CHAPTER 8

The Concept of ‘Individual Equivalents’

PART 1:

Assessing harvesting impacts for species used medicinally in South Africa: estimates of the number of individual trees debarked annually

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Abstract
Commercial harvesting of bark for the medicinal plant trade is a major cause of resource depletion. The impacts of harvesting depend on the part of the plant removed and the level of harvesting effort and efficiency of the gatherers. One way to assess such impacts is to estimate the number of trees debarked annually but, until recently, no data were available on the quantity of bark that could be removed from a tree stem by gatherers. Using the relationship between bark thickness and stem diameter, and the records of the thicknesses of bark traded in the Johannesburg medicinal plant markets between 1995 and 2001, the stem size-classes most likely targeted by bark harvesters were determined. Thereafter, estimates of the mean harvestable bark per stem size-class were used to calculate the number of 'individual equivalents', i.e. the number of individual trees debarked annually equivalent in size to the trees for which the bark mass was estimated. The estimates included scenarios for trees experiencing different degrees of bark removal below 2 m (e.g. 10% - 100%). The results showed a decrease in the availability of trees from the larger size-classes for some species between 1995 and 2001. In 1995, most *Warburgia salutaris* bark in the markets was >9 mm and estimated to come from trees >40 cm diameter at breast height. By 2001, most of the bark was <5 mm thick and estimated to come from trees <25 cm dbh. Depending on the extent of bark removal on the stem, the number of *W. salutaris* trees estimated to be damaged ranged from 781–7806 trees in the 15–19 cm dbh size-class. These methods clearly provide a method for assessing harvesting impacts in a way not previously possible.

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

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1. Introduction

Commercial harvesting for the medicinal plant trade is a major cause of resource depletion (Cunningham 1988), and harvesting impacts depend on the plant part removed, as well as the level of harvesting effort and efficiency of the gatherers. Plant populations can be driven to extinction if increases in harvesting effort chase an ever-diminishing yield (Begon *et al.* 1986). For bulbous plants, or smaller herbs and shrubs where the roots are entirely removed, often little sign remains of their former presence in a locality (Cunningham 1988), and field estimates of resource depletion for these species are therefore difficult. Damage assessments to tree populations can, however, be based on the presence of debarked trunks (Fig. 1).

Fig. 1: Complete ring-barking of *Cryptocarya transvaalensis* to ± 2.5 m in the Blyfstaanhoogte Natural Heritage site, Mpumalanga, South Africa.

The paucity of data on plant population sizes makes it difficult to judge the annual rate of decline for a species based on off-take for the medicinal plant trade. While data on the estimated mass of plants harvested annually informs the magnitude of resource depletion, these data would be of more constructive value if they could be translated into the number of individual plants harvested annually. To appreciate the extent of damage to wild populations, and the scale of cultivation required to replace harvested stocks, it is important to know how many trees are debarked (Cunningham and Mbenkum 1993). In an effort to quantify the damage by commercial harvesters, this paper investigates the number of trees potentially debarked using the concept of 'individual equivalents'.

'*Individual Equivalents*' is an original concept conceived specifically to estimate the number of individual plants harvested for the medicinal plant trade from market information. Estimates for the number of individuals harvested are based on the number of individuals equivalent in size (e.g. stem dbh or bulb width) to individuals for which the harvestable mass has been determined. If, for example, it was determined that 11 kg of fresh bark could be removed from trees that were ring-barked to 2 m in the 20–29 cm dbh size-class, and that 110 kg of bark were known to be sold in a period of time, then the *equivalent* number of *individual* trees for which bark mass was estimated is 10 individual trees or, 10 'individual equivalents'.

Research for the investigation into the number of plants affected annually by the medicinal plant trade was initially conducted in 1995 for 20 species of different plant part types (e.g. bark, bulbs and tubers), including seven tree species (V.L. Williams unpublished data). In the preliminary study, the harvestable bark mass from one individual per species was determined. These data were used to estimate the number of trees damaged during bark harvesting for the 1995 *muti* shop trade. This study was of limited value because there was only one replicate per species, and there were no data for trees of different sizes. For this reason, a more comprehensive investigation was undertaken in 1998 to calculate the harvestable bark mass for trees of different stem size-classes. In addition, bark thickness was related to stem diameter so that tree size could be predicted from the records of bark thicknesses known to be sold in Johannesburg *muti* shops and street markets.

This paper estimates the number of trees damaged though bark harvesting and evaluates the change in availability of stem size-classes for five species over a six-year period from bark thickness records acquired during market surveys in Johannesburg between 1995 and 2001. From bark thickness records in the markets, the corresponding stem size-classes likely to have been targeted by harvesters were determined and the number of individuals equivalent in size to the most prevalent tree size was estimated. The mean harvestable bark mass per stem size-class, presented in the preceding paper (Williams *et al.* in press 1), and an estimate of the annual mass of bark sold per annum, was used to estimate the size-class specific number of individual equivalents potentially debarked annually.

2. Methods

2.1 Preliminary investigation

A preliminary investigation into harvestable bark mass and the potential number of individual stems debarked annually was conducted in 1995. Seven species were selected, namely *Albizia adianthifolia*, *Balanites maughamii*, *Cunonia capensis*, *Elaeodendron transvaalense*, *Rhus chirindensis*, *Warburgia salutaris* and the naturalised exotic *Cinnamomum camphora* (subsequent research in 1998 excluded *C. capensis* and *C. camphora* and included *Acacia xanthophloea*). The species represented various risk categories of over-exploitation (V.L. Williams unpublished data). One individual per species was sampled, and the following information collected: a visual estimate of tree height; three circumference measurements to 2 m height, usually at 0.5 m, 1.5 m and 2.0 m; and, at least three 10 cm x 10 cm bark samples, removed with a hammer and chisel. The mass and thicknesses of the bark samples were measured using a digital scale and Vernier callipers respectively. The total harvestable fresh bark mass per stem to 2 m was determined by multiplying the estimated surface area of bark on the stem, by the mass per unit area of the bark samples removed. Bark surface area was calculated by dividing the stem into cylindrical subsections and then multiplying the circumference of the subsection by the height. However, given that only one individual per species was sampled, the absence of replicates limited the capacity of this preliminary investigation to be justifiably applied across a broader scale. Therefore, further research was conducted in the summer of 1998 that improved on and refined the methods that were used.

2.2 The primary investigation

Six species were sampled at fifteen woodland sites in three South African provinces between March and May 1998 (see previous paper). At each sample site, individuals were selected from representative size-classes based on stem diameter at breast height. The diameter of the stem was measured at five height intervals (termed $D_{0.5}$, $D_{1.0}$, $D_{1.3}$, $D_{1.5}$ 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. Circular bark samples were removed using a 50 mm diameter hole-saw attached to a hand-held brace (Fig. 2). This method for removing bark samples proved to be extremely efficient and accurate. Each sample was exactly the same diameter, and the samples could be easily and conveniently removed.

The harvestable bark mass per stem to 2 m was determined by multiplying the estimated surface area of bark on the stem, by the mass per unit volume (i.e. density) of the bark samples removed (see previous paper). By measuring the mass and thickness of the bark samples weekly as they air-dried, the change in harvestable bark mass over time could be estimated and bark of a known thickness and age (i.e. time after harvesting) could be more accurately used to determine the dbh of the tree from which it was harvested. Given that the bark harvested from a stem will decrease in mass as it air-dries, and that bark sold in the markets is often more than six weeks old, it might not always be appropriate to compare the annual bark mass likely to be traded with figures derived for freshly harvested bark. Doing so could result in an underestimate of the number of stems likely to have been debarked. Therefore, estimates of the number of individual stems debarked can be based on age-related predictions of bark mass and thickness if necessary, and the results presented for the harvestable bark mass in the previous paper give the option for doing so.

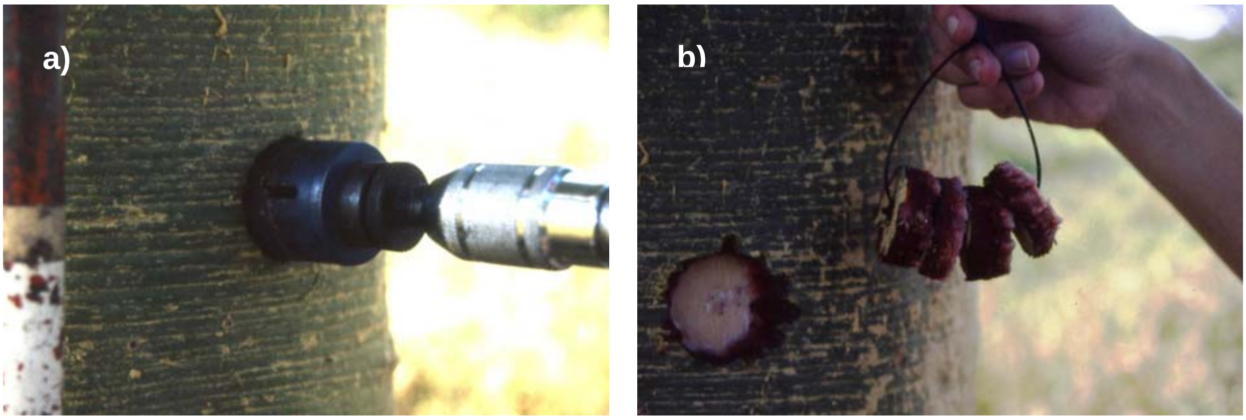


Fig. 2: a) Bark samples being removed from the stem of *Acacia xanthophloea* with a hole-saw attached to a hand-held brace; b) Each sample was threaded on to a cable-tie.

2.3 Determining the relationship between bark thickness and stem diameter

To predict the dbh of a tree stem from which bark sold in a market is likely to have come from, stem diameter was regressed with bark thickness at various height and time intervals (i.e. weeks after harvesting). But, while bark thickness is commonly correlated with dbh (Cunningham 2001), bark thickness is generally thicker at $D_{0.5}$ than at $D_{1.3}$ (Williams *et al.* in press 2). To minimize the likelihood of overestimating stem dbh if the measured bark was actually from near the base instead of dbh, regression analysis was used to describe the relationship between bark thickness and stem diameter for bark harvested at $D_{0.5}$ and $D_{1.3}$. In addition, equations were also derived to estimate $D_{1.3}$ from $D_{0.5}$. Hence, bark of a certain thickness harvested at $D_{0.5}$ can be related to dbh, and the predictions can incorporate a broader range of tree sizes most likely to have been debarked. Methods and results presented by Williams *et al.* (in press 2) show how bark of a known age and thickness (e.g. 6 mm bark 5 weeks after being harvested) can be narrowed down to stems of a certain size.

2.4 Market surveys and quantitative resource inventories

The prevalence of bark of varying thicknesses sold in the traditional medicine markets was determined from three studies conducted in 1995, 1996 and 2001. Between May and September 1995, 23 species, seven of which were used for bark, were measured in 27 *muti* shops in Johannesburg, South Africa. Pieces of bark, generally representative of the thickness of the stock on sale, were selected and bark thickness was measured using a Vernier calliper. Measurements were to the nearest millimetre. In addition, traders were asked how many bags per annum they purchased of each species. In a second study, between July and September 1996, plant samples were purchased on ten visits to the Faraday Street informal street market in Johannesburg. The bark samples were measured to the nearest millimetre using a Vernier calliper, but no data on the annual volume sold in the market were collected.

In January 2001, an extensive semi-quantitative study of the Faraday Street market was conducted on behalf of the provincial Directorate for Nature Conservation, DACEL (Williams 2003, 2004). One hundred traders were interviewed and a quantitative inventory of every plant sold by each trader was compiled, including the quantity present and the plant part size. Given time constraints and the number of species in the market (500+) (Williams 2003), it wasn't practical to measure each bark sample with a Vernier and so thickness was visually assessed and categorised into several size-classes at intervals of 3 mm. The pieces of bark selected for measurement were representative of the average thickness of the bark sold by each trader. Traders were also asked how often they purchased plant stock equivalent in size to a 50 kg maize bag.

