CHAPTER 7

The Relationship between Bark Thickness and Tree Size

PART 1:

Relationship between bark thickness and diameter at breast height for six tree species used medicinally in South Africa

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Abstract
Bark is the most popular product harvested for traditional medicine in South Africa. Harvesting is sometimes selective for particular stem size-classes and the effect of bark removal and the sustainability of harvesting practices are species-specific. However, baseline autecological data that would assist conservation and trade monitoring efforts are not easily measured and rarely available. In an effort to link bark thicknesses recorded during three ethnobotanical surveys in the traditional medicine markets of Johannesburg, the relationship between bark thickness and stem diameter at breast height (dbh) was investigated for six species used medicinally in South Africa. Samples of bark were removed from 207 stems and subsequently weighed and measured. Thereafter, the samples were placed in a phytotron chamber to dry out over a period of 12 weeks. The change in bark thickness over time was regressed with stem diameter in order to predict stem diameter from bark thickness records. The strength of the relationship between bark thickness and diameter was strongly influenced by the macroscopic bark morphology of the species. Species where the rhytidome tended to stay on the stem exhibited similar stronger r^2 values (r^2=0.80–0.88) compared to the lower values for species that shed their bark (r^2=0.005). Using *Warburgia salutaris* as an example, the prevalence of bark of certain thicknesses in the medicinal markets was used to evaluate the change in tree size-classes over a 6-year period. Results showed that whereas trees larger than 40 cm dbh were available in 1995, in 2001 bark from trees less than 25 cm dbh were more prevalent.

Key words: bark thickness, DBH, medicinal plants, resource use, rhytidome

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1. Introduction

A consequence of early African traditional utilisation practices based on culture and constraints was the conservation of plant resources and the low levels of exploitation of commonly used resources such as traditional medicines (Cunningham 1988, Netshiluvhi 1996). However, increasing pressures on the agricultural and rural land base have resulted in plant resources providing one of the main sources of non-farm income to millions of people in rural households (Arnold 1996, Shackleton *et al.* 2001, Dovie *et al.* 2002). The reliance of these households on natural resources appears to be increasing rather than decreasing (Shackleton *et al.* 2001) and, coupled with the breakdown of customary conservation controls brought about by the commercialisation of the traditional medicine trade, unprecedented levels of resource exploitation and depredation are being reached. As the demand for traditional medicines continues to grow, an estimated 20000 tonnes of plant material is traded annually in South Africa (Mander 1998), most of which is derived from woodland and forest habitats (at least 68% of the mass sold) (Williams 2004).

In South Africa, bark is the most popular medicinal product harvested from trees and accounts for at least 31% of the plants harvested and traded annually in KwaZulu/Natal (Mander 1998, Grace *et al.* 2002) (Fig. 1). In the Witwatersrand markets for traditional medicine, centred in Johannesburg, approximately 205 (33%) of the species estimated to be sold are trees (Williams 2004). Sixty-eight percent of these species are harvested for medicinal bark, of which 51% are exclusively harvested for bark and not for other products such as roots, fruits and leaves.

Fig. 1: A group of *Elaeodendron transvaalense* (formerly known as *Cassine transvaalensis*) stripped for bark in the Ngwavuma region of KwaZulu-Natal in 1998. The tree in the foreground was recently ring-barked, while the 6 trees behind it had been previously stripped and were dead. Two of the trees had been felled. Near this tree clump were at least 8 other mature individuals that had been ring-barked, sometimes to a height of 2.5 m. A 2 m height pole is to the right of the tree.

Bark harvesting is often selective for particular stem size-classes or bark quality (Cunningham 2001). In southern Africa and Uganda, for example, herbalists prefer to harvest thick bark from more mature trees as it is considered more potent and effective (Kamatenesi 1997, Cunningham 2001). The effect of bark removal on trees, wound re-growth and the sustainability of harvesting practices is species-specific and depends on factors such as stem diameter, wound shape and depth (Geldenhuys 2003, Twine 2004), the direction of the wound in relation to the sun (VL Williams unpublished data), the intensity of bark removal (harvesting frequency and bark quantity) and plant physiology (Cunningham 2001). The sustainability of harvesting bark is also assessed according to knowledge of tree distribution, abundance, population structure (e.g. age/size distribution) (Hall and Bawa 1993) and factors such as tree growth and bark recovery rates (Geldenhuys 2004a). This knowledge informs the status of a population in question, and insight into how this status might change over time. Baseline autecological data, however, are rarely available and are not easily measured.

Data from three surveys of medicinal plants traded in and around Johannesburg, South Africa, between 1994 and 2001 revealed a change in bark thickness size-classes sold by street sellers and herbal chemists or '*muti*' shops. The size of plant parts traded is a useful indicator of species availability (Botha *et al.* 2001) and bark generally gets thicker as the tree grows. It is important to link records collected in ethnobotanical surveys of local markets to field measurements (Cunningham 2001), and a question that arises is: how does one translate bark thickness records from local markets to tree size, population structure and the size-class of trees available to the bark harvesters in the wild, as well as the sustainability of harvesting practices?

In the absence of practical techniques to determine the age of trees, size can be used as a surrogate (van Wyk *et al.* 1996). Tree stems generally increase in girth as the plants get older, and diameters are therefore the most appropriate measure for grouping plants into size classes (Cunningham 2001). Measuring the relationship between bark thickness and aspects of the tree stem profile (e.g. diameter at breast height, dbh) enables tree size to be correlated with bark thickness for individual plants, and in addition ascertain potential bark yields for different tree size-classes (Cunningham 2001).

Literature on the relationship between bark thickness and stem girth are limited for African species. In South Africa, van Laar and Geldenhuys (1975) derived six regression equations for the relationship between double bark thickness and branch-free stem length for groups of species in forests of the southern Cape (now Western Cape Province) (double bark thickness equals the over-bark diameter minus the under-bark diameter of the stem at a certain point) . Geldenhuys also undertook research on trees in the Southern Cape Afrotemperate Forests and derived equations for bark thickness and dbh for about 20 species (unpublished research, CJ Geldenhuys *pers. comm.*). Botha (2001) correlated bark thickness with basal diameter for *Warburgia salutaris* (Bertol.f.) Chiov., *Catha edulis* (Vahl.) Forsk. ex Enfl., *Rapanea melanophloeos* (L.) Mez and *Acacia xanthophloea* Benth. And, Wilson and Witkowski (2003) examined the relationship between trunk circumference and bark thickness for the savanna tree *Burkea africana* Hook. in the Nylsvley Nature Reserve in the Limpopo Province, South Africa. In Uganda, Kamatenesi (1997) correlated bark thickness and dbh for three species of *Rytigynia*, important medicinal plants harvested for bark. Cunningham *et al.* (2002) derived a quadratic regression for the relationship between dbh and mean bark thickness for *Prunus africana* (Hook.f.) Kalkm. trees in Cameroon, the most exploited of any African medicinal plant in international trade.

Bark thickness can vary considerably with changes in stem diameter. In a study on *Pinus kesiya* Royle ex Gordon in Tanzania, bark thickness was shown to attain its highest value closest to the ground and decrease with increasing height up the stem (Eerikäinen 2001). The tapering of a stem therefore has an effect on bark development, although Kamatenesi (1997) did not find these differences to be significant in *Rytigynia* spp. De Jong and Bonnor (1995) assumed that the bole of the Pacific Yew (*Taxus brevifolia* Nutt.) was conical, and derived an equation for bark thickness that decreased linearly with increasing height up the stem, depending on the dbh.

This paper quantifies the relationship between bark thickness and dbh for six tree species used medicinally in South Africa. The purpose of this investigation is: 1) to develop practical methods that estimate, from bark thicknesses recorded in medicinal plant markets, the dbh of the trees harvested for bark to enable assessments of the tree sizes that are targeted by harvesters to be made; 2) to examine the weekly decrease in the thickness of bark samples until they are oven dried after 12 weeks; and 3) to evaluate the change in available tree size-classes over a 6-year period from bark thickness records acquired during three ethnobotanical surveys in Johannesburg between 1994 and 2001, using *Warburgia salutaris* as an example. The relationships between bark thickness and tree girth are discussed in conjunction with macroscopic bark anatomy to better describe and understand the results.

2. Bark Anatomy, Morphology and Re-growth

The term 'bark' is used in a non-technical context to describe all tissue external to the vascular cambium regardless of its specific structure (Borger 1973, Trockenbrodt 1990, Junikka 1994). In this sense, therefore, the bark is an aggregation of secondary phloem, cortex and periderm. Periderm is secondarily developed protective bark tissue replacing the epidermis and consists of: the phellogen, the lateral meristematic tissue that produces the periderm; the phellem, the dead chiefly suberized or lignified protective tissues formed outwardly by the phellogen; and the phelloderm, a living parenchyma formed inwardly from the phellogen (Trockenbrodt 1990, Biggs 1992, Junikka 1994). In some species, the same phellogen is active each year and a thick layer consisting solely of phellem is formed. In most species, however, '*sequent periderms*' develop at successively greater depths (Trockenbrodt 1990, Biggs 1992), i.e. a new phellogen arises annually in the cortex, and the bark thus consists of alternating and accumulated layers of phellem and dead cortex tissue (Blackmore 1984). This aggregate of layers of dead tissues is referred to as 'rhytidome' – a term often considered synonymous with 'outer bark' (Borger 1973). However, the term 'outer bark' should be applied to all dead tissues exterior to the innermost phellogen, and includes species without a rhytidome (i.e. species that maintain the same phellogen, such as smooth-barked species) (Borger 1973, Biggs 1992). The outer bark is cut off by the periderm from the still living secondary phloem and includes the dead tissue of the last formed periderm (Junikka 1994). 'Inner bark' refers to the living organs of the bark that includes the phloem and the living tissue up to the last formed periderm, namely phellogen and phelloderm. The inner bark is therefore the principal assimilate conducting tissue usually located outward of the xylem and inward of the periderm (Junikka 1994).

As a tree grows in diameter, the bark tissues are stretched and eventually crack when the periderm is unable to contain the increased girth (Penfold and Willis 1961). In older trees, a new phellogen is then originated in the phloem (in younger trees the origin is in the cortex) and the tissues outside this new layer die and dry out. As a tree grows in circumference and the thickness of the bark increases, the outer layers of bark may either become fissured (e.g. *Albizia adianthifolia* (Schumach.) W.F.Wight) or be shed (e.g. *Acacia xanthophloea*). Bark thickness generally increases with stem age and diameter (Borger 1973). In some species, a straight-line relationship exists between bark thickness and stem diameter – this relationship probably results from the resistance of the bark to weathering and to the persistent nature of the rhytidome (Borger 1973). In other species, however, the relationship is weak or curvilinear, owing to shedding of the bark tissue (Borger 1973) to a greater (e.g. sheets of bark) or lesser (e.g. flakes) extent. For many species, the diagnostic characters of the rhytidome that determine bark patterns and types are only evident in older trees. This is because rhytidome is influenced by weathering processes, tangential strains, the growth pattern of the periderm, the arrangement of the phellem, and the amount of tissue cut off by the periderm from the inner bark (Junikka 1994). The thickness of the rhytidome may also be genetically controlled, and vary with tree growth, age and exposure.

From the literature available on the development and shedding of characteristic bark types (e.g. Borger 1973, Junikka 1994), *W. salutaris* and *A. adianthifolia* appear to resemble fissured barks, characterised by blocks of bark in older trees that do not separate and shed owing to an inter-locking system of fibres (Borger 1973) and bark that is cracked lengthwise into fissures separated by ridges (Junikka 1994). As a result, the rhytidome may accumulate to great depths in older trees and hence show a strong linear relationship (as results later show, e.g. Fig. 5) between bark thickness and stem diameter. The bark of *Balanites maughamii* Sprague and *Rhus chirindensis* Baker f. resembles tessellated bark because the surface is marked by more or less regular square or oblong plates or blocks remaining on the stem for a long time (Junikka 1994). The rhytidome is short-fibred, breaks up into small plates, and the blocks are usually retained on the trunk (Junikka 1994). The linear relationship between bark thickness and stem diameter in these species was shown to be intermediate in strength. *Elaeodendron transvaalense* (Burtt Davy) R.H.Archer (formerly *Cassine transvaalensis*) resembles patchy bark because of the lighter blotches on the outer surface of the rhytidome resulting from the irregular dehiscence of old rhytidome plates. As a result, the relationship between bark thickness and stem diameter would not be expected to be very strongly linearly correlated because some of the rhytidome flakes persist and others do not. The bark of *A. xanthophloea* resembles smooth and powdery bark, and the attrition of tissue is usually commensurate with the rate of formation of phellem cells (Borger 1973). The term 'xanthophloea' implies the presence of the photosynthetic yellow-green accessory pigment 'xanthophyll' in the secondary phloem of the inner bark. The outer phellem cells are sloughed off in small clusters, giving the bark a powdery appearance. In addition, tangential stresses in *A. xanthophloea* induce the tearing of the outer phellem and the loss of the outer bark as large strips when the diameter of the tree becomes too large for its bark (O. Grace pers. comm.). This therefore results in a weak linear correlation between bark thickness and stem diameter.

3. Study Sites and Species

Between March and May 1998, various aspects of the tree stem profile were measured and 1026 bark samples removed from 207 individual stems of six species at fifteen woodland sites in three South African provinces. Seven of the sites were on privately owned land, four were in protected areas, three on then state-owned forestry land and one on communal land (Table 1).

Table 1: Description of the sample sites and the number of individuals sampled per species at each site. The species are: *Acacia xanthophloea* Benth.; *Albizia adianthifolia* (Schumach.) W.F.Wight; *Balanites maughamii* Sprague; *Elaeodendron transvaalense* (Burtt Davy) R.H.Archer [formerly *Cassine transvaalensis* (Burtt Davy) Codd]; *Rhus chirindensis* Baker f.; *Warburgia salutaris* (Bertol.f.) Chiov.

Province	Site code	Area in province	Ownership and management regime	Species sampled (No.)
Limpopo	L1	Western Soutpansberg	Private game farm	*R. chirindensis* (11) *W. salutaris* (27)
	L2	Western Soutpansberg	Private farm	*B. maughamii* (17) *E. transvaalense* (1) *R. chirindensis* (9)
	L3	Western Soutpansberg	Private farm	*E. transvaalense* (5)
	L4	Western Soutpansberg	Private farm	*B. maughamii* (13)
	L5	Nylstroom	Protected area	*E. transvaalense* (13)
	L6	Eastern Soutpansberg	Forestry	*A. adianthifolia* (29)
	L7	Eastern Soutpansberg	Forestry	*A. adianthifolia* (13)
	L8	Eastern Soutpansberg	Forestry	*R. chirindensis* (4)
Mpumalanga	M1	Nelspruit	Protected area	*A. xanthophloea* (1) *B. maughamii* (2)
	M2	South of Malalane	Private farm	*R. chirindensis* (5)
	M3	South of Malalane	Private mine	*R. chirindensis* (5)
KwaZulu-Natal	K1	Maputaland	Protected area	*A. xanthophloea* (12)
	K2	Maputaland	Communal land	*A. xanthophloea* (1) *B. maughamii* (3) *E. transvaalense* (6)
	K3	Zululand	Protected area	*A. xanthophloea* (1) *A. adianthifolia* (4) *B. maughamii* (1)
	K4	Zululand	Private company protected area	*A. xanthophloea* (19) *A. adianthifolia* (1) *B. maughamii* (3) *E. transvaalense* (6)

The six tree species investigated were previously selected to represent various risk categories for over-exploitation by the medicinal plant trade (V.L. Williams unpublished data). All the species, except for *R. chirindensis*, have been short-listed in other studies as being over-exploited or more in demand than other species for their bark (e.g. Mander 1998, Netshiluvhi 1999, Grace 2002). *W. salutaris* is the most threatened of the six species. Endangered and protected in KwaZulu-Natal, it is nationally endangered and has a high risk of extinction in the near future (J. Victor, SANBI, pers. comm.). *E. transvaalense* is currently the most prevalent bark species in the Johannesburg markets (Williams, 2003). The species is high in demand, vulnerable to bark harvesting and declining in numbers (Cunningham 1988, Netshiluvhi 1999, Grace *et al.* 2002, Twine 2004). *A. adianthifolia* is widely used and there is evidence of declining availability and increased scarcity (Grace 2002). The yellow bark of the fever tree, *A. xanthophloea*, is frequently demanded by customers in the Johannesburg and KwaZulu-Natal markets (Mander 1998, Grace 2002, Williams 2003) but the species is not currently threatened by harvesting although some scarcities have been reported (Grace 2002). The bark of *B. maughamii* is sought after and classed as declining in KwaZulu-Natal (Cunningham 1988, Twine 2004). *R. chirindensis* is not a highly sought after species, but in South Africa it shares a common Zulu name (inyazangoma-elimnyama) with the globally threatened species *P. africana*. The two species could potentially be confused during market surveys and assessments if the bark is not positively identified. Geldenhuys (2003, 2004b), however, reported *R. chirindensis* to be one of the important tree species harvested intensely for bark in the Umzimkulu Forests of the Eastern Cape.

4. Field Methods and Data Analysis

At each sample site, trees were selected from various size-classes based on the stem diameter at breast height (dbh, 1.3 m above the ground). None of the individuals sampled had suffered any prior harvesting damage and the bark on the bole was intact. Stem diameter-classes for *A. xanthophloea, A. adianthifolia, B. maughamii and E. transvaalense* were in increments of 10 cm, starting at 10 cm and ending at 50 cm, 60 cm, 60 cm and 50 cm for each species respectively. Diameter-classes for *R. chirindensis* and *W. salutaris* were in increments of 5 cm, starting at 5 cm and ending at 35 cm and 30 cm respectively due to the prevalence of individuals in these size ranges. Individuals larger than 25 cm were infrequently encountered in 1998 for these two species (except for a very large *W. salutaris* specimen with a dbh >65 cm that was sampled), although a revisit to two of the sites in 2004 located populations with many individuals in the 30–39 cm size-class that had not previously been located. A minimum of 5 and a maximum of 10 trees per diameter-class were sampled in total (but not per site), although specimens in the ≥40 cm size-classes were sometimes more difficult to find and between 2 and 4 trees were often sampled in this class (except for *A. adianthifolia*, where trees larger than 60 cm dbh could have been sampled). *Balanites maughamii* individuals larger than 60 cm dbh were found in the communal land; these were not sampled, however, as commercial bark harvesters had previously damaged them. The method for harvesting *B. maughamii* bark is different to other species: the tree has a fluted trunk and in many cases a whole flute with the timber and bark is chopped off, clearly reducing the dbh of the tree (VL Williams unpublished data). *Rhus chirindensis* and *W. salutaris* were well sampled up to the 25 cm and 20 cm diameter-classes respectively; thereafter, larger trees were not very prevalent in the populations visited.

Once a tree at a site was selected, the following information was recorded: 1) characteristics of the site and habitat; 2) a sketch of the tree indicating important and potentially relevant features (e.g. bole shape, multiple stems and branching); 3) the diameter of the stem at five height intervals [termed $D_{0.5}$; $D_{1.0}$; $D_{1.3}$ (dbh); $D_{1.5}$ and $D_{2.0}$ to represent the respective diameters of the stem at 0.5 m, 1.0 m, 1.3 m, 1.5 m and 2.0 m]; 4) the approximate height of the tree; and 5) the approximate branch-free bole length. Stem diameter was measured using a forestry 'diameter tape' that allows diameter to be read directly from a circumference measurement. Vertical height and branch-free bole length were estimated using a height pole marked in 0.5 m intervals.

Using a hole-saw attached to a brace, 50 mm diameter circular bark samples were cut and removed at $D_{0.5}$, $D_{1.0}$, $D_{1.3}$ and $D_{1.5}$ (Fig. 2). The $D_{2.0}$ level was too high to be reached with the hole-saw and so a 10 mm-diameter sample was removed with a belt punch and hammer. The 50 mm circular bark samples had a 5 mm hole in the centre and were threaded on to a labelled cable-tie (species, specimen number, date sampled). Bark thickness was measured on site using a digital Vernier calliper (accuracy: 0.01 mm), and the wet mass was determined with a portable digital balance. Samples were taken to the laboratory at the University of the Witwatersrand approximately four days after harvesting and re-measured, this time using an electronic balance accurate to 0.0001 g. The samples were then placed in a phytotron chamber for 11 weeks to dry out. The chamber was set at a temperature and relative humidity (RH) that mimics mean day and night summer conditions in September – March in Johannesburg (and in the conditions in Johannesburg that bark would be exposed to in the open-air medicinal plant markets), namely: day T^o=20 ^oC; night T^o=16 ^oC; day RH=59%; night RH=66%; length of day=12 hours.

Fig. 2: Field methods for sampling the trees. (a) Bark samples are removed from *Acacia xanthophloea* at 0.5 m intervals up to 2 m and including 1.3 m, (b) The diameter is measured using a forestry 'diameter tape', (c) 50 mm circular samples are removed from the tree using a hole-saw and brace and then (d) threaded on to a labelled cable-tie in the order that they were removed from $D_{0.5}$, $D_{1.0}$, $D_{1.3}$ and $D_{1.5}$.

The bark thickness and mass of the samples in the chamber were re-measured every 7 days to monitor any changes in thickness or mass. After 11 weeks in the chamber (12 weeks after harvesting), the samples were oven dried at 80 ^{o}C for four days to determine the oven-dry bark thickness and mass. A total of 14 time intervals were therefore recorded and are abbreviated as follows in the paper: W0=on-site measurements the day the bark was removed from the tree; W1=first of the laboratory measurements approximately 4 days after the bark was harvested and just before being placed in the chamber; W2=first measurement after one week in the chamber and two weeks after harvesting; W3=second measurement after two weeks in the chamber and three weeks after sampling; W4 to W11=third to tenth measurements after being placed in the chamber and four to twelve weeks after sampling; W12=last measurement after 11 weeks in the drying chamber and 12 weeks after harvesting; W13=final measurements after oven drying.

Regressions between $D_{0.5}$, $D_{1.0}$, $D_{1.3}$, $D_{1.5}$, $D_{2.0}$ and the bark thickness of the samples were calculated for the six species at the 14 time intervals using STATISTICA 6 and Excel 2000. In this paper, however, only the results of the $D_{1.3}$ (dbh) and bark thickness regressions are presented. Outliers greater than 2 standard deviations were removed from the calculations only if the same outliers appeared in the first (W0) and last (W13) regressions. Hence, each regression equation is calculated using the same set of data. Between one and four outliers were removed per species. In a subsequent paper by the authors, regressions between stem diameter ($D_{0.5}$, $D_{1.0}$, $D_{1.3}$, $D_{1.5}$, $D_{2.0}$) and bark mass, area and volume will be described. The regression equations for predicting bark thickness from dbh were used to construct the tables in the Appendix 1 that predict dbh from bark thickness, depending on the number of weeks after bark harvesting has occurred. However, an assumption one has to make when using the prediction tables in this paper, is that the bark has been harvested at dbh.

5. Results

5.1. Bark thickness, tapering and height up the stem

Bark thickness varies on different parts of the stem. Thicker bark is commonly found near the base of the stem and decreases in thickness with increasing height up the stem (Fig. 3a-f). For species that do not shed their rhytidome, e.g. *A. adianthifolia*, *B. maughamii* and *W. salutaris*, the differences between bark thickness at 0.5 m and 2.0 m are more pronounced. Bark thicknesses for the smooth barked species *A. xanthophloea,* which periodically sheds its bark in large strips, are variable between the base of the stem and 2.0 m with no clear decrease with stem height. Not only is bark thickness affected by the height up the stem, but also by the age of the individuals (assuming age is related to size). The generally larger and older trees exhibit a more pronounced decrease in bark thickness between 0.5 m and 2.0 m than do the smaller individuals. The degree of stem tapering is shown in Fig. 4a-f. For all species, except *A. xanthophloea*, there is a general decrease in stem diameter with increased height up the stem. This tapering is especially prominent between 0.5 m and 1.0 m. Because this paper addresses only bark thickness in relation to dbh (the most commonly used comparative tree measurement in quantitative forest inventory analyses; Brokaw and Thompson 2000, Cunningham 2001), figures 3 and 4 also illustrate where the results at 1.3 m lie in relation to the remainder of the stem up to 2 m.

