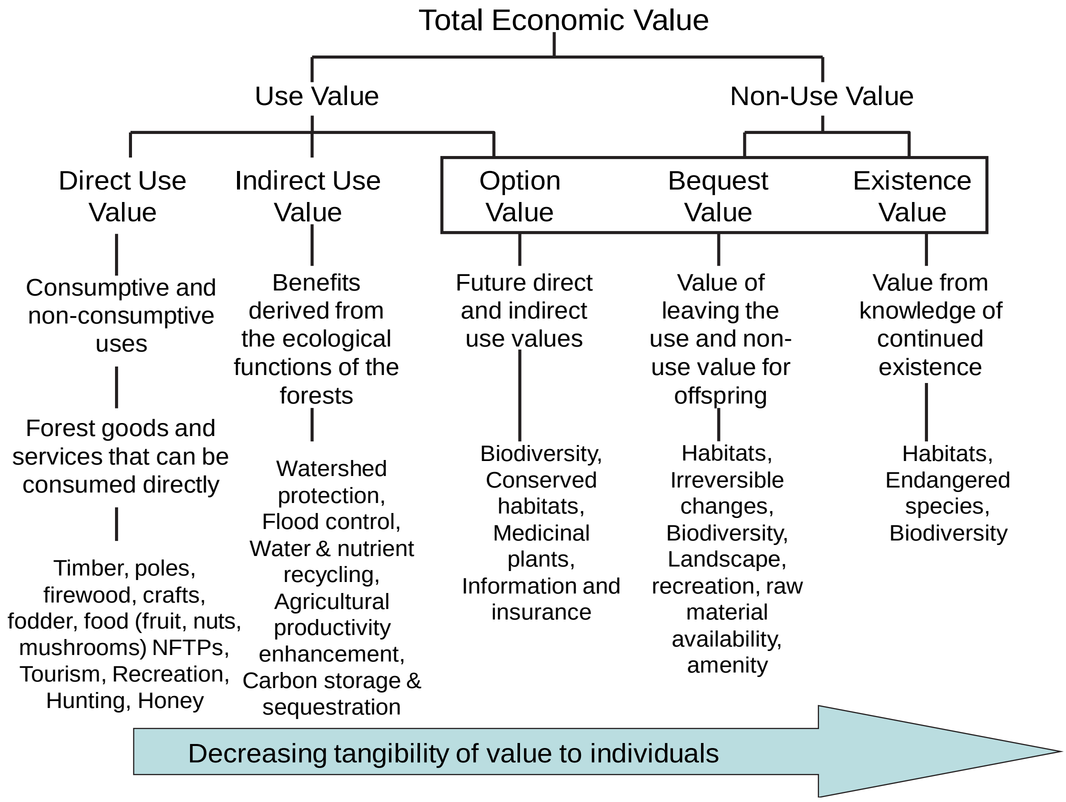

Figure 15. The total economic value of natural resources, modified from Merlo and Croitoru (2005).

The various uses identified in a TEV framework can be further classified as having either a stock or flow value (Secretariat of the Convention on Biological Diversity, 2001, Merlo and Croitoru, 2005). For instance: in a forest the stock is made up of the standing trees, while the flows are represented by the goods and services provided by this standing stock within a specific period, usually one year (e.g. edible fruit, ecosystem goods and services). Once the standing trees (stock) are cut down, flow values are also affected as these two variables are interconnected: most flow values will discontinue until a new stock of trees in the forest/plantation is planted or the trees start to grow again.

Forests provide a multitude of both use and non-use values. Examples include consumptive direct use value (timber, bark, non-timber forest products, etc.); non-consumptive direct use value (tourism and culture); ecosystem services (e.g. carbon sequestration); option value (e.g. potential medicinal uses that have not yet been discovered or developed); as well as existence and bequest values (the value derived from knowing that forests exist or that they will be available to future generations).

Various attempts have been made to value selected use and non-use values of forests in South Africa, but methods, study areas and assumptions differ which hampers comparisons. These studies provide insight into the various uses and values of forests (Geldenhuys, 2004, Lawes *et al*., 2004b, Banks *et al*., 1996) (the book Indigenous forests and woodlands in South Africa, edited by Lawes, M.J., Eely, C.M., Schackleton, C.M. and Geach, B.G.S. (2004) contains numerous chapters on wood and timber use, medicinal plants, woodcarving and the woodcarving industry, foods from forests and woodlands and alternative uses). This report focuses on direct use values only; specifically, physical products derived directly from trees, including both timber as well as non-timber products such as fruit. Other non-timber forest products *not* derived from trees (e.g. mushrooms) are ignored, as are ecosystem services such as carbon sequestration. A number of techniques exist for valuing non-market (e.g. environmental) goods and services. Some of these techniques are discussed briefly below.

<u>Stated preference methods</u>

- **Contingent valuation method**

The contingent valuation method (CVM) is a survey method in which people are asked directly to state their willingness to pay (WTP) for receiving a hypothetical benefit (e.g. an improvement in environmental quality), or for avoiding a hypothetical loss; or, conversely, their willingness to accept (WTA) compensation to forego a benefit or tolerate a loss (Eshet *et al*., 2005). It is called the contingent valuation method because the respondents' valuations are contingent or dependent on the hypothetical market setting that is established by the researcher. The method is intuitive in principle, and seemingly easy to apply and widely applicable to a range of different situations (since it is based on hypothetical scenarios, such as hypothetical improvements or deterioration of the environment). However, the method is actually challenging to apply properly in practice, and the accuracy of results is subject to debate. In particular, conducting a proper CVM survey that meets best practice requirements is data-intensive, costly, and time-consuming (European Commission, 2000). Nevertheless, the CVM method is one of few methods capable of estimating non-use values.

- **Choice modelling**

Choice modelling, also known as conjoint analysis, is a broad term for a variety of survey methods (such as choice experiments, contingent ranking/rating, paired comparisons, etc.) that ask individuals to rank/rate/choose alternatives rather than explicitly express a WTP or WTA. Each alternative is characterized by a number of attributes, of which one will be monetary (Eshet *et al*., 2005: 489). A monetary value is obtained based on the trade-offs respondents make between the monetary and non-monetary attributes. A baseline status quo alternative is usually included to help establish the other alternatives in relation to the respondent's actual experience (Eshet *et al*., 2005: 489).

Revealed preference methods

- **Hedonic pricing method**

In the hedonic pricing method (HPM), the impacts of a particular environmental, health or social hazard on closely-related market prices (e.g. the prices of properties located near to a site which causes noise, visual or air quality impacts) are isolated from other factors affecting those prices, in order to estimate the value that people place on avoiding the impact. For example, in the context of air quality, the HPM reveals the value individuals place on an environmental attribute (e.g. air quality) from differences in housing prices (Eshet *et al*., 2005: 490) between properties that are identical in every respect, with the exception of ambient air quality.

- **Averting behaviour/defensive expenditures**

The averting behaviour method is based on the assumption that the value of an environmental impact equals the amount of money households spend to offset the impact (Eshet *et al*., 2005: 490). For example, it assumes that expenditure on water filters can provide an approximate estimate of the damage to groundwater caused by contamination of water supplies. Technically speaking, it provides only a minimum estimate of actual damages, because people are unlikely to spend more on averting the damages than they suffer as a result of incurring the damages.

- **Travel cost method**

The travel cost method assumes that the costs of a trip to a recreational site in terms of travel, entry fees, on-site expenditures and time can be used as a proxy for the use value of the site and for changes in its quality (Eshet *et al*., 2005: 490). It is particularly useful for valuing recreational amenities or tourism resources, and may therefore prove to be appropriate in the case of valuing, for example, potential losses in forest tourism at Mazeppa Bay hotel near Manubi, resulting from forest degradation.

Market-based methods

- **Change in output of marketable goods**

This method seeks to value environmental changes by observing physical changes in the environment and estimating what difference these changes will have on the value of goods and services (European Commission, 2000: 61).

For example, changes in water quality can affect crop production. Thus, the costs associated with reduced water quality can be valued in terms of the resulting changes in the value of agricultural output.

- **Cost of illness method and human capital approach**

The cost of illness (COI) method estimates external costs through changes in private and public expenditures on medical goods and earnings lost due to days not worked (Eshet *et al*., 2005: 490) as a result of illness associated with impacts arising from the activity. A recently developed tool for measuring burden of disease (including morbidity and mortality) is the disability adjusted life years (DALYs) approach. The human capital approach estimates adverse health effects stemming from for example air pollution by measuring the effect on the productivity of employees (European Commission, 2000: 61).

Cost-based methods

- **Clean-up/rehabilitation cost method**

The clean-up cost method assumes that once the damage resulting from pollution is done, the costs of rehabilitation to achieve the pre-damage situation will appear as a (minimum) proxy economic value of damage (Eshet *et al*., 2005: 490). In this context, the damages to a particular ecosystem as a result of mining operations can be valued in terms of the costs that would have to be incurred in order to rehabilitate the ecosystem in question to its pre-degraded state.

- **Control/abatement/avoidance cost method**

The control cost method purports to infer the value that society attributes to pollutants, from the costs of implementing regulations that society imposes on itself in order to abate pollution (avoiding damage) (Eshet *et al*., 2005: 490). It is parallel to the clean-up cost approach in many ways (European Commission, 2000: 66); although in the avoidance cost approach the basic principle, is estimation of costs associated with avoiding rather than cleaning up a particular pollution that has already occurred to prevent adverse impacts (European Commission, 2000: 67). For example, the cost of measures to control contamination of water supplies provides a minimum estimate of the value that society places on avoiding such contamination, and therefore of the damage costs to society associated with the contamination.

- **Replacement cost method**

The replacement cost method uses the cost of replacing or restoring a damaged asset to its original state as the proxy value of the damage (Eshet *et al*., 2005: 490). In other words, the cost of the damage is estimated by using the value that it costs to put the harm right (European Commission, 2000: 61).

- **Relocation cost method**

In much the same way as the replacement cost method, the relocation cost approach uses estimated costs of a forced relocation of a natural or physical asset due to environmental damage (Dixon and Pagiola, 1998: 10) as a proxy for the damage cost.

- **Experts' assessments of damage costs**

In expert assessment, environmental damages are simply valued according to the knowledge, experience and mainly the intuition and judgment of professionals in particular fields that estimate, ex-ante or ex-post, the costs of repairing, restoring, or replacing a damaged asset, or abating impacts (Eshet *et al*., 2005: 490).

<u>Benefit transfer</u>

Often, it can be expensive and time-consuming to conduct original valuation research in support of specific policy actions. Because of this, analysts often draw upon existing valuation estimates (European Commission, 2000: 72) and apply them to new contexts. Benefit transfer (BT) is an econometric tool for transferring existing estimates of non-market values (benefit or damage) (Eshet *et al*., 2005: 490) from one study site to another, and making appropriate adjustments to account for differences in the two sites, with the aim of saving the time and money associated with conducting a new primary study. The original estimates could have been obtained via any of the methods discussed above. Thus, in cases where resources (time and/or financial resources) are lacking, the BT method offers an efficient way to use primary data from other studies (Eshet *et al*., 2005: 490).

An obvious limitation of this method lies with the accuracy of the value adjustment process. Here it becomes extremely important that the methods being followed for the adjustment process must be made explicit and that the process is done in a transparent way. The observed contextual differences between the reference sites and the target research study area must be clearly presented and the consequent adjustment of the original value must be explained and justified. Last mentioned step is often neglected, which means that BT estimates needs to be used with caution (Moeltner *et al*., 2007, Wilson and Hoehn, 2006, Bergstrom and Taylor, 2006). Furthermore, if BT values are derived from other BT values, a study can lose credibility very fast.

The above-mentioned limitation was particularly relevant to this project since it was found that several past studies has not only generalised benefit transfer values out of context, but also used derived BT values from other BT values. Consequently it was decided to do primary data collection and not to rely on benefit transfer to derive the values based on studies being done in other socio-economic and bio-physical contexts.

5.3 Economic Characteristics of Selected Indigenous Tree Species

5.3.1 *Millettia grandis* (Umzimbeet)

<u>Tree description and distribution</u>

Milettia grandis is a spreading, semi-deciduous, pod-bearing tree with a good canopy (Figure 16). It is found on the Eastern Cape and KwaZulu-Natal coasts, where it occurs on the margins of evergreen forests (Johnson & Johnson, 2002).

Figure 16. *Millettia grandis* (Umzimbeet) tree (Photo: M. Gush).

Wood description

The fine-textured, straight-grained, yellow/brown hard wood of *Milettia grandis*, with its attractive coloration (Figure 17), is valued for the manufacture of furniture and small domestic implements. It is an extremely heavy and hard timber, with an oily feel. A very durable wood, it is also quite resistant to impregnation with preservatives. It is hard to work with and difficult to plane, but polishes well and is good for wood turning. It glues well, but is difficult to nail, requiring preboring prior to nailing, but the nail holding properties are good. The planked wood must be seasoned very slowly to avoid deep checking. The wood doesn't have a distinct odour or any irritant properties. For detailed information on the wood properties of this and other indigenous tree species, refer to Dyer *et al*. (in press).

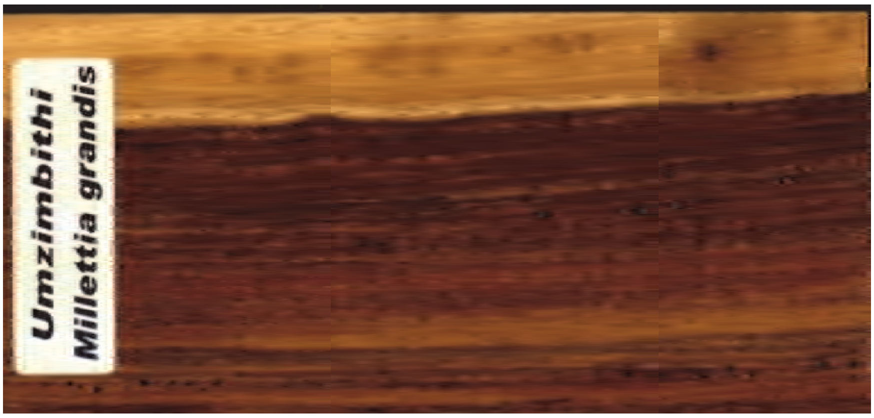

Figure 17. Sample of *Millettia grandis,* with a bleached Shellac finish (Photo: B. James).

Uses

Uses of the wood are for construction, industrial flooring, mining, tool handles, sports goods, agricultural implements, musical instruments, drawing tables and instruments, poles, toys, turnery, joinery, walking sticks and batons. It is used extensively by rural communities, who harvest it from forests, particularly for building huts and kraals and for wood carving (Oribi, 1997). It is also used for making tough, bicoloured walking sticks, which are sold to tourists by rural people (Venter and Venter, 2009). Traditional uses of the tree include using the powdered root as a fish poison, but the fish must be boiled before consumption. Other recipes exist for sleep-inducing cures, based on the roots. The ground seed, soaked in milk, is used as a remedy for roundworm, but with caution as consuming too many seeds is poisonous. Ground seed can also be used as an arrow poison (van Wyk & Gericke, 2000). The only animals to utilise the plants are baboons, which strip and eat the bark, and some butterflies, whose larvae feed on the pods. *M. grandis* bark is often stripped for use as a rope to tie up bundles of sticks, poles and laths taken from the forest (Cawe and Geldenhuys, 2007).

Availability and pricing

Millettia grandis was never available on SANParks auctions or commercially. However, it is used extensively by rural communities, who harvest it from forests (Oribi, 1997), although harvesting rates have been considered unsustainable. Reported annual extraction volumes are small, with 40.87 m^3 harvested and sold during the period 2000-2006 (Cawe and Geldenhuys, 2007). The wood could command a decent price in the market place, perhaps at least R10 000-R12 000 m^{-3}. If grown in sufficient quantity, and with sufficient demand, it could be exported as a specialist wood and there is potential to use it for a range of musical instruments.

Potential for cultivation

The growth rate of *Milletia grandis* is fairly rapid, about 80 cm per year (Johnson & Johnson, 2002) which is faster than Sneezewood, but slower than Yellowwood. It can be planted along pastures and fence lines to act as a windbreak and shelters for animals and can be harvested at 10-15 years for planks in high rainfall areas. It is a good tree for large-scale shade plantings, such as in avenues, sports grounds and municipal parks. It also makes an attractive garden and street tree and it does not have an aggressive root system. The tree has several features which give it tremendous agroforestry potential for rural community development. For example, it has a compact crown, making it particularly suitable for planting in limited spaces; it does not compete vigorously with other crops; and being a legume, it enhances soil fertility through nitrogen fixation. Another benefit is its ease of propagation from either vegetative material or seeds (Obiri, 1997). Some farmers around Port St. Johns have realised this agroforestry potential (Bangelman, 1996) and have integrated the tree into their vegetable gardens. It is a pioneering species which requires more open conditions for good regeneration, and it occurs in abundance in forest gaps and along the forest margin of natural forests along the Eastern Cape Wild Coast (Cawe and Geldenhuys, 2007). Umzimbeet contributes substantially to the socio-economic status of the Mpondo people in the Eastern Cape. Despite its high importance, few studies have been conducted on this species, as most research has concentrated on the inland indigenous forest trees (Cawe and Mckenzie, 1989).

Millettia grandis lends itself to be grown in woodlots adjacent to impoverished communities and could provide a source of wood for all of their domestic needs, as well as for the development of a local craft industry, with woodturning as the core activity. If it gets to the point where larger trees, which can yield decent timber, are available, the craft endeavour could be expanded to include cabinet-making.

5.3.2 Ptaeroxylon obliquum (Sneezewood)

Tree description and distribution

Ptaeroxylon obliquum is an evergreen semi-deciduous tree that grows up to 35 m tall; however specimens of this height are rare since the trees are usually harvested long before they can reach this height. The tree is found throughout most of the south-east and eastern part of South Africa, and also occurs in northern Namibia, Angola and further north into tropical Africa. It is locally common in the mist-belt forests, but less common in coastal forests. It also occurs on cliff faces and in deciduous woodland (Johnson & Johnson, 2002). The growth form depends on the environment in which it grows. In forests, the tree grows tall and straight and open-grown trees tend to be short, with low-down branching (Figure 18).

Figure 18. *Ptaeroxylon obliquum* (Sneezewood) trees (Photo: M. Gush).

Wood description

The heartwood of *Ptaeroxylon obliquum* is reddish/brown wood, with white sapwood and fine and even texture (Figure 19). The grain is straight to wavy. The wood dries with no degrading (warping, or cracking) if well stacked and dried under cover. However, deep surface cracks develop if wood is dried too rapidly. The low water content facilitates short drying periods. It has small movement in use and is a very durable wood that was historically used extensively as fence posts. Many of these old fence posts still stand today. It is extremely resistant to penetration with preservatives, but there is no need to use preservatives with this species. The wood is very hard, but not difficult to saw. Slightly defective centres may cause boards to split shortly after sawing. It planes to a lustrous, glassy, smooth finish and is good for wood turning. Pre-boring is essential prior to nailing to prevent splitting due to hardness. It takes a high gloss varnish, stains without difficulty and polishes well. It has a distinct odour and causes irritation to nose membranes when dry wood is processed, hence the name Sneezewood. The pungent essential oil in the wood causes irritation (sneezing) and makes the wood easily inflammable.

Figure 19. Sample of *Ptaeroxylon obliquum,* with unbleached Shellac finish (Photo: B. James).

Uses

This species is protected by the National Forests Act of 1998 and may not be harvested or sold without a license. Potential uses for *Ptaeroxylon obliquum* are heavy construction, industrial flooring, wagon bodies, furniture and cabinet work, tool handles, sports goods, agricultural implements, musical instruments, drawing tables and instruments, poles, carving, vats, toys and turnery (Figure 20). The Sneezewood tree has many uses in rural areas, not only as a source of general purpose timber and poles, but also in human and veterinary medicine. The wood has been used for railway sleepers, but is fine furniture wood and is an important source of hut poles. The irritant turpenoids in the wood make Sneezewood poles very durable and they last for many years (van Wyk & Gericke, 2000). Because of the oil, it burns even when wet and consequently also makes an excellent fire wood; and is often even used as a firelighter for wet wood (Venter and Venter, 2009). The Chopi people of Mozambique have a reputation for *timbila* (xylophone making) and Sneezewood is the most important timber for making the keys. In earlier times, the wooden keys were heated over coals in a pit, but these days they are baked in an oven, at high temperatures, for a few hours. On removal from the heat, the wood is almost flexible, but hardens with an almost metallic resonance. Due to its resistance to fungal attack, old Sneezewood fence posts can still be found and utilised for various products. The bark of *P. obliquum* is used as a snuff to relieve headaches and infusions of the bark are said to be useful against rheumatism and arthritis. The bark has numerous medicinal uses (http://databases.mrc.ac.za/Tramed3), while other uses include an effective insect repellent.

Figure 20. Carving of a Scottish Quaich (a traditional toasting vessel) made from *Ptaeroxylon obliquum* (Sneezewood) by Chris Morewood (Photo: Peter Upfold).

Potential for cultivation

Ptaeroxylon obliquum trees grow about 1 m per year under favourable conditions. Johnson & Johnson (2002) state that *P. obliquum* might prove to be a commercial timber proposition and that it has the finest wood of any indigenous tree and grows better than any rival species. In the past the species was utilised extensively, which led to a moratorium on the harvesting and sale of *P. obliquum* timber between 1995 and 2004. Volumes sold increased thereafter (27.91 m^3 was sold from five Eastern Cape forests during the period 2004-2006) but sales remain low (Cawe and Geldenhuys, 2007). Although it is definitely one of South Africa's finer woods, it all depends on what the wood is used for, as there are many species that have much more attractive figure, grain or colour. It depends upon application and personal taste, and there are alternatives. For example, a species such as *Vepris lanceolata* (White Ironwood) grows faster and also has a very attractive light-coloured wood.