2.5 Estimating the annual quantity of bark mass traded

Medicinal plants are frequently transported to the markets in 50 kg-size maize bags. The actual mass of a bag depends on the plant part (e.g. bark, bulbs or leaves), and the number of individuals represented by the mass depends on the dimensions of the plant (e.g. bark thickness, bulb size etc). One 50 kg-size bag of bark was estimated to weigh approximately 49.8 kg (Williams 2003), although Mander (1998) estimated that a bag was equivalent to 24 kg and Geldenhuys (2004) assumed a bag to weigh 35 kg. These differences in estimates for a 50 kg bag might be related to species specific bark density and/or water content depending on the time elapsed after harvesting before the estimate was calculated. The annual quantity of bark sold by the *muti* shop traders was estimated by determining the mean number of bags sold per trader per annum, and then multiplying this by the mass of a bag and the proportion and number of traders in the region that potentially sold the species. The annual quantity of bark sold by the street traders in Faraday was determined from the mean frequency with which traders purchased one bag of the species, and then calculating the number of bags that would have been bought per annum depending on the proportion and number of traders that sold the species. Once the number of bags sold per annum per trader was established, then the total mass sold could be determined.

2.6 Determining temporal changes in stem size-class availability

The records of bark thicknesses measured between 1995 and 2001 were plotted on histograms to show the percentage availability of each bark size-class per market study. Using the tables compiled by Williams *et al.* (in press 2) and the results of the regressions presented in this study, an estimate of the stem dbh was determined. Where the age and thickness of the bark was known, more accurate estimates of the stem size-class could be obtained. The change in availability of bark thickness and corresponding stem size-classes could therefore be determined. The harvestable bark mass of the most prevalent dbh size-class sold per species in 1995 and 2001 was used in the estimates of the number of individual stems harvested annually.

2.7 Calculating the number of individual equivalents

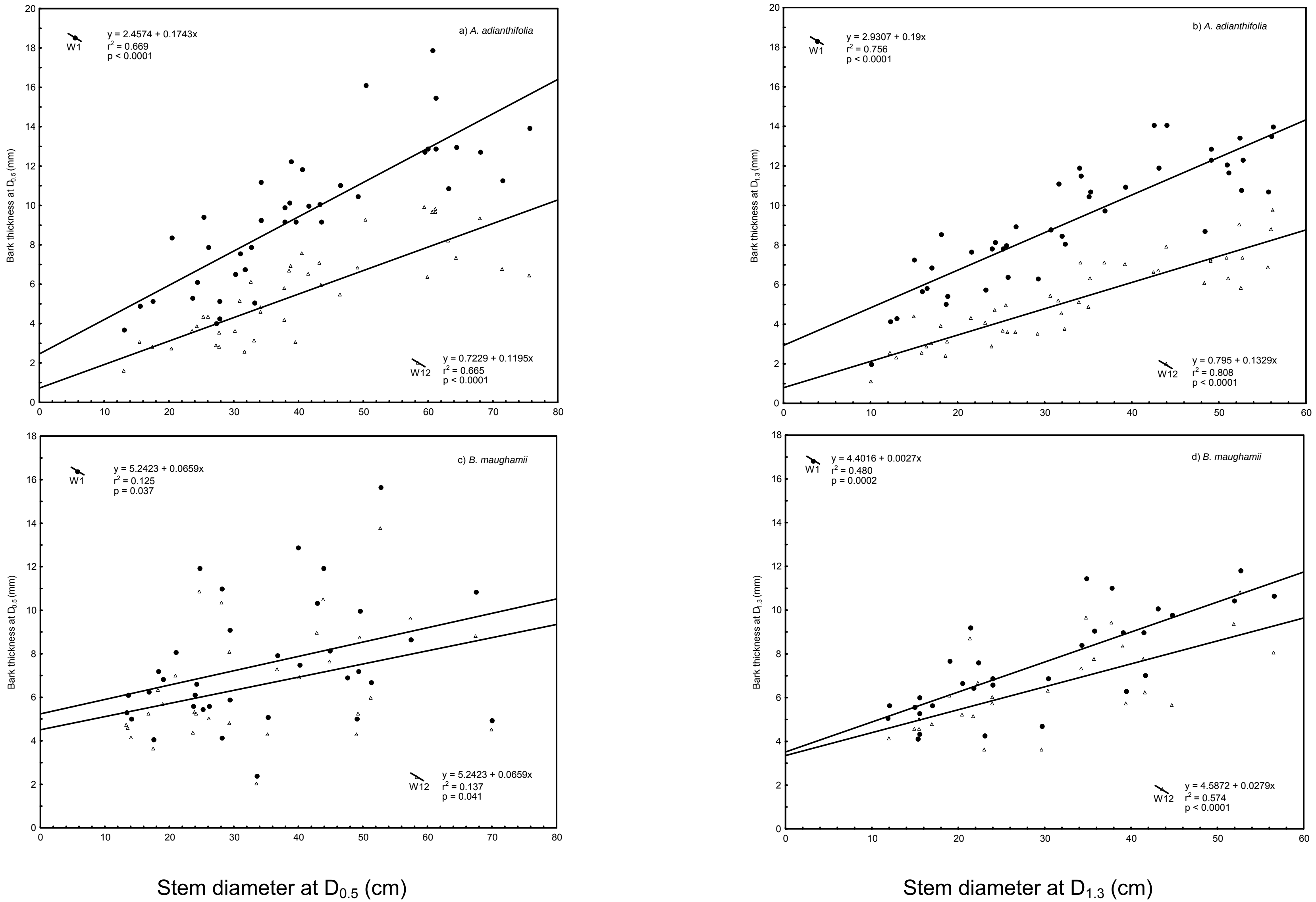
Once the harvestable bark mass per stem is known, and the quantity traded annually has been determined, then estimates for the number of trees debarked annually can be calculated. The number of trees harvested would be *equivalent* in size to the individuals for which the bark mass estimates were calculated. The bark mass tables presented in Table 1 of the previous paper, and used here to determine the number of individual equivalents, assume that the stem is totally ring barked to 2 m, i.e. 100% bark removal. However, stems may suffer varying degrees of damage depending on the popularity of the species and the intensity of harvesting. Estimates of the bark mass harvested can therefore be adjusted to reflect scenarios for the different degrees of average bark removal on a stem, e.g. 10% or 100%, and the number of I.E. would vary accordingly.

Calculations of the number of Individual Equivalents per species are based on the stem size-classes estimated to be most frequently targeted by harvesters in 1995 and 2001. The most likely scenario for the percentage stem damage per species was based on findings by Cunningham (1988), Botha *et al.* (2002, 2004) and Twine (2004). Estimates are not calculated for *R. chirindensis* because there was no certainty that quantitative data collected from the markets were for that species.

3. Results

3.1 The relationship between bark thickness and stem diameter

Thicker bark is commonly found near the base of the stem, and decreases in thickness with increasing height up the stem. The relationship between bark thickness at 0.5 m and 1.3 m at $D_{0.5}$ and $D_{1.3}$ respectively show this trend (Fig. 3). In addition, the results show the effect of air-drying by comparing the bark thickness of the samples one week after being harvested ('W1') with bark thickness twelve weeks after harvesting ('W12'). *Albizia adianthifolia* and *W. salutaris* bark become significantly thinner after twelve weeks of air-drying than bark from *E. transvaalense* and *B. maughamii*. Bark thickness after six weeks of air-drying is not significantly different from bark thickness after twelve weeks, hence the regression line for W12 can be used to estimate stem diameter from bark of a known thickness harvested more than six weeks earlier.



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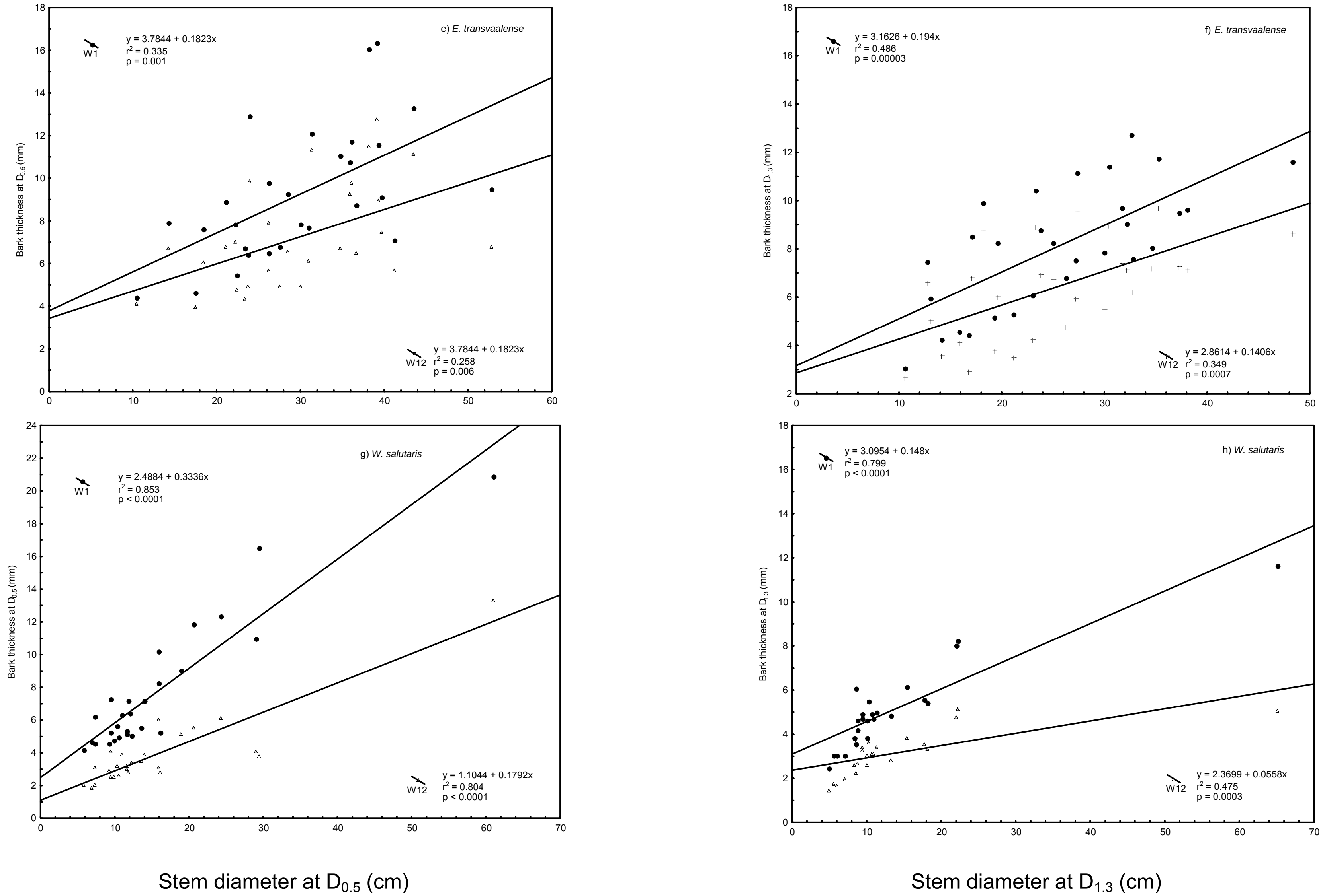

Fig. 3: Regression relationships between bark thickness and stem diameter at $D_{0.5}$ and $D_{1.3}$ for one week (W1) and twelve weeks (W12) after harvesting.

For species that do not shed their rhytidome (outer bark), such as *A. adianthifolia* and *W. salutaris*, the linear relationship between bark thickness and stem diameter (especially at W1) is stronger than species that do shed their bark to a greater (e.g. *A. xanthophloea*) or lesser extent (e.g. *B. maughamii* and *E. transvaalense*) (Fig. 3). Due to the natural periodic shedding of *A. xanthophloea* bark in large strips, there is no relationship between bark thickness and stem diameter (r^2 = 0.005, p = 0.91 for bark thickness at dbh) (regression line not shown), hence bark found to be sold in the markets cannot be related to trees of a certain size.