5.2. Regression of bark thickness and dbh at Week 0

The relationship between dbh ($D_{1.3}$) and bark thickness measured on the day of sampling (time=W0) ranged from a highly significant positive linear relationship for *W. salutaris* (r^2=0.88, P<0.00001) (Fig. 5f) to a weaker linear relationship for *E. transvaalense* (r^2=0.50, P=0.00002) (Fig. 5d). The linear regression for *A. xanthophloea* indicated no relationship between bark thickness and dbh (r^2=0.005, P=0.91) (Fig. 5a); hence, bark thickness cannot be predicted from the diameter of the tree stems for this species.

The strength of the linear relationships between bark thickness and dbh for the six species corresponds with the development and shedding of characteristic bark types. The fissured and non-shedding barks of *A. adianthifolia* and *W. salutaris* show a strong linear relationship between bark thickness and dbh ($r^{2=}$0.80 and 0.88 respectively). *B. maughamii* and *R. chirindensis* have tessellated bark, and the relationship is not as strong ($r^{2=}$0.61 and 0.68 respectively). Species that shed bark do not have strong linear relationships between bark thickness and dbh. The irregular dehiscence of the rhytidome plates (patchy bark) on the stems of *E. transvaalense* results in a weak linear relationship of $r^{2=}$0.50. Bark on *A. xanthophloea* peels off in large strips resulting in no relationship with dbh (r^2=0.005).

5.3. Changes in bark thickness over 12 weeks relative to dbh

Linear regression models were fitted to estimate bark thickness from diameter measurements at breast height. Additionally, the models were fitted to estimate the thickness of bark between one and twelve weeks after having been removed from the tree at $D_{1.3}$, as well as the final oven-dried thickness at W13. The relationships are depicted in Fig. 6 (a-f) and the equations given in Appendix 1. The change in bark thickness can be estimated with high accuracy at dbh for *A. adianthifolia*, *B. maughamii*, *R. chirindensis* and *W. salutaris* (P<0.00001) (Appendix 1). However, there is a less significant positive relationship for *E. transvaalense* (Appendix 1). No relationship between dbh and bark thickness exists for *A. xanthophloea* for the change in thickness over time as the bark dries out

(*P*=0.91 and 0.52 for W0 and W13 respectively) (Appendix 1), and hence bark thickness cannot be predicted from dbh.

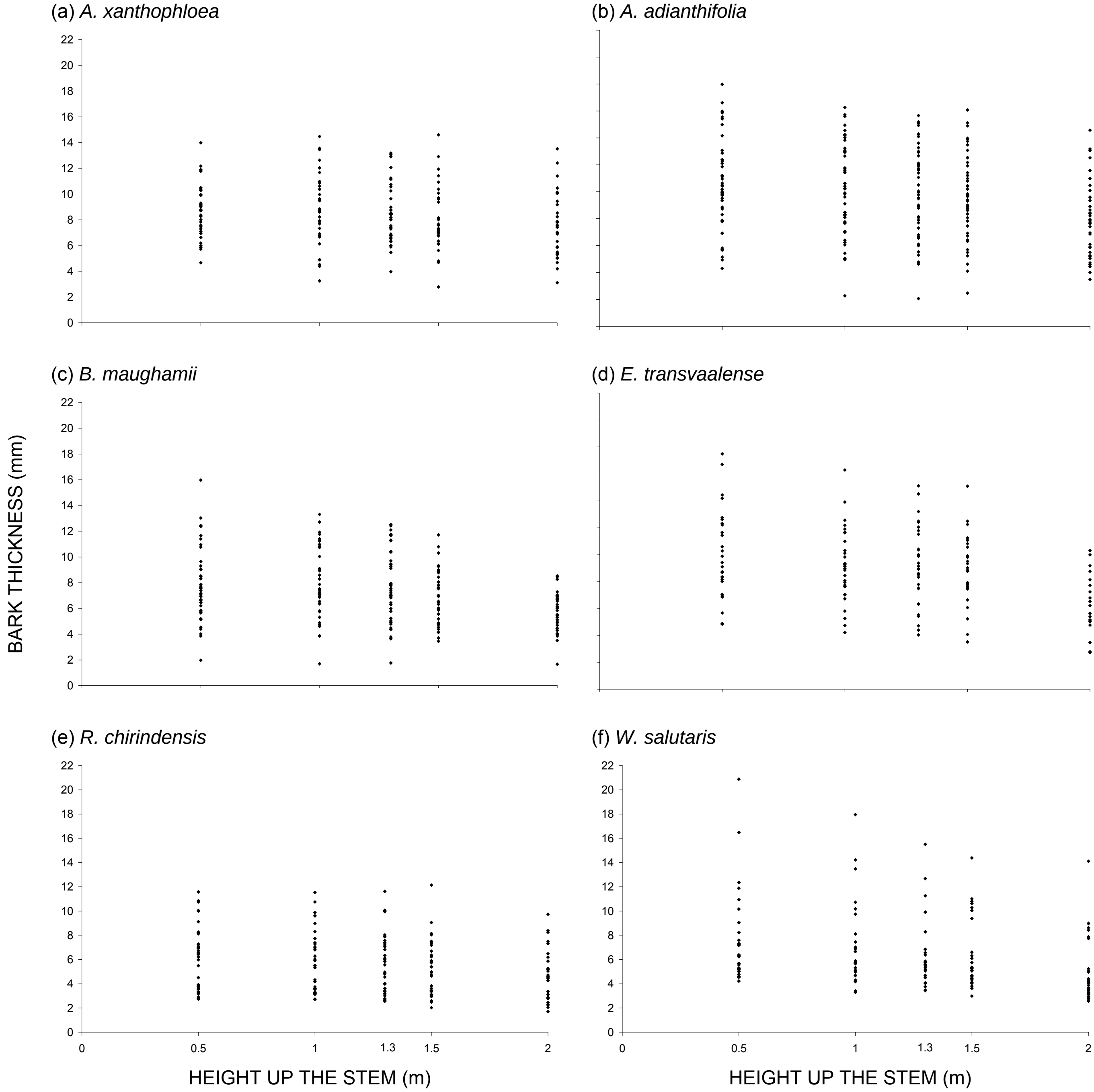


Fig. 3: Development of bark thickness up the tree stem. The smallest bark thicknesses are for the smallest individuals sampled and the largest thicknesses for the largest individuals sampled. Measurements were taken up the stem to 2 m and include 1.3 m

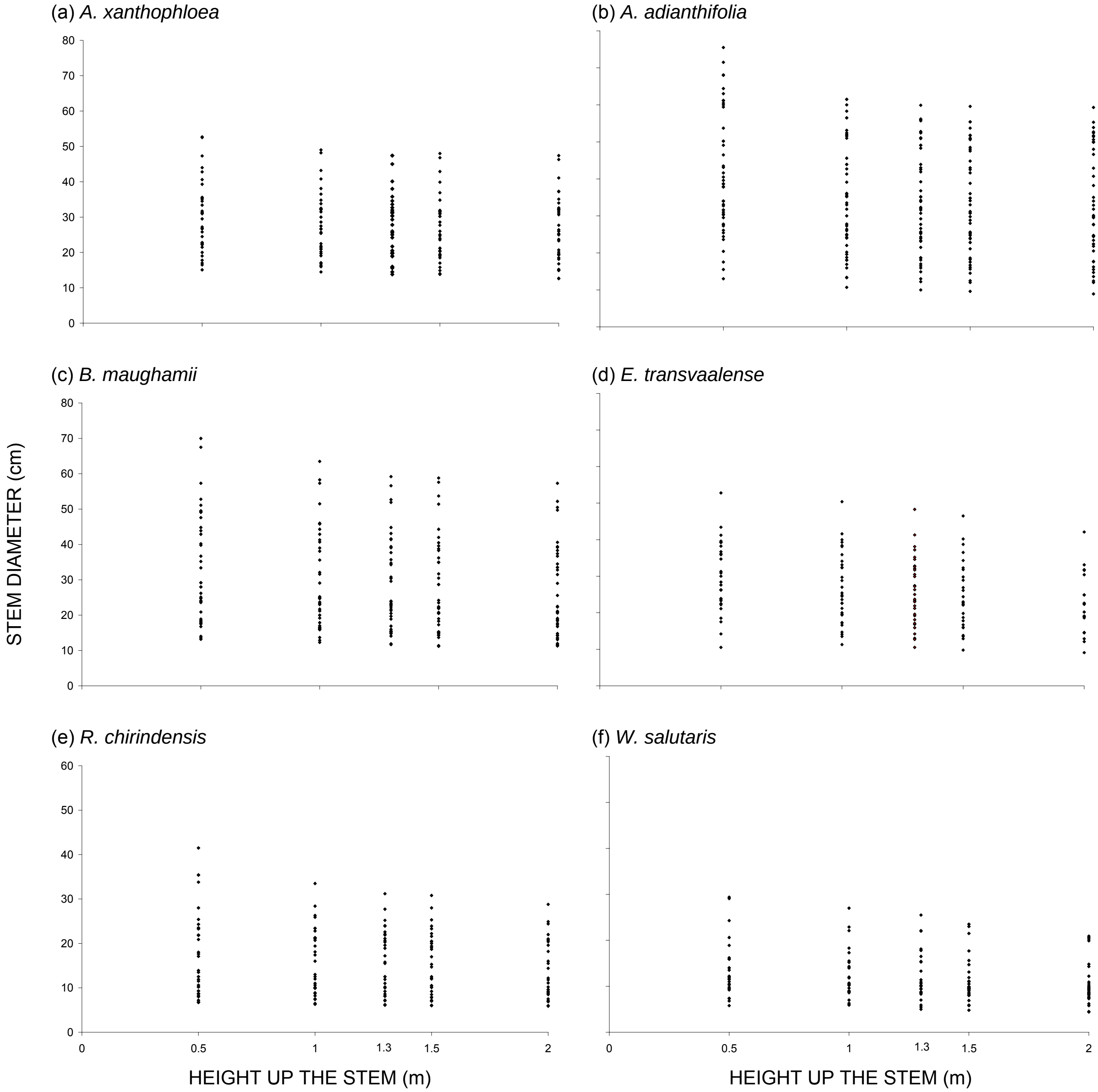


Fig. 4: Tapering of the tree trunk with increasing height up the stem. The smallest stem diameters at a given height are for the smallest trees and the biggest diameters for the biggest trees.

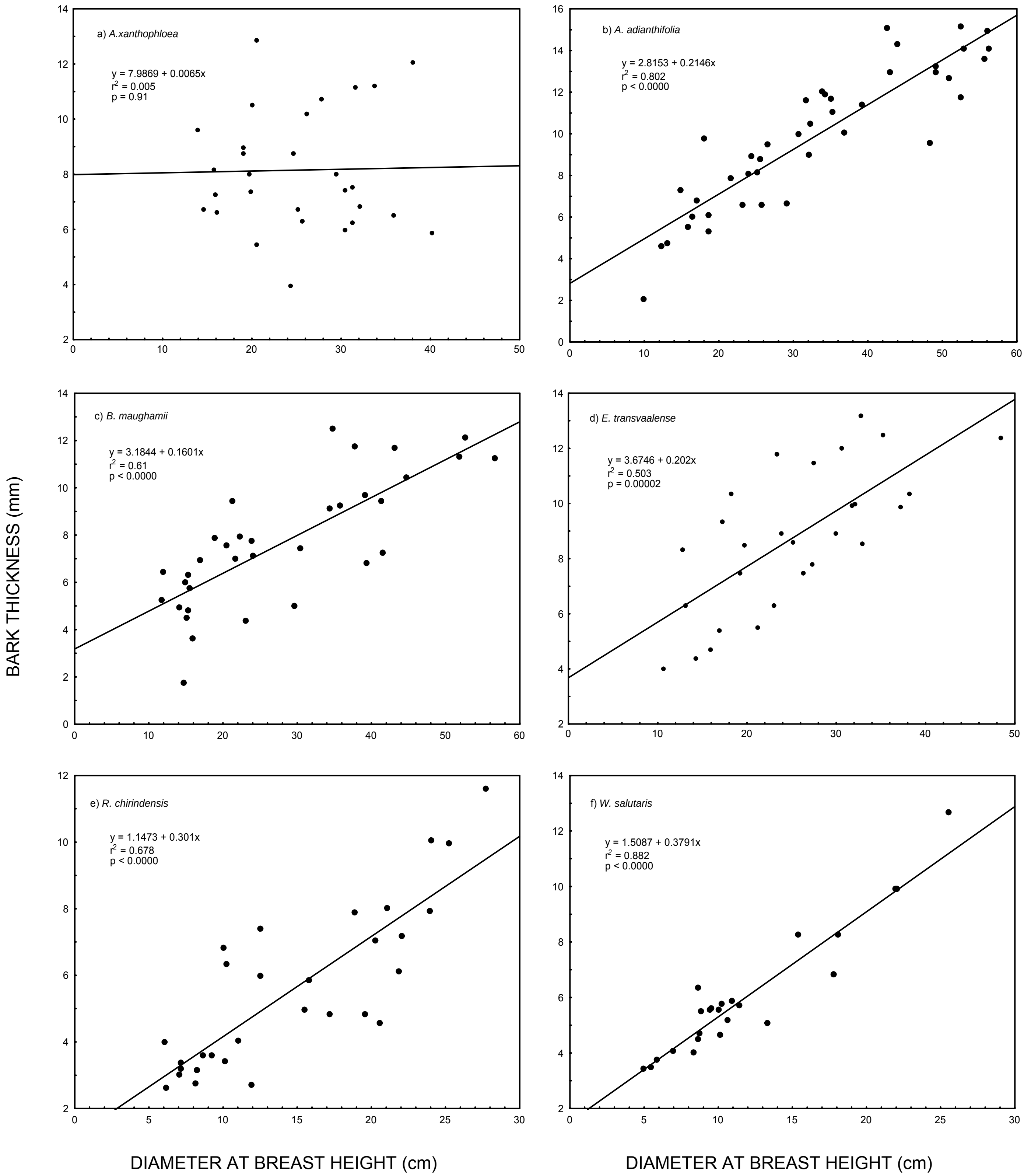


Fig. 5: Relationship between fresh bark thickness and diameter at breast height at time W0 – the day the bark samples were removed from the tree trunk. Note: one *W. salutaris* individual of dbh ≈68cm was found; however branching occurred around this level and so no measurements were taken at $D_{1.3}$. Girth was recorded for this tree at $D_{0.5}$ and $D_{1.0}$, but the results are not presented in this paper. (See text for definition of codes)

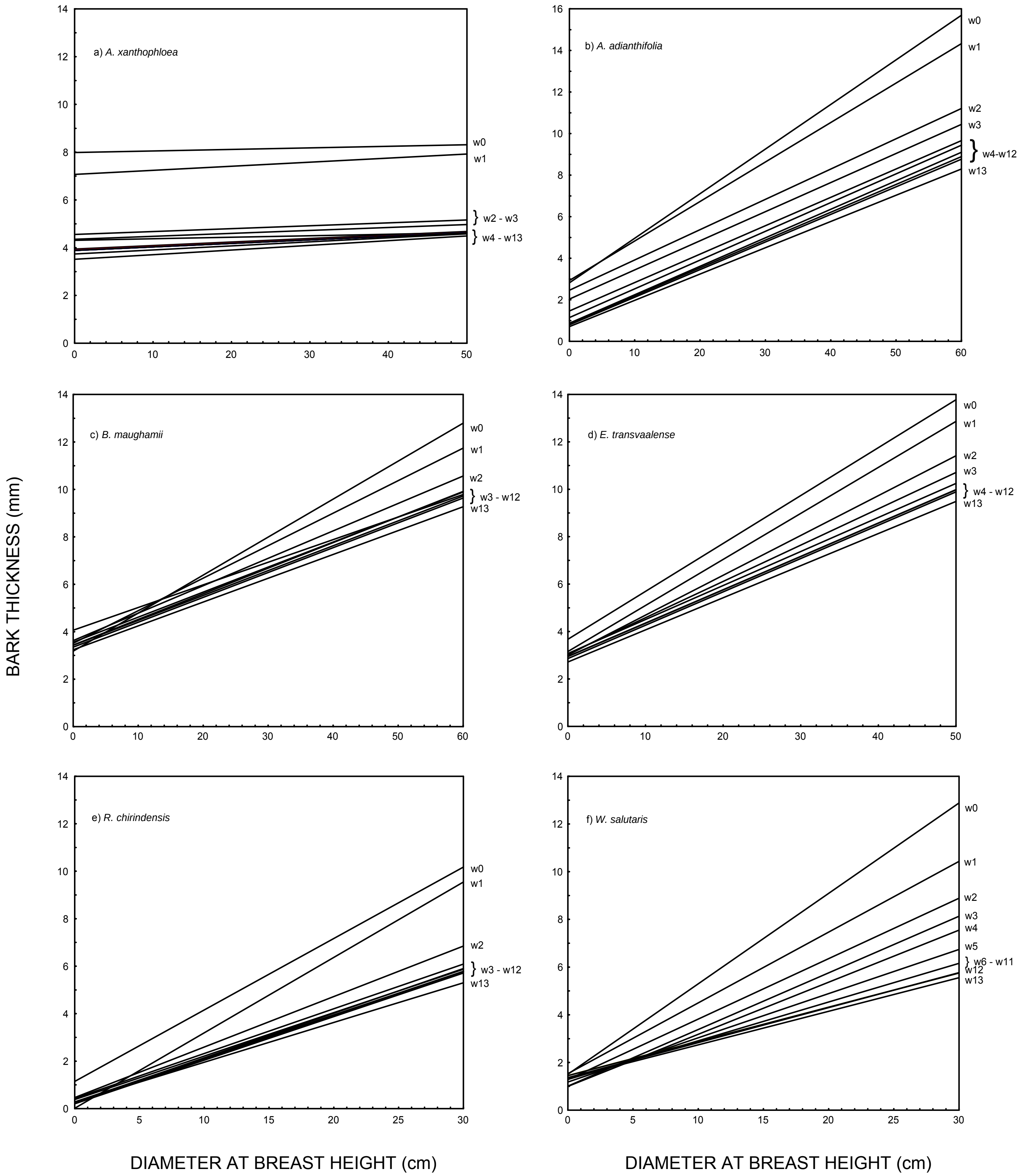


Fig. 6: Relationships between bark thickness and diameter at breast height between time W0 (day of bark sampling) and W13 (measurements taken after oven drying of the bark samples). Graphs show the decrease in bark thickness over 12 weeks and the final oven-dried relationship between bark thickness and dbh (W13). The regression equations, r^2 values and probability level of each regression line are listed in Appendix 1 a-f. W0 regression lines are the same as those in Fig. 5 (e-f)

The percentage weekly decrease in bark thickness as the bark dries out varies between species (Table 2, Fig. 6). On average, the bark decreased in thickness by 48% after twelve weeks and was at 50% of its original thickness after oven drying. *B. maughamii* and *E. transvaalense*, however, only experienced decreases of 24% and 30% respectively after oven drying, indicating that the bark is denser and/or retains less water in the inner bark than the other species. For most species, the largest decrease in bark thickness occurred between weeks 1 and 2 (Table 2, Fig. 6), especially for *A. xanthophloea*, which decreased by 33.9%.

Fig. 6 shows the estimated thickness of bark removed, for example from a tree of 30 cm dbh, and the rate of decrease in thickness of that bark as it dries out over twelve weeks. Additionally, if the thickness and the age of bark are known, then the dbh of the tree from which it was originally harvested can be estimated. Any bark older than 12 weeks is presumed to be characterised by the final, W13 oven-dried linear regression model, which in most cases is not very different from W12.

5.4. Predicting dbh and bark thickness

Tables for predicting the dbh of a tree given the bark thickness and time after harvesting (Appendix 2 a-e), as well as tables for predicting the thickness of bark on a tree given the dbh (Williams *et al.* 2005) were constructed from the regressions. The purpose of the prediction tables is to assess the stem diameter-class of trees (from the dbh) preferentially harvested and/or available in the wild – directly from the thickness of the bark sold in medicinal plant markets. By taking into account the rate at which the bark desiccates, the actual dbh's of the trees targeted by harvesters are less likely to be underestimated and hence assessments of resource use and change in availability are more reliable.

Using the table in Appendix 2e and the results of the three surveys between 1995 and 2001 that measured the thickness of bark sold by vendors of traditional medicine, the change in availability of *W. salutaris* bark from corresponding size-classes of trees was explored (Fig. 7). *W. salutaris* is cited as an example due to its rarity in South Africa and its highly sought after bark. Results showed there to be a decline over 6 years in the availability of thicker *W. salutaris* bark in the markets, and a corresponding decrease in the dbh of the trees in the wild from which the bark was harvested. The smaller trees harvested for bark are indicative of the decline in availability of large trees in South Africa. The most prevalent bark thickness size-class is 3–5 mm, which Appendix 2e predicts is harvested from trees of dbh's between 5–10 cm (if bark is a week old) or 11–23 cm (if the bark is six weeks old).

The differences in the predictions of dbh size-classes from bark thickness related to bark age in the market emphasizes the importance of knowing how long the bark has been in the market. In Table 3, the dbh predictions from Figure 7 are re-assessed where the actual age of the bark in the market is known. Results show that bark sold in the *muti* shops in 1995 were mainly derived from trees with a dbh >42.3 cm, whereas bark sold in the Faraday market in 2001 were usually from trees <24.8 cm dbh. This represents a huge decline in the availability of *W. salutaris* trees in the larger size-classes. The 18–20 mm thick bark sold in a *muti* shop in 1995 was predicted to be derived from a 115–129 cm dbh tree. However, considering the largest *W. salutaris* tree found during the research was ≈68 cm, it is debateable whether many trees exist within current harvesting source areas that are larger than 70 cm dbh. This bark was therefore either from an area on the stem below 0.5 m, or had been in the shop for less than the cited 8 weeks, or environmental circumstances had prevented it from drying out too much and resulted in a larger than expected predicted dbh. An alternative, and more reliable, way to have assessed the predicted dbh would have been to oven-dry the bark samples purchased from the market and to then read the dbh values from W13.

Table 2: Weekly percentage decrease (mean and standard deviation) in the thickness of the bark samples, as well as the overall difference between wet and oven-dry bark thickness. Note: a zero percent change in bark thickness indicates that the digital Vernier callipers could not detect a decrease smaller than 0.01 mm.