5.3.3 *Podocarpus (Afrocarpus)* species (Yellowwood)

Tree description and distribution

Yellowwood trees (Figure 21) are synonymous with South Africa, and *Podocarpus latifolius* (Real Yellowwood) is the National tree. *Afrocarpus falcatus* (syn. *Podocarpus falcatus*) (Outeniqua Yellowwood, Afrikaans = "Kalander") and *Podocarpus latifolius* (Real Yellowwood, Afrikaans = "Opregte

Geelhoud") are found in the southern Cape, over much of KwaZulu-Natal and on the eastern Escarpment, wherever there are indigenous forests. They are large and majestic trees, the largest in the forests in which it grows, reaching heights of 30-50 m. Many of these trees (particularly the Outeniqua Yellowwoods) are known as the "Big Trees" of the Garden Route in the southern Cape and are great tourist attractions. The bark has a regular flaking pattern, which is a haven for lichens, such as the beard lichen (*Usnea* sp.). Because the canopy is so dense, the trees are often used as a roost and nest site by small birds. Parrots, louries (Turacos) and fruit bats eat the yellow berries (Johnson & Johnson, 2002). The name Kalander is derived from "Outeniqua Lander", after the Outeniqua Mountains in the southern Cape. The word "Outeniqua" means, "*the land where honey comes from*". *Podocarpus henkelii* is a localised endemic, being found only in the mist-belt forest in the west of KwaZulu-Natal. Ingele Forest is particularly well-known for *P. henkelii* (Johnson & Johnson, 2002). It is a medium sized tree, with a comparatively short trunk. *Podocarpus elongatus* (Breede River Yellowwood) is localised to the Western Cape.

Figure 21. *Afrocarpus falcatus* (Outeniqua Yellowwood) (left), *Podocarpus henkelii* (Henkel's Yellowwood) (centre) and *Podocarpus latifolius* (Real Yellowwood) (right). Photo's: M. Gush.

Wood description

Yellowwood trees generally have straight, well-formed boles, which results in a high timber recovery. The wood has a light yellow to caramel colour, with no differentiation between heartwood and sapwood in younger trees (Figure 22). The texture is fine and even and the grain is straight to spiral. Freshly worked wood is very light in colour (Figure 23), but darkens and gets richer over time. Kalander planes, and sands, to a fine finish and takes stains and polishes well. It also gives a high finish under a cabinet scraper and is good for wood turning. The straight grain does make it somewhat brittle and it must be drilled prior to screwing and nailing to avoid splitting. It is not durable outdoors and needs to be treated if used for that purpose. Although the wood is not durable, it is quite permeable to preservatives. The wood has a tendency for surface checking, particularly in thicknesses above 5 cm and it is particularly susceptible to blue staining fungi, which is aggravated by storage in damp or poorly ventilated conditions. The freshly cut wood should therefore be treated with a good “anti-blue” fungicide and be stacked and stickered properly to allow for good air flow to prevent this (Ferguson & Huisamen, n.d.). The wood of *P. henkelii* is fairly similar to *Afrocarpus falcatus* and *Podocarpus latifolius.* It is documented in a slightly different format by Alewyn Burger in a private publication (Burger & Kennard, 2005). He records that it works easily with hand and power tools, cuts and planes cleanly and can be carved and turned with relative ease. It takes screws and glue well, can be pleasant to work with, but can be brittle in joints. It smooths to a slight lustre and takes finishes well.

Figure 22. Standard untreated sample of *Podocarpus latifolius* (Photo: B. James).

Figure 23. Outeniqua Yellowwood turned bowl (turned by T. Matchette). Photo: B. James.

Uses

All Yellowwood species are protected by the National Forests Act of 1998 and may not be harvested or sold without a license. Potential uses of *Afrocarpus falcatus* are railway sleepers, wagon bodies, boat building, domestic flooring, interior trim, joinery, furniture and cabinet work, picture framing, panelling and jewellery boxes (Venter and Venter, 2009). Much antique furniture was made from timber from this species (Palgrave and Palgrave, 2002). Historically, the wood was used extensively as an all-purpose timber because of the absence of other softwoods, particularly for joints, beams and flooring in buildings and for boat building and railway sleepers. Towards the end of the 19th Century, vast quantities were treated with creosote and use as railway sleepers. Kalander and Yellowwood (*Podocarpus latifolius*) were used for wagon beds, side planks and the wagon chest (wakis). For the most part, Kalander wood has no appeal to overseas buyers because of its flat, bland appearance (Ferguson & Huisamen, n.d.). None of the indigenous tree books, or any books on medicinal plants, record any medicinal or cultural uses in any of the Yellowwoods. However, the bark has high tannin content (3-6%), and was therefore widely used for tanning leather before *Acacia mearnsii* was introduced to fulfil this need (the modern tanning industry uses artificially produced chemicals). *A. falcatus* has also been propagated as a windbreak for commercial orchards as it is adapted to South African conditions (uses less water, frost hardy), its tap-roots do not compete with those of the orchards and it provides a habitat for birds (e.g. eat fruits from the tree) (Gamtoos Nursery, 2010).

Availability and pricing

Afrocarpus falcatus used to be sold at the SANParks auctions. Between 1998 and 2008, it constituted 3.14 % of the total volume of indigenous species on offer, i.e. an average of 42.43 m^3 per year. The timber can also be obtained from Geo Parkes & Sons and Indigenous Timbers Ciskei. Timber dealers usually do not make a distinction between *A. falcatus* and *P. latifolius* (although the general impression is that *A. falcatus* yields a slightly superior timber to *P. latifolius*) selling them both as Yellowwood. In actual fact, according to S. Dyer of Timber Information Services (pers. comm.), it is almost impossible to tell the two apart macroscopically. Retail pricing varies from R7 500 m^{-3} for short planks to R20 000 m^{-3} for counter tops (i.e. large, wide and thick slabs). Pricing for *P. henkelii* is similar to the other Yellowwood species. Yellowwood counter tops that have been simply sanded and varnished sell for as much as R30 000 to R40 000 m^{-3} in places like Timber Village in Knysna. A small quantity of turning blanks were exported to the Netherlands in 2012 by Brousse-James & Associates, at a price of €3 000 m^{-3}. However, medium-sized furniture manufacturers such as Johnson Brothers in Howick prefer to use Cypress rather than yellowwood because it gives very much the same look, but Cypress costs half the price of Yellowwood and people are not prepared to pay the premium for Yellowwood. Cypress is also more stable and predictable.

Potential for cultivation

The rate of growth of *Afrocarpus falcatus* is fairly rapid, at about 80 cm per year in deep soil, but much slower in poorer soil (Johnson & Johnson, 2002). The Gamtoos Nursery (2010) suggests it can grow up to 60cm a year under ideal conditions, and up to one metre per year under fertigation. However, the rate of growth of *Podocarpus latifolius* is suggested as slow (Boon, 2010) and *Podocarpus henkelii* is only estimated to grow about 30-40 cm per year. *P. henkelli* likes high rainfall and does not do well in areas where the summer is hot (Johnson & Johnson, 2002). Given the slow growth rate, the possibility of planting *Podocarpus henkelii* commercially is questionable.

5.3.4 *Vachellia*[7] *(Acacia) karroo* (Sweet Thorn)

Tree description and distribution

Vachellia (Acacia) karroo (or the *V. karroo* complex) is the most common *Vachellia* (*Acacia*) species in South Africa and is widely distributed. *Vachellia karroo* was the name given to a complex of species that has only relatively recently been separated into different species[8]. Consequently, trees within the *V. karroo* complex vary from being a fairly short tree, branching low down inland, to a tall tree with a clean, straight trunk on the coast. There are now the following six species/varieties in the *V. karroo*-complex:

a. ***Vachellia dyeri*** – a shrub with many stems originating from the root, always shorter than 1 m, endemic to the grass-veld of Kei River Mouth area, north of East London.
b. ***Vachellia karroo*** – a tree, although branching very close to the ground. It has 2-3 (max. 5) pairs of pinnae.
c. ***Vachellia kosiensis*** – 10-17 m high (Figure 24), yellow powder-puff inflorescence hidden among the leaves; rachis and rachillas are finely

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[7] A retypification of African species of the genus Acacia into two distinct genera, namely Vachellia and Sengalia, was approved in 2011 (Boatwright *et al*. 2014; Dyer, 2014).

[8] *Vachellia kosiensis* recently separated from the *Vachellia karroo* complex (see: http://www.acacia-world.net/index.php/africa-me/south-africa/the-vachellia-karroo-complex). South African National Tree No. 172.2.

hairy, but leaflets are without hairs. Along KwaZulu-Natal coast, north of Tugela River to Mozambique.

d. ***Vachellia natalitia*** – a white-barked tree or shrub with short spines and 4-13 pinna pairs per leaf, mainly found in the Eastern Cape, KwaZulu-Natal, Swaziland, Mpumalanga, Zimbabwe and Mozambique.
e. ***Vachellia robbertsei*** – 6 or more pair of pinnae; all parts of the compound leaf are densely hairy.
f. ***Vachellia theronii*** – 4-6 m high, flowers and ripe pods together on tree.

Figure 24. *Vachellia kosiensis* (Dune Sweet Thorn) tree (Photo: M. Gush).

<u>Wood description</u>

Wood of the taller varieties (now separate species) is useable as timber. Some of the salvage wood (*V. kosiensis*) that comes off the Richards Bay Minerals mine path has been cut up for Railway Sleepers by Mr Louis Tiran in the last few years and a very small quantity was cut by Red Ivory Trading for wood turning blanks and sold locally. The heartwood colour is reported to be yellow/brown, but it can also be pink to reddish/brown (Figure 25) and the sapwood is yellow/white. The timber is tough and resilient, moderately durable, and with a coarse and even texture and wavy grain. It is moderately resistant to penetration by preservatives. The wood seasons well, apart from pith areas, which tend to form cracks, though this is a common feature of many woods. The wood is liable to twist if not properly stacked and can be attacked by wood borer. In processing the wood, it is prone to go mouldy if there is insufficient airflow. This seems to be a tendency with woods that have a high sugar content (it gives off sweet gum). In terms of workability, the wood saws cleanly and planes well to a fairly smooth finish, but it is hard and slow processing is recommended. Blunting of tools is slight to moderate. Pre-boring is necessary before nailing to avoid splitting, especially near edges. The wood glues well and takes a good varnish finish.

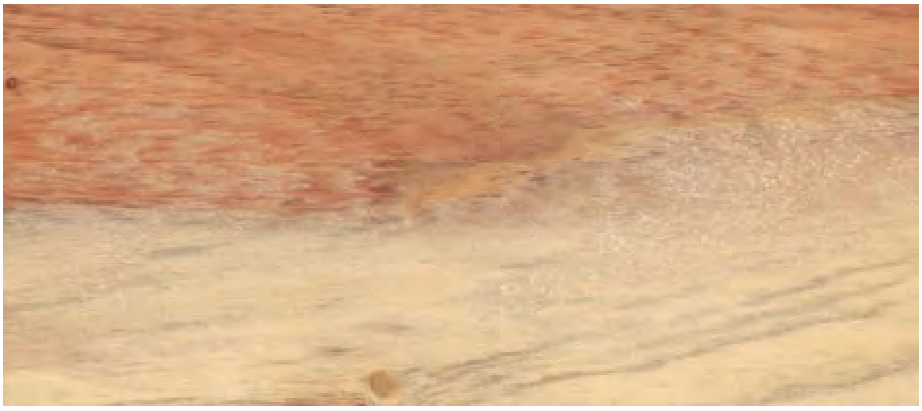

Figure 25. Standard untreated sample of *Vachellia kosiensis,* ex RBM mine path, showing the pink colouring of the heartwood (Photo: B. James).

Uses

Potential uses are agricultural implements, woodwool, interior trim, furniture and cabinet work, fuelwood and wagon making, although, as mentioned earlier, it is almost never available commercially. It has been used successfully for wood turning (Figure 26), but, not being readily available, is not well known. Many of the indigenous *Vachellia* species have similar uses, but wood from these are also almost never available commercially. Apart from minimal use for the wood, *V. karroo* is used extensively for firewood in many dry parts of southern Africa. It burns brightly, with calcium oxalate crystals that give its embers high temperatures and make them long lasting, with very little smoke and no odour (Matsika *et al.,* 2013). These clean burning traits, ideal for cooking and heating, make it excellent firewood wherever it grows and it is an excellent wood for charcoal production. The seeds of *V. karroo* are sometimes roasted as a coffee substitute and the bark is used for dying and tanning of leather. It is said to give the leather an acceptable colour, but an unpleasant smell (van Wyk & Gericke, 2000). The wood itself also has an unpleasant odour. Occasionally, the bark wounds exude a clear, pale yellow-brown gum, which has a slightly sweet taste and which is sought after by bushbabies (Galago). This gum has been marketed as Cape gum, and it has traditionally been used for various ailments, including haemorrhaging, mouth ulcers and oral thrush. In parts of South Africa (Namaqualand), the berries of *Rhus pendulina* are mixed with the gum to make a sticky sweet, with a taste similar to dates. In Botswana, the gum of *V. karroo* is sometimes applied to mouth ulcers and to treat oral thrush. Cape gum is similar to gum arabic and has, in the past, also been used in the pharmaceutical industry.

Figure 26. Turned bowl from *V. kosiensis*, showing the darker heartwood with a finish on it (Photo: B. James).

<u>Availability and pricing</u>

For the most part, the wood is really only used as firewood and is never available commercially. Most trees are far too small for any viable conversion into planks, except those from places like coastal forests. In terms of pricing of sawn timber, it would be reasonable to aim at around the same range as *Acacia melanoxylon* (Australian Blackwood), keeping in mind that different grades sell at different prices. Good quality, dark Australian Blackwood in thicker, longer pieces can sell for R10 000 m^{-3} and short or lighter coloured planks will sell at around R4 000-R5 000 m^{-3}. The average would be around R7 000 m^{-3}.

<u>Potential for cultivation</u>

In general, *Vachellia karroo* grows in any soil, in any climate, and grows about 1 m or more a year (Johnson & Johnson, 2002). If *V. karroo*, or any of the species in the complex are to be cultivated commercially, it would be important to have a clear end-use in mind and plant only seeds/seedlings that originate within the region in question. It is likely to be used more as a pioneer species (which it is) to stabilise disturbed or degraded areas, with the ultimate goal of either thinning it out or allowing later successional species to outcompete it. It could be grown in woodlots adjacent to rural communities, where its primary purpose would be to provide firewood.

5.3.5 *Ilex mitis* (Cape Holly)

<u>Tree description and distribution</u>

Ilex mitis (Figure 27) is a widespread species, extending all the way from the south-western Cape to the far north-east of South Africa. It is found in evergreen forests and nearly always next to streams. It is also found in Botswana, the mistbelt forests of Swaziland and throughout tropical Africa, as far as Ethiopia. It is a tall tree, with smooth, almost white bark, although old trees can become quite gnarled. The tree bears a heavy crop of small, red berries, which are eaten by birds (Johnson & Johnson, 2002).

Figure 27. *Ilex mitis* (Cape Holly) tree (left), foliage (right) and fruit (inset-right). Photos by Abu Shawka.

Wood description
The light (white/grey) wood makes good, durable furniture and, after many years of oiling, takes on a beautiful honey colour. There is no differentiation between heartwood and sapwood, but it starts off as a white to grey-green colour (Figure 28). The wood has a fine, even texture and is close-grained, fairly soft and light, with a low lustre. When quartersawn it exposes a silver grain effect, similar to Beech wood (*Fagus sylvatica*). It is particularly susceptible to staining fungi and insect attack and needs to be handled with care during all stages of conversion, avoiding dampness and treating it against fungi and insects (Ferguson & Huisamen, n.d.). Although the fungal stain does not produce attractive black streaks (spalting) like some other woods, sometimes the fungal stain and even the borer holes are used as a feature in the finished product. The fungal stain gives the wood a “distressed” appearance, which has recently gained popularity. The wood is also prone to warping, unless carefully seasoned, but, once it has dried, it is quite stable and works easily. The wood doesn’t have a distinct odour or any irritant properties. Green stock saws easily and blunting of tools is minimal. Planing produces an acceptable surface, but severe picking-up (“fluffy” look) may occur in certain stock. It peels easily for veneers and can be used for construction plywood. It nails satisfactorily, but stock thicker than 50 mm must be pre-bored. It glues well and takes a good paint or clear varnish finish.

Figure 28. Standard untreated sample of *Ilex mitis* (Photo: B. James).

Uses
Potential uses of *Ilex mitis* are domestic flooring, boat building, wagon bodies, furniture and cabinet work, veneer and plywood, pulp and paper, boxes and crates, interior trim, core stock, matches, hardboard and particle board, vats, toys and chopping blocks. Historically, it has been used for interior flooring, wagon floorboards, boxes, vats and toys. There are many medicinal uses for the bark, such as being chewed as a purgative. Because it bends well, it has been traditionally used for furniture (Figure 29) and boat building. Richard

Henley, a cabinet maker based in Knysna, makes laminated "bentwood" chairs out of *Ilex mitis* and Kluyts & Co in Knysna has made a range of children's bedroom furniture with the wood.

Figure 29. Range of children's bedroom furniture made out of *Ilex mitis,* on show at Kluyts & Co in Knysna (Photo: B. James).

Availability and Pricing

The tree is nowhere abundant and at the SANParks auctions, between 1998 and 2008, it constituted only 1.28 % of the total volume of indigenous species on offer, i.e. an average of 17.34 m^3 per year. Apart from small quantities that can also be obtained from Geo Parkes & Sons and Indigenous Timbers Ciskei, it is almost never available commercially from other sources. It is very seldom offered for sale by timber dealers, but is listed with Rare Woods at R7 000 m^{-3}. Owing to its scarcity, it is seldom used in large quantities, but some specialist furniture manufacturers "discovered" it and used to buy directly from the SANParks auctions. With it becoming more popular, and because of its rarity, the price should be closer to R12 000 m^{-3}. Based on knowledge of the wood turning market, turning blanks could be sold in Europe for €4 000 m^{-3} (R43 000 m^{-3}).

Potential for cultivation

The tree grows rapidly, about 80 cm per year (Johnson & Johnson, 2002).

5.3.6 Ocotea bullata (Black Stinkwood)

Tree description and distribution

Ocotea bullata occurs in most of the high forests in South Africa, from the protected kloofs of Table Mountain, to the slopes of the Drakensberg, but it is absent in the forests of the Amatola Mountains of the Eastern Cape and is under threat in KwaZulu-Natal. It is an evergreen tree, reaching heights of 25-30 m (Figure 30). The best specimens are found in the moist, wet and very wet high forest types in the southern Cape, where they are sparsely, but evenly, distributed. *Ocotea* is a sprouting species, with a long straight and cylindrical trunk, which buttresses at the base. The tree has a dense crown, which reaches into the forest canopy.

Figure 30. *Ocotea bullata* (Black Stinkwood) tree (left) and characteristic leaf bullae (right). Photo's: M. Gush.

Wood description

Black Stinkwood has even, straw-coloured sapwood, darkening to gold-brown and black in the heartwood (Figure 31). It has a fine and even texture and is naturally lustrous, with straight to spiral grain and interlocked fibre and is moderately hard and heavy. It saws easily, turns well, but because of the high silica content, is hard on tools. When planing, it is inclined to rough up in patches, but use of a cabinet scraper produces a good surface. It polishes well, to a fine lustre. It also has good glueing and nailing properties. The freshly cut wood gives off a musty/sweet pungent odour, thus the name Stinkwood. The wood is moderately durable and stable and is moderately resistant to penetration by preservatives. Today, it is extremely highly priced and is used for high class furniture and panelling, framery and joinery. In the past, it was important for wagon-making, being used for most parts of the wagon at one time or another. It was used extensively for door and window frames and, historically, shipyards preferred Stinkwood to most other available timbers because it works and weathers well. It was also used successfully as gun stocks. The wood becomes progressively darker by oxidation with age, until it eventually becomes a uniform dull colour, with almost total loss of its interesting and variable grain and figure. In thick slabs, the wood is susceptible to honey-combing if it is dried too rapidly.

Figure 31. Standard untreated sample of *Ocotea bullata*, showing the light and dark colouring of the wood (Photo: B. James).

Uses

This species is protected by the National Forests Act of 1998 and may not be harvested or sold without a license. Uses are listed in the CSIR wood properties database as light construction, domestic flooring, wagon bodies, furniture and cabinet work, tool handles, sports goods, agricultural implements, joinery, battery separators, toys and turnery (Figure 32). The bark of *Ocotea bullata* is an important traditional medicine, used mainly for headaches, urinary and nervous disorders and for treating diarrhoea in children.

Availability and pricing

Ocotea bullata used to be sold at SANParks auctions, and was usually the most expensive species sold there. Between 1998 and 2008, it constituted 10.87 % of the total volume of indigenous species on offer, i.e. an average of 146.84 m^3 per year. Small quantities were also available from Geo Parkes & Sons. Dark black Stinkwood is difficult to obtain and most logs yield a straw-coloured wood, which darkens with age. The retail price ranges between R8 000 m^{-3} for the lighter wood, to R25 000 m^{-3} for darker wood. Turning blanks have been sold by Red Ivory Trading to the USA in 2008 for US$4 500 m^{-3} (R37 000 m^{-3}) and by Brousse-James & Associates in 2012 for €4 000 m^{-3} (R43 000 m^{-3}).