The regression lines in Fig. 3 can be used to estimate stem diameter from bark of known thickness and age (i.e. between one and twelve weeks after being harvested). In addition, the estimated stem diameter at $D_{0.5}$ can be converted to dbh ($D_{1.3}$) by using the linear regression equations listed in Table 1. Given that one cannot know what part of the stem bark sold in a market has been harvested from, and that bark generally becomes thinner with increasing stem height above ground, it is practical to calculate the dbh range for a tree from which bark of a certain thickness might have been harvested. The graphs in Fig. 3 and the equations in Table 1 make this possible. For example, if a piece of *A. adianthifolia* bark one week old and 10 mm thick was removed from the stem at $D_{0.5}$, then $D_{0.5}$ = 43 cm (Fig. 3a). Using the regression equation for *Albizia* in Table 1, the dbh ($D_{1.3}$) of the tree is then estimated to be 35 cm. However, if the same piece of bark had been removed from $D_{1.3}$, then dbh = 37 cm (Fig. 3b). Therefore bark 10 mm thick and one week old, and potentially removed from the stem between 0.5 m and 1.3 m above ground, could have come from a tree with a dbh = 35–37 cm. This method and reasoning was used to estimate the range of stem diameters from bark thicknesses found to be sold in the traditional medicine markets between 1995 and 2001 (see section 2.3).

Table 1: The linear regression equations for estimating dbh ($D_{1.3}$) from stem diameter at 0.5 m ($D_{0.5}$)

Species	Equation (y = $D_{1.3}$; x = $D_{0.5}$ in cm)	r^2	p
A. xanthophloea	y = 0.911x – 0.3563	0.984	< 0.0001
A. adianthifolia	y = 0.8219x – 0.4297	0.906	< 0.0001
B. maughamii	y = 0.8604x + 0.0805	0.970	< 0.0001
E. transvaalense	y = 0.9029x + 0.0359	0.967	< 0.0001
W. salutaris	y = 0.9915x - 1.0727	0.956	< 0.0001

3.2 The mean harvestable mass per stem size-class

The mean harvestable mass, area and volume of fresh and oven-dry bark per stem size-class per species are shown in Table 1 of Williams *et al.* (in press 1). Figures are for harvestable bark from the ground to 2 m stem height. In addition, the mean harvestable mass of bark air-dried for 1–2 weeks and 6 weeks respectively are also calculated. Bark tends to lose a lot of moisture within the first two weeks following harvesting (± 27%, Table 3, previous paper) and this is the time during which the bark is transported to the markets and sold. Results were also presented for bark air-dried for 6 weeks because this was found to be the average age of bark present 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.

3.3 The change in availability of bark size-classes related to stem classes

Bark thickness availability in the *muti* shops and the Faraday Street traditional medicine market between 1995 and 2001 are shown in Appendix 1. The results show how time after harvesting can make a difference in estimating the dbh of the tree from which the bark could have been harvested. For example, *A. adianthifolia* bark that is 6–8 mm thick and harvested one week prior could have come from a stem with a dbh = 16–27 cm (Appendix 1b). However, the same bark could have come from a tree with dbh = 33–52 cm if it was harvested six weeks earlier instead. These results show how important it is to factor in the time since the bark was harvested when estimating stem diameter from bark thickness records. And, while results indicate a general decline in the availability of thicker bark from larger trees between 1995 and 2001, the bark had been in the markets for varying lengths of time. Hence, each bark thickness record had to be individually assessed, based on time in the market, to estimate the most prevalent and probable corresponding dbh range.

Given that one cannot estimate stem diameter from bark thickness for *A. xanthophloea*, it is not possible to assess how the tree size-classes targeted by bark harvesters may have changed using the methods described above (Appendix 1a). However, it is possible to do this for the other four species. Table 2 shows the estimated prevalence of trees of certain size-classes in 1995 and 2001 based on bark thickness records. Between 1995 and 2001, gatherers appear to be harvesting bark from trees of decreasing stem diameter.

Table 2: The most prevalent stem diameter (dbh) size-classes sold in the *muti* shops in 1995 and the Faraday Street market in 2001. The size-classes were estimated from bark thickness records compiled during surveys of the markets.

Species	1995	2001
A. adianthifolia	50 – 59 cm	20 – 29 cm
B. maughamii	60 – 69 cm	40 – 49 cm
E. transvaalense	40 – 49 cm	10 – 19 cm
W. salutaris	> 40 cm	15 – 19 cm

3.3.1 *Albizia adianthifolia*
The most prevalent bark size-class present in the *muti* shops in 1995 was 9–11 mm (Appendix 1b). Given the time when traders had reportedly purchased the stock, this bark was estimated to have been harvested from trees larger than 50 cm dbh. There were infrequent estimates of bark having been removed from trees less than 32 cm dbh. Bark sold by the Faraday Street traders in 2001 was most commonly between 3–5 mm. Based on the length of time in the market, the bark was estimated to have been harvested from trees 15–30 cm dbh. While there were no stem size-classes missing from market, bark estimated to be from trees larger than 35 cm dbh were uncommon.

3.3.2 *Balanites maughamii*
Bark from *B. maughamii* sold in the *muti* shops in 1995 was generally 12–20 mm thick, or estimated to have come from trees larger than 60 cm dbh (Appendix 1c). There were a few records of trees 25–40 cm dbh having been harvested, but none less than 20 cm dbh. In 2001, the bark was generally less than 11 mm thick or less than 60 cm dbh. Mostly the bark was estimated to have been removed from trees 40–49 cm dbh. There were no missing stem size-classes, but there was a decrease in the frequency of bark having been removed from larger trees. Given the weaker relationship between bark thickness and stem diameter (especially at $D_{0.5}$) compared to the other species (except for *A. xanthophloea*), it is difficult to estimate the range of stem diameters likely to have been debarked by harvesters.

3.3.3 *Elaeodendron transvaalense*
In 1995, *muti* shop traders generally sold bark between 6–14 mm in thickness (Appendix 1d). Given the age of the bark, this translates into trees 25–60 cm dbh having been damaged and debarked, but mostly in the 40–49 cm dbh category. There were infrequent estimates of trees less than 20 cm dbh having been harvested. In the Faraday market in 2001, however, bark was frequently 3–8 mm thick, and estimated to have been removed from trees less than 25 cm dbh, but mostly from 10–19 cm dbh. There were no records of trees larger than 50 cm dbh having been harvested and very few records that could be linked to trees 25–40 cm dbh.

3.3.4 *Warburgia salutaris*
Muti shops in 1995 kept a broad range of bark thicknesses for *W. salutaris* compared to traders in 2001 (Appendix 1e). In 1995, there were no tree size-classes estimated to be missing, and bark from trees larger than 40 cm dbh (>9 mm bark) were common. In 2001, most of the bark was 3–5 mm thick and from trees 5–25 cm dbh. There were a few records of bark having been harvested from trees 26–40 cm dbh, but no trees larger than 45 cm appeared to have been available.

3.4 The quantity sold per annum
The mean number of 50-kg size bags of bark sold per *muti* shop trader per annum in 1995, and the percentage traders keeping the species, are shown in Table 3. The number of bags sold per annum translated into between 8.5–41.4 tonnes being sold annually per species by shops traders in Johannesburg (Table 4). By comparison, a total of 4.5 to 18.1 bags were recorded during an inventory of the amount of bark present in the Faraday market in January 2001 (Table 3). This translated into between 4.2–11.2 tonnes of bark sold per species per annum within the market (Table 3). Given the differences of the retail and wholesale nature of the *muti* shop and Faraday Street market trade respectively, and changes in market structure and species availability between 1995 and 2001, it is

not simple to elaborate on the observed differences in the quantities traded. Instead, we have chosen to focus the results and discussion on translating quantity into number of individuals harvested.

Table 3: Quantities sold by traders, based on surveys conducted in Johannesburg in 1995 and 2001

Species	*Muti* shops 1995		Faraday Street traders 2001	
	Mean number bags* sold (trader^{-1} a^{-1})	% traders with species (n = 50)	Total number of bags* present during survey 11-24 Jan.	% traders with species (n = 100)
A. xanthophloea	No data	68%	12.1	38%
A. adianthifolia	1.6 ± 0.9	60%	18.1	42%
B. maughamii	1.7 ± 1.1	54%	6.9	19%
E. transvaalense	4.2 ± 3.7	70%	16.1	48%
W. salutaris	6.7 ± 10.6	66%	4.5	21%

* bag = 50 kg size

Table 4: Estimated quantities sold per annum in Johannesburg in 1995 and 2001

Species	*Muti* shops 1995		Faraday Street traders 2001	
	Estimated no. bags sold by 189 traders (bags a^{-1})	Quantity per annum in the market (kg)	Estimated no. bags* sold by 164 traders (bags a^{-1})	Quantity per annum in the market (kg)
A. xanthophloea	No data	No data	160	7 990
A. adianthifolia	181	9 047	211	10 537
B. maughamii	172	8 549	84	4 195
E. transvaalense	557	27 771	224	11 155
W. salutaris	830	41 360	86	4 215

* A bag equals one 50 kg-size bag weighing 49.8 kg; see methods.

3.5 The number of individual equivalents

Estimates for the number of trees debarked in 1995 that were equivalent in size to the individual for which harvestable mass was calculated, range between 2,556 – 4,069 trees for *A. adianthifolia* and *E. transvaalense* respectively (Table 5). The estimates were based on the stem size-class most commonly harvested in 1995 (Table 2, Appendix 1), and the likely degree of stem damage within 2 m. For example *Warburgia salutaris*: assuming that all the trees were 40–49 cm dbh and 50% of the bark was removed from the stems below 2 m, then the number of trees debarked that were equivalent in size and extent of stem damage equals 2,556 trees. Similarly, estimates for the number of trees damaged to meet the demand for bark in the Faraday market in 2001 ranges from 1,041 – 12,112 trees for *W. salutaris* and *A. adianthifolia* respectively (Table 5).

The number of individual equivalents will vary depending on tree size and extent of stem damage, and Appendix 2 graphs show additional scenarios for the number of trees debarked for the Faraday trade in 2001. The calculations are for the same annual quantities listed in Table 5, but the number of trees varies depending on the stem size-class and percent bark removal. The estimates encircled in Appendix 2a,b,d are those shown in Table 5; however, the graphs show how the order of magnitude can change depending on the tree size selected.

Table 5: Estimated number of Individual Equivalents debarked for the *muti* shop trade in and the Faraday Street market in 2001, based on the mostly commonly available stem size-class and estimated percentage of stem damage (i.e. bark removal).

Species	Stem size-class (cm)	Fresh harvestable bark mass to 2 m (kg)	% stem damage within 2 m	Estimated mass sold per annum (kg)	Number of Individual Equivalents (trees)
Muti shops 1995					
A. xanthophloea				No data	-
A. adianthifolia	50-59	35.4	10	9 047	2 556
B. maughamii	50-59	127.3 (26.7)[1]	10	8 549	672 (3 202)
E. transvaalense	40-49	27.3	25	27 771	4 069
W. salutaris	40-49	29.0[2]	50	41 360	2 852
Faraday Street 2001					
A. xanthophloea	20-29	11.0	10	7 990	7 264
A. adianthifolia	20-29	8.7	10	10 537	12 111
B. maughamii	40-49	64.4 (16.1)[1]	10	4 195	651 (2 606)
E. transvaalense	10-19	6.9	50	11 155	3 233
W. salutaris	15-19	5.4	75	4 215	1 041

[1] Most of the bark on *B. maughamii* is contained within the flutes of the trunk. Figures in brackets are the harvestable mass and number of individuals if ± 21% of the bark is not in the flutes (Williams *et al.* in press 3).
[2] Estimated from Figure 2a previous paper

4. Discussion

There have been various attempts to quantify the number of individual stems debarked annually, but the paucity of quantitative data on the harvestable bark mass per stem has restricted these endeavours. Cunningham and Mbenkum (1993) estimated that the 1,923 tonnes of *Prunus africana* bark harvested annually in Cameroon would represent 35,000 trees year^{-1}, assuming that mean bark yield was 55 kg tree^{-1} and that only bark on the opposing quarters of the trunk was removed. Mander (1998) estimated that the 17.2 tonnes of *W. salutaris* bark sold annually in the Durban medicinal trade would represent 1,075 trees, assuming a dry weight of 16 kg tree^{-1}. Similarly, 1 581 *Ocotea bullata* and 1 494 *Curtisia dentata* trees were estimated to be used per year (Mander 1998).