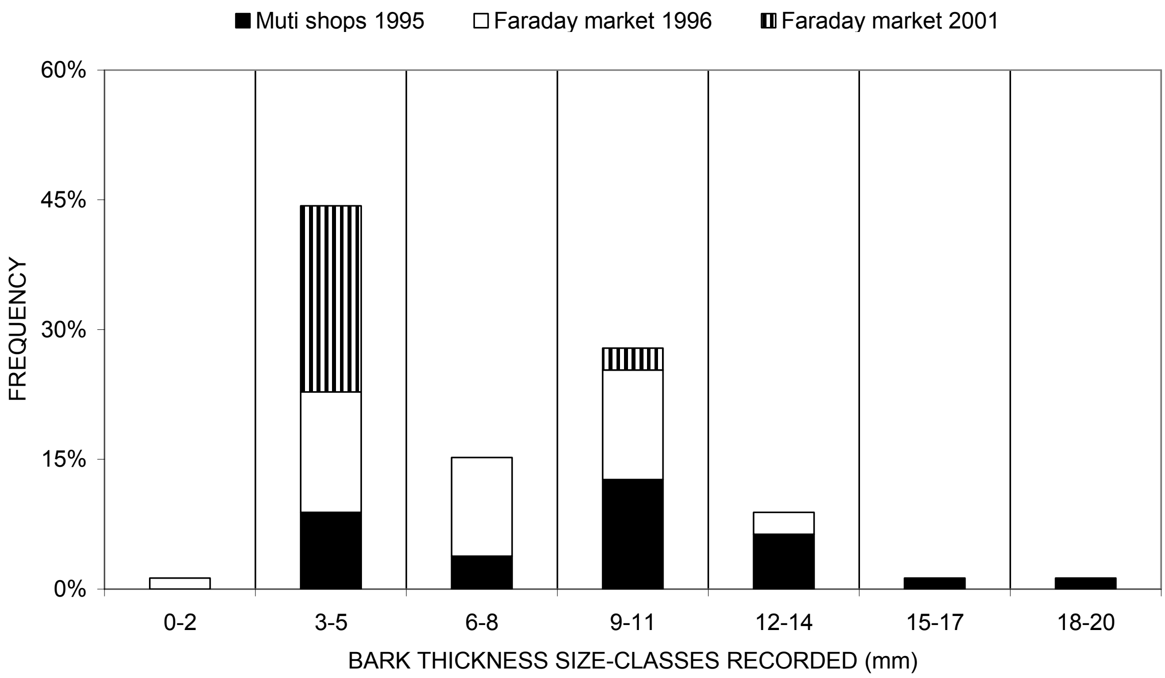
Time difference	*A. xanthophloea*	*A. adianthifolia*	*B. maughamii*	*E. transvaalense*	*R. chirindensis*	*W. salutaris*
W0 to W1[a]	7.8 ± 4.5%	6.9 ± 5.5%	6.6 ± 3.9%	8.1 ± 6.7%	17.9 ± 14.1%	16.0 ± 8.0%
W1 to W2[b]	33.9 ± 8.3%	20.4 ± 8.2%	7.1 ± 5.8%	10.5 ± 5.0%	19.5 ± 16.1%	15.0 ± 5.4%
W2 to W3	3.8 ± 4.9%	8.6 ± 5.9%	4.0 ± 3.6%	4.7 ± 3.3%	10.3 ± 7.7%	11.3 ± 6.2%
W3 to W4	4.6 ± 5.5%	9.4 ± 6.8%	2.2 ± 2.9%	3.1 ± 2.9%	4.5 ± 3.9%	5.9 ± 3.7%
W4 to W5	3.7 ± 5.1%	6.8 ± 6.9%	0.8 ± 1.5%	2.9 ± 3.8%	2.8 ± 3.9%	5.1 ± 4.6%
W5 to W6	0.9 ± 1.7%	5.7 ± 5.5%	1.4 ± 1.8%	0	1.2 ± 4.5%	3.3 ± 3.9%
W6 to W7	0.4 ± 1.4%	2.3 ± 3.7%	0.1 ± 0.3%	0	0.5 ± 1.5%	1.5 ± 3.5%
W7 to W8	0	0	0	0	0.1 ± 0.3%	0.1 ± 0.3%
W8 to W9	0	0	0	0	0	0
W9 to W10	0	0	0	0	0	0
W10 to W11	0	0	0	0	0	0
W11 to W12	2.1 ± 3.4%	2.0 ± 2.7%	1.2 ± 1.6%	1.4 ± 1.4%	2.1 ± 1.8%	1.7 ± 2.2%
W12 to W13[c]	3.8 ± 1.6%	5.7 ± 3.6%	3.7 ± 1.9%	3.8 ± 3.4%	5.2 ± 2.4%	3.6 ± 1.9%
W0 to W12	48.5 ± 4.3%	49.3 ± 11.2%	21.1 ± 8.2%	27.6 ± 8.6%	48.0 ± 10.2%	47.4 ± 7.3%
W0 to W13	50.5 ± 4.2%	52.3 ± 10.5%	24.0 ± 8.3%	30.4 ± 8.5%	50.7 ± 9.7%	49.3 ± 7.6%

[a] Represents the mean decrease in bark thickness approximately 4–5 days after harvesting, before being placed in an environment-regulated chamber.
[b] Represents the mean decrease in bark thickness after one week in an environment-regulated chamber.
[c] Represents the mean decrease in bark thickness between twelve weeks after harvesting and final oven-drying measurement at W13.

Table 3: Predictions and prevalence of *W. salutaris* diameter and breast height size-classes, when the number of weeks the measured bark was in the market was actually known. Figures in superscript after the dbh classes are the frequency of individuals recorded. No data for the 1996 street market survey are included because only the thickness of the bark and not the age in the market were recorded

	Number of weeks in the market[a] and the predicted dbh size-classes							
Bark size-classes	1 week	2 weeks	3 weeks	4 weeks	5 weeks	8 weeks	10 weeks	> 13 weeks
Muti shops 1995								
3-5mm						10.8 – 24.8 [1]		
6-8mm								
9-11mm				42.2 – 53.0 [1]		52.7 – 66.7 [1]		54.5 – 68.7 [6]
12-14mm				58.4 – 69.2 [2]				75.8 – 90.0 [1]
15-17mm								
18-20mm						115.5 – 129.2 [1]		
Street market 2001								
3-5mm	6.8 – 14.7 [1]	8.4 – 16.8 [2]	9.2 – 18.3 [3]		10.5 – 22.9 [1]	10.8 – 24.8 [1]	10.8 – 24.8 [1]	
6-8mm								
9-11mm						52.7 – 66.7 [1]		

[a] Note: a 1-week travel allowance time to the market was considered when using the table in Appendix 2e. Therefore, bark that was in the market for 1 week was assumed to be 2 weeks old and the corresponding dbh values for 2 weeks were inserted in this table.



Time after harvesting	Tree dbh (cm) predicted by the model for converting bark thickness classes (above) to tree size-classes (below), depending on the number of weeks after bark harvesting (Based on Appendix 2e)						
1 week	< 2	5 – 10	15 – 22	26 – 32	35 – 42	45 – 52	56 – 62
6 weeks	≤ 4.4	11 – 23	29 – 41	48 – 60	66 – 78	84 – 97	103 – 115

Fig. 7: The availability of *W. salutaris* bark size-classes sold between 1995 and 2001 in the muti shops and Faraday market, and the prediction of the tree size-class dbh from which the bark was harvested (in the table below the figure).

6. Discussion

Harvesters tend to select plants in the larger size-classes to maximise their returns (Botha *et al.* 2001), and a decrease in the availability of thick bark in the markets is indicative of the decline in availability of larger trees. Furthermore, the decline also offers evidence of plants and bark not being given sufficient time to re-grow after being repeatedly harvested (Botha *et al.* 2001). This paper (Botha *et al.* 2001) does not specifically quantify the risks to species, except to use an example of the decline in the prevalence of thick *W. salutaris* bark in the market over 6 years, and hence the corresponding decrease in the diameter-class of trees that are being targeted (this is discussed in more detail in Williams *et al.* in press). What is essential to note when using the prediction tables, given the rate of bark desiccation, is that the approximate time when the bark was harvested should be known in order for the dbh to be more accurately predicted. Bark sold by traders that is 9–11 mm thick and that has been in the market for less than 2 weeks may have come from an individual tree with dbh=26–32 cm (Fig. 7). Alternatively, if the bark was harvested about 6 weeks prior, the actual tree dbh could range between 48–60 cm.

Results for *W. salutaris* in Table 3 showed a decline in the availability of stems predicted to have originated from larger trees, and the prevalence of bark harvested from smaller and younger trees. Research by Botha *et al.* (2004) on the commercial impact of harvesting on *W. salutaris* in the province of Mpumalanga, South Africa, showed a reduction in the availability of individuals in the larger size-classes in commercially harvested populations compared to protected populations, as well as a decrease in the number of size-classes. Exploitation of *W. salutaris* for the medicinal plant trade is hence a major threat to the species, and it is currently extinct outside of conservation areas in the province of KwaZulu-Natal (Mander 1998, Lawes *et al.* 2004). Most of the thick bark sold in the markets originates from Mozambique, where populations of larger trees apparently still exist.

The rate of bark desiccation (Table 3) is an important factor for determining the original thickness of the harvested bark, especially where the dbh of trees cannot be predicted because of a weak relationship between thickness and girth – for example *A. xanthophloea*. Botha *et al.* (2002) speculated that the reason that *A. xanthophloea* bark sold in the markets in Mpumalanga was significantly thinner than that of populations measured in the field was because the individual trees being harvested were considerably smaller than the assessed populations. However, results from this study showed that *A. xanthophloea* bark loses at least 41.7% of its original thickness after two weeks (which is at least the time it takes for plants to reach the market), and 48.5% after 12 weeks. This is a considerable decrease in bark thickness, and could explain the apparent disparity between bark thickness measured in the field and bark sold in the markets. Botha *et al.* (2002) calculated the mean thickness of *A. xanthophloea* bark in the wild to be 12.4 mm; however, based on predictions in this present paper, after two weeks the bark could have shrunk to 7.6 mm and reached 6.4 mm after 12 weeks – a figure similar to the mean bark thickness of 6.3 mm measured in the Mpumalanga markets. It is therefore likely that the bark in the market did not originate from smaller trees but instead decreased significantly in thickness after harvesting due to desiccation. However, no age-related relationship between tree size and bark thickness can be predicted for *A. xanthophloea*, primarily because the stem sheds bark in large strips.

The results of this research have shown the relevance of rhytidome formation and bark exfoliation and their relationship to tree girth and age. Wilson and Witkowski (2003) noted that there was a strong positive relationship in *Burkea africana* between bark thickness and trunk circumference for plants with a trunk circumference less than 40 cm (measured at 20 cm above ground) but a poor relationship for larger trees. They postulated that *Burkea* trees attain a fire resistance size at 40 cm, and it is therefore unnecessary thereafter to invest so heavily in bark. However, as Wilson and Witkowski (2003) further noted, 40 cm is also the size at which bark commences to fall off the tree in response to incremental growth – suggesting, therefore, that trees do not necessarily reduce investment in bark production after a certain age and size but that rhytidome shedding and formation are integral to age-thickness relationships in trees.

If bark growth, accumulation and weathering continue at a more-or-less constant rate throughout a tree's life, the relationship between bark thickness and tree girth would be expected to be consistent (O Grace, pers. comm.). Where rhytidome exfoliation occurs, a weak linear or curvilinear correlation is expected. If the rhytidome accumulates with little or no exfoliation, and there is no age-related reduction in the rate of bark investment, then a close relationship between bark thickness and age would exist because the inner bark and rhytidome would both continue to increase with age. There is no evidence of bark shedding or age-related reduced investment into bark production in *A. adianthifolia* (Fig. 5b), and hence no levelling off in bark thickness after a certain age and size – even in mature trees where dbh >40 cm. There is similar, albeit not conclusive, evidence for mature *W. salutaris* individuals. A tree with dbh ≈68 cm was located but not measured for bark thickness at this level because branching occurred at 1.4 m on the tree. However, the relationships between bark thickness at $D_{0.5}$ and $D_{1.0}$ (>60 cm) were still strongly linear and significant when this individual was included in the regression analysis (results not shown).

If rhytidome exfoliation is integral to age-size-thickness relationships, then in trees where bark shedding occurs, a smaller bark thickness relative to girth in mature individuals could represent the rate of exfoliation of the rhytidome rather than a decrease in the rate of bark production. There is irregular dehiscence of old rhytidome plates in *E. transvaalense,* and therefore a weak but significant relationship exists between bark thickness and dbh (Fig. 5d). Because of the peeling of large strips of bark in *A. xanthophloea*, there is no age- or size-related relationship between bark thickness and stem diameter (Fig. 5a), and hence no conclusive evidence of a decrease in the rate of bark production with age. The stronger the relationship between bark thickness and girth, the better are the regression models able to predict the girth of a tree if the bark thickness is known.

While age-related decreases in bark production probably occur in some species, there was no conclusive evidence of this in the species investigated (with respect to bark thickness and girth relationships) that could not also be accounted for by rhytidome exfoliation (age/size-related or not) or site conditions. The quadratic regressions derived for *P. africana* trees in Cameroon (Cunningham *et al.* 2002) and *Rytigynia* spp. in Uganda (Kamatenesi 1997) appear to show some levelling out of bark thickness with increased dbh. Similarly, curves for double bark thickness and dbh for *Ocotea bullata*

(Burch.) Baill., *Podocarpus falcatus* (Thunb.) R.Br. ex Mirb. and *P. latifolius* (Thunb.) R.Br. ex Mirb. in forests in the southern Cape exhibit size-related levelling (van Laar and Geldenhuys 1975) but the curves for *Olea capensis* subsp. *macrocarpa* (C.H.Wright) I.Verd and two groups of "other" species do not. It is also possible that age-related decreases in bark production are evidenced in dbh versus relative available bark mass; however, this discussion is not elaborated upon in this paper.

Within species, bark thickness also varies with the location of the tree (Cunningham 2001) and the site conditions. Intra-species variations of bark thickness versus dbh were most evident for *B. maughamii* individuals growing in the provinces of KwaZulu-Natal and Limpopo (results not shown). In general, *B. maughamii* individuals growing in KwaZulu-Natal had relatively thinner bark than did individuals growing in the drier Limpopo Province. Similarly, *R. chirindensis* individuals growing in two sites in Mpumalanga were generally thinner than individuals from three sites in the Limpopo Province. Intra-site differences of bark thickness relative to dbh were observed for *R. chirindensis* and *W. salutaris* growing in site L1 (results not shown). Individuals growing in the more protected valleys usually had thinner bark than trees growing in the open areas or on the exposed slopes. This difference could reflect intra-species variations of bark thickness for individuals growing in forest or woodland habitats respectively, and possibly a response to different fire regimes. However, without precise habitat and rainfall data or micro-climate records, these observations cannot be adequately substantiated.

Bark thickness also relates to stem diameter (Cunningham 2001) and it generally increases with tree size (Fig. 5) and decreases with height up the stem (Fig. 3). This paper describes bark thickness in relation to measurements taken at 1.3 m above ground. Hence, a caveat for the use of the prediction tables is the following: bark harvested at 0.5 m on a tree that may be thicker, will be predicted from the tables in Appendix 2 to have come from a tree larger than the one it was originally harvested from, especially if stem tapering has a significant effect on bark thickness. The tables assume that bark is harvested at 1.3 m and/or the bark thickness is constant up the stem to 2m. Figures 3 and 4 are therefore important for relating how different measurements at dbh are from measurements taken along the rest of the stem. Despite the assumptions and caveat, the prediction tables are a starting point for judging bark thickness relationships and making preliminary assessments of the extent of resource utilisation. The single figures predicted by the tables are therefore a guide to the diameter-class range.

In a study on the age of plant parts sold in a street market for traditional medicine in Johannesburg (Williams 2003), it was found that the average length of time bark products sold by traders had been in the market was six weeks. If the tables are to be used to predict dbh from bark thickness records from medicinal plant markets, and the time since harvesting is not known, it is recommended that values at W6 and W7 are used in the prediction of dbh. Alternatively, samples purchased from the markets should be oven-dried and the predicted dbh values read from W13. It may also be possible to establish when the bark was harvested by comparing the dbh predicted by the oven-dried bark thickness with the dbh predicted from the original bark thickness.

How appropriate would it be to apply these data to the prediction of dbh from bark thickness for other species? Cunningham *et al.* (2002) similarly questioned whether the *Acacia mearnsii* De Wild. models of bark production developed by Schönau (1973, 1974) could be applied to bark mass data for *P. africana*. Unless one had sound, scientific and justifiable reasons for grouping species and extrapolating the results, the outcomes would be speculative at best. The only basis on which we would venture to recommend that the models be used for other species is according to macroscopic bark type (e.g. fissured or smooth). Species with similar bark types exhibited similar r^2 values (e.g. *W. salutaris* and *A. adianthifolia*), however more research into bark thickness relationships, macroscopic bark anatomy and rhytidome formation would have to be conducted before any conclusive recommendations were to be made.

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APPENDIX 1

Regression equations, r^2 values and probability levels for regression lines in Fig. 6 (a-f): the relationship between bark thickness (Y) and dbh (x). Each regression line represents a specified time period after the bark samples were removed from the tree trunk, starting with W0 = day bark samples were harvested from the tree, and ending with W13 = final oven dried measurements. Times W1 to W12 represent 1 to 12 weeks respectively after bark samples were placed in a chamber to dry.

Time after harvesting	***A. xanthophloea***			***A. adianthifolia***			***B. maughamii***		
	Equation	r^2	*P*	Equation	r^2	*P*	Equation	r^2	*P*
Week 0 (on site)	Y = 7.9869 +0.0065x	0.005	0.91	Y = 2.8153 + 0.2146x	0.802	0.0000	Y = 4.3409 + 0.0331x	0.569	0.0000
Week 1	Y = 7.0708 + 0.017x	0.0035	0.76	Y = 2.9307 + 0.19x	0.756	0.0000	Y = 4.5872 + 0.0279x	0.574	0.0000
Week 2	Y = 4.5554 + 0.0121x	0.0050	0.72	Y = 2.4601 + 0.1458x	0.714	0.0000	Y = 4.4021 + 0.025x	0.522	0.0001
Week 3	Y = 4.3541 + 0.0123x	0.0054	0.71	Y = 2.0413 + 0.14x	0.774	0.0000	Y = 4.5150 + 0.0219x	0.460	0.0004
Week 4	Y = 4.3124 + 0.0063x	0.0014	0.85	Y = 1.4662 + 0.1366x	0.755	0.0000	Y = 4.3526 + 0.0227x	0.461	0.0004
Week 5	Y = 3.9444 + 0.0148x	0.0077	0.65	Y = 1.146 + 0.1383x	0.820	0.0000	Y = 4.2511 + 0.023x	0.476	0.0003
Week 6	Y = 3.9127 + 0.0144x	0.0076	0.65	Y = 0.8736 + 0.1371x	0.831	0.0000	Y = 4.2114 + 0.0225x	0.472	
Week 7	Y = 3.8846 + 0.0148x	0.0081	0.64	Y = 0.8579 + 0.1339x	0.811	0.0000	As above		
Week 8	As above			As above			As above		
Week 9	As above			As above			As above		
Week 10	As above			As above			As above		
Week 11	As above			As above			As above		
Week 12	Y = 3.7382 + 0.0169x	0.011	0.59	Y = 0.795 + 0.1329x	0.808	0.0000	Y = 4.4016 + 0.0027x	0.480	0.0002
Week 13 (after samples oven dried)	Y = 3.5113 + 0.0196x	0.016	0.52	Y = 0.713 + 0.1264x	0.798	0.0000	Y = 3.9566 + 0.0218x	0.458	0.0004

Time after harvesting	***E. transvaalense***			***R. chirindensis***			***W. salutaris***		
	Equation	r^2	*P*	Equation	r^2	*P*	Equation	r^2	*P*
Week 0 (on site)	Y = 3.6746 + 0.202x	0.503	0.00002	Y = 1.1473 + 0.301x	0.677	0.0000	Y = 1.5087 + 0.3791x	0.882	0.0000
Week 1	Y = 3.1626 + 0.194x	0.486	0.00003	Y = 0.0177 + 0.3176x	0.736	0.0000	Y = 1.5344 + 0.2966x	0.827	0.0000
Week 2	Y = 3.0145 + 0.168x	0.433	0.0001	Y = 0.468 + 0.2127x	0.662	0.0000	Y = 1.2870 + 0.2534x	0.837	0.0000
Week 3	Y = 3.053 + 0.1531x	0.386	0.0003	Y = 0.4373 + 01885x	0.671	0.0000	Y = 1.0101 + 0.2374x	0.849	0.0000
Week 4	Y = 3.0726 + 0.1435x	0.357	0.0006	Y = 0.3838 + 0.183x	0.660	0.0000	Y = 1.0011 + 0.2183x	0.847	0.0000
Week 5	Y = 2.9534 + 0.1406x	0.345	0.0008	Y = 0.2594 + 0.1881x	0.687	0.0000	Y = 1.185 + 0.1852x	0.774	0.0000
Week 6	As above			Y = 0.2871 + 0.1831x	0.663	0.0000	Y = 1.29 + 0.1623x	0.801	0.0000
Week 7	Y = 2.9444 + 0.1406x	0.346	0.0008	Y = 0.2545 + 0.1842x	0.678	0.0000	Y = 1.4542 + 0.1432x	0.742	0.0000
Week 8	As above			Y = 0.2489 + 0.1844x	0.679	0.0000	Y = 1.4506 + 0.1434x	0.745	0.0000
Week 9	As above			As above			As above		
Week 10	As above			As above			As above		
Week 11	As above			As above			As above		
Week 12	Y = 2.8614 + 0.1406x	0.349	0.0007	Y = 0.2064 + 0.1836x	0.681	0.0000	Y = 1.3675 + 0.1467x	0.743	0.0000
Week 13 (after samples oven dried)	Y = 2.7176 + 0.1354x	0.373	0.0004	Y = 0.2797 + 0.1675x	0.662	0.0000	Y = 1.3340 + 0.1407x	0.714	0.0000

APPENDIX 2

Bark thickness and dbh prediction tables based on changes in thickness as the bark dries out (W1-12) and final oven-dried thickness (W13). The tables were constructed from the equations in Appendix 1. The shaded column of week 6 represents the mean age of bark found to be sold in a street market in Johannesburg (Williams 2003), and can be used as a reasonable estimate of the age of the bark if the actual age is not known. Bark older than 12 weeks is presumed to be represented by the final, W13 oven-dried predictions. No prediction table was constructed for *A. xanthophloea* because there was no significant linear relationship between bark thickness and dbh (Fig. 6a).

To find the dbh of a tree from a piece of bark of known thickness and time after harvesting:

a. Go to the bark thickness column on the LHS and select the known bark thickness; also select a column representing the known age after harvesting. The columns intersect at the predicted dbh (in cm) of the tree from which the bark was originally harvested.
b. For example, a piece of *A. adianthifolia* bark 5 mm thick harvested approximately 6 weeks ago is from a tree of dbh = ±27.9 cm. Alternatively, bark 11mm thick measured the same day as harvesting is from a tree of dbh = ±38.1 cm.