Figure 32. Traditional Yellowwood/Black Stinkwood table and chairs at Kluyts & Co in Knysna, and a turned Stinkwood bowl, showing the light and dark colouring (Photo's: B. James).

<u>Potential for cultivation</u>

Growth of *Ocotea bullata* is relatively fast, about 60 cm per year. The tendency to sprout or coppice is important when considering issues of harvesting of the tree, particularly with regard to bark harvesting. In many areas, *O. bullata* bark is harvested illegally, particularly in KwaZulu-Natal, and the trees are frequently ring-barked, resulting in the eventual death of the tree. There is also very little recruitment of young trees in areas where it is being heavily utilised. The decline of the species in KwaZulu-Natal is partly attributed to the change in diet by the African Olive Pigeon, whose diet is now dominated by the invasive *Solanum mauritianum* (Bugweed) (Boon, 2010). The irony is that when logs of *O. bullata* are sold on auction in the southern Cape, the bark is invariably discarded after milling. If a careful harvesting process were to be instituted in areas where the bark is most heavily utilised, certain trees could be targeted for felling, the wood could be utilised, all of the bark could be used and the tree would coppice naturally instead of dying due to the stress of being ring-barked.

5.3.7 *Prunus africana* (Red Stinkwood)

<u>Tree description and distribution</u>

Prunus africana (Figure 32) occurs naturally in the Eastern Cape, the temperate parts of KwaZulu-Natal and the eastern Escarpment. It is confined to evergreen forest and is locally common in the mist-belt (Johnson & Johnson, 2002). *Prunus africana* is a tall tree, with a spreading crown when mature. The fruits are fleshy and very popular with birds, especially the Rameron Pigeon and the Knysna Loerie (Turaco) (Johnson & Johnson, 2002).

Figure 33. *Prunus africana* (Red Stinkwood) tree and bark (main photo: M. Gush, inset photo: D. Johnson).

<u>Wood description</u>

The wood is reddish/brown (Figure 34) with a fine and even texture has a straight to interlocked grain. It is hard-wearing, durable and resists abrasion. The wood is also resistant to penetration with preservatives. It dries slowly and is difficult to season without splitting and warping. Degradation may be lessened by careful stacking and seasoning under cover. It saws exceptionally well and planes well by hand to a lustrous, smooth finish, but the grain picks up (becomes rough) on machine planing. It turns easily and finishes beautifully. It glues well, takes a high polish and stains easily. Pre-boring is necessary before nailing to prevent splitting near edges. The wood doesn't have a distinct odour or any irritant properties.

Figure 34. Standard untreated sample of *Prunus Africana* (Photo: B. James).

Uses

This species is protected by the National Forests Act of 1998 and may not be harvested or sold without a license. Potential uses of *Prunus africana* are wagon bodies, bridges, heavy construction, furniture and cabinet work, veneers, plywood and turnery (Figure 35). In December 2011, a dying tree became available on a farm in the Dargle, near Howick (KwaZulu-Natal). Since it is a protected species, a permit was obtained to harvest it and to sell the wood and bark. The wood proved to be easy to turn, but has a tendency to warp and twist whilst drying. Since many woodturners prefer to turn wet wood, this resulted in distorted items. Nevertheless, reports are that it was worth working with. Attempts made to sell the bark of this tree to local inyangas have proved unsuccessful.

Figure 35. Red Stinkwood bowl (turned by T Matchette). Photo: B. James.

Availability and pricing

Prunus africana was never available on SANParks auctions and is not available commercially in South Africa. Occasionally, a tree is harvested after it dies naturally or is cleared for some or other development. The bark was previously harvested extensively in other parts of tropical Africa, particularly Cameroon, for export to Europe, America and Japan for the manufacture of medicine to treat prostatic hypertrophy. Figures given by Cunningham *et al*. (1997) show that about 3 200 to 4 900 tons of this bark is used every year, at an estimated retail value of about $220 000 000. The species is currently listed in Appendix II of CITES indicating that trade is strictly regulated and export permits are required. A small quantity of turning blanks was exported to the Netherlands in 2012 by Brousse-James & Associates, at a price of €4 000 m^3.

Potential for cultivation

Growth of *Prunus africana* is about 1 m per year under favourable conditions. It thrives in a cool climate, provided that the frost is not severe. It does not do well in heat and survives only an average winter drought (Johnson & Johnson, 2002).

5.3.8 *Rapanea melanophloeos* (Cape Beech)

Tree description and distribution

Rapanea melanophloeos (Figure 35) occurs naturally in the wetter parts of South Africa, ranging from the South-western Cape to the eastern Escarpment. It is common in evergreen forests, from lowland swamps to high mountain kloofs (Johnson & Johnson, 2002).

Figure 36. *Rapanea melanophloeos* (Cape Beech) trees, with bark (inset, top-left) and seedling (inset, bottom-right). Photo's: M. Gush and D. Dyer.

<u>Wood</u>

The wood is almost white when freshly sawn and darkens on exposure to a dull pinkish-brown colour (Figure 37). It has a short reticulated grain and is fairly hard, heavy and elastic, but strong and moderately durable. The wood saws easily and cleanly to true edges and planes well to a smooth finish, but needs to be scraped for the best finish. It is an easy and attractive wood for turning. It nails well at extreme ends if gauge 13 nails are used, otherwise pre-boring for large nails is necessary. It glues well and also stains, polishes and varnishes well. Because of uneven shrinkage with surface checking, if kiln-dried, it requires a mild drying schedule (20 days per 25 mm). When drying, the wood may split and cup unless stacked carefully and dried slowly under cover. Uneven shrinkage in boards may result in a bump in the centre portions. Tangentially sawn boards are apt to check if dried too rapidly and the wood is at its best, both in terms of movement (stability in use) and in terms of attractiveness when it is quartersawn. Spalting (streaking caused by mould) is quite common and this can be used to great advantage in turned items (Figure 38). As with many species that spalt spectacularly, borer can be a big problem if the bark is left on logs and the logs are not sawn before the borer can get to work. Although the wood is susceptible to borer and mould, it is permeable to preservatives. The wood doesn't have a distinct odour or any irritant properties.

Figure 37. Red Standard untreated sample of *Rapanea melanophloeos* (Photo: B. James).

Figure 38. *Rapanea melanophloeos* turned bowl (spalted) (by B Howells). Photo: B. James.

<u>Uses</u>

Potential uses include light and heavy construction, domestic flooring, furniture and cabinet work, agricultural instruments, veneer and plywood, interior trim, joinery, carving, toys, turnery, pattern making, musical instruments and shoe heels. The wood has been used for furniture and violin making, but also successfully recently for wood turning. Medicinally, the bark is used for respiratory, stomach and heart complaints and also as *intelezi*, a charm to ward off evil.

Availability and pricing

Rapanea melanophloeas was sold at SANParks auctions, but, between 1998 and 2008, it only constituted 2.63 % of the total volume of indigenous species on offer, i.e. an average of 35.48 m^3 of logs per year. Apart from small quantities that can be obtained from Geo Parkes & Sons and Indigenous Timbers Ciskei, it is almost never available commercially from other sources. Retail prices for timber range from R7 000 m^{-3} (Rare Woods) to R8 000 m^{-3} (Woodmans). Turning blanks have been exported by Red Ivory Trading to the USA in 2008 for $3 000 m^{-3} (R25 000 m^{-3}) and to Germany in 2009 for €4 000 m^{-3} (R43 000 m^{-3}).

Potential for cultivation

The rate of growth is moderate – about 50cm per year and it grows best where rainfall is high and summers are temperate to warm. (Johnson & Johnson, 2002).

5.4 Methods

5.4.1 Financial analysis

Some previous studies have focused on the present value of the net returns to a Yellowwood plantation production system expressed per unit of water used. However, all of the input values were sourced by means of the benefit transfer method with the total production cost structure of Yellowwood remaining unknown. This project presents the production cost side of Yellowwood in a monoculture model with a 45 year rotation period. This decision was made since it was argued that an assessment from the output side alone presents a skewed picture of the financial viability of the system. The time period for the analysis was determined through identifying the dominant commercial forestry use of the study area and restricting the analysis period to one rotation – in this study this period has been defined as 45 years, which corresponds to one rotation period required for Yellowwood (and approximately two for pines) to reach maturity and hence allows comparability with pines.

The financial analysis was done according to standard crop enterprise budget protocol (Boehlje and Eidman, 1984, Cramer and Jensen, 1994) in order to facilitate comparison with commercial tree species and other crops. Such protocol consists of a systematic account of the production cost over the crop rotation cycle, which implied a model accounting for a 45 years. The protocol required some assumptions regarding the production technique, and the impact of inflation. Production techniques were assumed to remain constant (i.e. the same) for 45 years, while the impact of inflation was accounted for by means of a sensitivity analysis.

The analysis focused on the private costs and benefits of individuals considering an investment in establishing and managing Yellowwoods as a monoculture plantation. Establishment, management, maintenance and harvesting costs of a plantation over a rotation period, and the expected income to be realised from the sale of timber, were obtained from personal communication with various experts operating in, or with extensive knowledge of, growing Yellowwood in the various areas. This allowed for the comparison with introduced species (such as pine) in a tree rotation model for the same areas. The model has been constructed to allow easy adjustment of the crop rotation cycle (i.e. growth rate) to account for differences in growth rates between areas.

The production cost model is followed with a short discussion on the market conditions for indigenous wood, a detailed discussion on the SANParks auction system and a detailed discussion on the market for Yellowwood specifically. The financial analysis is concluded with a discussion on factors affecting the recovery, pricing and overall profitability of indigenous wood (including yellowwood).

5.4.2 Economic analysis

The economic analysis differs from the financial analysis in that the latter is restricted to the private costs and benefits of individuals undertaking the investment to establish and manage the plantation, and it is assumed that property rights are assigned to the forest or plantation. Whereas the financial analysis considered establishment, management, maintenance and harvesting costs of a plantation over a period of time, and the income to be realised from the sale of timber/other products from the plantation by the individual or company to whom it belongs, the economic analysis, however, is not restricted to property rights and looks broader to include costs and benefits of a forest or plantation (e.g. benefit of clean water from forests to downstream users) for private landowners as well as society. The case-specificity of socio-economic contexts in the assessment effectively ruled out the use of benefit transfer as valuation method, and along with it the use of secondary data from alternative study sites. Consequently, the economic analysis was more explorative in nature and the focus was on gathering information on the direct use value of the selected species.

5.5 Results

5.5.1 Yellowwood plantation financial analysis

It should be noted that this assessment was area- and species-specific, which implies that the values are representative of the sites, and that the results can only be generalised to similar contexts. We first present the production cost model developed for Yellowwood in plantation rotations in South Africa, after which the market for indigenous wood, the SANParks auction system and the market for Yellowwood specifically is discussed. Lastly, we present some factors affecting recovery, pricing and profitability of wood.

Production cost model

This section provides some financial information on the use of *Podocarpus/Afrocarpus* species (Yellowwood) for the indigenous tree timber market. The information can be used to assess the suitability of the species for plantation tree production systems. The case study area was the Karkloof area in the KwaZulu-Natal province and consists of a same-age Yellowwood stand owned by the Mondi Group, in an area dominated by an affluent commercial forestry and agricultural sector. The stand is estimated to be approximately 28 years old (planted in 1983), with the objective of establishing a plantation of valuable indigenous timber, similar to the yellowwood plantations in Tzaneen (owned by KLF and Hans Merensky). There is no long term historical growth data on the Yellowwood at the Karkloof site itself, and it was consequently decided to use production cost data of the Merensky plantation (as mentioned above) as a substitute for the Karkloof site (while the value of physical products derived from trees is highly site-specific, production costs for similar types of plantations are more likely to be similar) (referred to in the model as “grower A”, Hollenstein, 2011). This production cost data was verified with field trail data obtained from Stellenbosch University (referred to in the model as “grower B”, De Wet, 2011).

The Karkloof yellowwood plantation is planted at a density of 1111 stems ha^{-1}, and the field data revealed an average tree volume of 0.097 m^3 $tree^{-1}$ (with a DBH = 203 mm), which works out to a plantation volume of approximately 108 m^3 ha^{-1}. This is very similar to the 0.091 m^3 $tree^{-1}$ (DBH = 153 mm) and 101 m^3 ha^{-1} for the 24yr-old trees at Tzaneen owned by Merensky. Production cost data was obtained from key individuals on the basis of which a generic production cost budget was constructed for Yellowwood in monoculture forestry rotations. The data was obtained from various growers (Hollenstein, 2011, Maree, 2011, De Wet, 2011), each with slight differences in cultivation practice and rotation cycle.

A crop enterprise budget was developed, based on 2011 prices (see Table 9 for input costs). The model was based on the same functionality as a standard cash crop model (for example carrots) and focused on creating a perpetual supply of produce. The only difference was in terms of rotation cycle, i.e. 45 years for the Yellowwoods instead of 90 days for carrots. The reason for this choice of model, rather than a standard multi-period budget for perennial crops (as used for example in deciduous fruit or vine cultivation), was that the entire tree is harvested (destroyed) after 45 years, with little or no income derived from the trees before that time. It therefore presents some of the distinguishing characteristics of field crops and stands in contrast to deciduous fruit or vines, where the initial growth period is four to seven years, followed by an annual harvest from the same plant. The cash-flow related risk of the latter type of enterprise is consequently much lower as compared to the case of indigenous trees, where no income is generated over a 45 year period for a particular stand of trees.

It was consequently decided to design the model according to a systematic establishment program to maximise the cash flow of the enterprise after the first production cycle (i.e. 45 years). The model was thus based on annual establishments (the model was calibrated to one hectare, so that it could be multiplied to any number of hectares) for the duration of the first rotation cycle, which then switches to annual harvest coupled with annual re-establishment. This implies that the grower will establish one hectare on an annual basis and for the duration of the rotation cycle (i.e. 45 years) before the first harvest is ready, but from there onwards, annual harvest and re-establishment will run in parallel. The production model will thus take a time equal to the rotation cycle to come into full production. In practice, this implies that if it is assumed that the smallest logical unit of production in forestry is indeed one hectare, it would take a producer 45 years to establish a 45 hectare plot, after which the producer will derive an annual income from 1 hectare from year 45 onwards. Table 9 summarises the inputs of the production cost model for a full production rotation cycle. Input data for the model (all in 2011 current prices)

Table 9. Input values used in the model (R ha^{-1} at 2011 prices) (variances due to different sources, i.e. Hollenstein, 2011 and De Wet, 2011)

Activity	Sub-activity	Prices and units
Site preparation and establishment	Spray and slash	Roundup or similar @ 4-6 L ha^{-1} at R250 L^{-1}
	Labour	4.9-5.5 man-days @ R122 man-day^{-1}
	Pitting	3-5.1 man-days @ R122 man-day^{-1}
	Labour for planting	400 trees man-day^{-1} @ R122 man-day^{-1}
	Trees	R4-R13 tree^{-1} @ 4-5 metre spacing = 400-625 stems ha^{-1}
	Fertiliser	50-100g NPK fertiliser tree^{-1} @ R325 per 50 kg bag (R117-R406 ha^{-1})
	Labour to fertilise	1 man-day @ R122 man-day^{-1}
Blanking	@ 3%-15% of establishment cost	R214-R667 ha^{-1}
Weed control		3-5 applications @ 3 L ha^{-1} + 2 man-days ha^{-1} application^{-1} (R1022-R1430 ha^{-1})
Pruning		2-3 follow-ups @ 2 man-day ha^{-1} (R244-R520 ha^{-1} follow-up^{-1})
Overheads		R10-R100 ha^{-1} yr^{-1}
Fire belt		R20-R1200 ha^{-1} yr^{-1} depending on the width and maintenance sequence.
Harvest cost		R14000-R90000 ha^{-1} depending on the terrain and harvesting process
Usable height after 45 years (metre)		20
DBH (metre)		0.4
harvestable yield in m^3 tree^{-1}		0.84
harvestable yield in m^3 ha^{-1}		335-523
average log length (metre)		4.5
number logs per tree		4
number of logs per ha		1778-2778
average log price		R1 450
average price per cube		R1 730.11
value per tree		R6 444

The above data was fed into the production cost model in order to obtain an annual production cost of between R122639 and R143914 (current prices) per hectare and the value of the harvestable yield being estimated between R2.5m and R4.1m per hectare. The model is scalable to the number of hectares in question. At first glance the profitability of the model seems impressive, however it should be mentioned that the production costs are the cumulative costs of a hectare of Yellowwoods over its production cycle, at current prices, i.e. the figure is only valid for a grower **who has been in production for the past 45 years** (i.e. who is already in full production with 45 one hectare plots of Yellowwood) and whose production model dictates that he establish one hectare of Yellowwoods each year in order to ensure a continuous annual harvest from year 45 onwards. The above-mentioned figure is thus only valid for a model which is already in full production. This has a major impact on the cash flow, and hence viability of the production system. One cannot therefore make an ex-ante call with regard to the viability of the model without accounting for inflationary impacts since last mentioned impacts are significant in the development phase of the model (i.e. the first 45 years) because of the long rotation cycle. Fortunately, it is easier to account for inflationary effects on the cost side (because the production process is known and one can confidently inflate using the producer price index) as compared to the income side of the equation (the market price for Yellowwoods 45 years from now is totally unknown) and it cannot even be guaranteed that a demand for the species will exists 45 years from now. When considering inflationary impacts from the cost side, it is possible to derive a minimum log market price to break even after 45 years, assuming the current yield estimate. If, for example inflationary impacts are accounted for, the accumulated cost to allow the establishment of one hectare plots of Yellowwoods on an annual basis for 45 years before harvesting the first hectare in year 46, is between R9 (Hollenstein) and R35million (de Wet). This implies a break even log price between R3286 and R20177 per log (assuming 4 logs per tree) in year 45. Whether these prices will be met is debatable. The associated present value of the direct cost stream ranges between R600k and R2.1m per hectare over the 45 year production cycle (the long term average PPI of 9.11% was used to deflate) and presents the required financial capital outlay required to account for above mentioned annual production cost.

What is worrisome however is the model’s extreme sensitivity to log prices, which is major unknown given the long rotation period. The model shows that a minimum annual log price increase of 5% is required to keep growers in business when the cost structure is inflated against the long term average producer price inflation of 9.11%. This means that the average annual price increase for logs should be 5% or higher to keep growers in business. It is understood that any grower will have a negative cash flow for 44 years until the first harvest is realised. However, from year 45 onwards the cost structure and market price of logs will have a determinative impact on the business. For example, if the average annual market price increase for logs is 4% and below, the cash flow of grower A will increase for only 4 years after year 44 (i.e. until year 48), where after the cash flow will start decreasing and become negative from year 68 onwards. This means that grower A will be out of business in year 68, *ceteres paribus*. Grower B is slightly better off, and will experience increasing cash flows for 15 years after first harvest (i.e. until year 60), after which cash flows will also decrease and eventually become negative from year 76 onwards if the annual market price for logs is 4% or lower. The cashflows remain positive for annual log price increases of 5% and higher, both growers thus requires average annual price increases for logs of 5% or higher to stay in business. [9]

Although the potential profits seems convincing, the extremely long production cycle is a formidable entry barrier and given that the actual window of uncertainty is 90 years (since a producer will need another 45 years after first harvest to complete his exit strategy), it should be clear that a period of 90 years is simply too long for any kind of risk assessment for an individual. It should thus be clear that the main reason for people being hesitant to invest in rotation production systems with indigenous trees is because of the long rotation cycle and consequent long turnaround time of capital, i.e. from the time the investment is made until the return on investment is realised). This implies that the enterprise become inter-generational, which means that the first generation will not reap any benefit from their efforts. Given that the cost structure is certain, this proposition is simply too risky for the private decision maker in order to make financial sense, i.e. no financial entity can sustain a negative cash flow for 45 years on a hectare basis before an income is generated. Until yellowwood has shorter rotation cycles it will remain an unfavourable proposition from a financial perspective, i.e. a motivation for the cultivation of growing Yellowwoods in a rotation model cannot really be justified on financial grounds alone.

Furthermore, it should be noted that since most of the bigger wood suppliers have yellowwood in stock (all report that sales of yellowwood are extremely slow) and that current supply of yellowwood from SANParks, GeoParkes and Sons, and Indigenous Timbers Ciskei exceeds the national demand for the

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[9] Due to the long rotations and phased planting plan simulated in the Production Cost Model it is not possible to represent it in a table. The full spreadsheet-based model is available from the CSIR.

species. It therefore does not seem that the demand for the species is set for radical growth in the near future. This, along with a rather low price ranging from R12 000-R18 000 m^{-3} (i.e. value added wood) predict nothing good for the future growth potential of the Yellowwood market.

It is interesting to note that yellowwood logs have the same processing costs as plantation-grown pine and while it is probably more attractive than pine for shelving and laminated beams, the willingness of consumers to pay a premium for the "sentimental value" of Yellowwood is uncertain/unlikely. Consequently, it would probably only catch on in the market if the price were to be brought down considerably, i.e. in line with pine, which is only likely to be realised if substantial tree improvement has taken place to increase growth rates.