Results in Table 2 from the previous paper suggest that trees for which the 16 kg dry weight was estimated for Mander's (1998) study were probably >40 cm dbh. However, research shows that most *W. salutaris* stems targeted by gatherers are less <30 cm dbh (Botha *et al.* 2004) and probably 15–19 cm dbh. Therefore, assuming a dry weight of 2.7 kg tree^{-1} (Table 2, Williams *et al.* in press 1), and 100% bark removal, the number of individual equivalent trees sold annually in Durban could be as high as 6 370. Furthermore, by assuming a fresh mass of 5.5 kg tree^{-1} (Table 2, Williams *et al.* in press 1), the number of individual trees would be 3,185. These estimates of individuals would also increase if only 50%, 25% or 10% of the stem were assumed to be debarked and damaged. Hence, a benefit of this research is the ability to appraise potential harvesting impacts on species populations by being able to estimate the number and size of trees debarked annually with greater discriminatory capacity.

Precise measures of the quantities sold annually are not possible, but recognition of the order of magnitude is necessary if resource management alternatives are to be seen in perspective (Cunningham 1988). It is not, however, a straightforward matter to evaluate differences in the bark quantities traded in the various regional and sectorial markets based on mass or volume. The mass traded annually might seem to be lower or decreasing, but there might not be a corresponding decrease in the number of trees being debarked. Instead, the number of smaller trees and the extent of damage to the stems may be increasing as the availability of larger trees in a population starts to decline. Therefore, the novel approach presented in this paper allows one to move away from discussing harvesting impacts in terms of the mass sold in the markets, and instead use bark size-class prevalence as a surrogate for knowing what stem size-classes are present in populations and are debarked by harvesters.

A question that arises is: how does quantification of the number of individual equivalents and the stem size-classes predicted from the bark size-classes actually compare with the size-class distributions of wild populations? Furthermore, do stem size-classes predicted to be damaged by bark harvesting represent what is available to be harvested or what is preferentially selected (assuming there is a preference)? Size distributions allow identification of poorly represented life history stages (Hall and Bawa 1993), and by reconstructing the size distributions estimated by the bark thickness frequencies, stages that are affected and impacted by variations in harvesting intensity become apparent, even if data on plant population sizes and size-class distributions are not known. Except for Cunningham (1988) and Botha *et al.* (2002, 2004), there are few studies in South Africa that record assessments of harvesting impacts based on size-class distributions and plant population sizes. This makes it difficult to judge the rates of decline for a species, even if the number of trees harvested annually is known.

Through data collected in the Johannesburg markets in 1995 and 2001, it was possible to compare the availability of bark thickness size-classes with corresponding tree stem size-classes. There appeared to be a decline in the availability of thick bark harvested from larger trees, especially for *W. salutaris*, *E. transvaalense* and *A. adianthifolia* (Appendix 1; Table 2). The results for *W. salutaris* verify research by Botha *et al.* (2002) conducted in Mpumalanga, South Africa. Stems from size-classes 6–30 cm basal diameter (dbh ≈ 4.8–28.7 cm, from Table 1) in commercially harvested populations had been harvested at levels >25% bark removal below 2 m. Ring-barking had occurred extensively in trees 16–20 cm and 26–30 cm (dbh ≈ 14.8–18.8 and 24.7–28.7 respectively). Size-classes >30 cm basal diameter in commercially harvested populations had frequencies of zero, but trees of this size were present in protected populations and ≤25% of the stems had been harvested (Botha *et al.* 2002).

The popularity of *E. transvaalense* bark in the markets, and the corresponding decrease in the availability of thicker bark from larger individuals (Appendix 1d), is supported in a study conducted by Twine (2004) in southern Maputaland, KwaZulu-Natal in 1996-97. *Elaeodendron transvalense* was the most sought after species, and 91% of all individuals had harvest wounds – 17% of which had been ring-barked, some to a height of 5 m (Twine 2004). Twine (2004) does not specifically describe the stem size-classes most commonly targeted by or available to harvesters, but cites the mean amount of bark harvested per individual stem to be 1.66 m^2. Referring to Table 2 of the previous paper, this suggests that the trees would have had stems >30–39 cm dbh. The decline over the last decade in the prevalence of bark harvested from size-classes >25 cm dbh (Appendix 1d) is of great concern. The species is very vulnerable to over-harvesting and trees are known to die following ring-barking, thereby severely threatening the status of the population. In addition, wounds show a very slow rate of recovery from edge growth (V.L. Williams unpublished data).

While there appeared to be a decrease in the availability of thicker bark in the markets for *B. maughamii*, this could not be conclusively linked to a sizeable reduction in the diameter of stems harvested – partly because the relationship between bark thickness and stem diameter is weak and difficult to predict. Twine (2004) noted, however, that *B. maughamii* was the third most sought after species harvested for bark in southern Maputaland and that 55% of all stems had harvest wounds. This species therefore faces future risks in terms of declining numbers of mature trees.

It was similarly not possible to assess whether there had been a decrease in the size of *A. xanthophloea* trees damaged by harvesters because there is no relationship between bark thickness and stem diameter. However, Botha *et al.* (2004) noted that the majority of *A. xanthophloea* trees damaged by bark harvesting on private land in Mpumalanga had been harvested at rates of <10% of the stem below 2 m. Only 4% of the stems had been ring-barked, suggesting that *A. xanthophloea* is not a species subject to excessive and intensive debarking because of demand in the *muti* markets across the country.

Communities and populations of plants are increasingly subjected to size reduction and fragmentation though human action (Lamont *et al.* 1993), especially if there is a decline in population viability and size resulting from extensive resource harvesting. Intense harvesting of mature trees (e.g. *W. salutaris* and *E. transvaalense*), results in density diminishing to a point where trees are difficult to find or are locally extinct (Hall and Bawa 1993). Bark that continues to be harvested from the remaining smaller individuals will be thinner, and the markets will reflect this prevalence. Harvesting may then shift to a different location (possibly giving the intensely harvested population a chance to recover) (Hall and Bawa 1993), and the medicinal plant markets will reflect these newly discovered localities by the occasional presence of unusually thick bark. Most *W. salutaris* sold in the markets is less than 5 mm thick (Appendix 1e) and harvested in South Africa. Bark >10 mm thick periodically appears in the markets, and is invariably harvested in Mozambique where gatherers have access to larger trees. The sustainability of harvesting is proportional to the size of the population and its ability to recover after harvesting, and inversely proportional to the level of harvesting effort and efficiency.

In conclusion, the intention was to demonstrate how bark thickness records collected during market surveys and inventories can be linked to wild plant populations in order to assess the extent of resource exploitation. By being able to correlate bark thickness with stem diameter, the size of the trees from which gatherers harvest bark can be assessed. The data presented also allow for time after bark harvesting to be taken into account, so that the effects of air-drying and subsequent decrease in bark thickness and mass do not confound results and compound the variation and standard errors of the estimates. These methods also allow for greater accuracy in determining the size and number of trees debarked by gatherers, and hence the change in the availability of these resources over time. This methodology should now be applied to a wide range of species that have bark harvested for traditional medicine. Moreover, extensive research on rates of bark recovery in relation to tree size, harvesting intensity and associated ecological factors would further assist the assessments of long-term harvesting impacts.

Acknowledgements

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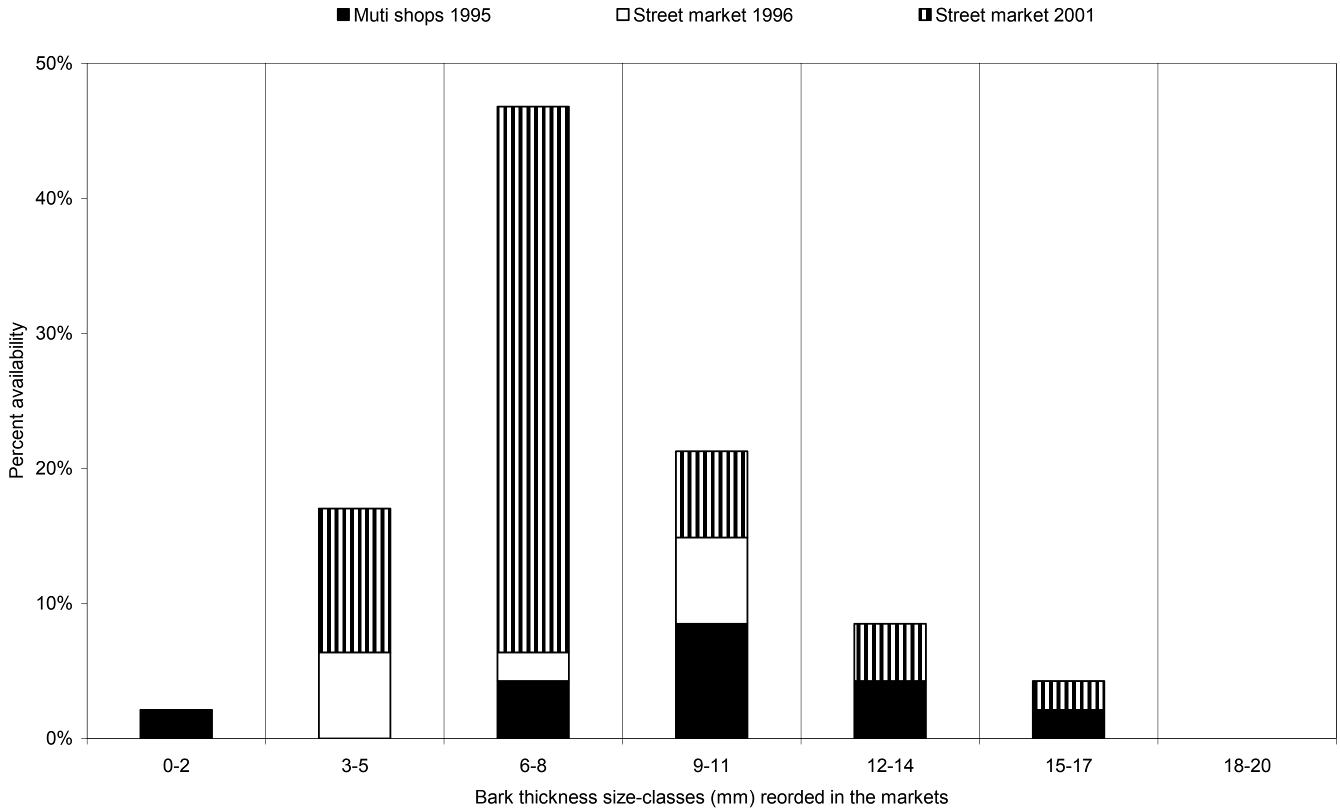
Appendix 1: a-e