2a. *Albizia adianthifolia*

Bark thickness (mm)	**Diameter at breast height ($D_{1.3}$) (in cm) based on the known time (in weeks) after bark harvesting from the tree trunk**															
	W0	Time after bark harvesting from 1 to 12 weeks	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	Prediction after oven drying of samples after week 12	W13
	On site															
1	<2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2		2.3
2	<2		<2	<2	<2	3.9	6.2	8.2	8.5	8.5	8.5	8.5	8.5	9.1		10.2
3	<2		<2	3.7	6.8	11.2	13.4	15.5	16.0	16.0	16.0	16.0	16.0	16.6		18.1
4	5.5		5.6	10.6	14.0	18.5	20.6	22.8	23.5	23.5	23.5	23.5	23.5	24.1		26.0
5	10.2		10.9	17.4	21.1	25.9	**27.9**	30.1	30.9	30.9	30.9	30.9	30.9	31.6		33.9
6	14.8		16.2	24.3	28.3	33.2	35.1	37.4	38.4	38.4	38.4	38.4	38.4	39.2		41.8
7	19.5		21.4	31.1	35.4	40.5	42.3	44.7	45.9	45.9	45.9	45.9	45.9	46.7		49.7
8	24.2		26.7	38.0	42.6	47.8	49.6	52.0	53.3	53.3	53.3	53.3	53.3	54.2		57.7
9	28.8		31.9	44.9	49.7	55.2	56.8	59.3	60.8	60.8	60.8	60.8	60.8	61.7		65.6
10	33.5		37.2	51.7	56.8	62.5	64.0	66.6	68.3	68.3	68.3	68.3	68.3	69.3		73.5
11	**38.1**		42.5	58.6	64.0	69.8	71.3	73.9	75.7	75.7	75.7	75.7	75.7	76.8		81.4
12	42.8		47.7	65.4	71.1	77.1	78.5	81.2	83.2	83.2	83.2	83.2	83.2	84.3		89.3
13	47.5		53.0	72.3	78.3	84.4	85.7	88.4	90.7	90.7	90.7	90.7	90.7	91.8		97.2
14	52.1		58.3	79.1	85.4	91.8	92.9	95.7	98.1	98.1	98.1	98.1	98.1	99.4		105.1
15	56.8		63.5	86.0	92.6	99.1	100.2	103.0	105.6	105.6	105.6	105.6	105.6	106.9		113.0
16	61.4		68.8	92.9	99.7	106.4	107.4	110.3	113.1	113.1	113.1	113.1	113.1	114.4		120.9
17	66.1		74.0	99.7	106.8	113.7	114.6	117.6	120.6	120.6	120.6	120.6	120.6	121.9		128.9
18	70.8		79.3	106.6	114.0	121.0	121.9	124.9	128.0	128.0	128.0	128.0	128.0	129.5		136.8
19	75.4		84.6	113.4	121.1	128.4	129.1	132.2	135.5	135.5	135.5	135.5	135.5	137.0		144.7
20	80.1		89.8	120.3	128.3	135.7	136.3	139.5	143.0	143.0	143.0	143.0	143.0	144.5		152.6

2b. *Balanites maughamii*

Bark thickness (mm)	Diameter at breast height ($D_{1.3}$) (in cm) based on the known time (in weeks) after bark harvesting from the tree trunk														
	W0	Time after bark harvesting from 1 to 12 weeks	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	Prediction after oven drying of samples after week 12	W13
	On site															
1	<2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2		<2
2	<2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2		<2
3	<2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2		<2
4	5.1		3.5	3.2	3.7	4.2	5.2	5.4	5.4	5.4	5.4	5.4	5.4	6.2		7.5
5	11.3		10.8	11.9	9.8	13.7	14.5	14.9	15.0	15.0	15.0	15.0	15.0	15.7		17.5
6	17.6		18.1	20.5	20.2	23.1	23.7	24.5	24.5	24.5	24.5	24.5	24.5	25.3		27.5
7	23.8		25.4	29.2	30.7	32.6	33.0	34.0	34.0	34.0	34.0	34.0	34.0	34.8		37.4
8	30.1		32.7	37.8	41.2	42.1	42.2	43.6	43.6	43.6	43.6	43.6	43.6	44.4		47.4
9	36.3		40.0	46.5	51.7	51.5	51.5	53.1	53.1	53.1	53.1	53.1	53.1	53.9		57.4
10	42.6		47.3	55.1	62.2	61.0	60.7	62.7	62.6	62.6	62.6	62.6	62.6	63.4		67.3
11	48.8		54.6	63.8	72.7	70.5	70.0	72.2	72.2	72.2	72.2	72.2	72.2	73.0		77.3
12	55.1		61.9	72.4	83.1	79.9	79.3	81.8	81.7	81.7	81.7	81.7	81.7	82.5		87.2
13	61.3		69.2	81.1	93.6	89.4	88.5	91.3	91.2	91.2	91.2	91.2	91.2	92.1		97.2
14	67.6		76.5	89.7	104.1	98.9	97.8	100.9	100.8	100.8	100.8	100.8	100.8	101.6		107.2
15	73.8		83.8	98.4	114.6	108.3	107.0	110.4	110.3	110.3	110.3	110.3	110.3	111.2		117.1

2c. *Elaeodendron transvaalense*

Bark thickness (mm)	Diameter at breast height ($D_{1.3}$) (in cm) based on the known time (in weeks) after bark harvesting from the tree trunk														
	W0	Time after bark harvesting from 1 to 12 weeks	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	Prediction after oven drying of samples after week 12	W13
	On site															
1	<2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2		<2
2	<2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2		<2
3	<2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2		2.1
4	<2		4.3	5.9	6.2	6.5	7.4	7.4	7.5	7.5	7.5	7.5	7.5	8.1		9.5
5	6.6		9.5	11.8	12.7	13.4	14.6	14.6	14.6	14.6	14.6	14.6	14.6	15.2		16.9
6	11.5		14.6	17.8	19.2	20.4	21.7	21.7	21.7	21.7	21.7	21.7	21.7	22.3		24.2
7	16.5		19.8	23.7	25.8	27.4	28.8	28.8	28.8	28.8	28.8	28.8	28.8	29.4		31.6
8	21.4		24.9	29.7	32.3	34.3	35.9	35.9	36.0	36.0	36.0	36.0	36.0	36.5		39.0
9	26.4		30.1	35.6	38.8	41.3	43.0	43.0	43.1	43.1	43.1	43.1	43.1	43.7		46.4
10	31.3		35.2	41.6	45.4	48.3	50.1	50.1	50.2	50.2	50.2	50.2	50.2	50.8		53.8
11	36.3		40.4	47.5	51.9	55.2	57.2	57.2	57.3	57.3	57.3	57.3	57.3	57.9		61.2
12	41.2		45.6	53.5	58.4	62.2	64.3	64.3	64.4	64.4	64.4	64.4	64.4	65.0		68.6
13	46.2		50.7	59.4	65.0	69.2	71.5	71.5	71.5	71.5	71.5	71.5	71.5	72.1		75.9
14	51.1		55.9	65.4	71.5	76.1	78.6	78.6	78.6	78.6	78.6	78.6	78.6	79.2		83.3
15	56.1		61.0	71.3	78.0	83.1	85.7	85.7	85.7	85.7	85.7	85.7	85.7	86.3		90.7

2d. *Rhus chirindensis*

Bark thickness (mm)	Diameter at breast height ($D_{1.3}$) (in cm) based on the known time (in weeks) after bark harvesting from the tree trunk														
	W0	Time after bark harvesting from 1 to 12 weeks	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	Prediction after oven drying of samples after week 12	W13
	On site															
1	<1		3.1	2.5	3.0	3.4	3.9	3.9	4.0	4.1	4.1	4.1	4.1	4.3		4.3
2	2.8		6.2	7.2	8.3	8.8	9.3	9.4	9.5	9.5	9.5	9.5	9.5	9.8		10.3
3	6.2		9.4	11.9	13.6	14.3	14.6	14.8	14.9	14.9	14.9	14.9	14.9	15.2		16.2
4	9.5		12.5	16.6	18.9	19.8	19.9	20.3	20.3	20.3	20.3	20.3	20.3	20.7		22.2
5	12.8		15.7	21.3	24.2	25.2	25.2	25.7	25.8	25.8	25.8	25.8	25.8	26.1		28.2
6	16.1		18.8	26.0	29.5	30.7	30.5	31.2	31.2	31.2	31.2	31.2	31.2	31.6		34.2
7	19.4		22.0	30.7	34.8	36.2	35.8	36.7	36.6	36.6	36.6	36.6	36.6	37.0		40.1
8	22.8		25.1	35.4	40.1	41.6	41.2	42.1	42.0	42.0	42.0	42.0	42.0	42.4		46.1
9	26.1		28.3	40.1	45.4	47.1	46.5	47.6	47.5	47.5	47.5	47.5	47.5	47.9		52.1
10	29.4		31.4	44.8	50.7	52.5	51.8	53.0	52.9	52.9	52.9	52.9	52.9	53.3		58.0
11	32.7		34.6	49.5	56.0	58.0	57.1	58.5	58.3	58.3	58.3	58.3	58.3	58.8		64.0
12	36.1		37.7	54.2	61.3	63.5	62.4	64.0	63.8	63.7	63.7	63.7	63.7	64.2		70.0
13	39.4		40.9	58.9	66.6	68.9	67.7	69.4	69.2	69.1	69.1	69.1	69.1	69.7		75.9
14	42.7		44.0	63.6	72.0	74.4	73.0	74.9	74.6	74.6	74.6	74.6	74.6	75.1		81.9
15	46.0		47.2	68.3	77.3	79.9	78.4	80.4	80.1	80.0	80.0	80.0	80.0	80.6		87.9

2e. *Warburgia salutaris*

Bark thickness (mm)	Diameter at breast height ($D_{1.3}$) (in cm) based on the known time (in weeks) after bark harvesting from the tree trunk														
	W0	Time after bark harvesting from 1 to 12 weeks	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	Prediction after oven drying of samples after week 12	W13
	On site															
1	<2		<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2		<2
2	<2		<2	2.8	4.2	4.6	4.4	4.4	3.8	3.8	3.8	3.8	3.8	4.3		4.7
3	3.9		4.9	6.8	8.4	9.2	9.8	10.5	10.8	10.8	10.8	10.8	10.8	11.1		11.8
4	6.6		8.3	10.7	12.6	13.7	15.2	16.7	17.8	17.8	17.8	17.8	17.8	17.9		18.9
5	9.2		11.7	14.7	16.8	18.3	20.6	22.9	24.8	24.8	24.8	24.8	24.8	24.8		26.1
6	11.8		15.1	18.6	21.0	22.9	26.0	29.0	31.7	31.7	31.7	31.7	31.7	31.6		33.2
7	14.5		18.4	22.5	25.2	27.5	31.4	35.2	38.7	38.7	38.7	38.7	38.7	38.4		40.3
8	17.1		21.8	26.5	29.4	32.1	36.8	41.3	45.7	45.7	45.7	45.7	45.7	45.2		47.4
9	19.8		25.2	30.4	33.7	36.6	42.2	47.5	52.7	52.7	52.7	52.7	52.7	52.0		54.5
10	22.4		28.5	34.4	37.9	41.2	47.6	53.7	59.7	59.7	59.7	59.7	59.7	58.8		61.6
11	25.0		31.9	38.3	42.1	45.8	53.0	59.8	66.7	66.7	66.7	66.7	66.7	65.7		68.7
12	27.7		35.3	42.3	46.3	50.4	58.4	66.0	73.6	73.6	73.6	73.6	73.6	72.5		75.8
13	30.3		38.7	46.2	50.5	55.0	63.8	72.2	80.6	80.6	80.6	80.6	80.6	79.3		82.9
14	32.9		42.0	50.2	54.7	59.5	69.2	78.3	87.6	87.6	87.6	87.6	87.6	86.1		90.0
15	35.6		45.4	54.1	58.9	64.1	74.6	84.5	94.6	94.6	94.6	94.6	94.6	92.9		97.1
16	38.2		48.8	58.1	63.1	68.7	80.0	90.6	101.6	101.6	101.6	101.6	101.6	99.7		104.2
17	40.9		52.1	62.0	67.4	73.3	85.4	96.8	108.6	108.6	108.6	108.6	108.6	106.6		111.3
18	43.5		55.5	66.0	71.6	77.9	90.8	103.0	115.5	115.5	115.5	115.5	115.5	113.4		118.5
19	46.1		58.9	69.9	75.8	82.5	96.2	109.1	122.5	122.5	122.5	122.5	122.5	120.2		125.6
20	48.8		62.3	73.8	80.0	87.0	101.6	115.3	129.5	129.5	129.5	129.5	129.5	127.0		132.7

PART 2:

Bark mass estimates for six tree species used medicinally in South Africa

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Abstract
Bark is a commercially important non-timber forest product harvested extensively for the medicinal plant trade. There are few data available on the quantity of bark harvestable from indigenous South African trees, and this paper quantifies the area, volume and mass of bark that can be harvested as a function of tree size for six species. The harvestable mass of bark per stem size-class was determined by multiplying the estimated surface area of bark on the stem by the mass per unit volume (i.e. the density) of bark samples removed at five height intervals up to 2 m. Regression analysis was used to describe the relationship between wet- and oven-dried mass and stem diameter so as to determine which stem height was the best predictor of the total mass per stem. The results showed that there is a strong positive relationship between total bark mass and stem diameter and that stem diameter at 1.0 m is a better predictor of bark mass than diameter at breast height. Results also showed that a ±1 mm difference in bark thickness does not significantly change the estimated harvestable bark mass present on the stem up to 2 m. The estimates of harvestable bark mass as a function of tree size are useful for assessing the impacts of the medicinal plant trade, by providing the means with which the number of trees that are potentially harvested annually can be estimated.

Key words: *Acacia xanthophloea*, *Albizia adianthifolia*, *Balanites maughamii*, bark mass, diameter at breast height, *Elaeodendron transvaalense*, medicinal plants, resource use, *Rhus chirindensis*, *Warburgia salutaris*

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1. Introduction

Reliable estimates of bark mass as a function of tree size are necessary for analysis of the impact of the traditional medicinal plant trade on resources of indigenous tree species. By knowing the potentially harvestable bark mass ('bark stock') per stem diameter-class of trees and the annual quantity sold, the number of trees harvested annually can be estimated and assessed, and species-specific management plans can be adopted.

There are few accounts in the literature on bark yield for trees. In the timber trade, the volume of bark is calculated as a by-product so that the net volume of wood can be determined, especially as most diameter measurements on standing trees have to be made 'over bark' (Philip 1983). Where bark is traded commercially, yield estimates are applied to the annual potential harvestable quantity and value of a product, for example cork.

There are roughly two dichotomies for estimating bark yield. The first is to fell and debark selected trees and carefully measure them to obtain an estimate of the size-specific bark volume and mass for that species (Peters 1996). Regression analyses were then used to derive a predictive equation relating plant size to the quantity of the resource present (Peters 1996). The second, less destructive, dichotomy is to treat the stem as a cone or cylinder, and then estimate bark surface area accordingly. Thereafter, yield is estimated from data on bark thickness and mass. Bark thickness data can come from direct measurement, or from models of bark thickness (Kleinn 2004). Bark mass can be obtained from samples taken from the stem. Regression models are then fitted to the data, and the slope of the regression line is used to predict the yield.

Refinements of the two methods involve relating yield to one or more predictor variables through the regression equations, for example dbh, total tree height, stem length and/or shape of the bole. Evert (1985) derived a set of multiple-regression equations for estimating oven-dry mass for stem bark for 18 Canadian tree species based on diameter at breast height (dbh) and total tree height. De Jong and Bonner (1995) calculated bark yield per tree for the Pacific Yew (*Taxus brevifolia*, a source of the compound Taxol) in British Columbia, Canada, using bark thickness and dbh. The tree bole was assumed to be conical, and the bark area and volume were calculated accordingly. Bark weight was estimated using a dry/green weight conversion factor.

The classic study on bark mass in South Africa is by Schönau (1973) for the exotic black wattle, *A. mearnsii*, used in the tanning industry. Based on data sampled from 1379 trees growing in widely varying site conditions, Schönau (1973) compiled metric bark mass tables and developed a multiple-regression equation using dbh, total tree height and bark thickness at breast height with an r^2 = 0.978. Schönau's (1973) bark mass tables estimated that trees 10–25.5 m high, with a dbh of 5–25 cm, and bark thickness of 3–8 mm, would yield 2.0–82.8 kg of bark per tree.

In Cunningham *et al's* (2002) investigation of bark production for *Prunus africana*, all bark was stripped from 7 tree trunks ranging from 7–26 cm dbh until the stem tapered to 5 cm diameter or a major fork. Thereafter, the wet bark was weighed and subsequently oven-dried to obtain the dry mass. There was a close correlation between dbh and bark mass, and a multiple-regression equation for predicting bark mass per tree was proposed based on dbh and total tree height. In a previous study in Cameroon, Cunningham and Mbenkum (1993) found the mean bark yield of *P. africana* to be 55 kg tree^{-1}, with variations in yields of 38 to 73.8 kg tree^{-1}. This had been calculated by dividing the known total mass harvested at a site in 1995 by the total number of trees harvested.

In Uganda, Kamatenesi (1997) evaluated data on bark mass and diameter from 237 stems between 1.3 and 24.0 cm dbh using regression analysis. Quadratic models were fitted to predict the total wet and dry bark weight and volume available (up to 2 m) from dbh for three *Rytigynia* species used medicinally for bark. The tree was treated as an "ideal" cylinder, and the bark mass within reach of harvesting from a standing tree was determined from samples taken at different heights up the stem.

There are few data on bark quantity from indigenous South African species. Cunningham (1988) estimated that one 50 kg-size bag of *Ocotea bullata* bark sold in the traditional medicine markets of KwaZulu-Natal might represent the yield from three trees with diameters of 40-44 cm at breast height. Given that a 50 kg-size bag of bark equals ± 49.8 kg (Williams 2003), each tree would therefore yield about 16.6 kg of bark, but it is unclear if this is wet or oven-dry mass and for bark available to 2 m up the stem or higher. Geldenhuys (2004) further estimated the mean volume of *O. bullata* bark per tree to range between 0.002–0.386 m^3, depending on the stem diameter class. In estimating the number of plants traded per year in KwaZulu-Natal, Mander (1998) assumed that 16 kg (dry weight) of bark could be harvested per tree. The assumption was based on the average mass of bark that could be harvested from three of the most popular bark species traded (Mander 1998), namely *O. bullata*, *Warburgia salutaris* and *Curtisia dentata* (S. McKean pers. comm.).

Some of the literature is imprecise over the correct use of the word 'yield'. Conventionally, bark 'yield' refers to the amount of bark that may be harvested/removed annually or periodically and is related to growth (Wong *et al.* 2001). Hence, the principle of 'sustained yield' is that it is this growth that can be removed in perpetuity (J. Wong pers. comm.). However, in many cases, authors use 'yield' when they are actually referring to the potentially harvestable amount of a resource, and not the amount that can be removed during a specific time period. To avoid confusion, 'bark stock' or 'bark mass' is used in this paper from this point forward to describe the total harvestable mass of bark that can be removed from the tree stem from the ground up to 2 m for a standing tree.

The aim of this paper is to determine bark area, volume and mass as a function of tree size for six species used medicinally in South Africa. Through regression equations, stem diameter is used as a predictor of wet and oven-dry bark mass. While diameter measurements at breast height (1.3 m) are typically correlated with mass to predict the potential bark stock, this paper investigates whether stem diameter at other heights up the tree results in a higher degree of accuracy in estimating harvestable bark mass per species. Bark mass was not correlated with the total tree height because the harvestable bark was only estimated up to 2 m on the stem and not the entire trunk. These data provide the basis for estimating the number of trees harvested annually for the medicinal plant trade, which will be further investigated (Williams *et al.* in press 1).

2. Field Methods and Data Analyses

2.1 Study sites and species

Six species were sampled at fifteen woodland sites in three South African provinces between March and May 1998. Seven of the sites were on privately-owned land, four were in protected areas, three on state-owned forestry land and one on communal land. The species, previously selected to represent various risk categories for over-exploitation by the medicinal plant trade (V.L. Williams unpublished data) are *Acacia xanthophloea* Benth., *Albizia adianthifolia* (Schumach.) W.F.Wight, *Balanites maughamii* Sprague, *Elaeodendron transvaalense* (Burtt Davy) R.H.Archer [formerly known as *Cassine transvaalensis* (Burtt Davy) Codd], *Rhus chirindensis* Baker f. and *Warburgia salutaris* (Bertol.f.) Chiov.

2.2 Sampling

At each sample site, individuals were selected from representative size-classes based on stem diameter at breast height (dbh, 1.3 m above ground). A minimum of five and maximum of ten trees was sampled per diameter-class per species, although specimens in the ≥40 cm size-classes were sometimes more difficult to find, and hence 2–4 trees were often sampled in this class (except for *A. adianthifolia*, where trees larger than 60 cm dbh could have been sampled). Stem diameter-classes for *A. xanthophloea*, *A. adianthifolia*, *B. maughamii* and *E. transvaalense* were in increments of 10cm, starting at 10 cm and ending at 50 cm, 60 cm, 60 cm and 50 cm respectively. Stem diameter-classes for *Rhus* and *Warburgia* were in increments of 5 cm, starting at 5 cm and ending at 35 cm and 30 cm respectively due to the prevalence of individuals in this size range. Individuals larger than 25 cm were infrequently encountered for *R. chirindensis* and *W. salutaris*, although a revisit to two of the sample sites in 2004 located populations with individuals in the 30–39 cm class that had previously not been observed.

The diameter of the stem was measured at 5 height intervals [termed $D_{0.5}$; $D_{1.0}$; $D_{1.3}$ (dbh); $D_{1.5}$ and $D_{2.0}$ to represent the respective diameters of the stem at 0.5 m, 1.0 m, 1.3 m, 1.5 m and 2.0 m] using a diameter tape. The tape was calibrated in π centimetres so that the circumference measurement was the equivalent of diameter (Philip 1983). Circular bark samples were removed from the stem using a 50 mm diameter hole-saw attached to a hand-held brace (See Fig. 2, Williams *et al.* in press 1). The 2.0 m level was too high to be reached with a hole-saw, and so a 10 mm sample was removed with a belt punch and hammer. The circular bark samples had a 5 mm hole in the centre, and were threaded on to labelled cable ties. Wet bark thickness was measured on site using a digital Vernier calliper, and mass was measured using a portable digital scale.

Once sampling at the site was completed, the bark samples were taken back to the laboratory at the University of the Witwatersrand, Johannesburg, approximately four days after harvesting and re-measured, this time using an electronic balance. The samples were then placed in a phytotron chamber to dry out for a further 11 weeks. The temperature and relative humidity (RH) in the chamber were set to mimic mean day and night summer conditions (September – March) in Johannesburg, namely: day T^o = 20 ^oC; night T^o = 16 ^oC; day RH = 59%; night RH = 66%. The bark thickness and mass of the samples in the chamber were re-measured every 7 days to monitor any changes in thickness or mass. Twelve weeks after the samples were harvested, they were oven-dried at 80 ^oC for 4 days to obtain oven-dry mass and thickness. A total of 14 time intervals were therefore recorded, and are abbreviated as follows in the paper: W0 = the day samples were harvested; W1 = ± 4 days after being harvested and just before being placed in the phytotron; W2 = after one week in the phytotron and two weeks after sampling; W3 – W12 = two to eleven weeks in the chamber, and three to twelve weeks after sampling; W13 = final measurements after oven-drying. The mean weekly percentage decrease in bark mass was calculated by comparing the differences between the mass of the samples at weekly intervals.

2.3 Calculating total bark quantity

The method for calculating the quantity of bark on the tree stem up to 2 m is shown in Fig. 1. Two metres is generally the height to which harvesters can debark trees without standing on a ladder. Each stem was divided into 5 cylinder subsections based on $D_{0.5}$, $D_{1.0}$, $D_{1.3}$, $D_{1.5}$ and $D_{2.0}$. Estimates of bark area and volume were calculated for each trunk subsection using measurements of stem circumference and bark thickness. The estimated bark density of a subsection was calculated from the area, volume, mass and density of the circular bark samples removed at each level, and this was used to estimate the mass of each subsection, and hence the total mass of bark on each stem. The mean total area, volume and mass were then calculated for the different tree size-classes. Total oven-dry bark mass was calculated from the oven-dry bark thickness and mass of the bark samples. Similarly, total mass for bark 1–2 and 6 weeks old was calculated from bark sample mass and thickness that was 1–2 and 6 weeks old respectively.

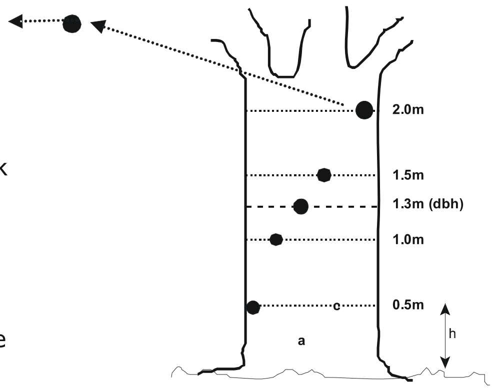
A slightly different method was employed to estimate bark surface area, and hence mass, for the fluted stems of *B. maughamii*. Two measurements were taken around the stem at each height interval, namely 'D1' and 'D2', which are girth measurements that respectively excluded and included the bark surface contained in the convolutions of the flutes. D2 measurements made it possible to calculate the total surface area of the stem and hence the total bark mass. This method is described in more detail in Williams *et al.* (in press 2).

To simulate how inaccuracies in measuring bark thickness might affect the bark mass calculations, the sensitivity of the method was tested against a 1 mm increase or decrease in bark thickness (at the 5 height intervals) whilst dbh and height were kept constant. The total bark mass was compared with the bark mass calculated from a ± 1 mm change in bark thickness to assess the percentage increase or decrease in bark mass.

2.4 Statistical analysis

Regression analysis was used to describe the relationship between wet and oven-dry bark mass (to 2 m) and stem diameter ($D_{0.5}$, $D_{1.0}$, $D_{1.3}$, $D_{1.5}$ and $D_{2.0}$). For each species, mass was regressed with the stem diameters at five height intervals to determine which stem height was the best predictor of total bark mass. Outliers ± 2 standard deviations were only removed if the same outliers occurred in both wet- and oven-dry mass data sets. Between one and four outliers were removed per species, hence the graphs were constructed using similar data sets. Paired two-tailed t-tests for dependent variables were also used to test whether the total fresh bark mass was significantly different from oven-dry mass calculated per tree stem. Excel 2000 and Statistica 6 were used for the statistical analyses.