Markets for indigenous wood

The bulk of South Africa's indigenous wood harvested for the timber market originates in the indigenous forests of the southern Cape. Here, thirteen tree species, including Olea capensis subsp macrocarpa, P. latifolius, A. falcatus, Ocotea bullata and Olinia ventosa make up 96 percent of the canopy stem numbers greater than 30 cm diameter at breast height and to date, this has also been the most regular supply. Trees are harvested in a sustainable manner, based on the senility criteria yield regulation system, which is also sometimes referred to as the maturity condition. This system is based on the selective harvesting of canopy trees whose productivity is in decline, while non-senile trees are preserved for future growth. Species-specific criteria, including information related to ingrowth, increment and mortality in relation to their natural rate of mortality were also developed to guide the sustainable harvesting of trees (Seydack and Vermeulen, 2004).

The supply of indigenous wood is thus a function of sustainable harvesting criteria which is based on science and control over harvesting operations, and is not directly related to market demands. Although the southern Cape forest species, especially *Ocotea bullata*, *P. latifolius* and *A. falcatus*, were over-exploited in the past, current evidence shows that the timber yield regulation systems which were put in place from 1967-1971 and after 1984 has resulted in these species presently being in a high ingrowth and low mortality phase. These species (*P. latifolius* (Real Yellowwood), *Ocotea bullata* (Black Stinkwood), *Olinia ventosa* (Hard Pear) and *Platylophus trifoliatus* (Wit Els)) are harvested to their full sustainable yield due to the strong demand for their wood (Seydack and Vermeulen, 2004), whilst others such as *Apodytes dimidiata* (White Pear) are not harvested anywhere near the availability because of the lack of demand. There are a number of species like *Apodytes* *dimidiata* that are under-utilised because of a lack of appreciation for their qualities (both attractiveness and workability).

In South Africa furniture and other products made from indigenous wood appeal to the 'niche' market, where the sustainability of the harvesting process of forests in the southern Cape is used as a marketing strategy by the industry. Furniture manufacturers of the southern Cape have built their entire businesses around a handful of species originating from the forests there and these are the species that are harvested to their full capacity and fetch the highest prices on auctions. A few specialist cabinet makers in South Africa, both professional and amateur, utilise a very small volume of a much wider range of species.

There is also a thriving market for wood turning blanks (blocks of wood cut to various dimensions), knife scales (blanks for knife handles), pen turning blanks, blanks for woodwind instruments such as clarinets, oboes and bagpipes and parts for string instruments such as guitars, as well as other instruments such as marimbas and xylophones. Interestingly there are two prominent timber dealers who live and trade in the USA who are South African and who deal in dimensioned pieces of wood as described above, namely Cormark International and the Exotic wood group (see www.cormarkint.com/and www.exoticwoodgroup.com for more information). Both mostly focus on a few species, namely *Spirostachys africana* (Tambotie), *Berchemia zeyheri* (Red Ivory – marketed as Pink Ivory), *Dalbergia melanoxylon* (African Blackwood) and *Olea europaea* subsp. *africana* (Wild Olive). It should be noted that neither of them sells any of the Yellowwood species because in the eyes of the USA wood users, there is nothing special or distinctive about Yellowwood. Another prominent South African based company which exports most of its stock is Pro-Sono (www.prosono.co.za), which is owned by a Swiss National. It specialises in only seven southern Africa species and sells very high quality turning blanks and wood for musical instruments. Four of these species are obtained in South Africa, namely *Colophospermum mopane* (Mopane), *Berchemia zeyheri* (Red Ivory – marketed as Pink Ivory), *Spirostachys africana* (Tambotie – marketed as Sandalwood) and *Olea europaea* subsp. *africana* (Wild Olive). The others are obtained mostly from Mozambique and Madagascar, namely *Dalbergia melanoxylon* (African Blackwood), *Diospyros gracilipes* (Madagascar Ebony) and *Dalbergia graveana* (Pallisandra).

It is important to note that these dealers focus on a small number of South African species and are very slow to release new species onto the market, which is one reason why they are successful. Substantial logistical and cash-flow problems could arise when a wide variety of species are offered. It should also be noted that the volumes being traded are extremely small due to the type of market these companies serves.

The SANParks auction system

In the past, South African National Parks (SANParks) was responsible for the complete harvesting operation associated with indigenous trees (and some introduced species) in the southern Cape forests. SANParks was in charge of the supply chain from identification and marking of trees to be harvested (according to the senility criteria) and the felling and transportation of logs, to the selling of the harvested timber at auctions. These auctions were held two to three times per year, depending on the volume of timber harvested. Approximately 29 indigenous species were harvested from time to time, but volumes sold per year fluctuated widely, because of the sustainable harvest criteria applied. A reserve price for logs from each species on auction was in place, which only really covered harvesting/operational costs, with no overhead, repair and management staff costs included (Whitcher, 2008). This meant that the reserve prices were not based on the full cost recovery of harvesting operations by SANParks and were in most probability very low. The reserve price typically included the cost for machines hired from the Department of Water Affairs at minimal cost (although due to the age of these machines productivity was low). Transport costs were very high as vehicles were rented and the terrain was varied. The factors which influenced harvesting costs were: volume harvested per hectare (biggest but most variable cost), terrain, availability and outlay of slip-paths which influenced turnaround times, and the species marked (if large crowned trees needed to be harvested more time would be spent topping branches and cutting their trunks into manageable sizes). An illustration of the wide fluctuations associated with harvesting costs due to accessibility is provided in the following example: in 2004/05 an *Afrocarpus falcatus* (Outeniqua Yellowwood) tree growing at the side of the road and which was struck by lightning was harvested at a cost of R127 m^{-3} (as the lightning exterminated its crown). The harvesting cost of a similar sized tree within the forest cost approximately R1000 m^{-3} to extract and transport to a depot, due to increased time spent on topping the tree and transporting it out to the road from its relatively inaccessible location (Whitcher, 2008).

Between 15 and 40 interested parties from around South Africa usually took part in the timber auctions from the southern Cape indigenous forests. While most were furniture makers, some timber merchants also took part and sometimes bought most of the wood to distribute it throughout the country to hobbyists and small furniture makers. The bidding procedure reflected bidders' willingness to pay and was therefore seen as a good indication of market prices. At the same time the auctioning system was seen as free, fair and transparent (Botha, 2010). It must be noted that no large furniture manufacturers utilised indigenous wood as they needed guarantees of consistent supply, both in terms of volume and quality of selected species.

Apart from the indigenous species, SANParks also sold reasonably large volumes of logs from introduced species at its auctions on a regular basis. *Acacia melanoxylon* was first planted in the southern Cape in 1909 and from the mid-1960s the volume of this species harvested from plantations and indigenous forests surpassed the volume of indigenous wood sold on the auctions and ranged between 66 percent and 150 percent of the total indigenous timber volumes sold (Seydack and Vermeulen, 2004). Figure 39 depicts the timber volumes of the five most prominent indigenous species as well as the introduced *Acacia melanoxylon* (Australian blackwood) harvested and auctioned from 1998-2009. It is clear that the volume of timber sold per species per year varied widely, due to the senility criteria used to harvest trees. The supply of timber from indigenous species is therefore the result of sustainability criteria and not the demand for it.

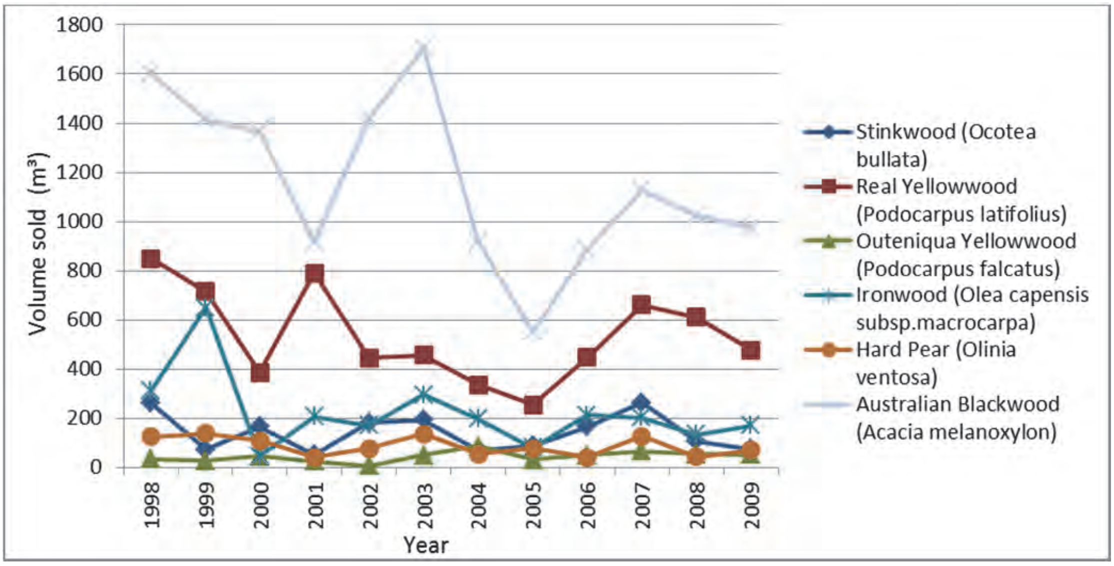

Figure 39. Timber volumes (m^3) sold of five most prominent indigenous species and *Acacia melanoxylon* at SANParks auctions: 1998-2009. Source: (du Plessis, 2010b).

The average nominal and real timber prices (R m^{-3}) received by SANParks for the five most prominent indigenous timber species and for the introduced *Acacia melanoxylon* are provided (Table 10). Real (also called constant) prices reflect the average timber prices when the effect of inflation (in this case the Producer Price Inflation (PPI)) has been accounted for, i.e. when the effect of price increases have been taken out.

Table 10. Average nominal and real prices (R m^{-3}) received by SANParks for the five prominent indigenous timber species and *Acacia melanoxylon*: 2008-2010.

Species	Average nominal prices (R m^{-3})			Average real prices (R m^{-3})		
	Year			Year		
	2008	2009	2010*	2008	2009	2010*
Stinkwood (Ocotea bullata)	1707	1942	3055	944	1075	1596
Real Yellowwood (*Podocarpus latifolius*)	1057	1318	2112	584	729	1103
Outeniqua Yellowwood (*Afrocarpus falcatus)*	1177	1040	1690	651	576	883
Ironwood (*Olea capensis subsp.macrocarpa)*	1219	1556	1260	674	861	658
Hard Pear *(Olinia ventosa)*	1968	570	2230	1088	315	1165
Australian Blackwood (*Acacia melanoxylon*)	1198	714	1513	663	395	791

* These prices only reflect those received at the May 2010 auction, while the others are averages from all auctions held within the respective year. Source: (du Plessis, 2010a) and own calculations.

A graphic summary of average nominal prices received (R m^{-3}) between 2008 and 2010, for the six most prominent species, is provided (Figure 40). The prices received for timber sold per annum does not vary as much as the volumes sold. While most of the timber volume bought on auction was from *Acacia melanoxylon*, it had the lowest price per cubic metre. The graph also indicates that the prices of most species increased during this period. Price movements can also sometimes be the result of these factors working together and the specific structure of the market, which might only become evident if studied in greater detail. The price fluctuations experienced in the price of *Olinia ventosa* (Hard Pear) timber between 2008 and 2010 provides an interesting example in this regard. A company who specialised in *Olinia ventosa* wood products used to buy up most of this species, which resulted in an artificially high price. Other buyers were not interested in buying small lots of this species for timber (leftovers), and as a result this species did not form a substantial part of their production lines anymore. These buyers would only bid for *Olinia ventosa* timber if they had a special order from a client or if the timber auctioned was of exceptional quality and size for cutting of large slab. When the company specialising in *Olinia ventosa* discontinued production, and other buyers were not interested in buying the timber, *Olinia ventosa's* price declined by 71 percent in 2009 (from average prices received in 2008).

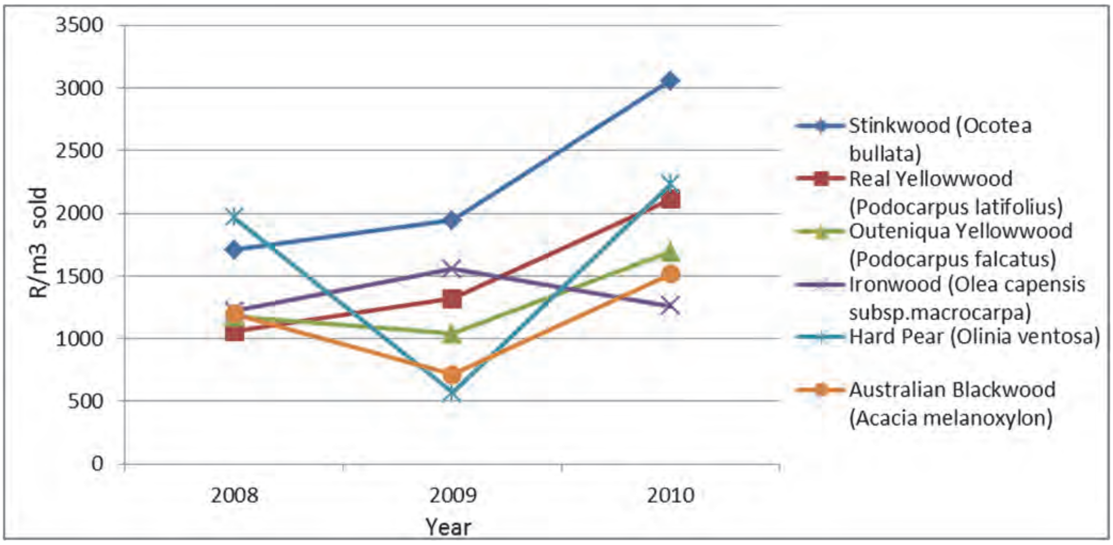

Figure 40. Average nominal prices received for timber from prominent indigenous timber and *Acacia melanoxylon* species sold (R m^{-3}) by SANParks: 2008-2010. Source: (du Plessis, 2010a).

During the same year two buyers at a SANParks auction had special interest in two particularly large logs of *Olinia ventosa*, which were available and evidently had the potential to yield highly figured wood. This timber was bought for R4000 m^{-3}, even though the average price for 2009 was R570 m^{-3}. This not only displays the extremely small size of the market (since a single buyer can have a disproportionate influence on the price of timber auctioned), but also that underlying market forces and timber issues (e.g. quality and availability) need to be identified and understood in order to reach the correct conclusions. This is one of the major concerns with implementation of a tender/concession system (Heyl, 1999), because bidding has previously been done on the basis of the perceived value of individual logs by buyers. With a tender system what buyers get in terms of quality and size will largely be the luck of the draw, which will make buying timber a risky venture for the buyers.

The traditional auctioning system was terminated in May 2010 when the auctioning was outsourced to KwaKhanyisa Co-operative. However, since even before then, the auctioning of indigenous timber from the southern Cape/Tsitsikamma forests was in decline. This was across the board, not only in terms of SANParks sales by also experienced by other suppliers (e.g. GeoParks). Stehle (2013) provides a number of reasons for this. Firstly institutional changes had a major impact, particularly the handover of 40 000 ha of the southern Cape indigenous forests to SANParks (Garden Route National Park) in 2005, who did not have the well-being of an indigenous timber industry as a major focus. The economic recession since 2008, also had profound implications for both SANParks and the industry, resulting in the need for cost-cutting measures. Linked to this was the substantial rise in reserve prices, caused by the fact that they had to be fixed on a full cost recovery basis. Consequently, interest in and attendance at auctions declined since 2010, with a few auctions taking place in 2012/2013, but with few to no auction sales, and logs remaining after auctions were then sold out of hand.

Since then (up to 2015) intensions to auction have been advertised, with requests for expressions of interest, but these have inevitably been cancelled due to lack of interest. Despite the current lull, SANParks are still hopeful about finding solutions to the stagnation of the business (e.g. through the establishment of an indigenous wood buyers co-operative), and remain committed to applying strict environmental standards (FSC certified) and equitable access to the resource (Len du Plessis, pers. Comm. Oct, 2015).

The market for Afrocarpus/*Podocarpus* (Yellowwood) species

The most consistent source of legally acquired Yellowwood in South Africa was the SANParks auctions. Three species of Yellowwood were sold on those auctions (although data on *P. henkelii* was scarce). In terms of volume sold, by far the most common one was *P. latifolius*. There is also a saw miller based in the Eastern Cape (former Transkei) who harvests Yellowwood trees under licence from the Department of Agriculture, Forestry and Fisheries (DAFF), but the trees are usually available due to storm damage and natural mortality, so the supply is not big or consistent. The major suppliers of Yellowwood in South Africa are:

- Woodmans (Knysna)
- Rare Woods (Cape Town, George, Knysna),
- Country Woods (Durban, Johannesburg)
- Silverton Houthandelaars (Pretoria)
- Teggs Timbers (Pietermaritzburg, Durban)

Table 11 provides more information on the market prices of logs and timber from Podocarpus species.

Table 11. Average Log prices of *Podocarpus* species

Species	Common Name	SANParks average auction price (R m^{-3})
Afrocarpus falcatus	Outeniqua Yellowwood	R1 450.00
Podocarpus henkelii	Henkel's Yellowwood	n/a
Podocarpus latifolius	Real Yellowwood	R1 400.00

Source: (du Plessis, 2010a) and own records.

Some retailers do not make a distinction in their price of the different *Podocarpus/Afrocarpus* species. For example Silverton timber merchants in

Pretoria have a single price for Yellowwood of R20 000 m^{-3} and makes no distinction between species, size or thickness. Teggs Timbers, likewise, have a list price of R13 500 m^{-3}. Other wood suppliers differentiate their prices in terms of size and thickness (Table 12), which complicates comparisons of the prices of Podocarpus timber products.

Table 12. Average Prices of different Yellowwood timbers

Supplier	Product description	Price range Lowest	Highest
Rare Woods	Narrow	16 720	17 765
	Wide (> 200 mm)	19 900	21 000
Woodmans	Select	13 000	
	Prime	11 300	13 000
	A grade	9 700	10 300
	Shorts	7 300	
	Counter tops	18 000	
Country Woods	25 mm	11 600	
	38 mm	11 900	
	50 mm	12 100	
	Slabs	19 600	

Sources: (Rare Woods, 2010, Country Woods, 2010, Woodmans, 2010).

It is uncertain whether an increase in the supply of *Podocarpus*/Afrocarpus timber (when commercially grown) would be absorbed by an increase in the demand for its timber. The Merensky group has about 30 hectares under *A. falcatus* plantations at four to five different sites in Limpopo, but their predictions are that indigenous trees cannot compete with introduced plantations volume wise, except if investors are prepared to wait about 60 years and if the price of Yellowwood timber is very favourable. It was also mentioned that in order to be commercially sustainable and economically viable a reasonable volume of indigenous timber needs to be made available on a regular basis, which is currently not the case. Part of this challenge lies in analysing the production cost of yellowwood in plantation rotation systems and the following section provide more information in this regard.

Recovery, pricing and profitability of indigenous wood

There are a number of difficulties associated with obtaining and processing indigenous wood that makes it less attractive to the wood dealer than obtaining introduced species directly from saw millers, wholesalers and importers. These challenges start with the logistical issues of getting wood out of remote places without adequate equipment, saw milling to get maximum recovery, understanding the behaviour of different species of wood whilst cutting and drying and storing without degradation. There are a few selected

South African woods that fetch high prices on the international hobby market (woodturning, knife-making and suchlike), but even though there may be other species that are as attractive there is a strong resistance in the wood industry to new species. This has been confirmed by discussions with many wood dealers during the marketing process undertaken by Red Ivory Trading and, as mentioned before, is the reason why Pro-Sono and others market a limited variety of southern African species and take a long time to introduce new species to the market.

Furniture makers and other woodworkers need wood of a consistent quality, and the timber logs need to go through a process of drying, either by air or through a kiln. Drying of the wood means that there can be a long lead time between acquiring the timber and the "end" wood product (Murray, 2010). For this reason the actual volumes of timber sold are not always a good indication of demand in the market, as there is a long production chain.

In addition, there is some difficulty with pricing a final wood product (such as wood turning blanks). These difficulties stem from a number of complex issues, namely:

- The variable shapes, sizes and quality of logs obtained from the field (in conventional saw milling, most commercial species are clones, which are usually long, straight and a similar size and processing requires no special insight on the part of the saw miller. In some instances, recovery is enhanced by computerisation of the process. Forests in Europe and the United States of America (USA) yield very large, straight logs, which are processed in a similar manner to commercial logs, whereas many South African species grow under harsh and variable conditions, which render logs incredibly difficult to deal with as they are very variable in size, shape and quality. Interestingly, the more difficult logs often yield the most interesting wood, which hence is considered as a value attribute.
- the difficulty in estimating useable volume within logs and the extreme variability in the final percentage recovery obtained from logs
- decisions regarding the most effective mix of product sizes that can be obtained from an individual log and the likelihood of selling those sizes
- the costs versus benefits of converting off-cuts to smaller and smaller saleable stock and the diminishing returns associated with the increased effort
- exchange rate fluctuations.

The capital requirements needed to start a wood business are quite large. Capital is not only required for vehicles, equipment and machinery, but also for the purchase and storage of wood and ongoing running costs. **Management of cash-flow is thus critical** and some very bold and risky decisions have to be made along the way. The potential for things to go wrong along the sourcing, production and supply chain is high. In addition, there are the difficulties associated with managing staff, maintaining and repairing machinery, marketing, selling and interacting with user groups, as well as continually “discovering” new species and understanding their properties for different uses.