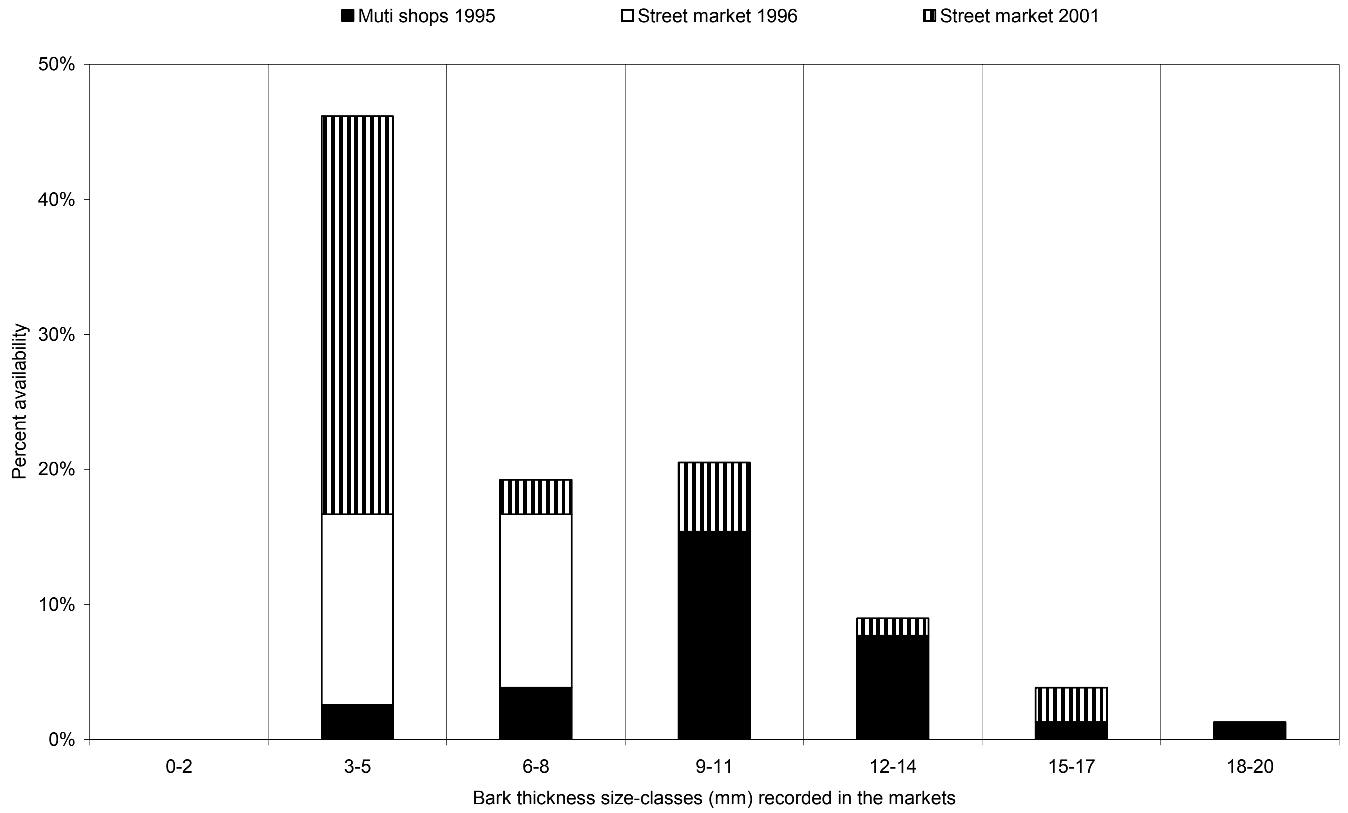
Bark thickness availability in *muti* shops and the Faraday Street market between 1995 and 2001. The table below the histogram indicates the estimated dbh range for each bark size-class, depending on when the bark was likely to have been harvested. The table assumes that the bark had been removed at a height between 0.5 m and 1.3 m on the stem.

a) *Acacia xanthophloea*



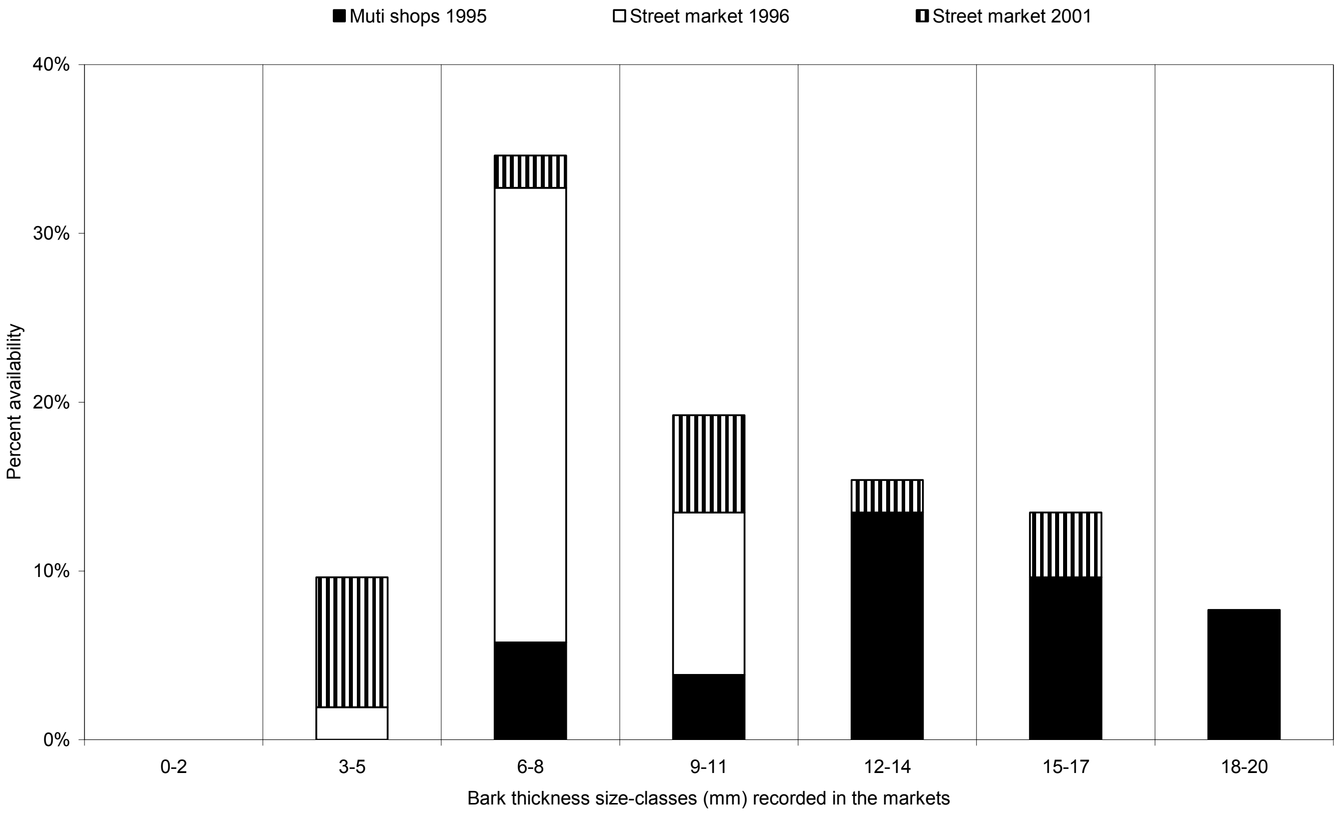
Time after harvesting	The estimated stem dbh (cm) range (below) for each bark thickness class (above), depending on when the bark was harvested
1 week 6 weeks	Not possible to estimate tree size from bark thickness for this species

b) *Albizia adianthifolia*



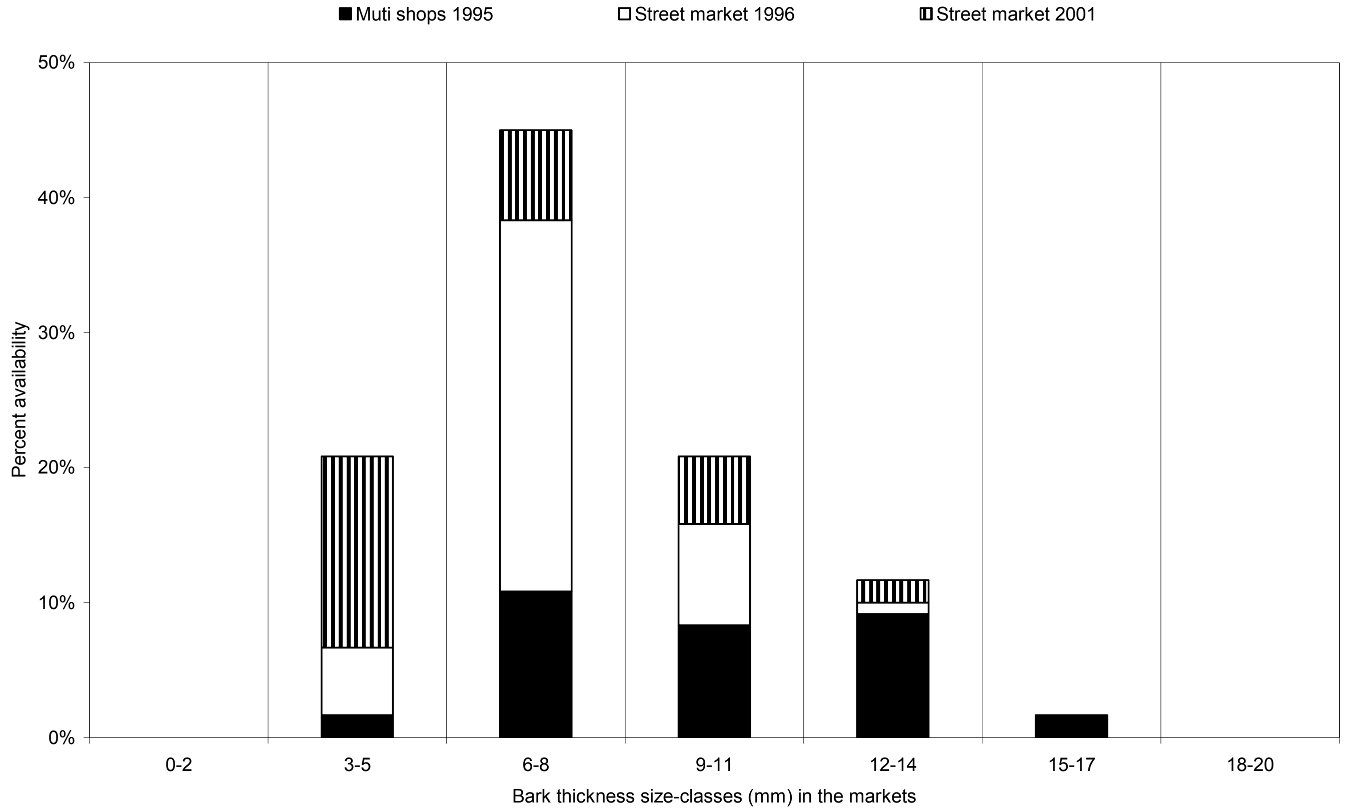
Time after harvesting	The estimated stem dbh (cm) range (below) for each bark thickness class (above), depending on when the bark was harvested						
Fresh		< 9	13 – 24	26 – 38	40 – 52	52 – 66	> 64
1 week		< 11	16 – 27	28 – 43	42 – 58	57 – 74	> 72
6 weeks		10 – 30	33 – 52	54 – 74	73 – 96	97 – 118	> 120