Area of the circular bark samples (cm^2)
($a_s = \pi * r^2$)



Bark area of each subsection of the tree stem to 2 m (m^2)
($a = c * h$)†

Volume of the circular bark samples (cm^3)
($v_s = a_s * t$)

Bark volume for each subsection of the trunk (cm^3)
($v = a * t$)

Density of the bark sample (kg/cm^3)
($d_s = m_s / v_s$)

(Assuming the density of the sample is the same as the density of the subsection, then the density of the sample is used to calculate the mass of the subsection of bark on the trunk)

Bark mass of the subsection (kg)
($m = d_s * v$)

Sum the area, volume and mass of the trunk subsections to get total area, volume and mass of harvestable bark to 2 m

Where:
a_s = area of the sample
r = radius of the sample (2.5 cm)
v_s = volume of the sample
t = bark thickness (wet or oven-dry)
d_s = density of the sample
m_s = mass of the bark sample (wet or oven-dry)

Where:
a = bark area of the subsection
c = circumference of the tree stem at a specified height
h = height of the stem subsection
v = bark volume of subsection
t = bark thickness (wet or oven-dry)
m = bark mass of the subsection (wet or oven-dry)

Fig.1. Summary of the method used to calculate the quantity of bark on the tree stem up to 2 m. Bark samples removed at each level are indicted by ●. † This is the same as calculating the surface area of a cylinder (area = $2\pi r * h$)

2.5 Comparing bark mass predicted by Schönau's equations

The Schönau (1973) multiple-regression equation for predicting bark mass from tree height, dbh and bark thickness for *A. mearnsii* has been cited for calculating single tree bark mass in other species such as *P. africana* and *Rytigynia* spp. (Kamatenesi 1997, Cunningham 2001, Cunningham *et al.* 2002). The usefulness of this equation was tested for the six species in this study. The equation for bark mass is as follows:

$$\text{Log BM} = 1.87253 (\log D) + 0.72118 (\log H) + 0.152919 (BT) - 0.11767 (BT * \log D) + 0.037728 (BT * \log H) - 0.04586$$

Where, BM = total undried bark mass per tree up to a tip diameter of 5 cm under bark (kg); D = dbh (cm); H = total height (m); BT = bark thickness at dbh (mm). Because bark mass was only calculated to 2 m height in this study, H in Schönau's equation was given the value of 2 m.

3. Results

Between the six species, 1026 bark samples were removed from 207 individual stems and used to calculate the stem size-specific bark area, volume and mass on the tree to 2 m. The dbh of the stems ranged from 5–65 cm.

3.1 Mean bark area, volume and mass

The results show a positive increase in mean bark quantity with increased stem diameter. With the exception of the fluted stems of *B. maughamii*, the average mass of wet/fresh bark per stem diameter size-class is: <2.0 kg for 5–9 cm dbh; 6.7 kg for 10–19 cm dbh; 10.4 kg for 20–29 cm dbh; 17.4 kg for 30–39 cm dbh; 26.9 kg for 40–49 cm dbh; and, >35.4 kg for 50–59 cm dbh (Table 1, Fig. 2a).

The oven-dry bark mass is presented because the measurement provides a standard for comparison with other species. Additionally, there is greater inter-species and stem size-specific variability in total oven-dry mass, which probably reflects the variation in moisture content and density between the different bark types, as well as the site and seasonal variations. The increase in mean bark mass with increased stem diameter is still evident, and the average oven-dry bark mass per stem diameter size-class is: <1.0 kg for 5–9 cm dbh; 4.1 kg for 10–19 cm dbh; 5.8 kg for 20–29 cm dbh; 10.7 kg for 30–39 cm dbh; and, 16.1 kg for 40–49 cm dbh (Table 1, Fig. 2b). The large quantity of bark per stem for *B. maughamii* is a result of the additional bark surface area contained within the flutes of the stem.

In addition to wet and oven-dry mass, we present the mean harvestable mass if the bark had been air-dried for 1–2 weeks and 6 weeks respectively (Table 1). Because bark looses a lot of moisture within the first two weeks following harvesting (Table 3), and this is the time during which the bark is transported to and sold in the *muti* markets, the average mass for weeks 1 and 2 is presented in the results instead of the individual results for the two time periods. Results are also presented for bark air-dried for 6 weeks because this was found to be the average age of bark in the street markets (Williams 2003). Bark in the *muti* shops, however, was usually more than three months old, but there is no significant difference in the estimated harvestable mass six to twelve weeks after harvesting. It is therefore acceptable to use the 6 week old bark quantity estimates for bark that is seven weeks and older.

The total wet and dry bark mass for species where no size-specific data are available can be extrapolated from the upward trend of the columns that show total mass increasing with increased stem size at dbh in Fig. 2. Data for *B. maughamii* are not shown on the graphs because the large quantity of bark (± 127 kg in the 50–59 cm class) obscures the details for the other species. Similarly, mass for the 5–9 cm class of *R. chirindensis* and *W. salutaris* is not shown because it clutters the graph. The graphs also provide a guide to the quantity of wet bark mass per stem size-class, irrespective of the species. Oven-dry bark mass is, however, more variable.

In testing how sensitive the total bark mass calculations are to ± 1 mm changes in bark thickness, results showed that if $D_{0.5}$, $D_{1.0}$, $D_{1.3}$, $D_{1.5}$ and $D_{2.0}$ and h are kept the same, and bark thickness at these levels is increased by 1 mm, then the increase in bark mass between the six species is only 0.2 – 1.5%. Similarly, if the bark thickness is decreased by 1 mm, then the decrease in calculated bark mass is only 0.5 – 1.2%. These increases or decreases in total bark mass based on ± 1 mm changes in bark thickness are not significant.

Table 1: Estimated mean wet and oven-dry mass of harvestable bark per species per stem diameter size-class up to 2 m height. The table also includes the mean estimated mass of the bark if air-dried for 1-2 and 6 weeks. Figures in parentheses represent the actual value of only one sample in the size-class.

Stem diameter class (dbh) (cm)	Wet mass (kg)	1-2 weeks mass (kg)	6 weeks mass (kg)	Oven-dry mass (kg)
Acacia xanthophloea				
10 – 19	7.7 ± 1.9	4.8 ± 1.2	3.1 ± 0.7	2.7 ± 0.6
20 – 29	11.0 ± 3.6	7.2 ± 2.6	4.7 ± 1.7	4.1 ± 1.4
30 – 39	15.7 ± 4.1	10.2 ± 2.9	7.0 ± 1.7	6.1 ± 1.5
40 – 49	24.7 ± 5.0	16.6 ± 5.9	11.1 ± 3.6	7.9 ± 0.4
Albizia adianthifolia				
10 – 19	5.6 ± 1.9	3.4 ± 1.2	2.5 ± 0.9	2.2 ± 0.8
20 – 29	8.7 ± 2.2	5.9 ± 1.4	4.4 ± 0.9	3.8 ± 0.8
30 – 39	16.1 ± 3.1	11.2 ± 2.6	8.0 ± 1.9	7.0 ± 1.7
40 – 49	28.9 ± 6.1	20.3 ± 4.5	14.1 ± 3.7	12.7 ± 3.2
50 – 59	35.4 ± 8.8	25.1 ± 4.8	17.6 ± 2.5	15.3 ± 2.4
Balanites maughamii ('D2')				
10 – 19	17.2± 4.5	16.5 ± 4.4	13.9 ± 5.1	12.4 ± 4.5
20 – 29	36.9± 8.6	28.9 ± 8.6	28.8 ± 6.0	24.7 ± 5.3
30 – 39	70.2 ± 24.7	57.8 ± 20.5	56.1 ± 20.0	49.7 ± 17.8
40 – 49	65.4 ± 10.5	55.6 ± 7.6	53.3 ± 8.4	47.5 ± 7.3
50 – 59	127.3 ± 35.9	105.7 ± 39.6	97.7 ± 38.2	86.5 ± 33.9
Elaeodendron transvaalense				
10 – 19	6.9 ± 2.9	5.8 ± 2.6	5.6 ± 2.3	4.9 ± 2.0
20 – 29	11.8 ± 3.4	10.2 ± 3.2	8.9 ± 3.0	7.8 ± 2.6
30 – 39	20.3 ± 4.9	18.3 ± 4.2	16.0 ± 3.4	14.1 ± 3.2
40 – 49	27.3 ± 4.5	25.7 ± 1.2	21.2 ± 1.1	18.8 ± 0.9
Rhus chirindensis				
5 – 9	1.2 ± 0.2	0.8 ± 0.3	0.7 ± 0.2	0.6 ± 0.1
10 – 14	2.6 ± 0.8	1.5 ± 0.4	1.4 ± 0.4	1.2 ± 0.2
15 – 19	8.2 ± 2.2	3.6 ± 1.8	3.5 ± 0.5	3.5 ± 1.2
20 – 24	8.4 ± 2.3	5.7 ± 1.0	5.3 ± 1.2	4.4 ± 1.5
25 – 29	10.9 ± 4.9	7.0 ± 0.3	6.7 ± 0.9	4.8 ± 0.4
Warburgia salutaris				
5 – 9	1.9 ± 0.8	1.1 ± 0.4	0.9 ± 0.4	0.8 ± 0.3
10 – 14	3.3 ± 0.5	2.0 ± 0.3	1.5 ± 0.5	1.4 ± 0.2
15 – 19	5.4 ± 1.9	3.2 ± 0.6	3.0 ± 1.0	2.7 ± 0.9
20 – 24	10.6 ± 0.5	6.2 ± 0.2	5.2 ± 0.2	4.6 ± 0.2
25 – 29	(12.9)	(7.8)	(6.7)	(5.9)
(68)	(39.5)	(25.8)	(24.2)	(21.0)

Table 2: Estimated mean volume and area of harvestable bark per species per stem diameter size-class up to 2 m height. Figures in parentheses represent the actual value of only one sample in the size-class.

Stem diameter class (dbh) (cm)	Volume (cm^3)	Area (m^2)
Acacia xanthophloea		
10 – 19	9 007 ± 2 193	1.12 ± 0.16
20 – 29	13 749 ± 4 149	1.59 ± 0.15
30 – 39	17 065 ± 4 692	2.09 ± 0.12
40 – 49	26 009 ± 5 352	2.86 ± 0.26
Albizia adianthifolia		
10 – 19	7 251 ± 3 441	1.09 ± 0.24
20 – 29	12 639 ± 1 880	1.61 ± 0.14
30 – 39	21 790 ± 3 145	2.22 ± 0.17
40 – 49	39 565 ± 3 666	3.11 ± 0.32
50 – 59	45 990 ± 6 416	3.57 ± 0.21
Balanites maughamii ('D2')		
10 – 19	19 233 ± 7 459	3.18 ± 0.50
20 – 29	40 842 ± 9 269	5.13 ± 0.80
30 – 39	82 221 ± 18 763	9.16 ± 1.01
40 – 49	88 204 ± 19 881	10.98 ± 0.22
50 – 59	141 910 ± 42 059	16.04 ± 0.79
Elaeodendron transvaalense		
10 – 19	6 609 ± 2 470	0.97 ± 0.21
20 – 29	12 730 ± 3 383	1.50 ± 0.16
30 – 39	23 263 ± 4 285	2.22 ± 0.14
40 – 49	30 157 ± 4 227	2.83 ± 0.29
Rhus chirindensis		
5 – 9	1 533 ± 320	0.48 ± 0.07
10 – 14	3 898 ± 576	0.71 ± 0.07
15 – 19	7 319 ± 2 359	1.12 ± 0.12
20 – 24	10 615 ± 1 597	1.43 ± 0.09
25 – 29	(14 270)	(1.641)
(31.2)	(17 582)	(2.118)
Warburgia salutaris		
5 – 9	2 643 ± 856	0.57 ± 0.11
10 – 14	4 148 ± 582	0.81 ± 0.10
15 – 19	8 961 ± 3 467	1.07 ± 0.17
20 – 24	18 388 ± 1 835	1.65 ± 0.05
25 – 29	(20 301)	(1.819)
(68)	(55 296)	(3.157)

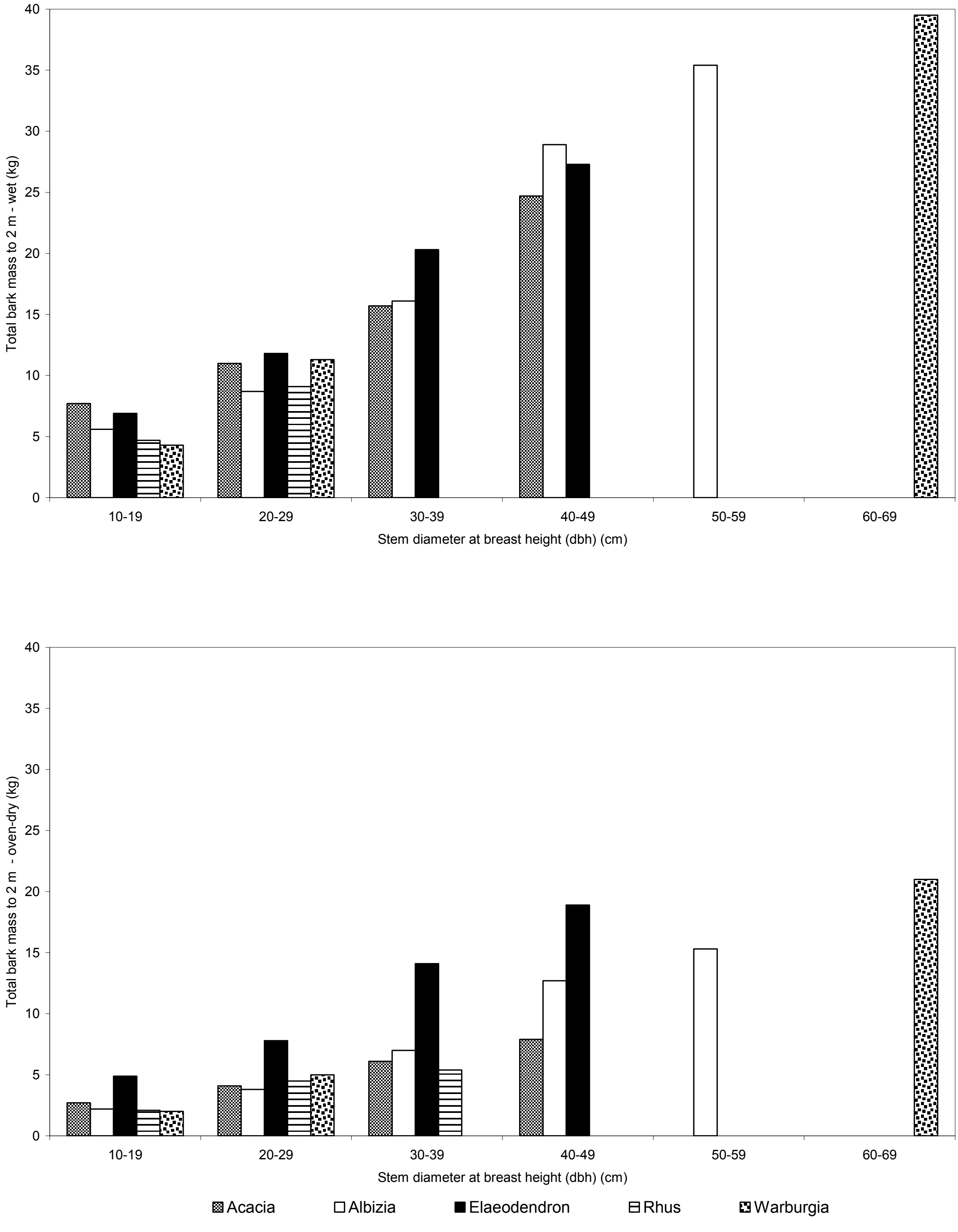


Fig. 2. Comparative mean a) wet and b) oven-dry bark mass per size-class per species, except for *B. maughamii* (see text) and the 5-9 cm size-class for *R. chirindensis* and *W. salutaris*. The histograms provide a guide to bark quantity per stem size-class, irrespective of the species.

3.2 Differences between wet- and oven-dried bark mass

The mean percentage weekly decrease in bark sample mass as the bark dries out varies between species (Table 3). On average, bark decreased in mass by 45% after twelve weeks, and was 51% of its original mass after oven-drying. *Balanites maughamii* and *E. transvaalense*, however, only showed decreases of 37% and 35% respectively after oven-drying, indicating that the bark contains less moisture and/or is denser than the other species. For most species the largest decreases in bark mass occurred between weeks 1 and 2 (Table 3), especially for *A. xanthophloea*, which decreased by 47.5%. These results corroborate the evidence of the weekly decrease in bark thickness exhibited by the same species (Williams *et al.* in press 3). Paired two-tailed t-tests comparing the difference between the total bark mass for wet and oven-dry bark were significant at $p < 0.0005$ for all six species.

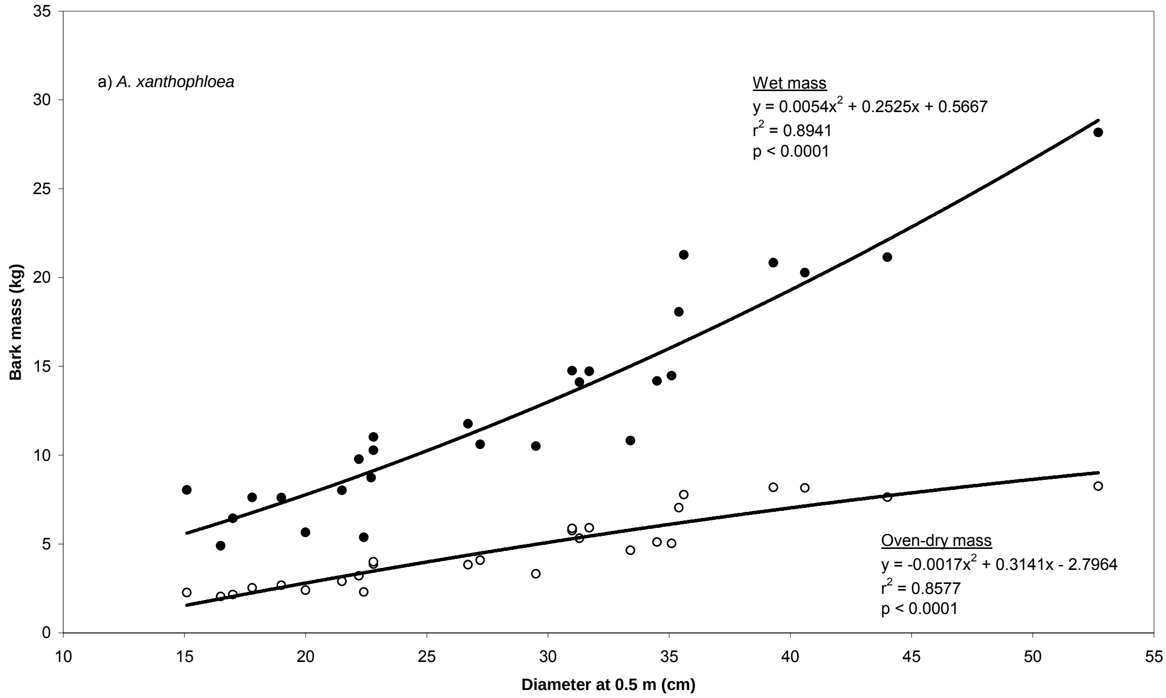
The extent of the decrease in total bark mass after oven-drying is also evident in Fig. 2. For example, the high moisture content in *A. adianthifolia* bark compared to *E. transvaalense* is obvious when comparing total wet and oven-dry bark mass in Fig. 2a and 2b respectively. The quantity of *A. adianthifolia* bark drops considerably compared to *E. transvaalense* after being oven-dried.

Table 3: Weekly percentage decrease (mean and standard deviation) in the mass of the bark samples, as well as the overall difference between wet and oven-dry bark thickness. Note: a zero percent change in bark mass indicates that the scale could not detect a decrease smaller than 0.0001 g.

Time difference	*Acacia xanthophloea (n = 119 to 135)*	*Albizia adianthifolia (n = 180 to 185)*	*Balanites maughamii (n = 124 to 134)*	*Elaeodendron transvaalense (n = 108 to 120)*	*Rhus chirindensis (n = 120 to 129)*	*Warburgia salutaris (n = 100 to 108)*
W0 to W1	20.2 ± 10.5%	18.1 ± 12.5%	19.1 ± 12.2%	11.5 ± 9.8%	28.8 ± 17.5%	34.3 ± 13.8%
W1 to W2	47.5 ± 6.7%	39.7 ± 6.6%	12.9 ± 8.8%	15.5 ± 6.3%	22.3 ± 14.5%	22.2 ± 8.0%
W2 to W3	1.5 ± 2.1%	1.7 ± 2.2%	0.4 ± 1.2%	2.3 ± 1.5%	2.4 ± 6.5%	2.0 ± 2.0%
W3 to W4	0.3 ± 0.8%	1.5 ± 2.4%	0.7 ± 0.6%	0.9 ± 0.6%	1.3 ± 2.5%	0.6 ± 0.5%
W4 to W5	0.5 ± 0.5%	0.5 ± 1.0%	0.0 ± 0.6%	0.5 ± 0.7%	0.6 ± 4.9%	0.5 ± 0.6%
W5 to W6	0.0 ± 0.3%	0.8 ± 1.8%	0.4 ± 0.6%	0.3 ± 0.4%	0.5 ± 0.9%	1.6 ± 0.9%
W6 to W7	0.0 ± 0.2%	1.3 ± 0.6%	0.1 ± 0.4%	0.1 ± 0.2%	0.1 ± 0.8%	0.0 ± 0.7%
W7 to W8	0.6 ± 0.3%	0.0 ± 0.4%	0.0 ± 0.4%	0.2 ± 0.3%	0.2 ± 0.9%	1.3 ± 0.3%
W8 to W9	0.0 ± 0.2%	0.9 ± 3.3%	0.0 ± 0.4%	0.0 ± 0.1%	0.0 ± 2.2%	0.0 ± 0.3%
W9 to W10	0.0 ± 0.1%	0.0 ± 0.3%	0.1 ± 0.4%	0.0 ± 0.1%	0.2 ± 0.5%	0.9 ± 0.2%
W10 to W11	0.4 ± 0.2%	0.0 ± 1.2%	0.1 ± 0.3%	0.1 ± 0.5%	0.0 ± 0.3%	0.0 ± 0.1%
W11 to W12	0.0 ± 0.1%	0.1 ± 0.2%	0.3 ± 1.9%	0.2 ± 0.2%	0.0 ± 0.6%	0.1 ± 0.6%
W12 to W13	12.6 ± 0.9%	11.2 ± 1.5%	10.6 ± 0.5%	10.9 ± 0.6%	12.8 ± 2.3%	10.8 ± 0.55
W0 to W12	58.7 ± 6.9%	53.6 ± 8.2%	29.8 ± 12.1%	27.8 ± 10.0%	46.9 ± 12.9%	51.1 ± 12.0%
W0 to W13	63.9 ± 6.1%	58.6 ± 6.7%	37.3 ± 10.8%	35.4 ± 9.3%	53.6 ± 11.4%	56.2 ± 10.6%

3.3 Regression of bark mass with stem diameter

The quadratic regressions of wet- and oven-dry bark mass against diameter at 1.0 m above ground were selected as the best models (based on r^2 values) for estimating total bark mass for *B. maughamii*, *E. transvaalense*, *R. chirindensis* and *W. salutaris* (Fig. 3c-e). The best models for predicting total bark mass for *A. xanthophloea* and *A. adianthifolia* were at 0.5 and 1.5 m above ground respectively (Fig. 3a, b). However, given that diameter at breast height is often used as a predictor of tree bark quantity (Kamatenesi 1997, Cunningham 2001, Wong *et al.* 2001), the results of the regression between dbh and bark mass are also presented (Table 4). Except for *E. transvaalense*, the best regression models at dbh are quadratic.