When one aims to compare the economics of indigenous wood versus commercially grown pine, it is important to remember that there are some significant and fundamental differences between the two. The major differences revolve around the difficulties and costs associated with extraction and saw milling. Saw milling is complicated: the methods used and efficiency of the saw milling operation affects costs and one cannot simply compare for example pines and yellowwood. It is much more costly to extract a single indigenous tree from a forest than it is to remove a tree that is part of a clear-felling operation in a plantation block. Similarly, indigenous tree logs are seldom uniformly round and/or straight and this inconsistency both slows down the sawmilling rate and decreases percentage recovery (yield) from logs. Growing indigenous trees in a plantation situation with standard silvicultural practices can reduce extraction and processing costs and result in straighter, more uniformly round logs, but the benefits of indigenous plantations will not necessarily be uniformly observed across different species, because of the inherent growth form of these species. For example, both *Olea europaea* subsp. *africana* (Wild Olive) and *Psydrax obovata* (Quar) have a twisted and gnarled growth form and it is impossible to get a consistent yield of good quality timber from these species.

In addition to the inherent qualities of the different woods, sawmilling of logs is commonly done by one of two different types of saws (band saw and circular saw), which yield different results and may affect the value of the resulting timber. A band saw with either narrow or wide blades is used to cut the log in continuous wide slices. The smaller saw millers most commonly use portable, horizontal, narrow-blade band saws (32 mm wide). Wide blade band saws are usually static and are capable of cutting much wider boards than the narrow blade saws. The diameter of the log to be cut and thus the width of the final planks are determined by the throat capacity of the band saw in use. The largest model of a popular narrow-blade band saw, is capable of cutting a log 900 mm in diameter, but this maximum width is constrained by how straight and symmetrical the log is and is usually closer to 600-700 mm. Wide blade band saws can cut slabs up to about a metre in diameter.

Advantages of a band saw mill are:

- the narrow kerf (thickness) of the blade (about 1 mm), which results in a greater recovery (about 12 % of the log becomes sawdust in a high production band saw mill as opposed to about 21% for a circular saw),
- much wider planks or “slabs” can be cut and this can substantially increase the value of the timber that is sold.

The main disadvantages of the band saw mill are:

- there is a limit to the size log that can be cut as described above,
- reduced ability of the blade to track effectively. This means that if the blades are not sharp or are incorrectly sharpened, or the feed rate is too fast the cut can be wavy and the effective recovery can be substantially diminished because the planks then need to be planed to get them flat. If a log is particularly hard or abrasive, the saw blade can be dulled after a single pass through a log, as has been frequently experienced with *Mimusops caffra* (Coastal Red Milkwood), which has a very high silica content, as well as *Colophospermum mopane* (Mopane), which contains Calcium Oxalate. Dry logs are substantially more abrasive than wet logs. There are some saw millers who argue that the risk and frequency of getting wavy cuts on a thin-kerf band saw negate the better recovery from having the thinner blade.

Circular saws (swing blades) typically consist of a single blade which is capable of cutting to a depth of 160-254 mm. The blade can be tilted either horizontally or vertically and it is supported on a moving trolley suspended between two rails above the log. The trolley can be moved down at predetermined intervals and the blade does a series of alternating horizontal and vertical passes to slowly “eat away” at the log. The result is a stack of even width (and usually even thickness) planks. The widest plank that can be cut will be double the cutting depth of the blade if a double cut is taken. Advantages of the swing blade circular sawmill are:

- the mill is highly portable and can be carried into remote locations by hand by a few people,

- there is no limit to the size log that can be cut, both in terms of diameter and length. Unlimited track extensions can be added, but there is obviously a practical handling limit to the length.

Disadvantages of the swing blade circular saw are:

- it is impossible to cut a wide slab using these saws, but if required, a single slab can be "cut" by sawing the log to a certain point and then turning it over and doing the same on the reverse side, thus leaving a slab behind,
- the loss to sawdust is in the order of 21% (from a 5-6.1 mm kerf), which is substantially higher than a well set up band saw mill.

In short the milling process for indigenous wood is not standardised, which negates the achievement of economies of scale and is thus comparatively more expensive to mill than pines. There are many other complications associated with saw milling that affect the quality, and thus price, of the wood. For example, cupping of the wood is more likely with planks that have been cut more or less parallel to the growth rings. Attractive figure of the wood is more likely to be evident where wood is cut at between a 60-90° angle to the growth rings (quarter sawing), but this can be more wasteful. Highly figured wood is more likely to have wild grain that makes effective machine planing difficult, if not impossible. Most commercial species are kiln dried, with hardwoods usually being dried at a slower pace than softwoods in a dehumidifying kiln. Nevertheless, there is a school of thought amongst specialist wood users that air-dried timber is superior to that which is kiln dried. In fact, there are some species, such as *Pterocelastrus tricuspidatus* (Kershout) that cannot be kiln-dried without substantial cracking.

Most commonly, indigenous wood is sold in plank form in the same manner as other hardwoods in standard dimensions of rough cut planks. The most common widths are usually related to the standard widths that a Lucas Sawmill can cut, namely 152 m (6") or 254 mm (10"). Pricing is normally thickness related and the thicker the planks, the higher the price per cubic metre. Most of the construction timber used in South Africa is locally grown Pine (Pinus species). Generally, solid lengths are used by the construction industry, but if the design specifications exceed what is available in standard solid lengths, then laminated beams can be used. At present timber is supplied in lengths of 300 mm increments, starting from 1.8 metres. Anything shorter than 1.8 m is usually described as "shorts" and timber dealers often discount the price on shorts in order to get rid of the stock. Solid timber longer than 6.6 metres is generally not available.

5.5.2 *Indigenous species economic analysis*

Data gathered from community members (Figure 41) was the preferred method for this phase of the project. An explorative phase was followed by two field surveys during November 2012 and August 2013 which utilised a questionnaire (Appendix A) designed to capture the required information for the economic analysis. Volumes of timber were specified either as numbers of individual poles or bakkie loads extracted. Among other information on harvesting volumes, "input" costs, transaction costs and price data of the products from the target species of the study was required. The fieldwork was done by students from Fort Cox, four field workers and the forest wardens of the study areas. Before presenting the results of the surveys, some context setting is provided in terms of the illegal trade of these species and the presentation of the study site. The findings of 121 responses that were completed, is presented in subsequent sections.

Figure 41. Data gathering with community tree users in the Manubi area (Photo: V. Masterton).

<u>The illegal trade in Sneezewood</u>

Ptaeroxylon obliquum (Sneezewood) is protected under the National Forests Act 84 of 1998 (Department of Water Affairs and Forestry, 1998), and licences are therefore required to harvest in limited quantities. However, the demand for this species remains high, and illegal trade is consequently becoming a common sight (Figure 42). A moratorium between 1995 and 2004 on the harvesting of this species inflated the price, which has created further perverse incentives for illegal harvesting/poaching. In the absence of a formal market for this species, black market prices are highly variable, and are predominantly a function of the risk of being caught while harvesting, transporting or transacting (making a deal) with the commodity. The direct value attributes of the species (i.e. being for example hardy) becomes comparatively less important in determining the price. Black market prices are therefore to be considered as relative, with low primary production costs and extremely high transaction costs adding to the price of the good/product. Black market prices are consequently a poor proxy for the inherent value attributes of the species.

Figure 42. Stashed mix of illegally harvested indigenous *Buxus natalensis* (Isixeza), with alien invasive *Psidium littorale* (Cherry Guava) in between, in the Manubi State forest (Photo: W. de Lange).

According to Obiri (1997), illegal harvesting of stems in the size class 20-25cm diameter is particularly high due to several characteristics of this class compared to others. Firstly, in comparison to stems above 25cm in diameter, this size class is the more abundant. Secondly, this size class is mostly distributed along the forest margin, and is not found on the steep, inaccessible slopes. It is thus much easier for people to locate and remove these stems. Thirdly, harvesters incur lower transport costs on the 20-25cm logs as compared to larger ones. As logging is banned, the poached logs are not pulled on oxen sledges as before; instead carvers carry them on their shoulders, passing along concealed forest tracks. Some poachers will hire other villagers on a casual basis to carry their heavier logs. However, these heavier logs do not necessarily yield more sticks, as they sometimes have rotten piths (Cwaba, 1996). Furthermore, medium sized trees usually have straight stems, which yield more of the longer sticks which are desired in the craft markets. Besides the transport difficulty, most carvers contend that larger logs tend to have cracks and insect borings in them. These act as entry points for pathogens, especially fungus, which cause stem decay. This is common on large stems and can be very costly to carvers (Cwaba, 1996).

The craft work trade has steadily increased over the last decade. In 1986, for example, the sale of Umzimbeet sticks and basketry craft in Port St. Johns was valued at about R100 000 (Cunningham *et al*., 1988). A more recent estimate for one middleman alone indicates an annual income of R120 000 in Port St. Johns (Cawe and Geldenhuys, 2007a). Similarly, the annual sales from three established middlemen is estimated to be over R500 000 (Cawe and Geldenhuys, 2007a). If unrecorded sales by the villagers are considered, a much higher annual income value for this trade would be obtained.

It is unclear how preferences with respect to stem size would change if the logging ban were to be lifted. Carvers would probably choose the larger stemmed trees with higher volume (Cwaba, 1996), and use the cheaper ox-drawn transport rather than manpower. Even though large trees are not always straight, and thus less suitable for stick carving, they could still be used to make products other than sticks, such as small ornamental curios. However, in the view of Obiri (1997), local preferences would still be oriented toward the middle sized trees, since in addition to their straight stems, they show less insect and fungal wood damage and are thus more valuable to carvers. Therefore, the advantages of stem straightness combined with reduced incidences of wood damage in middle sized trees would be likely to prevail over the higher volumes that could be obtained from larger trees. The likelihood that medium sized trees would still be preferred even after lifting the logging ban would, however, result in management problems, as continued preference for medium trees would adversely alter the forest structure. In this regard, forest managers need to monitor cutting of the various diameter size classes and ensure that the composition of age size class and forest recruitment remains unaltered (Obiri, 1997).

Manubi site (Eastern Cape)

The Manubi State forest (32.44287°S, 28.60909°E) covers approximately 762 ha and is regarded as a mixed species, mixed age indigenous forest surrounded by poor rural communities. The Eastern Cape Forestry Department draws a distinction between a forest reserve (or state forest) and a headman forest. Historically, this can be traced to the frontier wars of 1779-1819, when tribes defeated in the wars had their land annexed. These became crown lands, which are today known as forest reserves (Johnson, 1983). However, chiefs who accepted colonial rule were given the authority to oversee resource use in the annexed forests. These became the headman forests which today still play an important role in the socio-economic needs of the rural people as they provide various resources (Table 13) that support local rural livelihoods. A Eucalyptus belt was planted around the forest to substitute in some of the consumptive uses of the immediate (within 5km radius) population.

Table 13: List of recorded uses for the three species under investigation (survey data).

Uses	Yellowwood	Sweet Thorn	Umzimbeet	Sneezewood
Fuelwood for cooking and heating		√	√	Excellent fire starter because of oil in wood
Timber for basic furniture			√	√
Timber for fine furniture	√			
Timber – roof trusses	√		√	√
Laths for roofing				
Withies for fencing				
Fencing poles			√	√
Timber – floorboards and parquet blocks for floor	√			
Timber – boat building	√			
Timber – underwater construction for bridges and jetties				√
Timber – window and door frames	√			
Timber – coffins	√			
Timber – railway sleepers				A past practice
Crafts weaving/rope				
Wood carving (off-cuts short pieces for carving, e.g. animals)			√	
Blanks for turning (pens, bowls, instruments, wood samples)				
Implements/Utensils ("knopkieries" + walking sticks, kitchen products – chopping block)				√

Uses	Yellowwood	Sweet Thorn	Umzimbeet	Sneezewood
Jewellery (beads necklaces)				
Fruit	√			
Medicinal use of fruit	Chest complaints			
Medicinal use of bark				Headache/sinusitis
Medicinal use of roots				
Medicinal use of leaves				
Medicinal use of seeds			Indo-parasites	
Medicinal use of sap	√			
Medicinal use of resin for warts				√
Chemical products – dye				
Chemical products – glue				
Chemical products – oils/perfumes/cosmetics/soap				
Chemical products – resin	√			
Chemical products – tannin for tanning industry	√			
Chemical products – insect repellent				√
Chemical products – fish tranquiliser			√	
Chemical products – snuff				√

No previous study could be found that focused specifically on extraction rates in this (Manubi) forest. However, a few studies focused on similar forests in close proximity (Cawe and Geldenhuys, 2007; Obiri, 1997). Cawe and Geldenhuys (2007b) obtained baseline data for the natural forests in the Port St Johns forest estate on the location and abundance of selected tree and plant species and extraction rates, to inform recommendations with regard to the formulation of sustainable extraction rates. Given that the total basal area (TBA) of all species in Manubi forest was estimated at 31.17 m^2 ha^{-1} in 2006 (down from the 1988 estimate of 33.3 m^2 ha^{-1}), the relative density of

Sneezewood and Umzimbeet (i.e. the percentage of Umzimbeet and Sneezewood relative to all species in Manubi forest) was estimated at 0.1% each, while the relative basal area (i.e. a percentage of TBA) for Sneezewood and Umzimbeet was estimated at 0.3%, which gives an estimated TBA for these two species of 0.1 m^2 ha^{-1}, or approximately one stem per hectare of both species, with a mean DBH of 303 mm per stem (Geldenhuys and Rathogwa, 1995). The mean DBH growth rate would be 0.02 mm yr^{-1}. These are comparatively low compared to yellowwood in the same forest, which have a relative density of 1% and relative basal area of 1.5% (or 0.5 m^2 ha^{-1}), which gives an estimated 12 spha, of 140 mm DBH. The mean DBH growth is estimated at 1.3 mm yr^{-1}.

The following figures are estimates of extraction rates in the Manubi area, based on interviews with headmen of the area, and the local state forest warden during the explorative phase of the project. In terms of pole requirements for construction, a traditional eight-sided house will typically require 30-35 poles for its walls and 28 poles for the roof, which adds up to 58-63 poles for the house. Umzimbeet is the preferred species for construction, followed by Sneezewood and Eucalyptus. We observed a marked change from the traditional round hut built of poles, laths and mud with thatched roofs, to cement bricks with corrugated iron roofs and Eucalyptus roof structures, and the use of Eucalyptus poles for fences. Current extraction rates of Eucalyptus were based on permits being issued; however, this represents a gross underestimation of the real extraction rate, based on evidence from the incidence records of illegal harvesting of protected species. Households normally have a pole fence around their property, which is on average 200 m long. Given that typically 2 m spacing is used, an estimated 100 poles will be used for such a fence. A typical cattle pen (Figure 43) of approximately 40 m will consist of 1.5 m pair-wise spacing of sneezewood poles (56 poles), which is cross-weaved with cherry-guava to make a strong fence.

Figure 43. Cattle pen made from Sneezewood poles (Photo: V. Masterton).

Locals were aware of the moratorium on Umzimbeet and Sneezewood. However, it was noted that illegal traders sell the poles for R18 per pole, whereas Eucalyptus poles (inferior in quality to Umzimbeet) go for R9 each (the local forest warden issues permits for the cut Eucalyptus poles at R9 per pole). Most permits are issued for batches of 15 poles, which present a transaction value of R135. The bulk of these buyers are within a 5 km radius from the site. Eucalyptus grows extremely fast (approximately 2.75 metres per year at Manubi), and are allowed to re-coppice three times before plots are de-stumped and replanted. The forest warden acknowledged that Eucalyptus poles were too expensive, and argued that a price of R6 per pole was considered to be fair. However, considering that it typically takes 2 years for an untreated Eucalyptus (gum) pole to rot in this area (receiving 1000-1300 mm of rain per year), whereas untreated umzimbeet poles start to show signs of wear (not rotting) only after 20 years, a conservative replacement ratio between these two species would be 1:10. This would imply that at a Eucalyptus price of R9 per pole, an Umzimbeet pole should cost R90. Alternatively, at an Umzimbeet price of R18, a Eucalyptus pole should cost R1.80; more than three times cheaper of what was considered a fair price by the warden. Furthermore, given that gum trees are fast growers, it seems justifiable to lower the price of gum poles. It was interesting to note that locals are aware of the difficulties of growing Umzimbeet in plantation rotations (it has been tried): indeed, they mentioned that the tree grows best in mixed forests. They also remarked on an observed decrease in stream flow after the establishment of the Eucalyptus belts.

We have obtained copies of the incidence records of the Manubi forest from 2007 to 2011 (Figure 44). Several incidents of illegal harvesting of specifically these three species were reported (see red circles in plates). Illegal harvesters typically prefer middle size poles, because these are easier to transport by hand and in 2011 alone four separate cases (on the 25/01/2011; 14/02/2011; 14/03/2011 and 24/03/2011) of theft of a total of 73 umzimbeet poles, and one case of theft of 200 yellowwood poles on the 1/09/2011; were reported. No incidents of illegal Sneezewood harvesting were reported. While these volumes are small, it should be compared to the estimated population of these species in the forest. Given that the Manubi forest is 762 ha, and that there is approximately one stem of each of Umzimbeet and Sneezewood per ha, one can assume that approximately 762 stems each of Umzimbeet and Sneezewood are to be found in the forest. The illegal cutting of 75 stems of Umzimbeet therefore amounts to a substantial 10% of the population in one year. The situation becomes worse if one recalls the slow growth rate (0.02 mm per year) of this species.

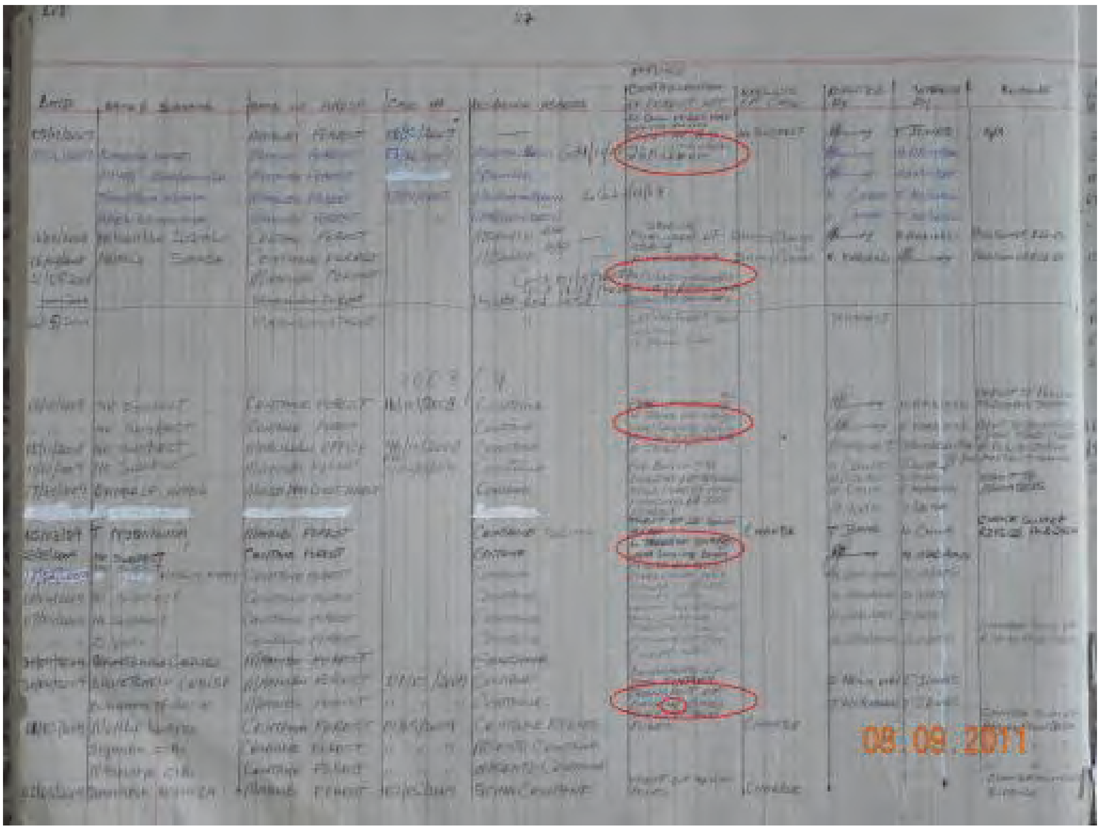

Figure 44. Reported incidents of illegal wood harvesting at Manubi (Photo: W. de Lange).

Obiri (1997) observed that carvers earned up to R1000 per month from carvings made specifically from Uzimbeet in 1997. This figure translates to R2203 in 2011 terms (using the CPI index), (Republic of South Africa, 2011). We observed that a typical Umzimbeet walking stick sold for R16 (and then by a middleman for R27). This latter figure is confirmed by our observed prices of Umzimbeet kieries at R30 each at the local market in Butterworth, where they are sold to urban traders. Urban traders in turn sell them for R111. However, some kieries sell for up R300 in the city, depending on the level of craftsmanship and the client. Black market prices will, in theory, under-appreciate the real value of the species, because carvers do not want to keep stock owing to the risks associated with this practice. This decreases their bargaining power and makes them 'price takers' in the market (i.e. they have little power over market prices). Thus, a carver will accept almost any price the middleman offers in order to clinch a deal.

Individuals who harvest bark for personal and household use argue that there is nothing wrong with harvesting such bark for medicinal or ritual purposes, as they derive their livelihoods from such activities (Figure 45). However, syndicates operate on a much larger scale. For example, the forest warden caught one such syndicate with 15 x 50 kg bags of bark for the Durban market in September 2011. Such illegally harvested bark trades for R400 per 50 kg bag, (a transaction value of R6000). However, the warden mentioned that the case came to nothing because of poor understanding of the local department of justice regarding the Forestry Act.

Figure 45. Bark harvesting for medicinal purposes in Manubi (Photo: M. Gush).