c) *Balanites maughamii*



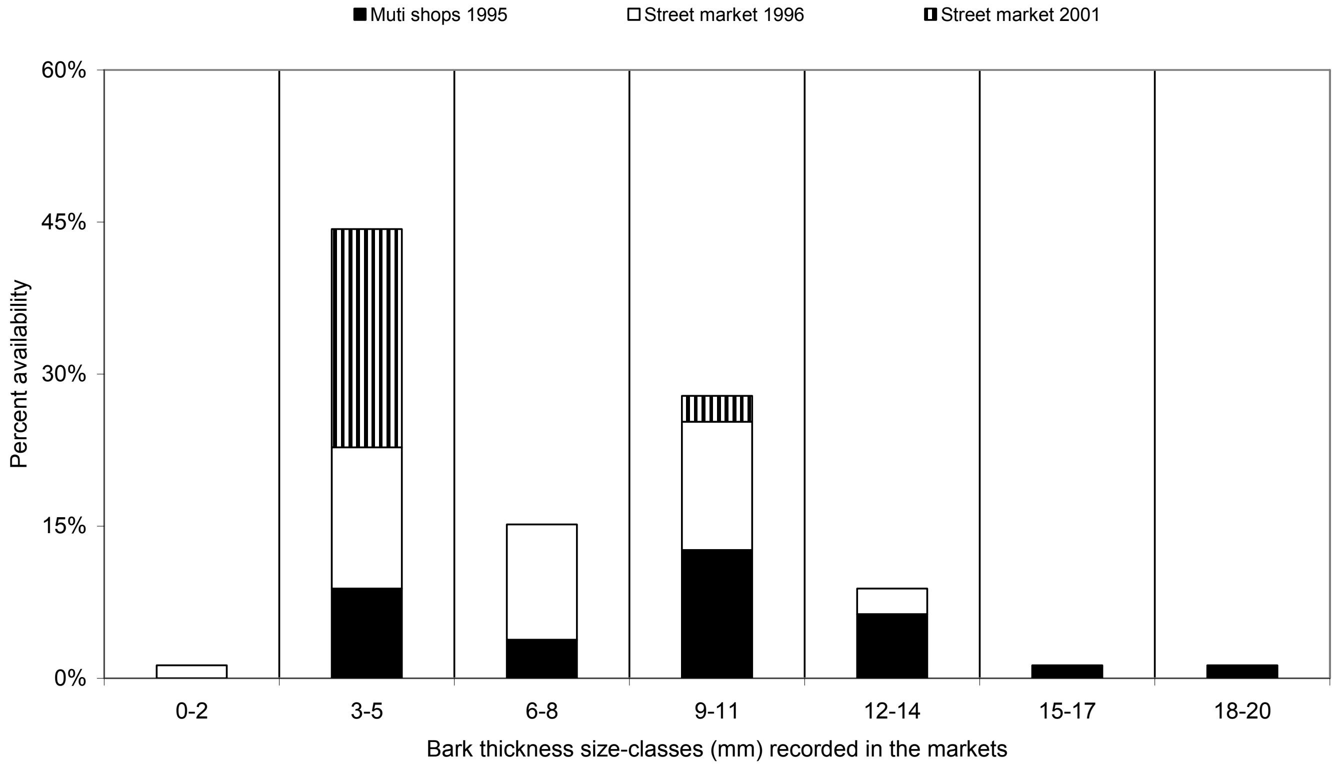
Time after harvesting	The estimated stem dbh (cm) range (below) for each bark thickness class (above), depending on when the bark was harvested						
Fresh		< 10	9 – 30	34 – 49	50 – 68	> 64	> 64
1 week		2 – 11	10 – 33	35 – 55	57 – 77	> 74	> 74
6 weeks		2 – 15	20 – 44	49 – 72	77 – 101	> 85	> 85

d) *Elaeodendron transvaalense*



Time after harvesting	The estimated stem dbh (cm) range (below) for each bark thickness class (above), depending on when the bark was harvested						
Fresh		< 7	10 – 21	23 – 36	35 – 51	> 49	
1 week		< 10	11 – 25	25 – 40	41 – 56	> 55	
6 weeks		< 15	17 – 36	39 – 57	54 – 79	> 80	

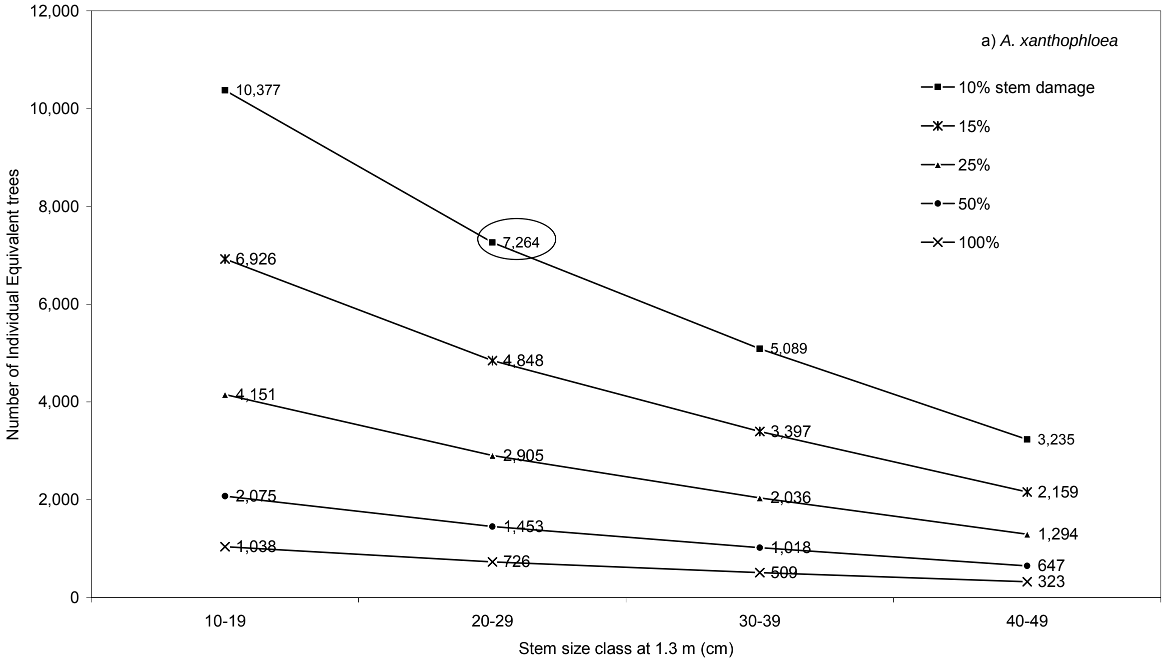
e) *Warburgia salutaris*

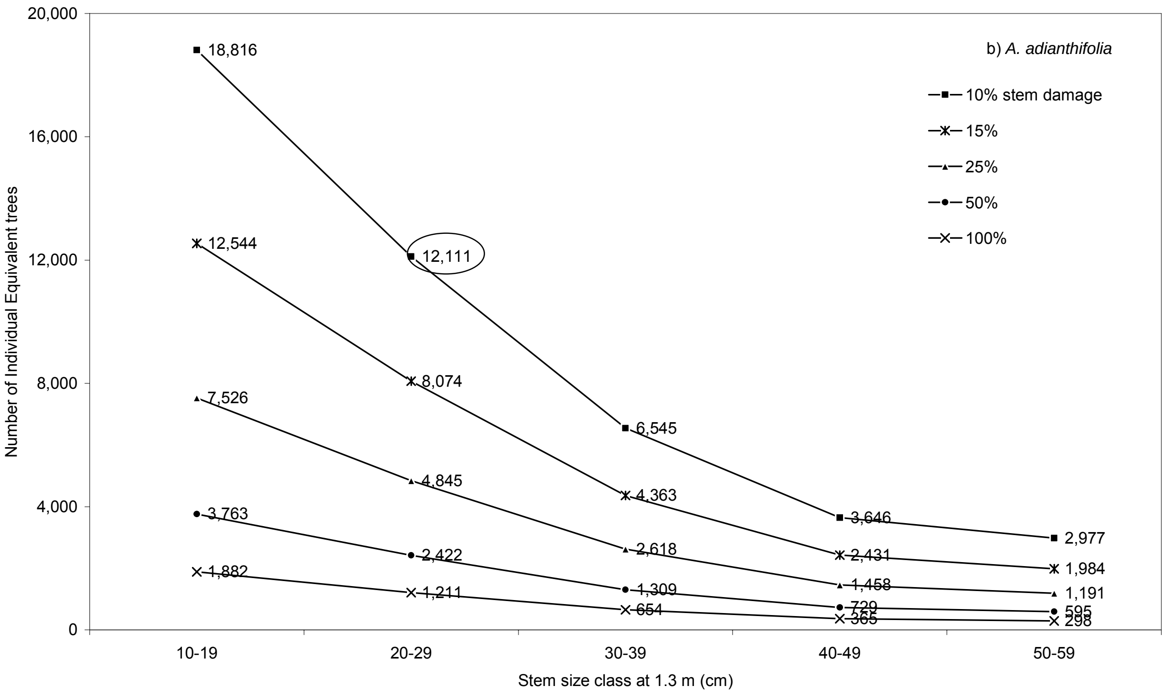


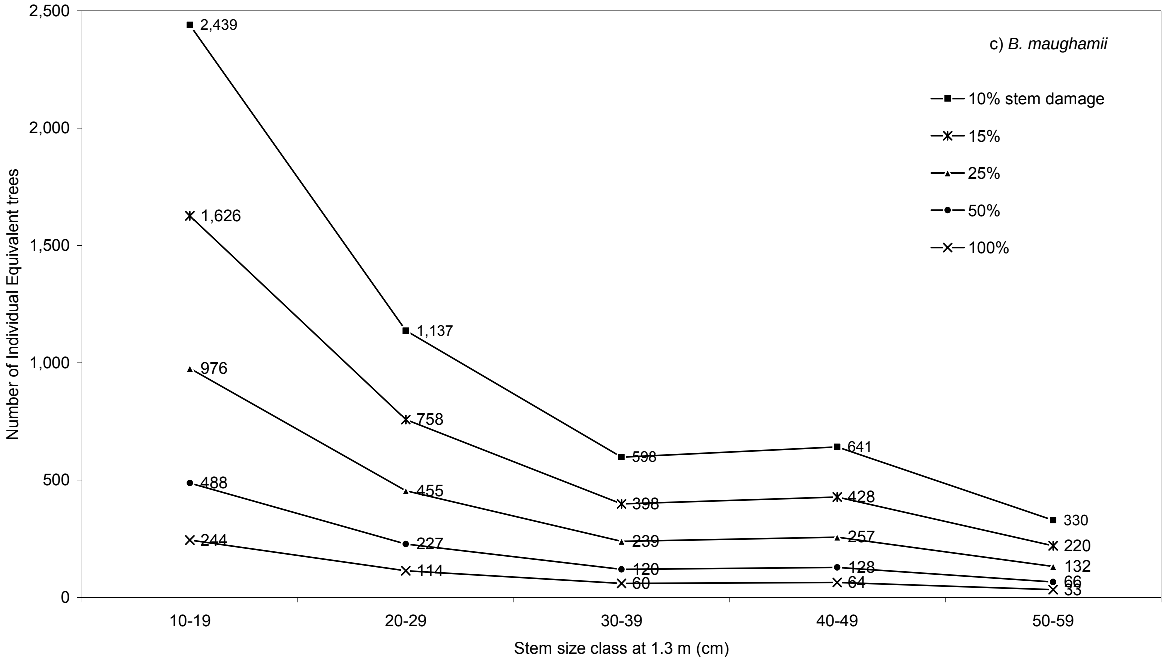
Time after harvesting	The estimated stem dbh (cm) range (below) for each bark thickness class (above), depending on when the bark was harvested					
Fresh	< 4	3 – 9	9 – 17	18 - 25	27 – 33	36 – 41	44 – 49
1 week	< 5	3 – 12	10 – 22	18 – 32	27 – 42	37 – 52	45 – 62
6 weeks	< 11	9 – 23	26 – 41	42 – 60	60 – 78	77 – 97	94 – 115