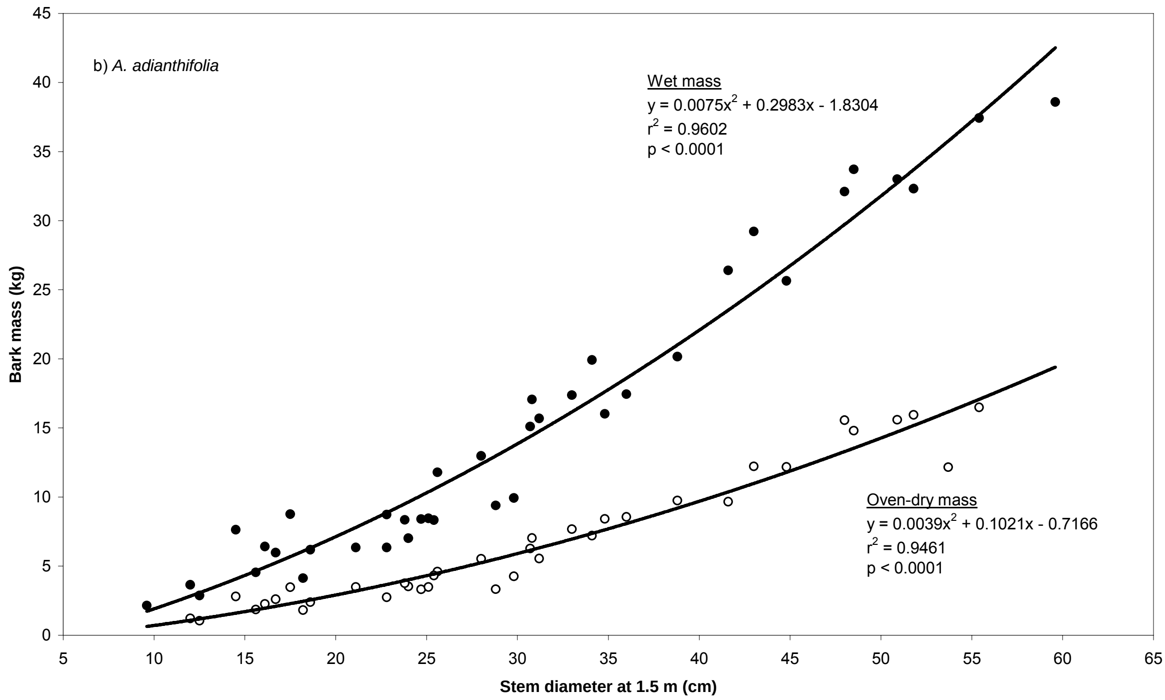


Fig.3. Regression equations for predicting total wet and oven-dry bark mass to 2m, where y = estimated bark mass (kg) to 2 m, and x = stem diameter at a specified height (cm)

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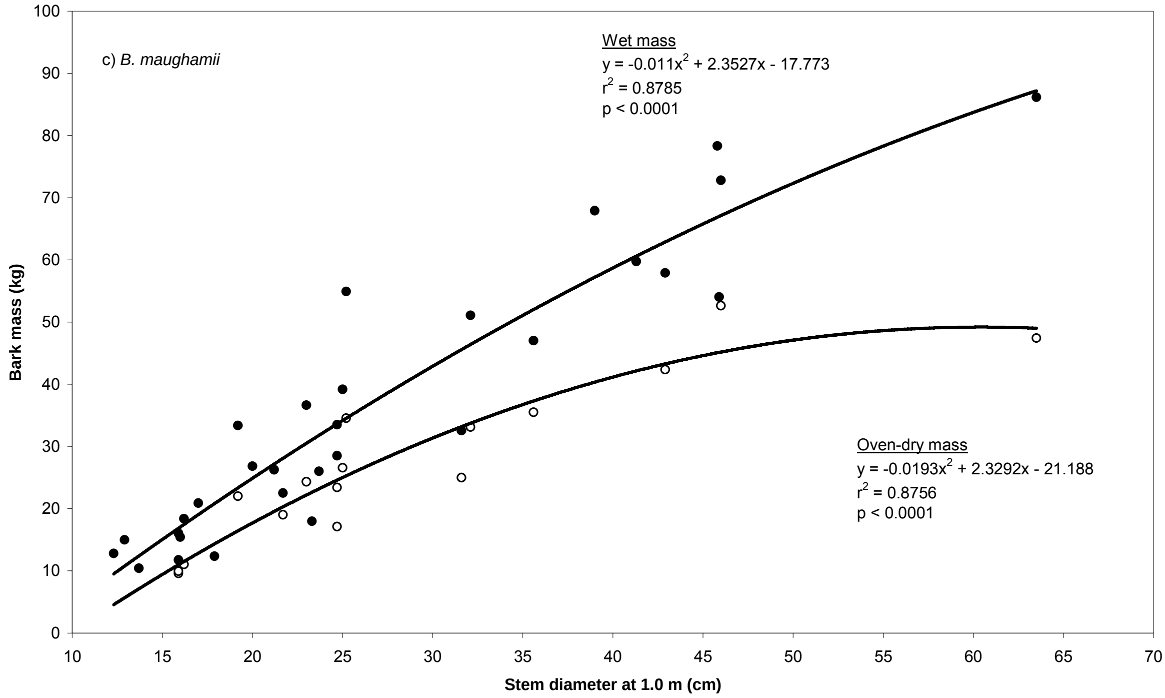

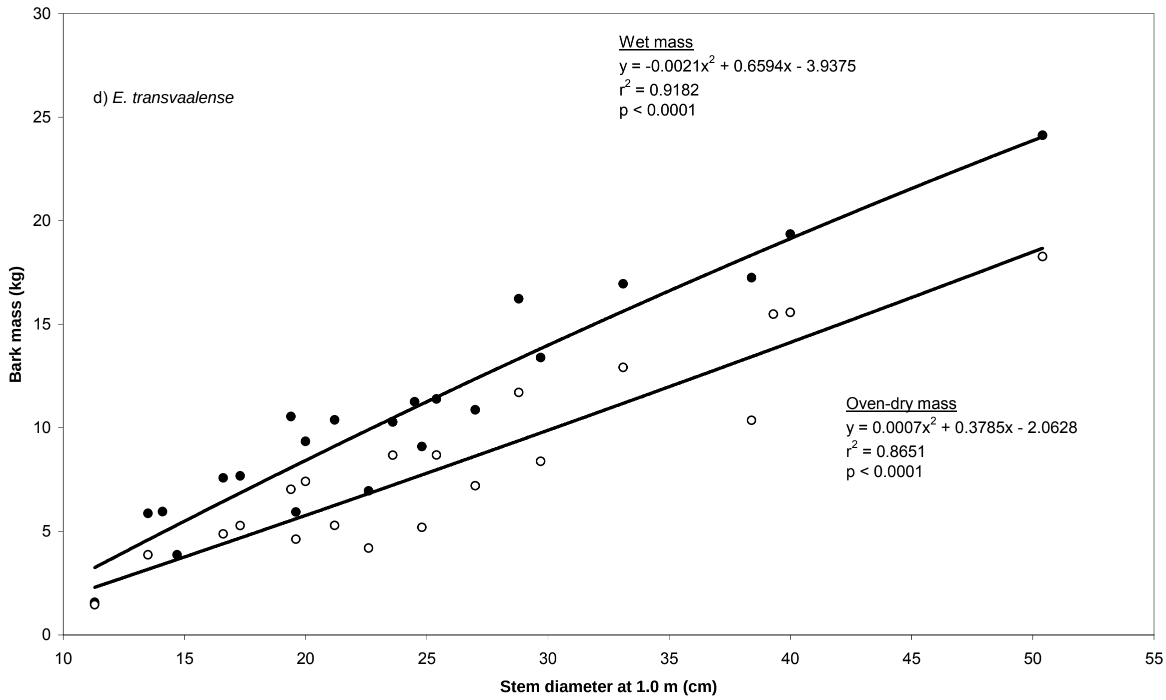

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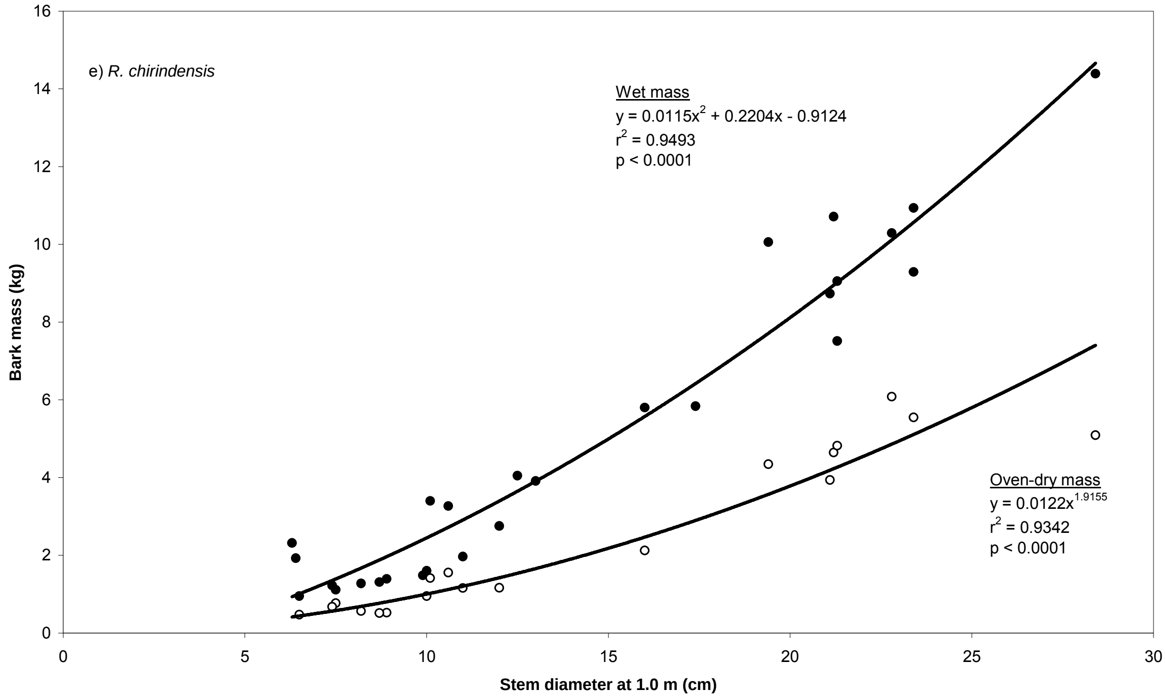

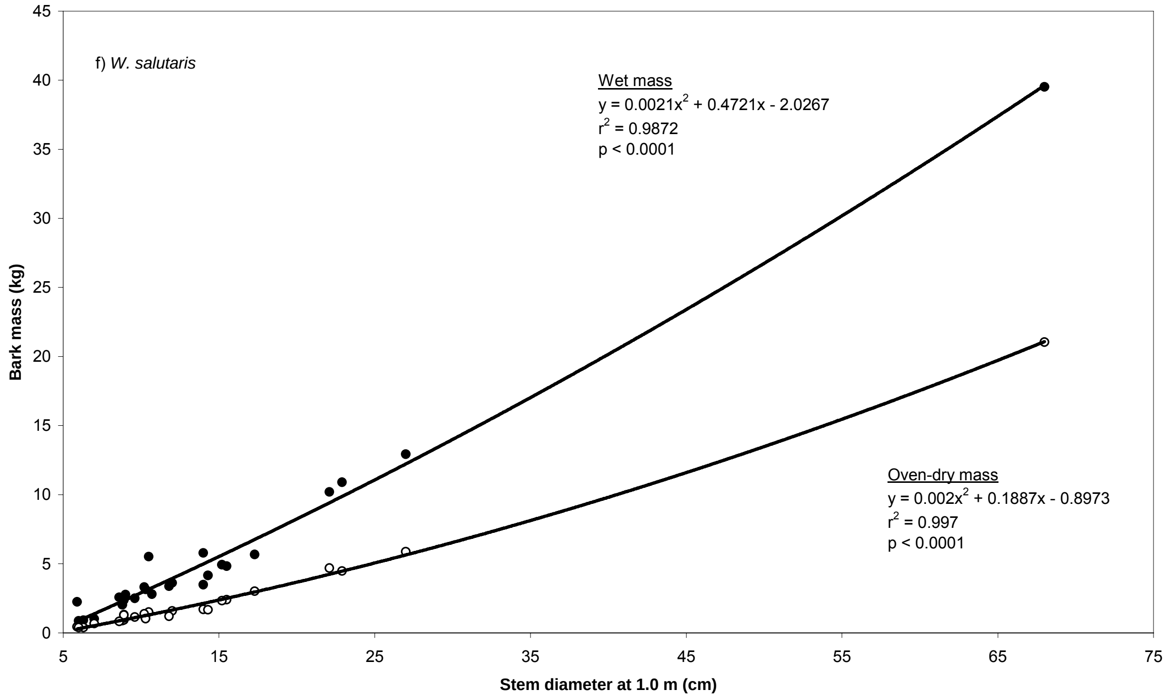

Table 4: Predictive regression equations relating stem diameter at breast height ($D_{1.3}$) to total bark mass to 2 m. y = bark mass (kg); x = dbh (cm)

Species	Regression equation	r^2
Wet mass		
A. xanthophloea	$y = 0.0074x^2 + 0.2208x + 1.427$	0.883
A. adianthifolia	$y = 0.0076x^2 + 0.2828x – 1.834$	0.959
B. maughamii	$y = -0.0124x^2 + 2.5043x – 18.367$	0.869
E. transvaalense	$y = 0.567x – 2.6314$	0.860
R. chirindensis	$y = 0.0097x^2 + 0.293x – 1.2718$	0.936
W. salutaris	$y = 0.0045x^2 + 0.3681x – 1.1932$	0.978
Oven-dry mass		
A. xanthophloea	$y = -0.0019x^2 + 0.3316x – 2.534$	0.844
A. adianthifolia	$y = 0.0034x^2 + 0.1309x – 1.166$	0.935
B. maughamii	$y = -0.0217x^2 + 2.4789x – 21.709$	0.881
E. transvaalense	$y = 0.432x – 2.359$	0.741
R. chirindensis	$y = -0.003x^2 + 0.3829x – 2.2607$	0.929
W. salutaris	$y = 0.0031x^2 + 0.1508x – 0.6$	0.993

All the results of the regressions were highly positive and significant, indicating that total bark mass can be predicted with sufficient accuracy from stem diameter measurements for the six species. The relationships between wet mass and stem diameter were generally stronger than the relationships between oven-dry mass and diameter, with r^2 = 0.894 – 0.987 and r^2 = 0.865 – 0.997 respectively (Fig. 3).

3.4 Comparing bark mass predicted by Schönau's equations

Results showed that the Schönau (1973) equation greatly underestimated bark mass by an average of 47% compared with the authors equations. The mean and standard deviation of the underestimates per species are: *R. chirindensis* 25.6 ± 31.3%; *W. salutaris* 30.4 ± 25.3%; *A. xanthophloea* 45.4 ± 18.7%; *E. transvaalense* 48.3 ± 22.7%; *A. adianthifolia* 48.8 ± 23.6%; and, *B. maughamii* 81.3 ± 10.2%, a tree with a distinctively fluted and buttressed stem.

4. Discussion

Pressures on woodland and forest resources have increased as the national trade in traditional plant medicines has grown (Geldenhuys 2004). Bark is the most popular medicinal non-timber forest product (NTFP) harvested from trees and traded annually in KwaZulu-Natal and the Witwatersrand (Mander 1998, Grace *et al.* 2002, Williams 2004). The current levels of use of some bark-providing species are unsustainable (Geldenhuys 2004), and it is imperative that the standing stocks of forest products, such as bark, are researched to improve our understanding of the ecology of these resources (Lawes *et al.* 2004) so that the potential for sustainable harvesting can be investigated.

The bark quantities listed in Table 1 and shown in Fig. 2 are a reasonable guide to the available bark stock per size-class per species. Fresh bark quantities may vary between sites and seasons for the species depending on the moisture content of the bark (Cunningham 2001), however ± 1 mm differences in bark thickness do not significantly change the estimated harvestable bark mass present on a stem to 2 m.

Cunningham (2001) noted the importance of taking accurate measurements of bark thickness, particularly when calculating the bark mass for a tree, because of Schönau's (1973) report that a 1 mm difference in bark thickness will cause an increase or decrease in bark thickness of about 10% in bark mass if dbh and tree height are kept constant. This premise was tested for the six species in this investigation, and no significant differences in bark mass were found. Results showed that a ± 1 mm change in bark thickness caused no more than a 1.5% change in bark mass if dbh and height were kept constant using the method of cylindrical subsections to calculate the mass. However, the Schönau (1973) multiple-regression equation for calculating total bark mass was based on trees that were 10–25.5 m high – and not harvestable bark mass to 2 m like this study. Hence, sensitivities to changes in bark thickness when it comes to calculating mass might only be evident when the quantity is calculated for the entire bole, and not a 2 m subsection thereof. Decreases in bark thickness of 1 mm or more due to air-drying are only detected 1–3 weeks after harvesting, depending on the original bark thickness, moisture content, bark type and species (Williams *et al.* in press 3). Hence, some inaccuracies in reporting the data can be accommodated when it comes to estimating bark mass, but not when it comes to describing the relationship between bark thickness and stem diameter.

When a stem is debarked, the bark has a specific fresh mass. As the bark air-dries over a period time, it becomes increasingly lighter. The percentage difference between wet- and oven-dry bark mass can be equated to the decreased water content of the bark. Bark moisture content varied between 35–64%, with an average of 51% (Table 3). This is similar to the decrease in bark thickness, where the same species lost 50% of their original bark thickness after oven-drying (Williams *et al.* in press 3). Similarly, the average water content of *Rytigynia* spp. bark was 59% (Kamatenesi 1997), and that of *A. mearnsii* was 50% (Schönau 1973). Given that the bark sold in the markets is unlikely to be fresh and is often more than 6 weeks old, it is not always prudent to compare the mass likely to be traded, and the bark thickness, with figures derived for freshly harvested bark. Therefore, in determining the harvestable bark mass per stem and the mean harvestable mass per stem size-class, figures were calculated that show what the bark would have weighed if it were fresh, then 1–2 weeks old, then 6 weeks old and finally oven dried.

There is a strong positive relationship between total bark mass (wet and dry) and diameter at breast height (1.3 m) (Table 4). However, regression analyses showed stem diameter at 1.0 m ($D_{1.0}$) to be a better predictor of bark mass for *B. maughamii*, *E. transvaalense*, *R. chirindensis* and *W. salutaris*. Similarly, the regression equations for bark mass and stem diameter at 0.5 m and 1.5 m ($D_{0.5}$ and $D_{1.5}$) were better models for *A. xanthophloea* and *A. adianthifolia* respectively (Fig. 3). While dbh is conventionally measured and correlated with response variables such as bark mass and thickness, it is recommended that diameter measurements taken at other height intervals are also correlated with mass in order to determine the best biomass predictor variables for the species.

The present study clearly indicates that bark quantity per tree increases with increasing stem diameter (Tables 1 and 2, Figs 2 & 3). While size-related decreases in the rate of bark production probably occur in some species, there was no conclusive evidence of this in the six species investigated (with respect to bark mass and girth relationships) that could not also be accounted for by species specific bark exfoliation (age/size-related or not) or site conditions (see Williams *et al.* in press 3 for more discussion). The quadratic equations derived for the species did not show any size-related levelling of bark mass with increased stem diameter (Fig. 3). The quadratic regressions derived for *P. africana* trees in Cameroon (Cunningham *et al.* 2002) and *Rytigynia* spp. in Uganda (Kamatenesi 1997) also appear to show no levelling out of bark mass with increased dbh. Similarly, size-related decreases in bark production were not evident in dbh versus bark thickness for the same species (Williams *et al.* in press 3). However, given that total bark mass was only calculated for the first 2 m of the stem and not for the entire trunk, it is possible that these changes cannot be detected for the height for which bark mass was calculated. Additionally, it is possible that disinvestments in bark production with tree size are only detected when comparing the bark mass with tree height, something not done in this investigation.

The large quantity of bark per stem for *B. maughamii* is a result of the bark surface area contained within the flutes of the bole. As the tree grows, the number and depth of flutes tends to increase, thus increasing the proportional quantity of bark contained within the convolutions of the flutes (Williams *et al.* in press 2). A tree of 10 cm dbh can have 2–3 flutes and a total stem circumference of 1.1 m; a tree of 49 cm dbh can have 6–10 flutes and a stem circumference of 6.7 m (Williams *et al.* in press 2). However, the amount of bark estimated to be present on the *B. maughamii* stem to 2 m, is not the same as the amount that could be practically harvested. Because of the fluted stem and the difficulties involved in removing bark from the trunk, bark harvesters tend to remove whole sections of the stem including the timber, thus leaving behind some of the bark contained in the depression of the flute. On average, about two-thirds of the bark area is contained in the convolutions of the flutes (Williams *et al.* in press 2). Therefore, ± 30% of the total bark mass is accessible without harvesters having to remove sections of the stem.

Using the Schönau (1973) formula to calculate the bark mass to 2 m resulted in a 26–81% underestimate of bark mass between the six species, the largest of which was for *B. maughamii*. The average underestimate is 47%, which is similar to the 40% lower bark mass estimates that

Kamatenesi (1997) found when using the formula to calculate bark mass for *Rytigynia* spp. (as compared to the cylinder formula that was originally used). However, Cunningham *et al.* (2002) found similarities with Schönau's (1973) predictions for *A. mearnsii* when comparing bark mass data from *P. africana* trees higher than 7.5 m and with 8 mm bark at breast height. In the case of the six species in this investigation and *Rytigynia* spp. bark mass was estimated to 2 m, whereas bark for *P. africana* and *A. mearnsii* were estimated for the full length of the bole. Schönau's equation appears, therefore, not to be appropriate for estimating bark mass for trees where the stem height is less than 7.0 m.

A recurring theme in this paper is the sensitivity of total bark mass estimates within 2 m stem height. It appears that height and bark thickness are important predictor variables in multiple regression models derived to predict total bark mass for species where bark is harvested beyond the 2 m mark. However, tree height becomes a less important variable when bark quantities can be obtained from dividing the stem into cylinder shaped subsections and then using regression analyses to derive predictive equations relating stem diameter to bark mass. Cunningham (2001) recommends that diameter measurements should be taken at regular intervals up the trunk so that calculations of bark quantity are made for stem subsections as a way of minimizing errors as the bole tapers. This method was practical for estimating the mean bark mass per stem size-class per species.

There is a tendency to conduct bark thickness studies by removing bark with a hammer and chisel, or using a bark gauge to measure the thickness. We propose that removing bark for these kinds of studies with a hole-saw and brace is more expedient. The wounds are clean, the sample is a good size (and can be altered depending on the size of the hole-saw selected), it is quick to do and many trees can be sampled in a short space of time. Additionally, the centre hole in the sample means that the samples can be threaded on to a cable tie and can be easily dried, weighed and measured.

The response of plants to exploitation and the implications of declining productivity under high frequency and/or high intensity exploitation are critical to policy development for particular species (Cunningham 1988). To be able to calculate the harvestable mass of bark for an individual and subsequently estimate the number of plants damaged annually from the quantity known to be sold by herb-traders, is a novel and invaluable tool for resource managers. Conservation efforts could consequently be directed at high priority species where many individuals are known to be damaged by harvesters of medicinal plants. The number of individuals estimated to be harvested annually is the subject of the paper that follows.

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Height, branch-free bole length and bark thickness for six tree species used medicinally in South Africa

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Information on tree stem characteristics and dimensions is sparse, especially information that would enhance conservation and trade monitoring efforts for species where bark is harvested for medicinal use. Several tree stem characteristics were investigated during a study on the relationship between bark thickness and stem diameter, and this paper presents the mean height, branch-free bole length and wet and oven-dry bark thickness per stem diameter-class for six species. Additionally, prediction tables are constructed that allow bark thickness to be determined from diameter at breast height.