It was interesting to note that most households had access to electricity from the national grid, but continue to use wood as an energy source for cooking, while electricity is mainly used for lights and appliances (Matsika *et al*, 2013, confirmed this finding). Furthermore, travelling cost to the nearest urban area (Butterworth) was noted to be R38 by bus or R56 by taxi. These travelling costs should be incorporated in a proportional fashion if one would like to calculate the replacement cost of substitutes for physical products harvested from these species. An example would be the proportional share of the travel cost that should be added to the direct cost of, for example, flu-medicine when compared to the medicinal use of Sneezewood bark (assuming that it has the same healing characteristics, which it does not) – it is however assumed that an individual will not travel for such medicine alone.

Overall it seemed that the indigenous tree product industry is heterogeneous and amorphous and it was decided to embark on two detailed surveys in order to extract more information on the same products in the area.

It should be noted that the average unit prices of tree products were imputed in order to clarify the variability in responses. This averaging was also done for the volumes of tree products used per month in order to determine the economic significance of the indigenous tree product industry.

A "pole" is the tree product that lends amenability to the several uses of Sneezewood and Umzimbeet, which enables economic analysis of the usage of these trees. The poles of these tree species, when traded have prevailing unit process depending on circumstances. Furthermore, the volumes of tree products traded were mostly presented in different and non-standardised metrics, depending on the perception and experiences of the respondents. For example, we observed the following: the average "bakkie" (LDV vehicle) typically accommodates 100 poles, and weighed between 800 kg and one tonne. It was noted that a "bakkie load" is sometimes rounded off to a tonne. This is not far-fetched based on the propensity of individuals that hire transport overload vehicles in order to save on costs. Furthermore, a head-load weights typically 50 kilograms; which implies that about 16 head-loads constitute a bakkie load.

None the less the variety and variance in reporting units did not allow for the construction of a production cost model to the same level of detail as was done for yellowwoods. One can however make rough comparisons, for example the average price of "poles" from sneezewood and umzimbeet was R29.50 which is slightly lower as compared to the average unit price of R33.65 for a selection of commercial "weatherwood" treated pine poles (Table 14). It is however not possible to assess whether pine poles are comparatively more expensive or cheaper because of the huge variance (and absence of a categorisation system) in length and thickness of sneezewood and umzimbeet poles and uncertainty with regard to the comparative strength and durability of Pine vs Sneezewood or Umzimbeet (i.e. a scientifically rigours comparative ratio is required to compare these).

Table 14: Average prices for "weatherwood" (CCA and wax) treated pine poles. Source: Barnard, 2014

Length	Class 2 (50-79 mm)	Class 3 (80-99 mm)	average
1.5 m	R19.83	R34.77	R27.30
1.8 m	R24.62	R42.58	R33.60
2.1 m	R29.41	R50.70	R40.06
Average	R24.62	R42.68	R33.65

Regarding fuelwood, respondents easily gave quantitative answers about the volumes of fuel wood traded, as well as accurate answers on the prevailing market prices of fuel wood. Hence, unit weight of fuel wood was deemed to be most amenable to economic investigation, and as such, could be used for further analysis.

5.6 Discussion

The economic viability of four species (Yellowwood, Umzimbeet, Sneezewood and Sweet Thorn) cannot be judged in a fully inclusive fashion at this stage, until field trial data becomes available to account for the earlier-mentioned limitations. There are currently simply too many unknown variables at play that could affect the viability, which does not allow a scientific (i.e. justifiable and repeatable) comparison at this stage. A greater form of standardisation and establishment of trial sites with all three species is necessary before a reliable viability assessment can be done. This study is thus an important descriptive presentation of the dynamics associated with the informal indigenous tree product market. It should be viewed as such and it is intended to be used as a platform to sanction further research.

Furthermore, we doubt that an argument based on the value of the physical products derived from indigenous species (either in mixed stands or monoculture) will suffice to promote indigenous forestry at this stage, as the full suite of indirect value attributes is required if indigenous species are to be compared with introduced tree species on financial grounds. Furthermore, although some ecosystem services as provided by natural forests are quite clear, others (for example recreation and tourism) could cater for both plantation forestry and natural forests. These services could cancel each other out when comparing indigenous forests with pine plantations.

In terms of the Yellowwood plantation, it was noted that the direct production cost of Yellowwood plantations are comparatively small relative to the opportunity cost of the extremely long rotation cycle when compared to an introduced plantation. The extremely long rotation period required, makes this option uncompetitive against introduced species such as pine. Unless it becomes possible to shorten growing periods (via breeding and selection programmes) of indigenous species, their successful cultivation remains a risky affair. However, this in turn poses the conundrum that water-use is often closely correlated with growth rates, and Yellowwoods which are genetically bred to grow faster would be associated with higher water-use rates (as is with introduced species such as pines), thereby possibly negating the water efficiency benefits claimed by having indigenous species in plantation rotations in the first place. Given that the price of Yellowwood is unlikely to compensate for this limitation, and that the market is totally underdeveloped and inadequate to justify large scale investment in indigenous monoculture, we remain sceptical with regard to the viability of this species in plantation rotation systems. The Yellowwood industry will consequently remain small for as long as these markets remain undeveloped.

The current cap in terms of hectares under introduced plantations, along with the comparatively faster growth rates of these species, makes a comparison between introduced and indigenous species inappropriate from an economic perspective, because the cash flow and risks associated with indigenous plantations are simply not comparable to introduced species. Private decision-makers will always maximise their hectares under introduced species first before switching to indigenous species if they need to cultivate more hectares under forestry. We would therefore argue that a comparison between indigenous species with an alternative land use (other than forestry) would make more sense at this stage, which is rather ironic since alternative land uses seems to be one of the future major threats for forests.

That being said, the value of indigenous forests in the upkeep and maintenance of rural livelihoods seems to be substantial, particularly if the opportunity cost of this function is accounted for. We observed that this value is a direct function of the level of poverty in the study area and it seems that the higher the associated poverty in a specific area, the higher the value in direct use of tree biomass becomes. It therefore seems that as communities become wealthier, the ability to switch from forest goods and services towards marketed goods and services (i.e. readily available substitutes) will improve, and hence their dependence on the forest will decrease. However, one could argue that if the dependence on the forest decreases, ‘stewardship’ of the forest may decrease along with it. This leads to a dilemma, where a wealthier and perhaps more “developed” community will have a comparatively smaller incentive to care for an adjacent forest, as compared to a marginalised community deriving its livelihoods from the forest and who understand their dependence on the forest. This highlights the need for renewed effort in awareness campaigns emphasizing the value of indigenous forests to local communities in order to promote the finding of a balance between utilisation and conservation (i.e. sustainable utilisation) of forests. Any argument that motivates for the expansion of forestry with indigenous species will need to stress the value of forest products in the upkeep of livelihoods as a “safety-net” for the rural population (which is essentially the same aim for most alternative land uses). It should be emphasised that this function is particularly important to augment marginalised households’ needs in times of hardship, thereby preventing the further intensification of poverty. Although the direct use value of forest products seems small in absolute monetary terms, it becomes significant when one accounts for the low incomes of these communities, as well as the marketed goods and services (e.g. education) that can be afforded as a result of cash savings from using substitute goods that can be collected from forests. It should however be noted that few rural households rely solely on forests to serve their livelihood related needs, but there are also equally few households that depend solely on wage labour or solely on agriculture. Forests conservation cannot therefore be seen as a panacea for alleviating poverty in rural communities; rather, they prevent intensification of poverty and further degradation of forests, which would be associated with a deepening level of poverty. Considerably more research is required on the downstream effects of such opportunity cost and the effects of small-scale enterprises based on forest products in order to support this argument.

Lastly, one should remember that forests are considered a common property resource owned and managed collectively by a community or society rather than by individuals (this should not be confused with “open access” resources, which refers to a good or service over which no property rights are recognized, see (Goodstein, 2008)). The Sneezewood and Umzimbeet in the Manubi study for example, were managed as public goods under a common property management regime and the question was asked as to how to improve the current management regime in order to improve current management practices, while maintaining the contribution to livelihoods and without compromising the limited income streams and state of the forests. We argue that “self-regulation” would be the most effective way to conserve, maintain and expand indigenous forests and forestry in South Africa. It will however, take a considerable amount of time to develop and implement a suitable regulatory system that is designed to make the main beneficiary of a common property also the main custodian of such property (asset) because suitable incentives for effective stewardship of forests is totally under-developed in South Africa.

6 RAPID SCREENING TECHNIQUES[10]

6.1 Introduction

At any site selected for establishment of an indigenous tree production system, an important initial decision is to select species that are likely to yield useful tree products of some kind, and which display a relatively high growth rate, low water use and high WUE under local site conditions. This project has seen a collation of valuable information on useful products (e.g. poles, firewood, carving wood, fruits, and traditional medicines) associated with indigenous South African trees, and these data can be used to narrow the field considerably. Further selections of potential species can be based on distribution maps. However, there is little detailed knowledge of site-species preferences, and so growth rates cannot be predicted with accuracy. There is much evidence from gardeners and foresters to show that the growth, form and vigour of trees are greatly affected by site conditions.

The quickest and probably the most reliable indicator to guide species selection is likely to be the presence of existing indigenous species already growing in the area on sites similar to that intended for tree establishment. Such a "bioassay" approach to assess tree productivity is adopted by commercial foresters who base their estimation of site index on the performance of trees which reflect in an integrated way the sum total of all site factors affecting tree growth. Rapid assessment of growth, transpiration and WUE displayed by these trees would be extremely useful in predicting which species show greatest promise as a viable land use. Various potential methods of rapidly quantifying growth, water use and WUE were reviewed during this project and are summarized below.

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[10] When making reference to this section, please cite as follows:

Dye, P.J. and Gush, M.B. 2015. Rapid screening techniques. In: Gush, M.B., de Lange, W.J., Dye, P.J. and Geldenhuys C.J. (Eds). 2015. Water Use and Socio-Economic Benefit of the Biomass of Indigenous Trees: Volume 1 (Research Report). Water Research Commission, Pretoria, RSA, WRC Report 1876/1/15, Section 6.

6.2 Measurements of Wood Attributes Correlated to Growth, Water-use and Water Use Efficiency

6.2.1 Growth

The use of tree structural or physiological correlates to growth (and water-use and WUE) is a very attractive goal, since it could greatly simplify data collection and analysis. Characteristics of stem or branch wood would be especially convenient for this purpose, given that samples are easily collected with an increment borer, and contain a record of the growth and hydraulic properties of the tree throughout its life. Samples may easily be stored for reanalysis at a later stage. In view of these advantages, a review of potential wood-based correlates was undertaken.

Except in rare instances, the age of indigenous trees growing wild is unknown, so current stem sizes cannot be used to estimate growth rates. Exceptions may occur where well-defined growth rings exist, but care would need to be taken to recognize false growth rings which form in some species in response to dry periods. A survey of useful indigenous species would be necessary to determine for what species and under what conditions this technique could be used. The requirement for such information to be available for a wide variety of species from many site-types counts against this approach.

Tree growth rates were reported by Bucci *et al*. (2004) to be usefully correlated to stem basic wood density in a sample of six tropical savanna trees in Brazil. However, a different result was reported by Fan *et al*. (2012), who found in a study of 140 tropical tree species of various sizes in China that wood density was a poor predictor of tree growth. Our results from a selection of six indigenous trees (Figure 46) also suggest a poor correlation between stem density and growth rate (Dye *et al*., 2008).

Fan *et al*. (2012) found however that superior growth prediction is possible based on an analysis of hydraulic conductivity as calculated from xylem traits. Across species, diameter growth rate was positively correlated to vessel lumen diameter and potential hydraulic conductivity. However, the variability in these relationships was still relatively high and our assessment is that they could only provide a very coarse ranking of species for growth.

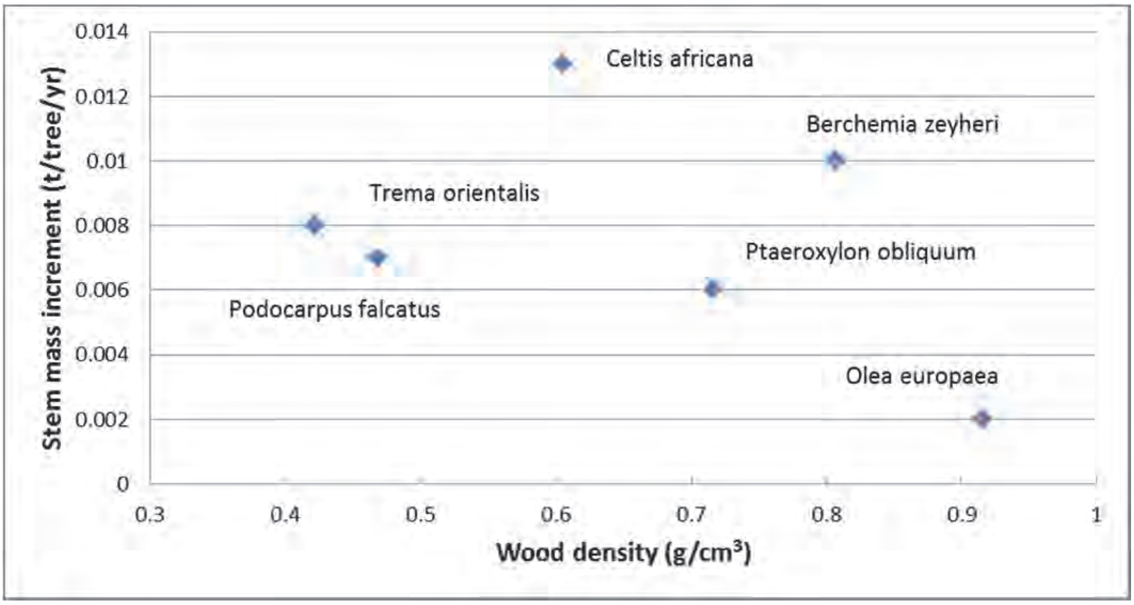

Figure 46. Relationship between 1-year stem mass increments and wood density (Dye *et al*., 2008).

6.2.2 Transpiration

Annual total transpiration is a key characteristic in assessing the WUE of trees. Selecting tree species with a relatively high growth rate and low transpiration rate ensures a high WUE which is desirable for wood production as well as minimizing the effects of the trees on catchment water yields.

The use of xylem attributes to predict water-use has received much recent attention, especially by John Sperry and colleagues in the USA. Recent work has focused on predicting flow rates and growth in trees (Sperry *et al*., 2012). These authors developed a 17-parameter numerical model linking tree mass to stem flow rate. This model was tested on 18 separate trees from two species, representing a broad range of stem diameters. They concluded that their model is useful for predicting rates of water consumption within and between species. However, this work has concentrated on understanding flow rates under controlled laboratory conditions and over short measurement periods, and the model requires a number of inputs that are difficult to measure without specialized instrumentation. A review of literature revealed no example of xylem anatomy being used to estimate year-long water-use patterns in a variety of tree species, suggesting that this is not feasible at the present time.

6.2.3 Water-use efficiency

WUE is defined here as the ratio of grams of above-ground utilizable wood per kilogram (or litre) of water transpired. Investigations of carbon isotopic composition in stem wood and twigs have provided insights into the efficiency of water-use in some plant species. The theory is well described and validated (Farquar *et al*., 1989). However, several studies of the isotopic composition of trees in South Africa (Olbrich and Olbrich, 1996; Woodborne *et al*., 2003) have produced unexpected results that have been difficult to interpret, leading the authors to believe that a thorough sampling methodology and a better basis for interpreting data still needs to be developed. Given the need to assess many different species of different ages and growing in different sites, this task was judged to be beyond the scope of this project.

6.3 Other Methods for Rapid Measurement or Estimation of Growth, Water-use and Water Use Efficiency

6.3.1 Annual biomass increments

In this study, annual biomass increments at the various study sites were estimated from periodic manual measurements of diameter at fixed points along stems, taken at the start and end of a full year. Wood density measurements were used to convert volumes to a mass increment. It is important to keep in mind that growth rate is not constant, but varies seasonally and even over shorter time intervals (Olbrich *et al*., 1993; Dye *et al*., 1997) in response to environmental factors such as rainfall and temperature. Thus, measurements for the purpose of defining WUE need to take place over at least a full year so that such growth cycles can be fully covered. The method was found to be practical, if not as rapid as we would have preferred. Nevertheless, measurements are generally easily completed in a few hours, and only need to be taken twice for each tree.

Difficulties may be encountered with species where no single main stem exists. In some indigenous species, there are multiple stems per tree and no clear dominant stem, or no clear division between stem and branch, so utilizable stem and branch may be a more appropriate measure of the biomass that can be harvested for, e.g. fuel wood.

6.3.2 Annual water use

Measuring tree transpiration over periods of a year or more is feasible with sap flow measurement systems, but finite quantities of costly equipment always limits the number of trees that can be sampled. The number of data loggers is generally the most limiting factor, as several trees can be connected to one data logger, but then these must be in close proximity for the probe cables to reach the logger. It is generally possible to find a range of sample trees growing close together in a tree plantation, but it is much more difficult to achieve when sampling wild-growing trees which are generally more widely spaced. Once again, clear seasonal differences in transpiration rate and total evapotranspiration are the norm, and so a full year of measurement or estimation is required to sample all seasons. It is possible to rotate equipment through several experimental sites and model sap flows during gap periods, but this is very labour intensive procedure and introduces considerably more complexity to data analysis. A further constraint on measurement of sap flow in sample trees in South Africa is the ever present risk of equipment theft. Another constraint is the amount of research time required to undertake such measurements and analyse large amounts of data. In view of all these constraints, we believe that direct measurement of annual sap flow in multiple trees at various sites is not practical for widespread assessment of tree transpiration.

6.3.3 Modelling

The multitude of factors governing tree transpiration, and the continuous variability of some of these over time has resulted in a reliance on soil-plant-atmosphere (SPA) models to describe patterns of water-use. A literature review was conducted to evaluate available SPA models suited to describing indigenous tree species with differing structural and physiological attributes, as well as simulating total evaporation from tree stands. Special emphasis was placed on whether the required input parameters could be practically obtained in the field. A crucial point was to assess to what extent the more detailed inputs could be species-specific. An attribute that needs to be measured only once for a species and thereafter can be assumed to be reasonably constant, is far easier to characterize than an attribute that varies continuously from site to site, and which needs to be measured repeatedly.

The MAESPA model stood out as having sufficient detail to take account of the various transpiration influences listed above. Although both growth and water-use are simulated by MAESPA, the focus here is on water-use estimation, to reduce the number of model parameters required. However, with time and further data acquisition, the model may prove useful in quantifying growth rates as well, making WUE estimation easier.

6.4 Discussion

The original intention of this aspect of the project was to identify quick and easily measured screening attributes that could be used with minimum effort to rank different tree species according to their WUE. Delving into the available scientific literature revealed many complexities and very few papers dealing with the question of how WUE differences among different tree species can be easily recognized. The overall impression gained is that there is not yet the necessary understanding to identify complex attributes like cumulative growth and transpiration from one or more easily measured attributes.

The next best option was to consider whether annual growth increments and annual water-use could be rapidly measured or estimated in the field, using any other methods. Growth increments have now been measured in many sample trees in this project and its predecessor, using a series of measurements of stem and branch diameters of various sizes, taken at the start and end of a 12-month period. Although this method is not as rapid as one would like, it is perfectly feasible and can yield accurate annual growth rates to compare among different species. Simple diameter bands can also be used for recording diameter changes.

Measurements of sap flow or total evapotranspiration are technically demanding and not suited to simultaneous measurements of a variety of different trees which are not in close proximity to each other. Various soil-plant-atmosphere models were evaluated to find one capable of simulating canopy processes in sufficient detail to be able to account for some of the known physiological differences among indigenous tree species. The MAESPA model was identified as a potentially suitable model for transpiration simulation and WUE ranking.

An important question is whether these techniques are rapid enough and practical enough to be suitable for comparing WUE among potential indigenous tree species across a wide range of sites and including trees of differing ages. We believe that they are, with the proviso that some further research work is necessary to examine some of the MAESPA physiological inputs to establish their within-species variability. Ultimately, the development of a graphical user interface for MAESPA would greatly improve ease of use of the model by foresters, researchers and students.

From the above review and conclusions, we believe that we have practical techniques to estimate annual growth increments and annual transpiration from selections of sample trees representing indigenous tree species growing in a particular area. Although not as rapid, simple and convenient as originally hoped, the methods are reasonably practical and quick, requiring perhaps 2-4 site visits to collect the necessary data over the course of a year. The advantage of the MAESPA model is that it can yield detailed information to support interpretation of water-use patterns, providing much scope for testing hypotheses relating to WUE. The inclusion of non-transpiration evaporation (wet canopy evaporation, soil evaporation, understory evaporation) is also seen as an important benefit. With further work on tree carbon balances and allocation patterns, the growth predictions of MAESPA may one day also prove useful for estimating WUE.

The above review has outlined some of the practical problems in rapidly assessing the growth potential and water use of individual indigenous trees at specific sites, in order to identify those with high biomass production and low water use. The conclusion drawn is that we could not identify any simple methods or correlates that are suited to the rapid assessment of growth, transpiration and WUE. We nevertheless recommend the following procedure for ranking tree species which is practical and avoids the difficulties of measuring transpiration.