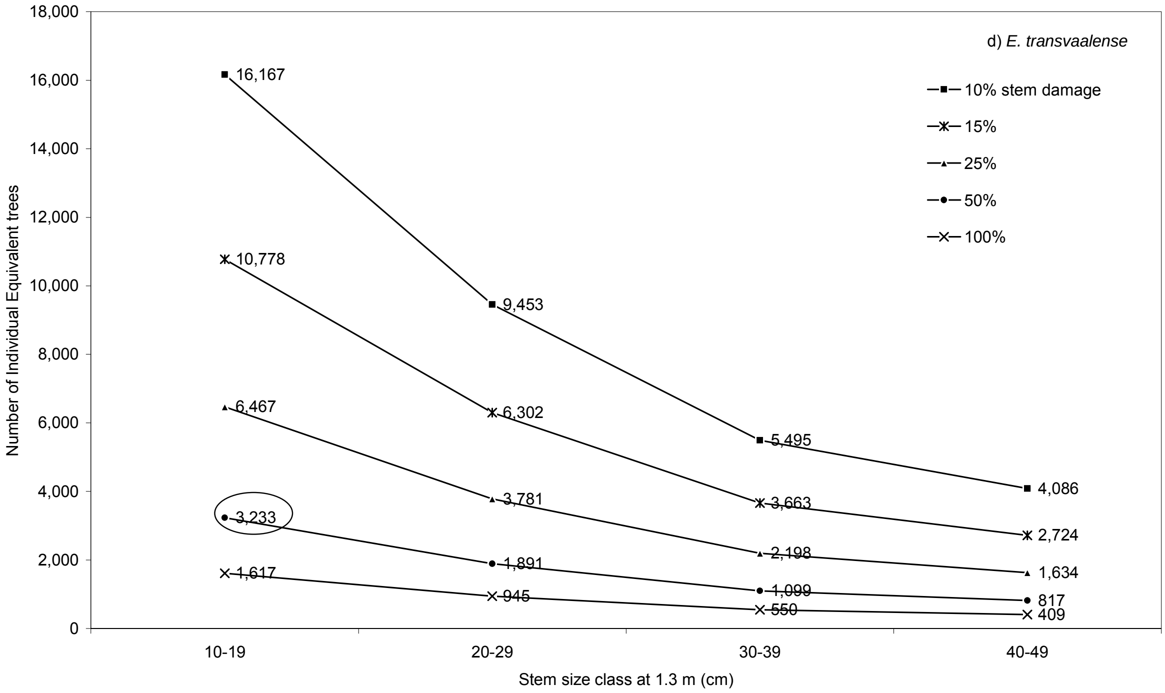
Appendix 2: a-e

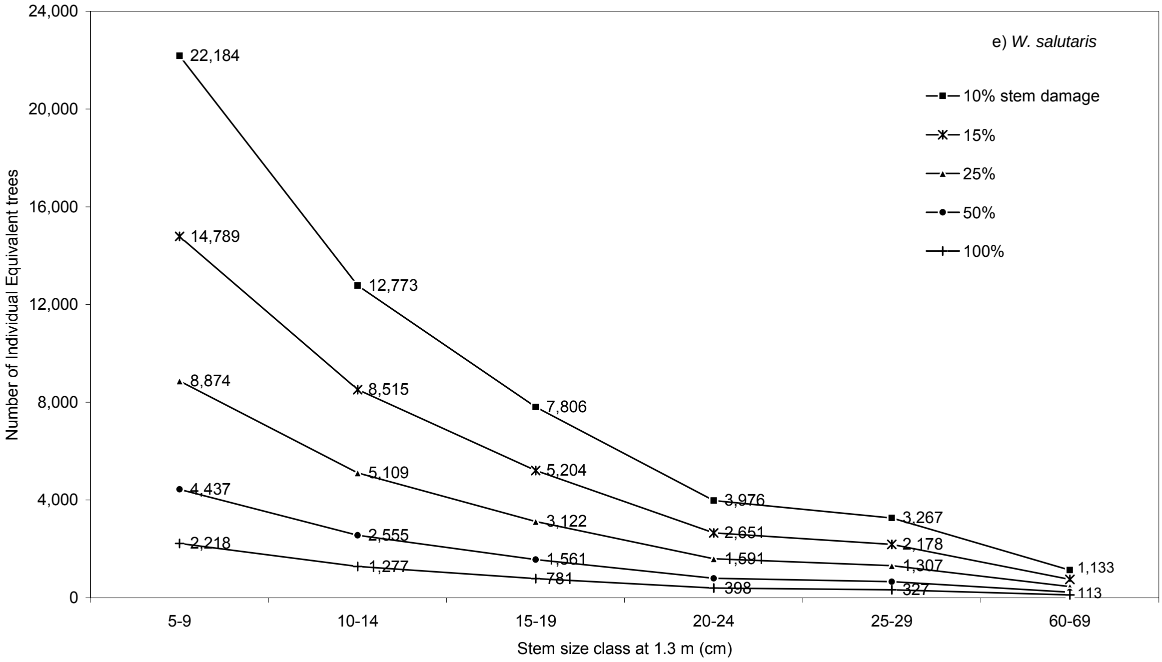
Scenarios for the number of individually equivalent trees debarked for the Faraday Street market trade in 2001. Each line represents a different degree of stem damage between 10-100%. In addition, each estimate of the number of individuals depends on the size of tree selected by the harvesters, and hence the equivalent amount of bark that can be removed per tree. Encircled estimates are those from Table 5 (Faraday 2001).






c) B. maughamii
10% stem damage
15%
25%
50%
100%
Number of Individual Equivalent trees
Stem size class at 1.3 m (cm)
10-19
20-29
30-39
40-49
50-59
2,439
1,137
598
641
330
1,626
758
398
428
220
976
455
239
257
132
488
227
120
128
66
244
114
60
64
33


d) E. transvaalense
10% stem damage
15%
25%
50%
100%
Number of Individual Equivalent trees
Stem size class at 1.3 m (cm)
10-19
20-29
30-39
40-49
16,167
9,453
5,495
4,086
10,778
6,302
3,663
2,724
6,467
3,781
2,198
1,634
3,233
1,891
1,099
817
1,617
945
550
409


e) W. salutaris
10% stem damage
15%
25%
50%
100%
Number of Individual Equivalent trees
Stem size class at 1.3 m (cm)
24,000
20,000
16,000
12,000
8,000
4,000
0
5-9
10-14
15-19
20-24
25-29
60-69
22,184
12,773
7,806
3,976
3,267
1,133
14,789
8,515
5,204
2,651
2,178
8,874
5,109
3,122
1,591
1,307
4,437
2,555
1,561
2,218
1,277
781
398
327
113

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Size-class prevalence of bulbous and perennial herbs sold in the Johannesburg medicinal plant markets between 1995 and 2001

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Abstract

Commercial harvesting of perennial herbs and geophytes for the medicinal plant trade has resulted in significant levels of resource depletion for several of the species concerned. One way to quantify the impacts is to estimate the number of bulbs harvested annually. Using records of bulb diameters sold in the Witwatersrand traditional medicinal plant markets between 1995 and 2001, the diameter size-classes most prevalent in the markets were ascertained. Thereafter, the number of 'individual equivalents' was estimated, i.e. the number of individual bulbs harvested annually equivalent in size to the mean diameter of the bulbs known to be traded. The estimates obtained include scenarios for bulbs of different diameters (reflecting the modal frequencies). The results showed there to be a significant decrease in the modal diameter of *Eucomis autumnalis* bulbs prevalent in the markets between 1995 and 2001 from 8 cm to 4 cm respectively. The diameters of *Drimia* spp. bulbs, the most popular species in the Witwatersrand markets, were also decreasing, but the differences were not significant by 2001. Scenarios for the number of *Drimia* spp. bulbs estimated to be sold to the Witwatersrand *TM* shops in 1995 ranged from 270 618 to 552 022 bulbs per annum. Gatherers are harvesting smaller and smaller bulbs over time and this is not sustainable at current rates, especially if more smaller bulbs are sold. It is thus clear that cultivation is necessary to mitigate the effects of further exploitation.

Keywords: Bulbs; Harvesting impacts; Medicinal plants; Perennial herbs; Resource use

1. Introduction

Commercial collecting for the medicinal plant trade is a major cause of resource depletion (Cunningham, 1988), the impact of which is partly dependent on the plant part removed and the level of harvesting effort and gatherer 'efficiency'. Plant populations can be driven to extinction if increases in harvesting effort chase an ever-diminishing yield (Begon et al., 1986). Damage assessments to tree populations have been based on the presence of debarked trunks (e.g. Botha et al., 2004; Geldenhuys, 2004; Twine, 2004), but for bulbous plants often little sign remains of their former presence in a locality (Cunningham, 1988). Hence, estimates on the extent of resource depletion based on population off-take are difficult to evaluate, especially if there is a paucity of data on plant population sizes and structures as well.

Whole plants, roots and bulbs account for ≈ 50% of the > 500 species and 48% of the volume of plants sold in the Faraday market for traditional medicine in Johannesburg (Williams, 2003). While data on the estimated volume of plants purchased by the traders informs the magnitude of resource depletion, the sustainability of harvesting and the scale of cultivation required to substitute wild-collected stocks would benefit from knowing how many individual plants are extracted. The intention of this paper was to quantify the negative impact of commercial harvesting by investigating and estimating the number of plants harvested annually using the concept of 'individual equivalents'.

'*Individual Equivalents*' is a concept conceived specifically to estimate the number of individual plants harvested, and the potential condition of the resource base, directly from trade and market information (Williams et al., in press). In the case of trees, estimates of the number of individual debarked stems were derived from the bark quantity traded and the number of individual trees that had a stem diameter and bark thickness equivalent to similarly sized individuals for which harvestable bark mass per stem was determined (Williams et al., in press). In this paper, estimates of the number of individual geophytes harvested were based on the number of individuals equivalent in

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Table 1
Perennial herbs investigated in this study

Species	Family	Common name	Underground organ-type
Drimia spp.	Hyacinthaceae	Skanama, isiKlenama	Bulb
Eucomis autumnalis	Hyacinthaceae	uMathunga	Bulb
Merwilla plumbea	Hyacinthaceae	inGuduza	Bulb
Hypoxis spp.	Hypoxidaceae	iLabatheka, iNkomfe	Rhizomatous tuber/corm
Scabiosa columbaria	Dipsacaceae	iBheka	Persistent woody rootstock
Dianthus mooiensis	Caryophyllaceae	Tjanibeswe	Persistent woody rootstock

size (i.e. bulb diameter) to the plants for which the number of individual bulbs per bag was determined. For example, if one 50-kg size bag contained ≈ 138 bulbs, each 8 cm in diameter, and ten 50-kg bags were known to be sold over a period of time, then the *equivalent* number of *individual* 8 cm bulbs estimated to be harvested is 1380 'individual equivalents'. If, however, a bag contained ≈ 282 bulbs, each 6 cm in diameter, then the number of 'individual equivalents' would be 2820 bulbs.

Trade data for six selected perennial herbs were acquired during three surveys of traditional medicine vendors in Johannesburg between 1995 and 2001 (Williams, n.d.). From the bulb diameter and mass records for four bulbous geophytes, the relationship between bulb diameter and mass was correlated, the most prevalent size-classes sold by vendors was established, the change in diameter size-classes over a six-year period was investigated, and the number of 'individual equivalent' bulbs extracted annually from the source populations was estimated.

2. Methods

2.1. Species investigated

A perennial herb is defined here as a vascular plant whose life span extends over more than 2 years, that does not produce persistent above-ground woody tissue but may have under- or partially above-ground storage organs (such as bulbs, corms, rhizomes or rootstock) (Van Wyk and Malan, 1988; Von Ahlefelt et al., 2003). Of the perennial herbs investigated, three species are bulbous, one is rhizomatous/cormous and two species have woody rootstocks with long, persistent, carrot-like roots (Table 1) (Fig. 1).

Drimia spp. are the most popular bulbs, and refer to at least two species traded in the markets by the common names *skanama* or *isiKlenama*. In Johannesburg, at least 60% of the *Drimia* spp. bulbs are the reddish-coloured *D. elata* Jacq. The remaining 40% are *D. altissima* (L.f.) Ker Gawl. (Also known as *white skanama*). *Eucomis autumnalis* (Mill.) Chitt. and *Merwilla plumbea* (Lindl.) Speta (formerly *Scilla natalensis* Planch.), known as *uMathunga* and *inGuduza* respectively, are also in high demand. *Hypoxis* spp. refers to *H. colchicifolia* Bak. and *H. hemerocallidea* Fisch. and Mey., known as iLabatheka or iNkomfe. The species investigated that have persistent woody rootstocks are *Scabiosa columbaria* L. (iBheka)

Fig. 1. The species investigated: (a) *Hypoxis* spp. corms; (b) *Merwilla plumbea* bulbs; (c) *Scabiosa columbaria* roots; (d) *Dianthus mooiensis* roots; (e) *Eucomis autumnalis* bulbs; (f) *Drimia elata* bulbs.

and *Dianthus mooiensis* F.N. Williams (Tjanibeswe). In KwaZulu-Natal, a similar species to *D. mooiensis*, namely *Dianthus zeyheri* Sond. (iNingizimu), tends to be used. Depending on the size, bulbs are sold in handfuls equivalent to 6±2.3 bulbs (Williams, 2003) whereas *S. columbaria* and *D. mooiensis* are sold in bundles consisting of ≈ 25 individual plants.