Key words: *Acacia xanthophloea*, *Albizia adianthifolia*, *Balanites maughamii*, bark, diameter at breast height, *Elaeodendron transvaalense*, medicinal plants, *Rhus chirindensis*, *Warburgia salutaris*.

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Introduction

Woodland and forest species account for at least 73 % of the income of traders in Johannesburg's traditional medicine street market (Williams 2004). Bark products account for the largest proportion (52 %) of the volume sold (Williams 2004). Despite the importance of bark in traditional medicine in South Africa, ethnobotanical literature about it is scant or inaccessible (Grace *et al.* 2002). Additionally, there is a lack of detailed information to empower conservation and trade monitoring efforts (Grace *et al.* 2002).

Uncontrolled bark harvesting for traditional medicine seriously impacts on forest ecosystems and species (Geldenhuys 2004), and harvesting is often highly selective for families, genera, species or tree size-classes based on particular bark qualities and secondary plant chemicals (Cunningham 2001). In an effort to monitor the availability of bark thickness size-classes in medicinal plant markets, as well as the impact of bark harvesting on tree populations, the authors explored the relationship between bark thickness and tree size for six species. In the absence of practical techniques to determine the age of trees, size can be used as a surrogate (van Wyk *et al.* 1996). Tree stems generally increase in girth as they get older, and diameters are therefore the most appropriate measure for grouping plants into size-classes. Bark thickness generally increases with diameter and stem age (Borger 1973). In some species, a straight-line relationship exists between bark thickness and stem diameter, owing to the persistence of the rhytidome (outer bark) and the resistance of bark to weathering (Borger 1973). In other species, however, the relationship is weak or curvilinear owing to the shedding of the bark to a greater or lesser extent (Borger 1973).

The authors have already described the strength of the linear relationship between bark thickness and stem diameter (at 1.3 m, diameter at breast height (dbh)) for six species, and constructed "tariff tables" to predict the dbh of the trees targeted by harvesters from the thickness and age of the bark found for sale in medicinal plant markets (Williams *et al. in prep*.). This paper presents the results of the mean wet and oven-dried bark thickness per size class of trees sampled, as well as the regressions and estimates of bark thickness at 1.3 m for trees of a specified diameter at breast height. Additionally, the mean height and branch-free bole length of individuals sampled from the six species are listed. The bark of the six tree species investigated are all used for traditional medicine and sold in the markets of KwaZulu-Natal, Gauteng and Mpumalanga (Cunningham 1988; Williams *et al.* 2000; Botha 2001; Williams 2003). The information presented in this paper will serve as base-line autecological data for the species concerned, and is expected to be of value to researchers in the field of ethnobotany as well as to forest and resource managers/ecologists investigating population dynamics and the change in resource availability over time.

Study sites and species

Six species were sampled at fifteen woodland sites in three South African provinces between March and May 1998 (Table 1). Seven of the sites were on privately-owned

Table 1
Description of sample sites and the number of individuals sampled per species at each site

Province	Site code	Area in province	Ownership and management regime	Species sampled (No.)
Limpopo	L1	Western Soutpansberg	Private game farm	*R. chirindensis* (11) *W. salutaris* (27)
	L2	Western Soutpansberg	Private farm	*B. maughamii* (17) *E. transvaalense* (1) *R. chirindensis* (9)
	L3	Western Soutpansberg	Private farm	*E. transvaalense* (5)
	L4	Western Soutpansberg	Private farm	*B. maughamii* (13)
	L5	Nylstroom	Protected area	*E. transvaalense* (13)
	L6	Eastern Soutpansberg	State-owned forestry land	*A. adianthifolia* (29)
	L7	Eastern Soutpansberg	State-owned forestry land	*A. adianthifolia* (13)
	L8	Eastern Soutpansberg	State-owned forestry land	*R. chirindensis* (4)
Mpumalanga	M1	Nelspruit	Protected area	*A. xanthophloea* (1) *B. maughamii* (2)
	M2	South of Malalane	Private farm	*R. chirindensis* (5)
	M3	South of Malalane	Private mine	*R. chirindensis* (5)
KwaZulu-Natal	K1	Maputaland	Protected area	*A. xanthophloea* (12)
	K2	Maputaland	Communal land	*A. xanthophloea* (1) *B. maughamii* (3) *E. transvaalense* (6)
	K3	Zululand	Protected area	*A. xanthophloea* (1) *A. adianthifolia* (4) *B. maughamii* (1)
	K4	Zululand	Private company protected area	*A. xanthophloea* (19) *A. adianthifolia* (1) *B. maughamii* (3) *E. transvaalense* (6)

Table 2
Descriptive data for the six tree species investigated

Species and family	Size (Height)	Bark type[a] and description	Other tree & habitat characteristics
Acacia xanthophloea Benth. MIMOSACEAE	Medium to large; average 10-15 m, up to 30 m	Smooth/scaly/powdery bark: smooth, exfoliating, greenish-yellow becoming powdery yellow; as tree gets bigger, bark peels off in huge, thick pieces	Semi-deciduous; fast growing 1-1.5 m in height per year; woodland
Albizia adianthifolia (Schumach.) W.F.Wight MIMOSACEAE	Large to very large; 10-20 m, up to +25 m	Fissured bark: smooth and grey when young, becoming rougher and forming fine yellowish-brown blocks with age	Deciduous; intermediate growing 0.6 m in height per year; forest
Balanites maughamii Sprague BALANITACEAE	Medium to large; 8-20 m, up to 25 m	Tessellated bark: smooth and grey when young, becoming rougher with age	Deciduous; older trunks strongly fluted and buttressed; slow growing; woodland
Elaeodendron transvaalense (Burtt Davy) R.H.Archer CELASTRACEAE	Shrub or small to medium multi-branched tree; 4-6 m, up to 10-15 m	Patchy bark: fairly smooth and pale grey when young, becoming darker, 'blocky' and deeply fissured with age; rhytidome exfoliates in thin scales	Semi-deciduous; slow growing 0.5 m in height per year; woodland
Rhus chirindensis Baker f. ANACARDIACEAE	Shrub or small to large tree; 3-4 m, occasionally 6-10 m; exceptional specimens up to 20 m	Tessellated bark: smooth and dark grey or brown when young, becoming dark and cracked with age	Semi-deciduous; fast growing up to 1 m in height per year; forest and woodland
Warburgia salutaris (Bertol.f.) Chiov. CANELLACEAE	Shrub or medium-sized to large; usually 5-10 m, up to 20 m	Fissured bark: slightly rough, mottled dark brown and grey when young, becoming courser and more fissured with age, lenticellate	Evergreen aromatic; fairly slow-growing, but can be as much as 0.9 m in height per year in warm, frost-free areas; forest and woodland

Sources: Archer & van Wyk (1998); Carr (1994); Grant & Thomas (1997, 1998, 2000); Hankey & Stern (2002); Immelman *et al.* (1973); Mander *et al.* (1995); Palgrave (1977); Pooley (1993); Schmidt *et al.* (2002); Scott-Shaw (1999); Turner (2003); Van Wyk (1974); Van Wyk & Van Wyk (1997); Van Wyk *et al.* (1997); Venter & Venter (1996).

[a] Bark classified according to macroscopic bark terminology given in Borger (1973) and Junikka (1994).

land, four were in protected areas, three on state-owned forestry land and one on communal land. The species were previously selected to represent various risk categories for over-exploitation by the medicinal plant trade (V.L. Williams unpubl. data). In high demand and at high risk are *Warburgia salutaris* (Bertol.f.) Chiov. and *Elaeodendron transvaalense* (Burtt Davy) R.H. Archer [formerly known as *Cassine transvaalensis* (Burtt Davy) Codd]. Also widely used but at a lower risk due to lower levels of exploitation are *Albizia adianthifolia* (Schumach.) W.F.Wight, *Balanites maughamii* Sprague and *Acacia xanthophloea* Benth. *Rhus chirindensis* Baker f. tends not to be as widely utilised as the other species, but in some areas significant damage to populations has been reported (Geldenhuys 2004). The species range in size, growth rate, bark type and habitat (Table 2).

Field methods and data analysis

At each sample site, individuals were selected from various representative size-classes based on the stem diameter at breast height (dbh, 1.3 m above ground). A minimum of five and maximum of ten trees was sampled per diameter-class per species, although specimens in the ≥40 cm size-classes were sometimes more difficult to find, and hence 2–4 trees were often sampled in this class (except for *Albizia*, where trees larger than 60 cm dbh could have been sampled). Stem diameter-classes for *Acacia*, *Albizia*, *Balanites* and *Elaeodendron* were in increments of 10 cm, starting at 10 cm and ending at 50 cm, 60 cm, 60 cm and 50 cm respectively. Diameter-classes for *Rhus* and *Warburgia* were in increments of 5 cm, starting at 5 cm and ending at 35 cm and 30 cm respectively due to the prevalence of individuals in this size range.

Various aspects of the tree stem profile were measured: 1) diameter of the stem at five height intervals (0.5 m, 1.0 m, 1.3 m, 1.5 m and 2.0 m); 2) approximate tree height; and 3) branch-free bole length. A diameter tape was used to measure the diameter of the stem directly from the circumference measurement. Vertical height and branch-free bole length were directly estimated using a two-metre-high pole that was marked in 0.5 m intervals. The number of pole lengths was then counted by eye to estimate height and length. Bark samples were removed from the stem using a 50 mm diameter hole-saw attached to a hand drill brace. Bark thickness of the samples was measured on site using a digital Vernier calliper (accuracy: 0.01 mm), and mass was measured using a portable digital scale (accuracy: 5 g). The bark samples were placed into a phytotron chamber at the University of the Witwatersrand to dry out, and thickness and mass measurements (this time with an electronic balance accurate to 0.001 g) were recorded weekly for each sample. The temperature and relative humidity (RH) in the chamber were set to mimic mean day and night summer conditions (September–March) in Johannesburg, namely: day T° = 20 °C; night T° = 16 °C; day RH = 59 %; night RH = 66 %. Twelve weeks after the samples were harvested, they were oven-dried at 80 °C for four days. Regressions between dbh, bark thickness and mass were calculated using STATISTICA 6 and Excel 2000. Refer to Williams *et al.* (*in prep*.) for detailed information on the methods and regression analysis between bark thickness and stem diameter, as well as the estimation of tree dbh from bark thickness and age (time after harvesting) records.

Results and discussion

Between the six species, 1026 bark samples were removed from 207 individual stems. The largest tree encountered was a mature *W. salutaris* located on a private farm in the Limpopo Province which had a dbh >68 cm (also the level that branching occurred, which could have rendered the dbh reading inaccurate) (Table 3). In terms of the availability of individuals within the various size-classes that could be sampled, most prevalent were stems between 10-39 cm dbh for *A. xanthophloea*, *A. adianthifolia*, *B. maughamii* and *E. transvaalense* (Table 4). Stems with dbh <10 cm were not measured for these four species. Mature trees with stems of dbh >40 cm were not as common (except

Table 3
Tree dimensions for the six study species

Species	N	Tree height (m) Mean ± SD	Tree height (m) Min; Max	Branch-free bole length (m) Mean ± SD	Branch-free bole length (m) Min; Max	LD
Acacia xanthophloea	33	10.2 ± 2.1	6.0; 15.0	4.3 ± 2.5	1.5; 10.0	47.4 cm (K4)
Albizia adianthifolia	46	9.9 ± 2.1	6.0; 14.0	4.6 ± 2.5	0.5; 11.0	59.9 cm (L6)
Balanites maughamii	38	7.9 ± 2.2	4.0; 12.0	2.9 ± 1.4	0.9; 7.0	59.2 cm (K4)
Elaeodendron transvaalense	30	5.1 ± 1.4	3.5; 8.0	2.1 ± 0.8	1.0; 4.5	48.3 cm (L5)
Rhus chirindensis	33	7.7 ± 2.6	4.0; 14.0	3.5 ± 1.8	1.7; 8.0	31.2 cm (L8)
Warburgia salutaris	27	8.1 ± 2.9	3.5; 14.0	2.8 ± 1.3	1.2; 6.0	>68 cm (L1)

LD = Largest diameter recorded at 1.3m (dbh) (site abbreviation, see Table 1) for *Albizia*, where individuals between 50-59 cm were abundant). For *R. chirindensis* and *W. salutaris*, however, the most prevalent size-classes were between 5-24 cm and 5-19 cm dbh respectively. Individuals larger than 25 cm were infrequently encountered (Table 4), although a revisit to two of the sites in 2004 located populations with individuals in the 30-39 cm class that had previously not been observed. The data for *A. xanthophloea* and *W. salutaris* correspond with population structure data obtained by Botha *et al.* (2002, 2004) for these species in the Lowveld, South Africa.

The minimum and maximum heights of the trees are consistent with the size range of the species in the wild (Tables 2 & 3). The mean heights of *A. xanthophloea*, *A. adianthifolia* and *B. maughamii* indicated that the individuals sampled tended to be at the lower end of the size range, whereas *E. transvaalense*, *R. chirindensis* and *W. salutaris* were at the larger end of the range. In the Umzimkulu forests of the Eastern Cape, the stem diameters of *R. chirindensis* are much larger than recorded in this study (C.J. Geldenhuys *pers. comm.*). The mean branch-free bole length indicated that on average, branching commences above 2 m—the level to which bark is assumed to be within reach for harvesting from a standing tree.

The mean wet bark thicknesses of the individuals sampled are shown in Table 4, as well as the minimum and maximum thickness measured. Wet-bark thickness was measured on the day the samples were removed from the trees. The results show a positive increase in bark thickness with stem diameter, except for *A. xanthophloea*. There is a weak relationship between bark thickness and dbh in this species (Table 5) because of the tendency for the bark to be shed in large strips and hence no age-related accumulation of the outer bark (Williams *et al. in prep*.).

The oven-dry bark thickness is also presented (Table 4) because the moisture content of the bark generally varies seasonally and between sites (Cunningham 2001), hence

Table 4

Mean wet and oven-dry bark thickness of the samples per size-class per species

Size-class (dbh) (cm)	Mean (mm)	SD	Min (mm)	Max (mm)	N[1]
Acacia xanthophloea					
a) Wet bark thickness					
10 - 19	8.22	1.27	6.65	10.56	10
20 - 29	8.62	3.09	3.96	13.05	10
30 - 39	8.83	2.74	5.99	13.18	10
40 - 49	7.02	1.6	5.89	8.15	2
b) Oven-dry bark thickness [mean decrease in thickness 50.5% ± 4.2% (SD)]					
10 - 19	3.87	0.60	3.07	4.68	10
20 - 29	4.34	1.71	1.83	7.11	10
30 - 39	4.60	1.58	3.05	7.50	10
40 - 49	6.24	5.34	2.54	12.36	3
Albizia adianthifolia					
a) Wet bark thickness					
10 - 19	5.83	1.99	2.07	9.77	10
20 - 29	8.75	2.54	6.55	15.66	11
30 - 39	10.92	1.01	8.99	12.05	10
40 - 49	12.25	2.65	7.69	15.06	7
50 - 59	13.55	1.27	11.73	15.18	8
b) Oven-dry bark thickness [mean decrease in thickness 52.3% ± 10.5% (SD)]					
10 - 19	2.63	0.84	1.05	4.16	10
20 - 29	3.84	0.86	2.73	5.70	10
30 - 39	5.40	1.10	3.45	6.68	10
40 - 49	6.20	1.18	4.08	7.67	7
50 - 59	7.08	1.33	5.20	8.90	9
Balanites maughamii					
a) Wet bark thickness					
10 - 19	5.73	2.08	1.76	10.38	13
20 - 29	8.04	2.57	4.37	12.42	10
30 - 39	8.80	2.80	3.78	12.52	8
40 - 49	9.69	1.87	7.26	11.67	4
50 - 59	9.91	3.33	4.95	12.1	4
b) Oven-dry bark thickness [mean decrease in thickness 24.0% ± 8.3% (SD)]					
10 - 19	5.31	1.62	4.05	8.74	7
20 - 29	6.26	2.41	3.33	9.89	10
30 - 39	6.88	2.27	2.32	9.32	8
40 - 49	6.18	1.09	5.24	7.37	3
50 - 59	7.87	2.77	4.07	10.59	4

[1] The discrepancies between N (wet bark thickness) and N (oven-dry bark thickness) result from some of the bark samples breaking and not being measurable after 13 weeks. Additionally, the discrepancy in N for wet and oven-dry thickness for the 40-49 cm and 50-59 size-classes of *A. xanthophloea* and *A. adianthifolia* respectively are the result of one bark sample not being measured on-site for wet bark thickness, but being measured every week thereafter until oven-dried.

Table 4 (*continued*)

Size-class (dbh) (cm)	Mean (mm)	SD	Min (mm)	Max (mm)	N[1]
Elaeodendron transvaalense					
a) Wet bark thickness					
10 - 19	6.90	2.23	4.05	10.36	10
20 - 29	9.21	2.87	5.53	15.11	10
30 - 39	10.81	1.59	8.54	13.20	8
40 - 49	13.46	1.48	12.41	14.51	2
b) Oven-dry bark thickness [mean decrease in thickness 30.4% ± 8.5% (SD)]					
10 - 19	4.86	1.86	2.64	8.40	10
20 - 29	6.45	2.24	3.31	10.79	10
30 - 39	7.84	1.33	6.00	9.70	9
40 - 49	8.74	0.37	8.48	9.00	2
Rhus chirindensis					
a) Wet bark thickness					
5 - 9	3.19	0.46	2.56	3.98	10
10 - 14	5.24	1.82	2.73	7.38	7
15 - 19	5.65	1.31	4.81	7.87	5
20 - 24	7.31	1.59	4.56	10.06	8
25 - 29	10.79	1.18	9.95	11.62	2
(31.2)	(7.36)[a]				1
[a] Only one bark sample for the size class hence figure is the actual, not mean, value					
b) Oven-dry bark thickness [mean decrease in thickness 50.7% ± 9.7% (SD)]					
5 - 9	1.59	0.25	1.14	1.99	9
10 - 14	2.24	0.90	1.22	3.89	7
15 - 19	3.12	1.06	2.32	4.94	5
20 - 24	3.72	1.33	2.30	5.87	7
25 - 29	5.23	0.55	4.84	5.62	2
30 - 34	(-)[b]				-
[b] Bark sample broke up and could not be oven dried					
Warburgia salutaris					
a) Wet bark thickness					
5 - 9	4.64	0.99	3.44	6.38	11
10 - 14	5.41	0.45	4.66	5.86	7
15 - 19	6.81	2.01	5.36	11.26	6
20 - 24	9.91	0.01	9.90	9.92	2
25 - 29	(12.68)[c]				1
(60 - 69)	(≈ 15.0)[d]				
[c] Only one bark sample for the size class hence figure is the actual, not mean, value					
[d] Sample not taken at dbh because of branching. Estimate based on bark thicknesses at 1.0 and 1.5m					
b) Oven-dry bark thickness [mean decrease in thickness 49.3% ± 7.6% (SD)]					
5 - 9	2.39	0.79	1.39	3.56	10
10 - 14	3.01	0.35	2.47	3.52	7
15 - 19	3.70	1.55	1.99	6.22	5
20 - 24	4.76	0.45	4.44	5.07	2
25 - 29	(4.48)				1
(60 - 69)	(≈ 9.0)				

[1] The discrepancies between N (wet bark thickness) and N (oven-dry bark thickness) result from some of the bark samples breaking and not being measurable after 13 weeks. Additionally, the discrepancy in N for wet and oven-dry thickness for the 30-39 size-class of *E. transvaalense* is the result of one bark sample not being measured on site for wet bark thickness, but being measured every week thereafter until oven-dried.

the measurement provides a standard for comparison with other samples. The increase in mean bark thickness with increased dbh size-class is still evident. The mean percentage decrease in wet- and oven-dried bark thickness is indicative of the amount of moisture stored and the density of the bark. In general, bark of the targeted species lose 50 % of their original thickness after oven drying, except for *B. maughamii* and *E. transvaalense*, which lose a quarter and a third of their original thickness respectively (Table 4).

The equations and strength of the linear relationship between wet bark thickness and dbh are shown in Table 5. These relationships are described in more detail in Williams *et al.* (*in prep.*), especially in relation to bark type and shedding. Here, however, we present tables derived from the regressions that predict the wet bark thickness and prediction limits at the specified dbh for each tree species (Table 5). These results represent bark thicknesses that would likely be encountered at 1.3 m trunk height during field measurements of tree populations. For species such as *A. adianthifolia* and *W. salutaris*, there is a strong positive correlation between bark thickness and tree size owing to the persistent nature of the bark on the stem (Williams *et al.in prep.*). The relationship is weaker in

Table 5

Predicted bark thickness (x ± 95% prediction range) from dbh. Predictions are for bark thickness on the day of sampling. No prediction table was constructed for Acacia xanthophloea *because there was no significant linear relationship between bark thickness and dbh. The regression equations,* r^2 *and p for the species are as follows, where y = bark thickness (mm) and x = dbh (cm):* Acacia xanthophloea: $y = 7.9869 + 0.0065x$; $r^2=0.005$; $p=0.91$. Albizia adianthifolia: $y = 2.1853 + 0.2146x$; $r^2=0.802$; $p<0.0001$. Balanites maughamii: $y = 3.1844 + 0.1601x$; $r^2=0.61$; $p<0.0001$. Elaeodendron transvaalense: $y = 3.6746 + 0.202x$; $r^2=0.503$; $p=0.00002$. Rhus chirindensis: $y = 1.1473 + 0.301x$; $r^2=0.677$; $p<0.0001$. Warburgia salutaris: $y = 1.5087 + 0.3791x$; $r^2=0.882$; $p<0.0001$