1. Selection of sites for indigenous tree species plantations.
2. Search similar sites in the area for existing indigenous trees, particularly those providing useful products.
3. Locate suitable sample trees belonging to this subset of species, ensuring that they are well exposed to sunlight, not suppressed by competing neighbouring trees, and not as old and tall as to make canopy sampling difficult.
4. Measure current stem diameters at various heights from the base upwards, and repeat after 12 months to determine the annual growth increment.
5. Parameterize the MAESPA model for each species and simulate the annual transpiration using representative weather station data and any additional relevant measurements that are possible to take in the field, in order to calibrate and validate the model predictions. Field observations of the sample trees at intervals over a year will provide valuable information on leaf dynamics and soil water availability to the trees.
6. Compare stem biomass increments to annual transpiration to estimate WUE.

7. Ultimately, stands of indigenous trees must be assessed for their overall ET, which includes non-transpiration losses such as canopy rainfall interception and evaporation, as well as understorey and soil evaporation. This requires measurement of whole-stand ET once the trees form a closed canopy and approach maximum leaf area index. The total evaporative loss will indicate the potential impact of the land use on catchment water yields.

We hope that this procedure will be tested in future as a means of establishing trial plantings of indigenous tree species in appropriate areas of South Africa.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 General Conclusions

The main conclusions from this study are as follows:

- Indigenous trees were found to use substantially less water than similarly sized “exotic” introduced tree species,
- Indigenous trees generally had correspondingly slow growth rates, resulting in similar water-use efficiencies (on average) to introduced tree species, from a bio-physical perspective,
- There was significant site, species and temporal variation in water-use, growth and resultant water-use efficiencies of trees,
- Genetic improvements (e.g. Provenance trials) on indigenous trees are likely to improve their growth rates, but would correspondingly increase their water use rates, due to positive correlations between the two,
- Single-species even-aged indigenous tree plantations could potentially be economically viable, but only over very lengthy rotations and only with guaranteed market access and annual log price increases exceeding 5% (for Yellowwood timber),
- The informal indigenous tree product industry is heterogeneous & amorphous; yet economically significant at a local scale.

The relatively low water-use characteristics of indigenous tree species suggests that they are promising for expanding natural and plantation tree production systems in South Africa, maximising benefits (goods and services) while minimising negative impacts (high water-use). Apart from the importance of accurate site/species matching, appropriate species for establishment need to be considered from environmental, social and economic perspectives. Potential benefits include suppression of alien invasive plants, biodiversity conservation, the provision of ecosystem services, supporting rural livelihoods, ecotourism and urban greening. Given the increasing pressure on water resources and a growing demand for timber and non-timber forest products, further exploration of the numerous multiple-use indigenous tree species that are found in this country, matched to the wide range of existing climatic and site conditions, is merited. There is surely potential for managed, productive and sustainable indigenous forest and woodland systems. Considering that further afforestation with commercial forest species is now restricted due to limitations in available land and concerns about reductions in catchment water yields, the possibility of expanding low water-use forms of forestry with indigenous trees deserves to be explored further.

The question remains, is it possible (and expedient) to expand areas under indigenous trees? In addressing this question it may be helpful to consider the southern Cape indigenous forests. Those forests cover a small area of South Africa, but are an excellent example of a sustainable, multiple use system that offers a wide range of benefits to society. Research over many years has culminated in a sustainable system of management, in which timber extraction of high-value logs has shown the potential to generate income without compromising the sustainability and species composition of the forest. On the other hand, heavy utilisation of indigenous forests by people in rural communal areas has been reported in several different parts of the country (Lawes *et al*., 2004). There is danger of over-utilisation in such situations (Obiri *et al*., 2002), and a potential solution is for alternative tree-production systems (woodlots) to be established as a way of alleviating harvesting pressure on indigenous forests.

Another potential application of these results could be the planting of indigenous tree species in riparian zones within commercially afforested areas. These zones are difficult to manage from grassland conservation and weed control perspectives as they are often narrow riparian corridors, in which it is dangerous to perform bi-annual burning regimes due to fire-risk within the plantations, and which are thus often heavily infested with alien invasive plants. If riparian zones are continuously weed-infested and have limited bio-diversity value then an indigenous tree cover could be considered preferable. Tangible benefits to this practice have been shown from research in Chile (Little *et al*., 2015) where streamside buffers of native forest within catchments planted to *Pinus radiata* and *Eucalyptus* spp. plantations, reduced adverse effects from the plantations on water provision (quantity and quality). It has also been shown locally (Seagrief, 1965; Geldenhuys, 1997) and internationally (Feyera *et al*. 2002, Kasenene, 2007; Farwig *et al*., 2009) that, under suitable conditions, commercial plantations of introduced trees may act as “nurse” stands, enabling the regeneration of indigenous trees and shrubs under the protection of their canopies, to eventually form forests.

From a purely economic/financial perspective, benefits of establishing indigenous tree production systems at this stage appear to be limited. In terms of a single species even-aged plantation (e.g. Yellowwoods), the economic model that was developed indicated that there is potential for a profitable enterprise, however the extremely long production cycle and extreme sensitivity to log prices (a major unknown given the long estimated rotation period of 45 years) are formidable entry barriers. The model showed that a minimum annual log price increase of 5% was required to keep growers in business when the cost structure was inflated against the long term average producer price inflation of 9.11%. This means that the average annual price increase for logs needs to be 5% or higher to keep growers in business. The main reason for hesitancy in investing in indigenous tree production systems is thus the long rotation cycles and consequent long turnaround time of capital. Few financial entities can sustain a negative cash flow for up to 45 years on a hectare basis before an income is generated. So the motivation for the growing of Yellowwoods in a rotation model cannot really be justified on financial grounds alone.

So indigenous tree plantations will never replace introduced tree species plantations from an economic perspective. It would be more realistic to expect that they could complement each other, within unique and separate contexts. It would be necessary to account for the full suite of indirect value attributes associated with indigenous trees and forests if they were to be compared with introduced tree species on purely financial grounds.

On the other hand the value of indigenous forests in the upkeep and maintenance of rural livelihoods seems to be substantial, particularly if the opportunity cost of this function is accounted for. This value is a direct function of the level of poverty in the study area and it appears that the higher the associated poverty in a specific area, the higher the value in direct use of tree biomass becomes.

This study has confirmed the important role of indigenous trees from an ecohydrological perspective, and the findings thus have wider scale applicability in fields such as forest restoration, erosion control, replacement of invasive alien species and multiple-use indigenous tree wood-lots, particularly where water-conservation is a priority. Given the wide range of climatic and site conditions around South Africa, the large number of multiple-use indigenous tree species that are found in this country, and increasing pressure on water resources, it is important to continue research on options for the expanded utilisation of indigenous tree production systems.

7.2 Recommendations and Future Research Needs

A dedicated, long-term research agenda for indigenous forestry research is required that includes the following focus areas:

- Continuation of the water use, biomass-growth and water-use efficiencies of different indigenous tree production systems and species,
- Expansion of empirical modelling capabilities to quantify their water use,

- Systematic recording of the economic costs and benefits of growing and harvesting indigenous forest/plantation systems, and
- Quantifying the non-use and indirect use values of these systems within different socio-economic contexts.

Modelling Studies

The MAESPA model is viewed as a powerful tool for estimating rates of water use, given the expense of field measurement systems, the security of this equipment in the field, and the complexity of data analysis. MAESPA is able to take into account weather conditions, a variety of soil characteristics governing soil water availability to trees, the structure and physiology of a wide range of tree species, and shading effects by other trees in the vicinity. Rainfall interception loss and understory ET may also be simulated, so the model is capable of describing both individual tree and forest plot water use. Stem growth increments of sample trees are relatively easily measured, permitting the calculation of WUE. Additional work is required to improve model parameterization of tree species. Due to the species-specific input information required, the model is best suited to scenarios where a limited number of different species are being simulated. Under these circumstances data on the following will improve model parameterization and lessen the need for set-up information from the field:

- Leaf area estimation. Allometrics, LA correlation to sapwood area, stem diameter, etc.
- Leaf nitrogen contents of various species and their correlation to site quality.
- Stomatal conductance patterns in a range of different species.
- Rutter model parameter values for estimating rainfall interception rates.
- Light penetration and leaf area distribution within different canopies.
- Patterns of leaf water potential over seasons on different sites, quantifying temporal pattern of soil water deficits.

It would be useful to apply a similar methodology (window periods of eddy ET measurements and MAESPA simulations) to examine other types of indigenous forest in South Africa to assess the variability of ET. Factors such as soil depth, rainfall seasonality and amount, degree of mistiness, soil texture, groundwater availability, hill-slope effects and species composition may all affect ET and cause variable patterns of water use.

Economic Studies

Severe data limitations posed challenges in assessing the economic/financial viability of indigenous tree production systems during this study. The lack of economic data was primarily attributed to the fact that most indigenous forest systems are currently not focused on market transactions and financial viability, but rather on the maintenance of livelihoods or conservation of natural resources. Consequently, the results presented in this report should be interpreted with caution when extrapolating or when generalisations are made based on these results. Errors can result if the results are applied to benefit transfer studies with no accounting and adjusting for the socio-economic context in which the studies were done.

There is a need for specific research on the economic/financial viability of a wider range of indigenous tree systems. This will provide the basis for studies such as marginal value product (MVP) assessments for water as used in indigenous forestry production systems. This will facilitate the comparison of indigenous forest production systems with introduced plantation tree systems in a more standardized and direct way, which will be far more effective for arguing a case for indigenous forestry. An MVP calculation of the water use for each species would also enable comparison with any other water use enterprise, including irrigation. However, the production function necessary for each scenario or study site, implies that the functional relationship between water and yield of the different products must be known, and all the goods and services to be included in the function properly quantified and valued, which is not yet the case.

There is also a need for research on the development of innovative policy mechanisms, coupled with appropriate institutional development, to facilitate the much needed investment to expand indigenous forestry in South Africa. Information on water use efficiency and income earning potential of these systems is central, but these are currently poorly quantified in the South African context. Research aimed at generating more water use data for different species, understanding the workings of market-based mechanisms of such an industry within a developing country context, suitable incentives for investment in these slow-growing and long-term indigenous forests/plantations (e.g. tax rebates), and a more inclusive valuation of the indirect and non-use value of such an industry (e.g. payments for ecosystem services under the UN-REDD programme (Agrawal, 2001) or in carbon-sequestration projects under the CDM (Van Kooten and Sohngen, 2007, Corbera *et al*., 2008, Miranda *et al*., 2006)) is necessary. It is strongly recommended that those involved with the conservation and research of indigenous tree species begin to record the costs incurred (establishment, management and harvest) and that a central database is created where these data can be stored and verified and made accessible to interested parties.

<u>Further Recommendations</u>

A number of additional topics associated with indigenous tree production systems have potential for further study. These include:

- The extent to which the WUE of indigenous tree species may be improved through more intensive management; and how the ratios of growth to water-use may change under conditions of increased productivity.
- The environmental and socio-economic costs and benefits associated with various indigenous tree production systems (e.g. single-species even-aged plantation stands, or mixed species mixed-age pioneer stands).
- Future indigenous tree stand management research. These could be in the form of trial plantings of indigenous tree species, in research stands, measuring and/or modelling growth, water use and economic data. Responsibility for the establishment and management of these trails could be assumed by the Dept. Agriculture, Forestry and Fisheries. Trials could consider various silvicultural aspects such as use of "nurse" stands, different planting densities, thinning and pruning regimes, weed control measures and species choices.

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DATA STORAGE

All processed data have been stored at:

CSIR, Natural Resources and Environment (NRE)
11 Jan Cilliers Street
Stellenbosch
7600
South Africa

APPENDIX A: FIELD QUESTIONNAIRE

PROJECT BRIEF: WATER-USE, GROWTH & ECONOMIC VALUE OF INDIGENOUS TREES

I am doing some work for the Council for Scientific and Industrial Research (CSIR). The CSIR is doing a research project on indigenous trees and indigenous forests, to measure how much water they use, how fast they grow, and what the economic value is of the products that they produce (wood, bark, roots, leaves and fruit). This 6-year project (2009 – 2015) was solicited by the Water Research Commission (WRC) and is funded by the WRC and the Working for Water Programme of the Dept. of Environmental Affairs. We are using special instruments to measure the water-use of indigenous trees and forests, and the growth rates of the trees have been measured over many years using study plots in different indigenous forests around South Africa. However, we need your help in gathering information on the economic value and use of indigenous trees. We would like to ask you about what tree species you use, what parts of the tree you use, what you use them for, and what monetary value they have to you, either for your own use, or to sell to others. We have certain indigenous tree species that we are most interested in, and we would be very grateful if you could assist us by providing information about those species, although information on other tree species that you use would also be useful.

Your participation is completely voluntary and you will not be identified by name when we publish the results of our study. By participating in the study, you will be helping us to better understand the importance of indigenous trees and indigenous forests in South Africa. Notes will be taken to record your answers, and to allow us to analyse the data. Your participation in this study is greatly appreciated. If you require any additional information about the project, please ask or contact the people below.

Contacts for more information on the project.

Dr. Mark Gush
Project Leader
CSIR, Stellenbosch
Tel: 021 888 2659
mgush@csir.co.za

Dr. Willem de Lange
Senior Scientist
CSIR, Stellenbosch
Tel: 021 888 2462
wdelange@csir.co.za

Today's date
Place of interview

The information on this answer sheet refers to:

- ☐ Acacia karroo (uMunga, Sweet thorn)
- ☐ Millettia grandis (umKunye, umSimbithwa, Umzimbeet)
- ☐ Ptaeroxylon obliquum (umThathi, Sneezewood)

1) From where do you obtain the wood?
2) What is it used for?
3) Why do you prefer this particular species?
4) Do you sell the wood or any products from the species?
5) How much do you use or trade per month? (Number of logs or kilos or head-loads etc.)
6) How much does it cost to harvest or make? (What are your expenses?)
7) To whom do you sell the species or product?
8) What's the price for the product that you sell?
9) How much of each product do you sell per month?
10) If you can't get hold of the species, what will you use or trade instead? and, how much will that cost you?
Notes:

Instructions:

Explain to the person what the study is about.

Make sure the information on each sheet refers to only one specie.

Question 6 need some explanation, any information on the cost involved would be useful. The responded could give examples.

Please return to Willem de Lange:
CSIR, PO Box 320, Stellenbosch, 7599
E-mail to: wdelange@csir.co.za

APPENDIX B: CAPACITY BUILDING

Staff development

1. Mr. Vivek Naiken (Technician, CSIR) – project experience with Heat Pulse Velocity (HRM) and Thermal Dissipation Probe (TDP) sap flow monitoring systems, eddy covariance total evaporation measurement systems, Campbell Scientific automatic weather stations, and various soil water monitoring systems.

Community development

1. Mr. Siyasanga Daka, an unemployed graduate residing in the Eastern Cape with a diploma in social forestry from Fort Cox College of Agriculture and Forestry, assisted the project team by conducting over 60 interviews with local rural inhabitants in the vicinity of Manubi State Forest during November/December 2012. Using a questionnaire designed by the project team, he was supported by the project to spend three weeks in the field conducting a survey on forest resource use in Manubi. In used the experience gained from this task, as well as from assisting with equipment installation in the field and an awareness of the overall objectives of the project, in fulfilling the experiential learning component of his studies.
2. Mr. Thembelani Nokwali, a DAFF employee based at the Manubi State forest assisted the project team with the installation and maintenance of instrumentation in the Manubi forest. During seasonal field trips, Mr. Nokwali assembled workers from the local community to assist with installing a temporary mast in the forest, on which total evaporation monitoring equipment was installed. He also arranged for workers to assist in the installation of heat pulse velocity sap-flow monitoring systems to measure the transpiration (water-use) of certain indigenous and introduced tree species. Mr. Nokwali was particularly helpful in assisting with the selection of suitable monitoring sites for the research and, with the help of the local workers, was able to identify suitable locations for particular tree species that were required for monitoring. Mr. Nokwali assisted with the maintenance of monitoring equipment which remained at Manubi for a year, namely an automatic weather station and heat pulse velocity systems.

Students that graduated during the course of the project

1. Hartley Bulcock (204501831) – PhD (Hydrology), University of KwaZulu-Natal. (Part Contribution to Project). Graduated April 2012.

"*An assessment of canopy and litter interception in commercial forest plantations and an indigenous forest in the KwaZulu-Natal Midlands, South Africa*." After graduating, Dr. Bulcock worked as a lecturer at the Centre for Water Resources Research at the University of KwaZulu-Natal for 2 years, before accepting a position as Senior Hydrologist with SRK Consulting in Johannesburg in September 2014.

Tatenda Mapeto (212200127) – MTech (Forestry) – Nelson Mandela Metropolitan University. Graduated April 2015 (Cum Laude). "A comparative analysis of the water use and water use efficiencies of indigenous and introduced forest species in the southern Cape." During her studies Ms. Mapeto was active in the International Forestry Students Association, and she is currently registered for a PhD, linked to WRC project K5/2443 (The Impacts of Commercial Plantation Forests on Groundwater Recharge and Streamflow).

Abstracts

Hartley Bulcock (PhD Hydrology) "*An assessment of canopy and litter interception in commercial forest plantations and an indigenous forest in the KwaZulu-Natal Midlands, South Africa*."

Understanding of the hydrological cycle and processes such as interception span as far back as the times of the Renaissance, when Leonardo da Vinci (1452-1519) first described it. However, there remains a gap in the knowledge of both canopy and litter interception in South African forest hydrology. Interception is typically considered to constitute only a small portion of total evaporation and in some models is disregarded or merely lumped with total evaporation, and not considered as a separate process. Interception is a threshold process, as a certain amount of water is required before successive processes such as infiltration and runoff can take place. Therefore an error introduced in modelling interception, especially disregarding it, will automatically introduce errors in the calibration of subsequent models/processes. In this study, field experiments to assess these two poorly understood hydrological processes, *viz*. canopy and litter interception were established for the three main commercial forestry genera in South Africa, namely, *Pinus, Acacia* and *Eucalyptus* as well as an indigenous *Podocarpus henkelii* stand, thus, accounting for interception of "broad leaf", "compound leaf" and "needle leaf" trees in order to provide further insight into these processes. The study took place at two locations in the KwaZulu-Natal Midlands over a period of three years. The first site is the Two Streams catchment, located in the Seven Oaks area, about 70km north-east of

Pietermaritzburg where the study on the commercial plantation species took place. The second site was the *Podocarpus henkelii* stand in Karkloof near Howick, 40km north of Pietermaritzburg.

From the field data collected (*cf*. Chapter 2) it was observed that canopy storage capacity, an important parameter governing interception, was not constant and changed with rainfall intensity, with lower intensity events resulting in a higher storage capacity. Building on these findings, a physically based canopy interception model that is based on the well-known Gash model was developed, and is referred to herein as the “variable storage Gash model”. While canopy interception is dependent on many factors including the storage capacity, potential evaporation, rainfall intensity and rainfall duration, the litter interception is largely dependent on the storage capacity due to the evaporative drivers under the canopy such as radiation, temperature and wind speed being moderated by the above canopy. From these finding, a litter interception model based on idealised drying curves from litter samples collected at the study sites was also developed (*cf*. Chapter 3). From the field data, it was found that the canopy interception for *Eucalyptus grandis, Acacia mearnsii* and *Pinus patula* was 14.9, 27.7 and 21.4% of mean annual precipitation (MAP) respectively. The simulated canopy interception using the “variable storage Gash model” was 16.9%, 26.6% and 23.3% for *E. grandis, A. mearnsii* and *P. patula* respectively. The litter interception measured for *E. grandis, A. mearnsii* and *P. patula* was found to be 8.5, 6.6 and 12.1% of MAP respectively, while the simulated litter interception using the idealised drying curve model corresponded well with the measured results and were 10.1%, 5.4% and 13.4% for *E. grandis, A. mearnsii* and *P. patula* respectively. The idealised drying curve model is site and species specific and is therefore not transferable to other locations. Conversely, the “variable storage Gash model” is transferable as it is not site and species specific, and relies on readily measureable and available information. Building on field studies, this was then used to simulate the canopy interception for *Eucalyptus, Acacia mearnsii* and *Pinus* in South Africa (including Lesotho and Swaziland) for all quinary catchments in which commercial forestry could be grown, i.e. a mean annual precipitation of greater than 600 mm.year^{-1} (*cf*. Chapter 4). It was found that, depending on the location and genus, canopy interception loss can be as high as 100 to 300 mm per year or approximately 10% to 40% of MAP. This relates to a mean interception loss of between 1.0 and 3.0 mm per rainday, highlighting the spatial variability of canopy interception. To further investigate the spatial variability of canopy interception, at various spatial scales, remote sensing technology was applied to estimate leaf area index (LAI) for use in modelling/estimating canopy storage capacity and canopy interception (*cf*. Chapter 6). The NDVI, SAVI and Vogelmann 1 vegetation indices were used in the estimation of the LAI. It was found the Vogelmann 1 index produced the best results. As models to estimate canopy interception typically require LAI and storage capacity, it was calculated that the ability to estimate these parameters over large areas is valuable for water resources managers and planners.

An often neglected consideration of canopy and litter interception is its role in determining the water use efficiency (WUE) of a forest stand (*cf*. Chapter 5). This component of the study was undertaken in an indigenous *Podocarpus henkelii* stand as well as a commercial *Pinus patula* stand in Karkloof in the KwaZulu-Natal Midlands. The sap flow (transpiration) was measured in both the *P. henkelii* and *P. patula* stands using the using the Heat Pulse Velocity (HPV) technique in order to determine the productive green water use. The canopy and litter interception was measured in the *P. henkelii* site, but was modelled in the *P. patula* site using the “variable storage Gash” and idealised drying curve models, in order to estimate the non-productive green water use. It was found that the canopy and litter interception for *P. henkelii* was 29.8% and 6.2% respectively, while the modelled canopy and litter interception for *P. patula* was 22.1% and 10.7% respectively. If only the productive green water use (transpiration) is considered, then the water use efficiency of *P. henkelii* and *P. patula* was found to be 7.14 $g.mm^{-1}$ and 25.21 $g.mm^{-1}$ respectively. However, from a water management perspective it is important to consider the total green water use efficiency (transpiration + interception), which reveals a substantially lower water use efficiency of 3.8 $g.mm^{-1}$ and 18.8 $g.mm^{-1}$ for *P. henkelii* and *P. patula* respectively.