Spp.	*Albizia adianthifolia*		*Balanites maughamii*		*Elaeodendron transvaalense*		*Rhus chirindensis*		*Warburgia salutaris*	
DBH (cm)	Predicted bark thickness (mm)	±95% prediction range (mm)	Predicted bark thickness (mm)	±95% prediction range (mm)	Predicted bark thickness (mm)	±95% prediction range (mm)	Predicted bark thickness (mm)	±95% prediction range (mm)	Predicted bark thickness (mm)	±95% prediction range (mm)
3	3.4	<1; 6.7	3.7	2.4; 4.9	4.3	<1; 8.6	2.1	<1; 5.1	2.6	0.9; 4.4
4	3.7	<1; 6.9	3.8	2.6; 5.1	4.5	<1; 8.7	2.4	<1; 5.4	3.0	1.3; 4.7
5	3.9	<1; 7.1	4.0	2.8; 5.2	4.7	<1; 8.9	2.7	<1; 5.7	3.4	1.7; 5.1
6	4.1	<1; 7.3	4.1	3.0; 5.3	4.9	<1; 9.1	3.0	<1; 6.0	3.8	2.1; 4.6
7	4.3	1.1; 7.5	4.3	3.2; 5.4	5.1	<1; 9.2	3.3	<1; 6.2	4.2	2.5; 5.9
8	4.5	1.3; 7.7	4.5	3.4; 5.6	5.3	1.2; 9.4	3.6	<1; 6.5	4.5	2.9; 6.2
9	4.7	1.6; 7.9	4.6	3.6; 5.7	5.5	1.4; 9.6	3.9	<1; 6.8	4.9	3.3; 6.6
10	5.0	1.8; 8.1	4.8	3.8; 5.8	5.7	1.6; 9.8	4.2	1.2; 7.1	5.3	3.6; 7.0
11	5.2	2.0; 8.3	4.9	4.0; 5.9	5.9	1.9; 9.9	4.5	1.5; 7.4	5.7	4.0; 7.3
12	5.4	2.2; 8.5	5.1	4.2; 6.1	6.1	2.1; 10.1	4.8	1.8; 7.7	6.1	4.4; 7.7
13	5.6	2.5; 8.7	5.3	4.4; 6.2	6.3	2.3; 10.3	5.1	2.1; 8.0	6.4	4.8; 8.1
14	5.8	2.7; 8.9	5.4	4.5; 6.3	6.5	2.5; 10.5	5.4	2.4; 8.3	6.8	5.2; 8.5
15	6.0	2.9; 9.2	5.6	4.7; 6.4	6.7	2.7; 10.7	5.7	2.7; 8.6	7.2	5.5; 8.9
16	6.2	3.1; 9.4	5.7	5.0; 6.6	6.9	3.0; 10.9	6.0	3.0; 8.9	7.6	5.9; 9.2
17	6.5	3.3; 9.6	5.9	5.1; 6.7	7.1	3.2; 11.0	6.3	3.3; 9.2	8.0	6.3; 9.6
18	6.7	3.6; 9.8	6.1	5.3; 6.8	7.3	3.4; 11.2	6.6	3.6; 9.5	8.3	6.6; 10.0
19	6.9	3.8; 10.0	6.2	5.5; 7.0	7.5	3.6; 11.4	6.9	3.9; 9.8	8.7	7.0; 10.4
20	7.1	4.0; 10.2	6.4	5.7; 7.1	7.7	3.8; 11.6	7.2	4.2; 10.1	9.1	7.4; 10.8
21	7.3	4.2; 10.4	6.5	5.9; 7.2	7.9	4.0; 11.8	7.5	4.5; 10.4	9.5	7.7; 11.2
22	7.5	4.4; 10.6	6.7	6.1; 7.4	8.1	4.2; 12.0	7.8	4.8; 10.7	9.9	8.1; 11.6
23	7.8	4.7; 10.8	6.9	6.2; 7.5	8.3	4.4; 12.2	8.1	5.1; 11.1	10.2	8.4; 12.0
24	8.0	4.9; 11.0	7.0	6.4; 7.7	8.5	4.6; 12.4	8.4	5.4; 11.4	10.6	8.8; 12.4
25	8.2	5.1; 11.3	7.2	6.6; 7.8	8.7	4.8; 12.6	8.7	5.6; 11.7	11.0	9.2; 12.8
26	8.4	5.3; 11.5	7.3	6.7; 7.9	8.9	5.0; 12.8	9.0	5.9; 12.0	11.4	9.5; 13.2
27	8.6	5.5; 11.7	7.5	6.9; 8.1	9.1	5.2; 13.0	9.3	6.2; 12.4	11.7	9.9; 13.6
28	8.8	5.8; 11.9	7.7	7.1; 8.3	9.3	5.4; 13.2	9.6	6.5; 12.7	12.1	10.2; 14.0
29	9.0	6.0; 12.1	7.8	7.2; 8.4	9.5	5.6; 13.4	9.9	6.7; 13.0	12.5	10.6; 14.4
30	9.3	6.2; 12.3	8.0	7.4; 8.6	9.7	5.8; 13.6	10.2	7.0; 13.3	12.9	10.9; 14.9
35	10.3	7.3; 13.4	8.8	8.1; 9.5	10.7	6.8; 14.7	11.7	8.3; 15.0	14.8	12.6; 16.9
40	11.4	8.3; 14.5	9.6	8.8; 10.4	11.8	7.7; 15.8	13.2	9.6; 16.7	16.7	14.3; 19.0
45	12.5	9.4; 15.6	10.4	9.4; 11.4	12.8	8.6; 17.0	14.7	10.9; 18.5	18.6	16.0; 21.1
50	13.5	10.4; 16.7	11.2	10.0; 12.6	13.8	9.4; 18.1	16.2	12.1; 20.3	20.5	17.7; 23.3
55	14.6	11.5; 17.8	12.0	10.6; 13.4					22.4	19.3; 25.4
60	15.7	12.5; 18.9	12.8	11.2; 14.4					24.3	20.9; 27.6
65									26.2	22.6; 29.7
70									28.1	24.2; 31.9

E. transvaalense due to the irregular shedding of the bark on the bole, and hence the actual thickness of the bark cannot be predicted with as much confidence as for the other species.

The present study aims to provide information that will facilitate conservation and trade monitoring efforts with respect to tree population studies and the harvesting of bark for the medicinal plant trade and domestic use. Commercial bark harvesters tend to select individuals in the larger size-classes to maximise their returns (Botha *et al.* 2001), and the tables are a useful guide to the sizes of trees from which bark traded in a medicinal plant market is likely to have been harvested. Additionally, the tables serve as a guide for quantitative assessments of bark thickness in tree populations if the actual bark thickness cannot be measured on site but the dbh can.

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PART 4:

Stem diameter and bark surface area of the fluted trunk of *Balanites maughamii*

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Abstract
Balanites maughamii (Balanitaceae) is a woodland tree used and harvested for bark products in the traditional medicine trade of South Africa. The tree has a distinctively fluted and buttressed stem, especially in mature individuals. This short communication quantifies the relationship between girth measurements 'D1' and 'D2' (diameter measurements around the stem based on circumference that respectively excludes and includes the bark surface contained in the convolutions of the flutes) at five height intervals up the stem to 2m. Regression results show D1 to be an accurate predictor of D2 (r^2 = 0.97 – 0.99), hence obviating the necessity to measure both D1 and D2. The circumference and surface area of bark on the stem was determined to estimate the quantity of bark that can potentially be harvested. At least two-thirds of the bark area was estimated to be contained within the convolutions of the flutes.

Keywords: *Balanites maughamii*, bark area, diameter at breast height (dbh), girth measurements, traditional medicine

In press with *Bothalia*

INTRODUCTION

Balanites maughamii Sprague (Balanitaceae) is a medium to large, slow-growing deciduous tree ranging from 8–20 m tall (Pooley 1993). The stem is straight and the trunks of older trees are distinctively fluted and buttressed (Pooley 1993; Van Wyk & Van Wyk 1997). The grey bark has medicinal value and is harvested and sold to consumers in traditional medicine markets in KwaZulu-Natal, Gauteng and Mpumalanga (Botha *et al.* 2001; Grace 2002; Williams 2003) (Figure 1). Based on the total amount of bark harvested (m^2), *B. maughamii* was ranked third out of 36 tree species harvested for bark in the woodlands of southern Maputaland, KwaZulu-Natal (Twine 2004). A detailed population study there revealed that 55% of all individuals [diameter at breast height (dbh) > 10 cm] had harvest wounds, and the mean amount of bark harvested per individual was 1.09 m^2 (Twine 2004).

FIGURE 1.—*Balanites maughamii* individual repeatedly harvested for bark on communal land in Ingwavuma region of KwaZulu-Natal in 1998. Parts of stem, including buttresses have been removed.

In KwaZulu-Natal (KZN), the species is classed as declining and considered to be heavily exploited for bark products (Cunningham 1988; Netshiluvhi 1999; Grace 2002). Its legal status in KZN is described as 'controlled' by Von Ahlefeldt *et al.* (2003), i.e. written permission is required from the land owner/holder for this species to be harvested or collected from the wild. The turnover from 23 traders in the Isipingo and Victoria Street informal herbal medicine markets in Durban was estimated to be 187 50 kg-size bags per annum (± 1995) (Netshiluvhi 1999). On the Witwatersrand, 56% of the *muti* shops sold the bark (Williams *et al*. 2001), and a volume equivalent to ≈ seven 50 kg-sized bags were present between 17 of the 100 traders surveyed in the Faraday Street traditional medicine market in Johannesburg in January 2001 (Williams 2003). On the western boundary of the Kruger National Park, 29% of the vendors sold *B. maughamii* bark and considered it a readily available resource (Botha *et al.* 2001). The mean price per 50 kg-size bag of *B. maughamii* bark bought by *muti* shops in Johannesburg in 1995 was R66.70 ± R33.50 (± standard deviation) (n = 15), and in 2001 a bag cost ≈ R100.

As part of an extensive investigation into the relationship between tree size and bark thickness of six tree species (including *B. maughamii*) to 1, determine the size of trees targeted by commercial bark harvesters from the thickness of the bark sold in the *muti* markets; 2, the mean wet and oven-dry bark thickness per tree size-class; and 3, the mean harvestable bark mass per stem (Williams *et al.* 2005; Williams *et al.* in press 1; Williams *et al.* in press 2), various aspects of the tree stem profile were measured. These aspects included: 1, approximate height of the tree and branch-free bole length; and 2, diameter of the stem at five height intervals. Bark thickness was also measured. Data collected for *B. maughamii* are a subset of the original study. This short communication describes specific aspects of the *B. maughamii* tree stem profile related to the fluted trunk, including: 1, the relationship between two girth measurements around the stem that respectively include and exclude the bark surface area contained in the convolutions of the flutes; 2, the number of flutes observed at 1.3 m (dbh); and 3, the percentage of the stem girth and bark present within the flutes.

METHODS

Between March and May 1998, 39 *Balanites maughamii* stems were measured at six sites in three South African provinces (Table 1). At each sample site, a population of trees was located and individuals were selected from five stem diameter size-classes based on diameter at breast height (dbh) ranging between 10 cm and 60 cm. A minimum of five and a maximum of ten trees were measured per diameter-class (not per site). None of the individuals had suffered any prior harvesting damage, and the bark on the bole was intact. *Balanites* individuals larger than 60 cm dbh were found in communal lands; however, these trees were not sampled as bark harvesters had previously removed whole sections of the stem and timber for bark between the flutes. The method used for assessing vertical height was a direct estimate using a 2 m height pole, with 0.5 m intervals. The number of pole lengths was counted by eye to estimate height and branch-free bole length. After the twenty-second *Balanites* stem was measured, the number of flutes observed and a categorization of their depth (subjectively, ‘shallow’ or ‘deep’) at dbh were also counted.

TABLE 1.—Sample sites and no. of individuals sampled per site.

Province	Area in the province	Ownership and management regime	*n*
Limpopo	Western Soutpansberg	Private farm 1 (south of Wyllie’s Poort)	17
	Western Soutpansberg	Private farm 2 (north of Wyllie’s Poort)	13
Mpumalanga	Nelspruit	Protected area	2
KwaZulu-Natal	Ingwavuma	Communal land	3
	Zululand	Protected area	1
	Zululand	Private protected area	3

It is standard practise in forestry to measure tree stem girth with a forestry ‘diameter tape’. The tape is calibrated in π centimetres so that a circumference measurement is converted directly to a diameter measurement (Philip 1983), and the measurement is thus recorded as a ‘diameter’ dimension rather than a ‘circumference’. Two ‘diameter’ readings were taken at five height intervals (0.5m, 1.0 m, 1.3 m, 1.5 m and 2.0 m, abbreviated as $D_{0.5}$, $D_{1.0}$, $D_{1.3}$, $D_{1.5}$ and $D_{2.0}$ respectively) from the *Balanites maughamii* stem: 1, a circumference measurement around the stem that excludes the area inside the flutes (‘diameter’ 1, D1); and 2, a circumference measurement into the convolutions of the flutes, measuring along the entire bark surface (‘diameter’ 2, D2) (Figure 2). Hence D1 is the typical stem ‘diameter’ measurement taken by foresters, usually at breast height (1.3 m, dbh), whereas D2 is a hypothetical ‘diameter’ where the flutes are pushed out to form a circle. Initially, only D1 was measured, but after six samples, D2 was also measured.

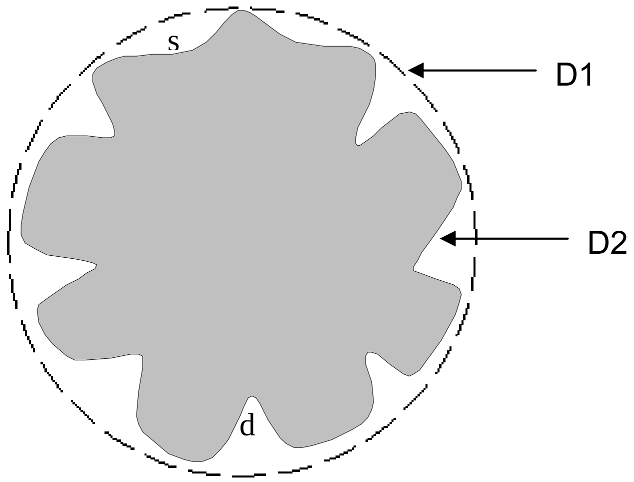

FIGURE 2.—Schematic representation of a cross-section through *Balanites maughamii* tree stem showing measurements D1 and D2. D1: measurement around stem that excludes bark surface in flutes; D2: measurement in concave convolutions of flutes, thereby measuring entire bark surface. Measurements were made using a forestry diameter tape, calibrated in π centimetres, which converts a circumference measurement of a stem directly into a 'diameter' measurement. Measurements of D1 at 1.3 m were used to construct stem diameter size-classes. s, subjective classification of 'shallow' flutes; d, 'deep' flutes.

RESULTS AND DISCUSSION

The *Balanites maughamii* individuals measured, ranged in height from 4 to 12 m, with a mean of 8 ± 2 m (standard deviation, SD). Branch-free bole length was 2.9 ± 1.4 m (SD). The dbh of the largest tree sampled was $D1_{1.3}$ = 59.2 cm and $D2_{1.3}$ = 260.0 cm (circumference equals 186 cm and 817 cm respectively), from a site in a private protected area in KwaZulu-Natal.

There was a very strong positive relationship between D1 and D2 at all height intervals up the stem (Figure 3A–E), especially at $D_{0.5}$ ($r^2 = 0.988$, $p < 0.0001$, Figure 3A). No branching occurred on the stem below 0.9 m, hence results for $D_{0.5}$ were not affected by the response of the tree to branching. The quadratic regressions were only slightly better fits than the linear regressions (results not shown). For example, $r^2 = 0.988$ for the quadratic equation at $D_{0.5}$, whilst $r^2 = 0.979$ for the linear equation at the same height.

These results show that by measuring D1 at a particular stem height, D2 can be accurately estimated, hence obviating the necessity to measure both D1 and D2. When compared with the *observed* D2, the D2 *predicted* by the quadratic regression equations was slightly overestimated [mean percentage error = 0.35 ± 5.99% (SD), n = 154]. By contrast, the linear regression equations tended to underestimate the predicted D2 [-1.22 ± 9.04% (SD), n = 154].

Most of the trunk girth is contained within the concave sections of the flutes (Figure 4). At 0.5 m above ground, 73.0 ± 4.0% (SD) of the stem girth was within the flutes. The percentage of the stem contained within the flute decreased with increasing height up the stem until it was measured to be 70.3 ± 4.3% (SD) at 2 m (Figure 4). Furthermore, as the dbh of the trees increased, a greater percentage of stem girth was present within the flutes.

By converting the observed D2 measurements to circumference, the area of bark (m^2) on the stem could be estimated. The mean amount of bark up to 2 m on the stem ranged from 3.3 ± 0.6 m^2 (SD) (n = 10) on trees in the 10–19 cm diameter (D1) size-class, to 16.1 ± 0.7 m^2 (SD) (n = 4) on trees in the 50–59 cm diameter size-class (Table 2).

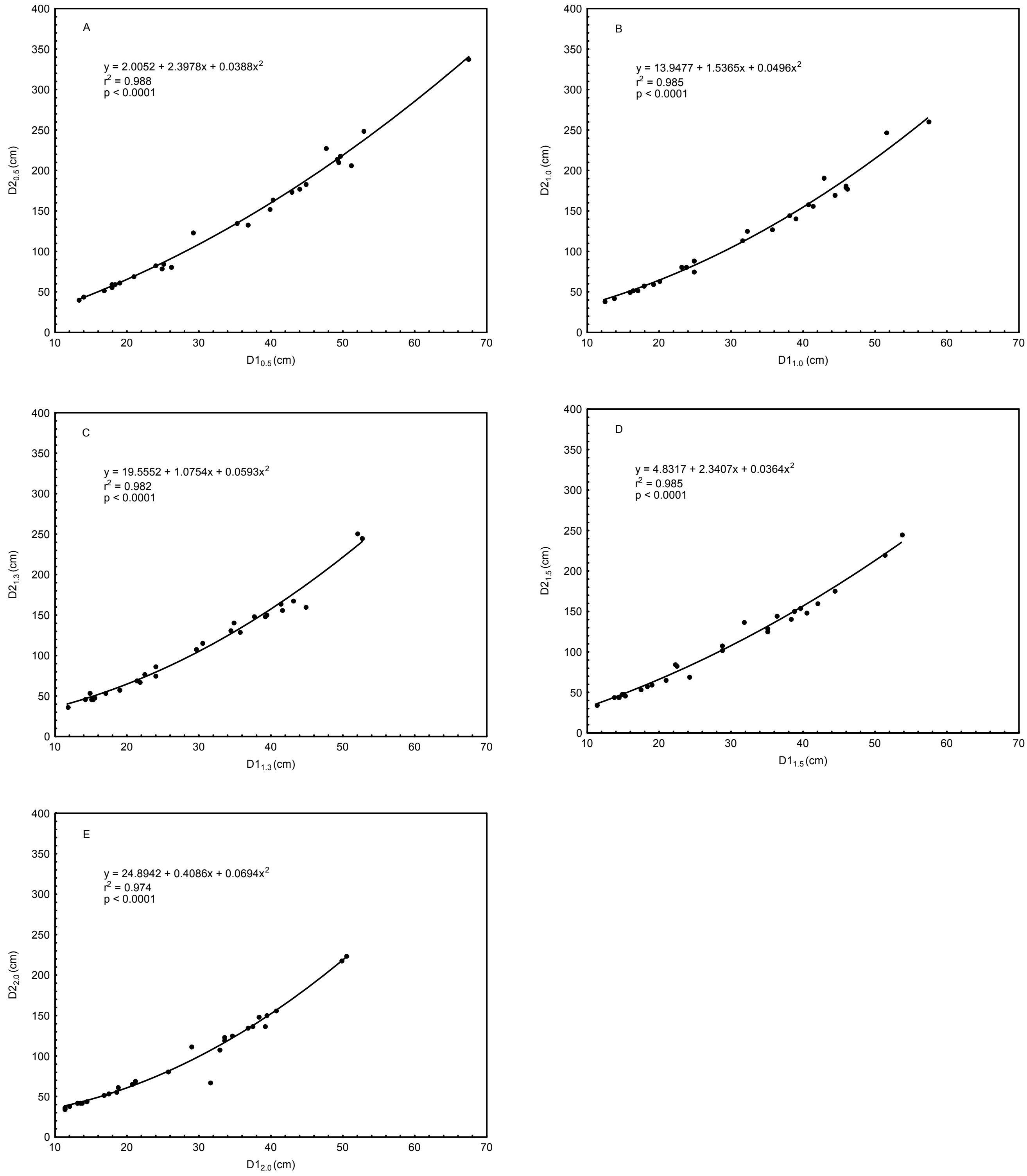

FIGURE 3.—Relationship between stem diameter 1 (D1) and stem diameter 2 (D2) measured at A, 0.5 m; B, 1.0 m; C, 1.3 m; D, 1.5 m; and E, 2.0 m above ground [n = 28 (all graphs)]. To obtain circumference, multiply D1 or D2 by π.

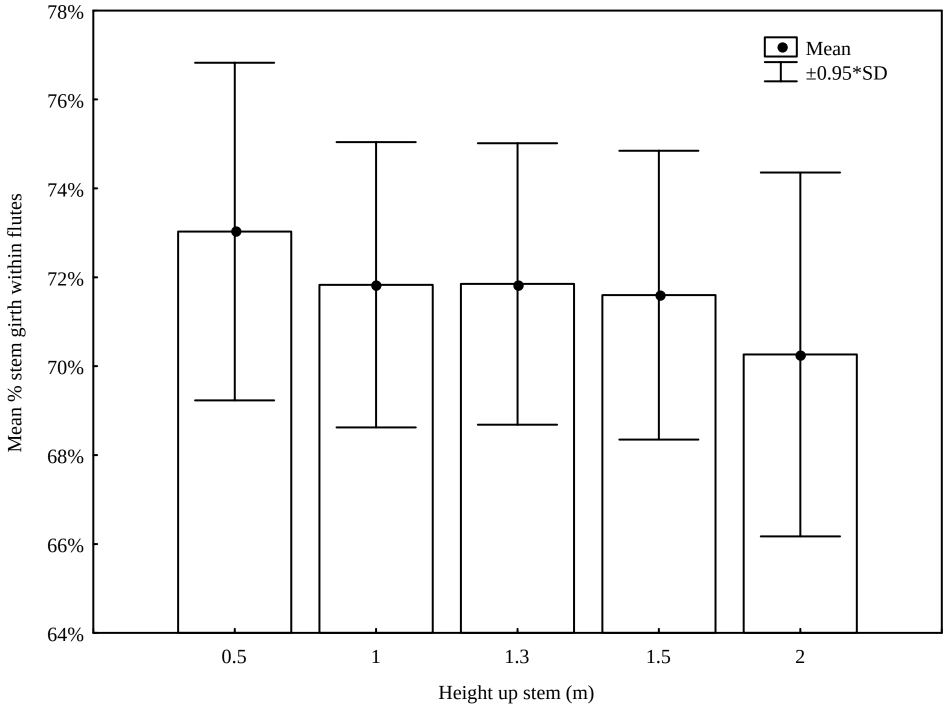

FIGURE 4.—Mean percentage of stem girth contained within concave sections of flutes at five height intervals up stem to 2 m, including diameter at breast height (dbh, 1.3 m). Means calculated for trees ranging from 11.7 cm to 52.7 cm dbh. SD, standard deviation.

TABLE 2.—Estimated mean bark area (m^2) harvestable per stem size-class

Size-class (dbh, cm) (D1)	Mean estimated bark area (m^2) to 2 m	SD	Min.	Max.	n
10–20	3.29	0.60	2.38	4.24	10
20–30	5.13	0.80	4.04	6.84	8
30–40	9.16	1.01	7.62	10.51	7
40–50	10.98	0.22	10.83	11.31	4
50–60	16.11	0.79	15.15	16.67	4

dbh, diameter at breast height; SD, standard deviation.

As the dbh of *B. maughamii* individuals increased, the number and depth of flutes at $D_{1.3}$ was observed to increase (Table 3), thus increasing the proportion of the bark surface area within the convolutions of the flutes. Trees in the 10–20 cm and 20–30 cm stem diameter (D1) size-classes generally had two shallow flutes and one deep one. As tree size increased, the shallow flutes became deeper until there were 2 or 3 and 4 or 5 deep flutes in the 30–40 cm and 40–50 cm size-classes respectively. Trees larger than 50 cm had more than six deep flutes with sometimes as many as 10 per stem approaching 60 cm dbh.

TABLE 3.—Observed number and depth of flutes per measured tree at $D_{1.3}$. Individual trees are enclosed in parentheses in column three

Size-class (dbh, cm) (D1)	No. trees measured (n = 15, out of 39)	Observed number and depth of flutes per tree at $D_{1.3}$ (dbh)
10–20	1	(1d, 2s)
20–30	4	(1s); (1d, 2s); (1d, 2s); (1d, 3s)
30–40	6	(2d); (3d); (3d); (3d); (3d, 1s); (4d)*
40–50	2	(4d); (5d)
50–60	2	(6d); (10d)

* dbh (diameter at breast height) of individual tree = 39.4 cm; s, no. of shallow flutes; d, no. of deep flutes (subjective descriptions of flute depth)

In general, more than two thirds of the bark area was contained in the flutes of the stem [mean = 72 ± 3% (SD), n = 31]. The proportion of the bark inside the flutes varied according to tree size, with up to 79% of the bark area to be found in the flutes of trees in the 50–59 cm stem diameter (D1) size-class, and 69% in flutes of trees in the 10–19 cm size-class. As tree size increased, a greater proportion of the diameter, area and volume of bark was enclosed within the convolutions of the flutes.

CONCLUSION

Despite the buttresses in the *B. maughamii* stems, it appears that D1 is an acceptable predictor of D2. Hence, the bark surface area can be estimated as well as the amount of bark than can potentially be removed from the stems. Because most of the bark area is contained within the convolutions of the flutes, it is difficult to ring-bark the tree trunks. Even when harvesters remove whole sections of the flutes/buttresses, including the timber, they leave behind some of the bark at the base of the flute. This may potentially enable wound recovery following harvesting.

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