To extend the study to a globally relevant issue, the possible impact of climate change on canopy interception was investigated, as forests growth is critically linked to climate (*cf*. Chapter 7). To achieve this, the CABALA model was used to model LAI and transpiration of *Eucalyptus grandis* and *Pinus patula* under 9 different climate change scenarios, including changes in temperature, rainfall and atmospheric CO_2. The simulated LAI values from the CABALA model for all 9 climate scenarios were then used to simulate canopy interception using the “variable storage Gash model”. Results show that LAI may increase by as much as 24% and transpiration may decrease by as much as 13%, depending on the scenario, location and tree species. However, it was found that canopy interception does not change greatly, leading to the conclusion that under climate change conditions, canopy interception may not become a more dominant component of the hydrological cycle than it currently is as the changes under climate change are likely to be less than the natural variability from year to year. However, canopy interception remains an important consideration for water resources management and planning both currently and in the future.

Tatenda Mapeto (MTech. Forestry) "*A comparative analysis of the water use and water use efficiencies of indigenous and introduced forest species in the southern Cape.*"

In South Africa, the limited extent of indigenous forests accelerated the development of fast-growing introduced species plantations, on which the country is now heavily reliant for its fibre and timber products. However, the plantation forestry industry is challenged with limited freshwater resources, the need for sustainable management of introduced tree species in commercial forest production systems, and a diversity of plant ecological production factors such as soils that have to be manipulated for the purposes of increasing production capacities. Additionally, plantations are established in the limited high rainfall regions of the country and the industry's water use has been regulated since 1972. Conversely, natural forests also provide valuable goods, however, their slow growth rates have restricted their development as commercial tree production systems. In this regard the forestry industry is continuously seeking to provide for the country's timber and fibre needs while ensuring the provision of other ecosystem services from tree production systems. Recent developments in the forestry industry have therefore been focused on water use efficiency in current and alternative tree production systems. There is also widespread unsubstantiated belief that indigenous tree species are efficient users of water. Against this background this study sought to explore the single tree water use and water use efficiencies of introduced commercial plantation species (*Pinus radiata*) and that of important indigenous species (*Ilex mitis, Ocotea bullata* and *Podocarpus latifolius*) for timber and fibre production in the southern Cape region of South Africa.

Single tree water use measurements were carried out for a year using the heat pulse velocity method. Growth measurements for utilisable stem wood were done on a quarterly basis for the specimen trees and growth increments over the year were determined. Single tree water use efficiency was a calculated as a function of grams of stem wood gained per litre of water transpired. Measurements of daily weather conditions and soil water content were concurrently taken during the year. The relationships between the variables that express daily climatic conditions, soil water content and daily volumes of transpired water were explored. Empirical models for the prediction of daily transpiration as a function of climate and soil water content were then developed using multiple linear regression analysis.

Pinus radiata trees exhibited higher totals of volumetric transpiration than the indigenous species. The water use patterns of *Pinus radiata* showed higher peaks of maximum and minimum daily and seasonal water use while the indigenous species showed temperate patterns of water use throughout the year. *Podocarpus latifolius* attained the lowest water use efficiency in the year (0.49g/L) while *Pinus radiata*, *Ocotea bullata* and *Ilex mitis* had comparable water use efficiency values ranging between 1g/L to 2.50g/L. Significant positive correlations existed between climatic variables and daily sapflow volumes of the tree specimens. Daily total solar radiation showed the highest positive correlation with daily transpiration and the average value of the correlation coefficient for solar radiation and water use for all tree species was 0.70 ($p < 0.001$). Empirical models for predicting daily water use integrated the variables expressing plant available water and energy. The study enhances our understanding of single tree water use, water use efficiency, the drivers of transpiration and the applicability of such studies in developing rapid estimation techniques for water use in current and alternative South African tree production systems.

APPENDIX C: KNOWLEDGE DISSEMINATION AND TECHNOLOGY TRANSFER

Scientific Articles

1. Bulcock, H.H., Gush, M.B. and Jewitt, G.P.W. 2014. A comparison of productive and non-productive green water-use efficiency of Podocarpus henkelii and Pinus patula in the KwaZulu-Natal midlands. Southern Forests: a Journal of Forest Science, 76 (2): 75-84.
2. Hughes, D.A., Gush, M.B., Tanner, J. and Dye, P.J. 2014. Using targeted short-term field investigations to calibrate and evaluate the structure of a hydrological model. Hydrological processes, 28: 2794-2809.
3. Everson, C.S., Dye, P.J., Gush, M.B. and Everson, T.M., 2011. Water-use of grasslands, agro-forestry systems and indigenous forests. Water SA, 37 (5): 781-788.
4. Wise, R.M., Dye, P.J. and Gush, M.B., 2011. A comparison of the bio-physical and economic water-use efficiencies of indigenous and introduced forests in South Africa. Forest Ecology and Management, 262: 906-915.
5. Gush, M.B. and Dye, P.J. 2009. Water-use efficiency within a selection of indigenous and introduced tree species in South Africa as determined using sap flow and biomass measurements. Acta Hort. (ISHS), 846: 323-330.

Conference Papers

1. Gush, M.B., Dye, P.J., Geldenhuys, C.J. and Bulcock, H.H., 2011. Volumes and efficiencies of water-use within selected indigenous and introduced tree species in South Africa: Current results and potential applications. In: Proceedings of the 5th Natural Forests and Woodlands Symposium, Richards Bay, 11-14 April.
2. Gush, M.B., Dye, P.J, Wise, R.M., Everson, C.S., Jarmain, C., Clulow, A. and Mengistu, M.G., 2009. Bio-physical and economic estimates of the water-use efficiency of an indigenous yellowwood plantation (Podocarpus falcatus). In: Proceedings of the 14th SANCIAHS Symposium, Pietermaritzburg, 21-23 September.

Presentations

1. Gush, M.B., de Lange, W.J., Dye, P.J., Mapeto, T. and Geldenhuys, C.J. 2015. Water use, growth and socio-economic value of the biomass of indigenous trees. Invited presentation delivered at the Water Research Commission Research Development and Innovation (RDI) Symposium and Water-tech Summit, Boksburg, South Africa, 16-18 September 2015.
2. Gush, M.B. 2015. How can the forestry sector make best use of the water it is allocated? Invited presentation delivered at the ICFR/IUFRO Research Symposium: Underpinning Sustainable Tree Plantations in Southern Africa, (World Forestry Congress, pre-event), International Convention Centre, Durban, 4 September, 2015.
3. Gush, M.B., Dye, P.J., Mapeto, T. and Pienaar, H. 2015. Water use and growth of indigenous tree species in South Africa. Presentation delivered at the 4th International Conference: Forests and Water in a Changing Environment, Kelowna, British Columbia, Canada, 6-9 July 2015.
4. Gush, M.B. 2015. What is the potential of *Vachellia (Acacia) kosiensis* as a dryland forestry species in terms of its water use, growth rates and resultant water use efficiency? Presentation delivered at the IUFRO Symposium: Silviculture and Management of Dryland Forests, STIAS, Stellenbosch, 16-19 March, 2015.
5. Gush, M.B., de Lange, W.J., Dye, P.J., Mahumani, B. and Geldenhuys, C.J. 2014. Sustainable forests: Water and resource use in the Manubi forest. Presentation delivered at the 6th ICFR/DAFF Forest Science Research Symposium, Hilton, 29-30 July 2014.
6. Gush, M.B., de Lange, W.J., Dye, P.J. and Geldenhuys, C.J. 2013. Sustainable forests: Water and resource use in the Manubi forest. Presentation delivered at the 2nd Symposium of Contemporary Conservation Practice, Howick, 4-8 November.
7. Gush, M.B., 2009. The Hydrological Effects of Changing Riparian Zone Vegetation in Afforested Areas. Presentation delivered at 3rd Annual Grasslands Partners Forum, Pretoria, 10-12 November.

Popular Articles

1. Gush, M.B. 2013. Measuring the water use of trees and forests. ScienceScope, Vol. 6, No. 4 (November, 2013): 68-69.
2. Gush, M.B. and James, B.M., 2011. Indigenous trees in South Africa: is the market for wood and water growing? Wood Southern Africa & Timber Times, Vol 36, No. 3:26-27.
3. Gush, M.B. and Dye, P.J., 2009. Indigenous trees could be the next commercial timber species. SA Forestry, (Nov/Dec 2009): 4-5.

4. Gush, M.B. 2009. Indigenous trees show benefits in terms of water and economics. ScienceScope, Vol. 4, No. 2 (August 2009): 16-17.

Poster Displays

1. Mapeto, T, Louw, J.H., Gush M.B. and Naiken, V. 2014, Single tree water use and water use efficiencies of selected indigenous and introduced species in the southern Cape region of South Africa, poster presentation, ICFR/DAFF 6th Forest Science Symposium, 29-30 July 2014, Pietermaritzburg, South Africa.

Other Outputs

1. Stakeholder workshop with interested and affected parties, held on 17th February 2010, to screen, shortlist and select indigenous tree species deemed to be most promising for natural and plantation tree production systems.
2. Gush, M.B., 2009. Short television documentary produced by SABC2 AgriTV about the Water Research Commission project K5/1876 (Water use and economic value of the biomass of indigenous trees under natural and plantation conditions).
   https://www.youtube.com/watch?v=phiOOTs6LzE&feature=youtu.be

APPENDIX D: USEFUL AND FAST-GROWING INDIGENOUS TREE SPECIES

Table 15. List of useful, fast-growing tree species associated with the main forest types in South Africa, extracted from the National Forest Type Classification descriptive document (Von Maltitz *et al.,* 2003). *N = Natural forest stands; P = Planted stands

Species	**National forest types (see Table 2.1 for meaning of type abbreviations)***																	**General comments: Successional status & seasonality; Regrowth ability; Leaf type; Use**
	I 1&2	**I 3**	**II 1&2**	**II 3&4**	**III 1**	**III 2**	**IV 1**	**IV 2**	**IV 3**	**V 1**	**V 2**	**V 3**	**VI 1&2 &A4**	**VII 1&2**	**VII 3**	**A 1**	**A 2&3**	
Acacia karroo			N									N	N					Small pioneer deciduous legume tree; Regrowth from seed; Compound leaf with small leaflets; Firewood, fibre, gum
Albizia versicolor/adiantifolia					N, P	N							N					Tall pioneer deciduous legume trees; Regrowth from seed; Compound leaf with medium-size leaflets; Poles, medicine
Apodytes dimidiata		N, P	N	N		N	N	N	N			N	N		N			Semi-evergreen canopy tree; advanced regrowth to mature forest; Vegetative regrowth; Simple medium-size leaf; Timber, construction

Species	**National forest types (see Table 2.1 for meaning of type abbreviations)***																	**General comments: Successional status & seasonality; Regrowth ability; Leaf type; Use**
	I 1&2	**I 3**	**II 1&2**	**II 3&4**	**III 1**	**III 2**	**IV 1**	**IV 2**	**IV 3**	**V 1**	**V 2**	**V 3**	**VI 1&2 &A4**	**VII 1&2**	**VII 3**	**A 1**	**A 2&3**	
Celtis africana		N	N	N	N	N	N	N	N			N	N	N	N			Deciduous canopy tree; Seed regrowth; Simple medium-sized leaf; Poles, construction, medicine
Combretum kraussii				N	N	N	N			N		N	N					Tall, multi-stemmed semi-deciduous canopy tree; Vegetative regrowth; Simple large leaf; Poles & laths
Croton sylvaticus					N								N					Early-regrowth deciduous canopy tree; Seed regrowth; Simple large leaf; Poles, Medicinal bark
Cunonia capensis	N	N, P						N	N									Tall evergreen canopy tree; Seed & vegetative regrowth; Compound leaf with large leaflets; Timber
Curtisia dentata	N	N, P	N	N	N	N	N	N	N			N						Tall evergreen canopy tree; Seed & vegetative regrowth; Simple medium-sized leaf; Timber, poles, medicinal bark

Species	**National forest types (see Table 2.1 for meaning of type abbreviations)***																	**General comments: Successional status & seasonality; Regrowth ability; Leaf type; Use**
	I 1&2	**I 3**	**II 1&2**	**II 3&4**	**III 1**	**III 2**	**IV 1**	**IV 2**	**IV 3**	**V 1**	**V 2**	**V 3**	**VI 1&2 &A4**	**VII 1&2**	**VII 3**	**A 1**	**A 2&3**	
Ekebergia capensis		N, P		N		N	N	N	N			N	N				N	Large semi-deciduous canopy tree; Seed & vegetative regrowth; Compound leaf with large leaflets; Timber, medicinal bark, fruit
Halleria lucida	N	N, P	N	N	N	N	N	N	N			N					N	Small early regrowth to mature forest understorey; Seed & vegetative regrowth; Simple medium-sized leaf; Landscaping
Harpephyllum caffrum							N	N	N	N	N	N	N	N				Tall semi-evergreen canopy tree; Seed & vegetative regrowth; Compound leaf with large leaflets; Timber, poles, medicine, fruit
Ilex mitis	N	N	N	N	N	N	N	N	N								N	Tall evergreen canopy tree in moist sites; Seed & vegetative regrowth; Simple medium-sized leaf; Timber, medicinal bark

Species	National forest types (see Table 2.1 for meaning of type abbreviations)*																	General comments: Successional status & seasonality; Regrowth ability; Leaf type; Use
	I 1&2	I 3	II 1&2	II 3&4	III 1	III 2	IV 1	IV 2	IV 3	V 1	V 2	V 3	VI 1&2 &A4	VII 1&2	VII 3	A 1	A 2&3	
Kiggelaria africana	N	N		N	N	N	N	N	N			N			N			Medium to tall pioneer to mature forest semi-deciduous canopy tree; Seed & vegetative regrowth; Simple large leaf; Poles, timber, laths,
Millettia grandis										N	N	N						Medium to tall pioneer semi-deciduous tree; Seed & vegetative regrowth; Compound leaf with medium-sized leaflets; Poles, wood-carving, fibre
Ocotea bullata	N	N, P		N			N	N										Tall regrowth to mature canopy tree; Strong vegetative regrowth; Simple large leaf; Timber, medicinal bark
Olea capensis macrocarpa	N	N, P	N		N	N	N	N	N	N		N		N				Tall mature forest evergreen canopy tree; Seed regrowth; Simple medium-sized leaf; Timber, construction, medicinal bark

Species	National forest types (see Table 2.1 for meaning of type abbreviations)*																	General comments: Successional status & seasonality; Regrowth ability; Leaf type; Use
	I 1&2	I 3	II 1&2	II 3&4	III 1	III 2	IV 1	IV 2	IV 3	V 1	V 2	V 3	VI 1&2 &A4	VII 1&2	VII 3	A 1	A 2&3	
Pittosporum viridiflorum		N	N	N		N	N	N	N			N						Semi-evergreen sub-canopy to canopy regrowth tree; Seed & vegetative regworth; Simple medium-sized leaf; Construction, medicinal bark
Afrocarpus falcatus	N	N, P		N	N	N	N	N	N, P			N	N	N			N	Tall canopy tree; Seed regrowth; Simple small leaf; Timber, construction, poles, wood-carving
Podocarpus henkelii				N			N	N, P										Tall canopy tree; Seed regrowth; Simple medium-sized leaf; Timber, construction, poles, wood-carving
Podocarpus latifolius	N	N, P	N	N	N	N	N	N, P	N, P			N		N				Tall canopy tree; Seed regrowth; Simple medium-sized leaf; Timber, construction, poles, wood-carving
Protorhus longifolia						N	N	N	N	N		N	N	N				Tall canopy tree; Seed & vegetative regrowth; Simple, large leaf; Poles

Species	National forest types (see Table 2.1 for meaning of type abbreviations)*																	General comments: Successional status & seasonality; Regrowth ability; Leaf type; Use
	I 1&2	I 3	II 1&2	II 3&4	III 1	III 2	IV 1	IV 2	IV 3	V 1	V 2	V 3	VI 1&2 &A4	VII 1&2	VII 3	A 1	A 2&3	
Prunus africana		N, P	N	N	N	N	N	N				N						Tall regrowth semi-evergreen canopy tree; Seed & vegetative regrowth; Simple large leaf; Medicinal bark, timber
Ptaeroxylum obliquum				N			N	N	N	N	N	N, P	N	N				Tall regrowth deciduous canopy tree; Seed & vegetative regrowth; Compound leaf with medium-sized leaflets; Timber, construction, poles, medicinal bark
Rapanea melanophloeos	N	N, P		N	N	N	N	N	N			N					N	Tall regrowth evergreen canopy tree; Seed regrowth; Simple large leaf; Timber, construction, medicinal bark
Schefflera umbellifera		N			N	N	N	N	N				N				N	Tall semi-evergreen regrowth canopy tree; Seed & vegetative regrowth; Compound leaf with large leaflets; ??

Species	**National forest types (see Table 2.1 for meaning of type abbreviations)***																	**General comments: Successional status & seasonality; Regrowth ability; Leaf type; Use**
	I 1&2	**I 3**	**II 1&2**	**II 3&4**	**III 1**	**III 2**	**IV 1**	**IV 2**	**IV 3**	**V 1**	**V 2**	**V 3**	**VI 1&2 &A4**	**VII 1&2**	**VII 3**	**A 1**	**A 2&3**	
Sideroxylon inerme		N							N				N	N	N			Large spreading multi-stemmed canopy tree; Seed & vegetative regrowth; Simple medium to large leaf; Timber, construction
Syzygium cordatum			N										N			N	N	Medium to large regrowth tree; Seed & vegetative regrowth; Simple large leaf; Construction, poles, fruit
Trema orientalis						N												Small to medium pioneer tree; Seed & vegetative regrowth from roots; Simple medium-sized leaf; Landscaping
Vepris lanceolata		N		N	N	N	N	N	N			N	N	N				Tall semi-deciduous regrowth canopy tree; Seed & vegetative regrowth; Trifoliate leaf with large leaflets; Poles, construction, medicinal bark
Virgilia divaricata/or oboides	N	N																Pioneer evergreen tree; Seed regrowth; Compound leaf with small leaflets; Landscaping

Table 16. Useful, fast-growing tree species, ranked according to their relative growth rates inside and outside the forest, and different noted uses (according to Palmer & Pitman 1972).

Species	Growth rate*		Uses																	Notes on coppice regrowth rate
	F	O	Wood					Medicine					Food		Crafts		Other			
			Furniture	Constructi	Poles	Fuel wood	Crafts	Leaves	Fruit	Bark	Roots	Other	Fruit	Other	Binding	Other	Horticultur	Other	Total	
Acacia karoo	0	2	1	1		1						1		1	1	1	1	1	9	None
Albizia adianthifolia	1	2	1	1	1	1				1							1		6	?
Apodytes dimidiata	1	1	1	1		1	1										1		5	Medium
Celtis africana	1	2	1	1			1										1	1	5	Medium
Combretum kraussii	1	2															1		1	Fast
Cunonia capensis	1	2	1									1					1		3	Fast
Curtisia dentata	2	2	1	1		1	1			1		1					1		7	Medium-fast
Ekebergia capensis	1	2	1							1	1		1				1		5	Medium
Halleria lucida	1	2					1					1	1				1		4	Fast
Harpephyllum caffrum	1	2	1			1				1			1				1		5	?
Ilex mitis	2	2	1	1		1		1		1							1	1	7	Fast
Kiggelaria africana	1	2	1	1								1					1		4	Fast
Millettia grandis	0	2	1	1			1		1		1						1		6	Fast
Ocotea bullata	1	2	1	2			1			1									5	Fast
Olea cap macrocarpa	1	1	1	1		1	1						1				1		6	None
Pittosporum viridiflorum	1	2								1							1		2	Medium
Podocarpus latifolius	1	1	1	1			1										1		4	None
Afrocarpus falcatus	1	2	1	1	1		1										1		5	None
Podocarpus henkelii	1	2	1	1													1		3	None
Protorhus	1	2	1	1						1							1	1	5	?

Species	Growth rate*		Uses																	Notes on coppice regrowth rate
	F	O	Wood					Medicine					Food		Crafts		Other			
			Furniture	Constructi	Poles	Fuel wood	Crafts	Leaves	Fruit	Bark	Roots	Other	Fruit	Other	Binding	Other	Horticultur	Other	Total	
longifolia																				
Prunus africana	0	2	1							1							1		3	Medium
Ptaeroxylon obliquum	0	2	1	1	1	1				1							1	1	7	Fast
Rapanea melanophloeos	0	2	1	1			1			1							1		5	Slow when big
Schefflera umbellifera	0	2						1									1		2	Medium
Sideroxylon inerme	1	1		1	1					1	1						1		5	Medium
Syzygium cordatum	0	1		1		1						1	1			1	1		6	Medium
Vepris lanceolata	1	2		1			1				1						1		4	Fast
Virgilia divaricata	0	2	1	1		1	1							1			1		6	None

*Growth rate indicated as 0=none (shade-intolerant); 1=slow; 2=fast, for inside Forest=F & Outside forest=O