2.2. Market surveys and quantitative resource inventories

The prevalence of the bulbous and perennial herbs of varying sizes sold by medicinal plant vendors was determined from three studies conducted between 1995 and 2001. Between April and October 1995, the six species were measured in 27 traditional medicine shops on the Witwatersrand. The Witwatersrand is an extensively urbanised area within the province of Gauteng, with Johannesburg located approximately at the centre of this region. Quantities of the species equivalent in volume to a typical retail sale to a customer were weighed and measured. Bulb diameter was measured using a Vernier calliper across the widest point along the horizontal axis. The bulbs were weighed using a portable digital scale accurate to 5 g. The length of the woody rootstock was measured from the leaf base to root tip. Additionally, traders were asked how many bags per annum of each species they purchased. In a second study between July and September 1995, plant samples were purchased on ten visits to the Faraday market. Faraday is a large, informal wholesale and retail street market in Johannesburg with currently more than 200 vendors. The plants were weighed and measured in the same way as the shop survey, but no data were collected on the annual volume sold.

In January 2001, an extensive semi-quantitative study of Faraday was conducted on behalf of the provincial Directorate for Nature Conservation within the Department of Agriculture, Conservation and Environment in Gauteng (Williams, 2003,

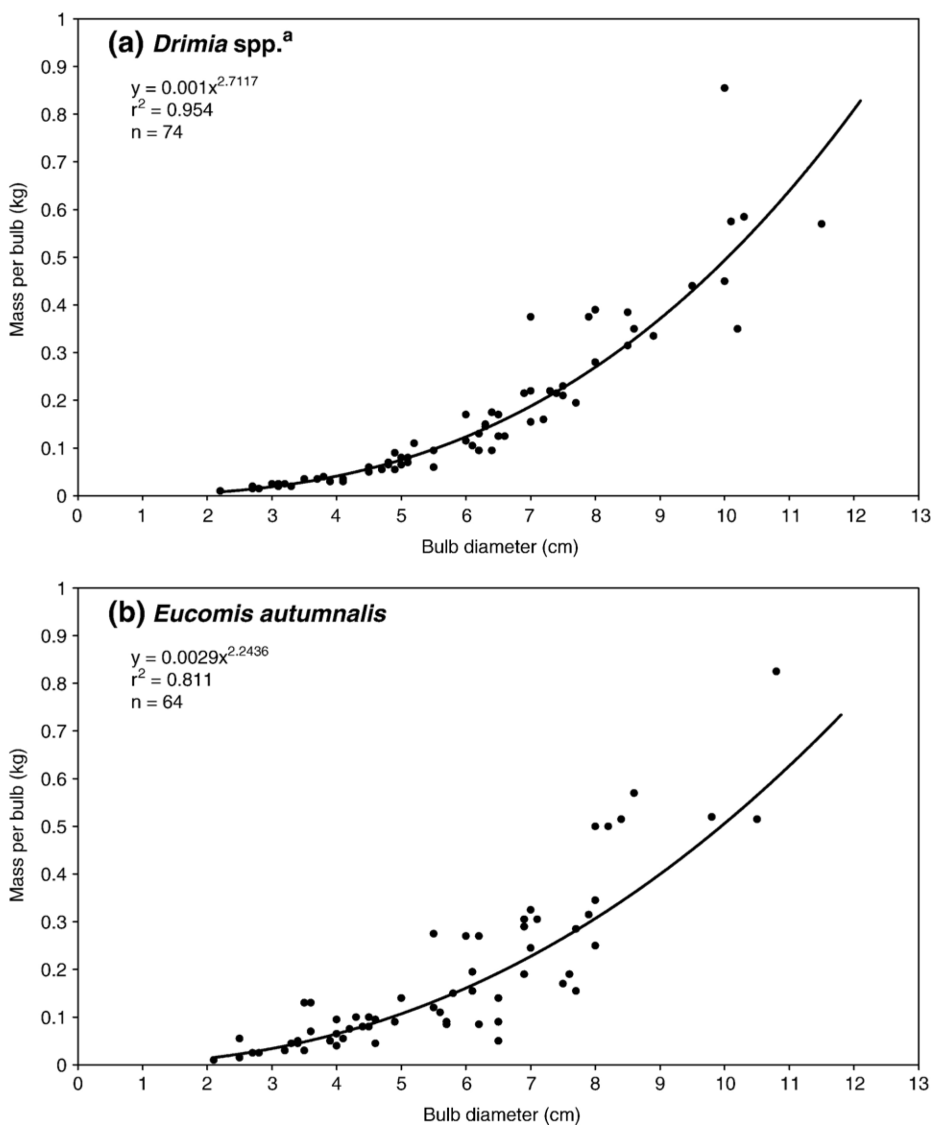


Fig. 2. Regression relationships between bulb/corm mass and diameter, for data collected in the traditional medicine shops and Faraday market in 1995, for (a) *Drimia* spp., (b) *E. autumnalis*, (c) *M. plumbea* and (d) *Hypoxis* spp. The diameter was measured as the widest point along the horizontal axis. [a]*Drimia* spp: *Drimia elata* and *D. altissima* (see text). [b]*Hypoxis* spp: *H. colchicifolia* or *H. hemerocallidea*.

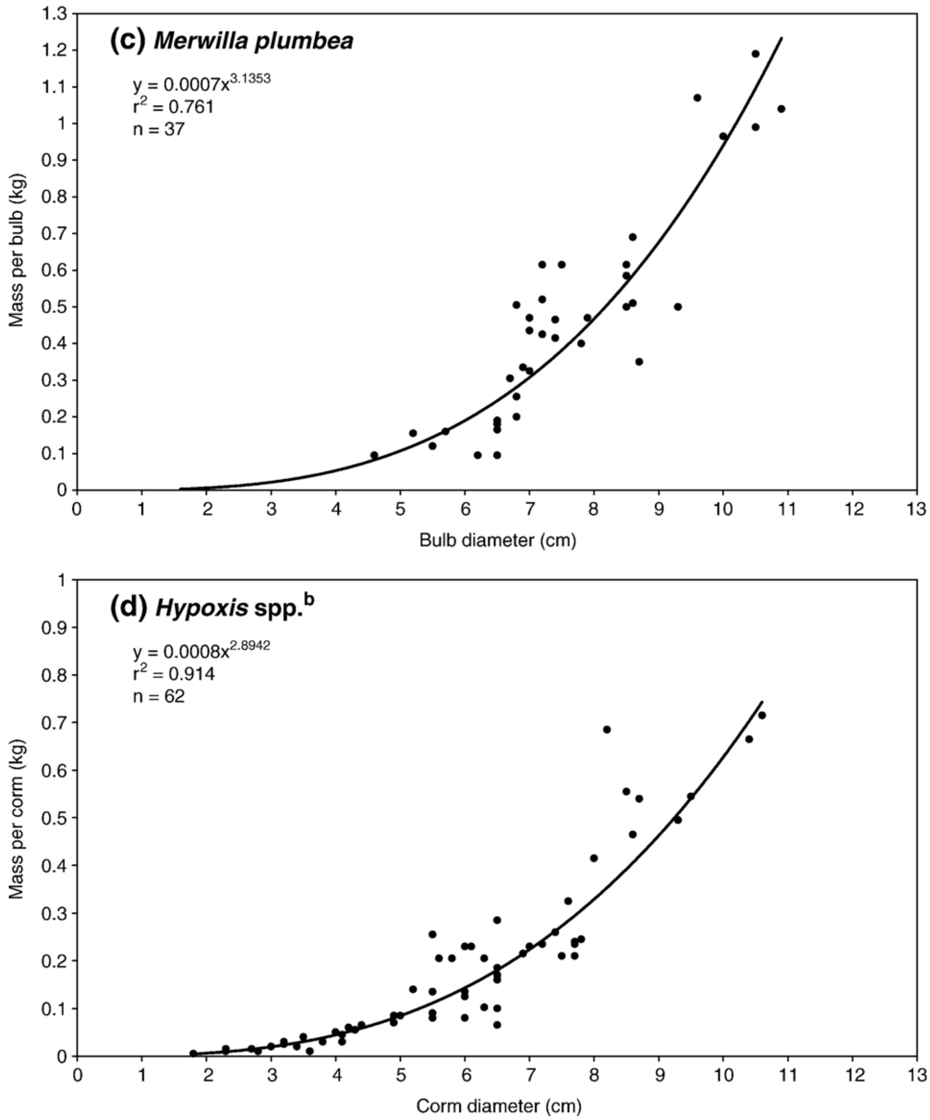


Fig. 2 (*continued*).

2004). One hundred traders were interviewed and a quantitative inventory of every plant sold by each trader was compiled, including the quantity of each species present in the market and the estimated size of the plant part. Given time constraints and the number of species in the market (>500) (Williams, 2003), it was not practical to accurately weigh and measure each individual bulb. Instead, bulbs that were generally representative of the size of the stock on sale were selected and bulb diameter was visually estimated and categorised into 1 cm diameter size-classes. None of the plants were weighed, and the length of woody rootstocks was not measured. Traders were also asked how often they purchased plant stock equivalent in volume to a 50-kg maize bag.

2.3. Estimating the annual quantity of bulbs and rootstocks traded

Medicinal plants are usually transported to the markets in 50-kg size bags. The actual mass of the contents of a bag depends on the plant part (e.g. bulbs or leaves) and its density and moisture content. The number of individuals in any bag depends on the size dimensions of the plant part. The annual quantity of plants purchased by the shops in 1995 was estimated by determining the mean number of bags purchased per trader per annum (bags a^{-1}), and then multiplying this by the proportion of shops selling the species. The annual quantity purchased by the traders in Faraday in 2001 was calculated slightly differently. The frequency with which the traders purchased one bag of the species was determined, and then the number of bags that would have been bought annually was calculated depending on the proportion of traders who sold the species.

2.4. Calculating the number of 'Individual Equivalents'

Bulbs range in size in the markets, and the bulb diameters used to calculate the numbers of 'Individual Equivalent' bulbs harvested annually were standardized to be equivalent to the modal bulb diameters sold by vendors in a specific year. From raw data for seven bulbous listed in Cunningham (1988, Table 5, page 31) on the mean number of bulbs of a mean specified size contained in a 50-kg bag, regression analysis was used to plot the relationship between bulb size and the number of bulbs per bag. Thereafter, the number of bulbs of a standardized size harvested annually was estimated from the number of bulbs per bag and the number of bags purchased per annum.

Bulb populations may suffer varying degrees of damage depending on the popularity of the species, the intensity of harvesting and the size and/or maturity of the bulbs harvested from wild populations. Estimates of the number of bulbs harvested can therefore be adjusted to reflect scenarios for the different bulb sizes removed, e.g. 6–8 cm, and the number of Individual Equivalents would vary accordingly. Estimates for the number of individuals harvested for species with woody rootstocks (namely *D. mooiensis* and *S. columbaria*) were based on the mean number of individual plants per bundle and Cunningham's (1988) estimate of 200 bundles of plants per 50-kg bag.

2.5. Statistical analyses

Regression analyses were used to describe the relationship between bulb diameter and mass for bulbs sold by the traders in 1995. One-way ANOVAs were computed to test the differences in the mean bulb sizes sold in the TM shops in 1995 (S 1995) and the Faraday market in 1995 and 2001 (F 1995 and F 2001 respectively). The significance between the group means for S 1995, F 1995 and F 2001 was determined using the post hoc Tukey HSD multiple comparison test for unequal *N*. Excel and Statistica 6 were used for the statistical analyses.

3. Results

3.1. The relationship between bulb mass and diameter

The strongest regression relationships between bulb mass and diameter were for *Drimia* spp. and *Hypoxis* spp. ($r^2 = 0.954$ and 0.914 respectively) (Fig. 2a and d). *Drimia* has somewhat fleshy bulb scales, often tipped with the remains of dead leaves,

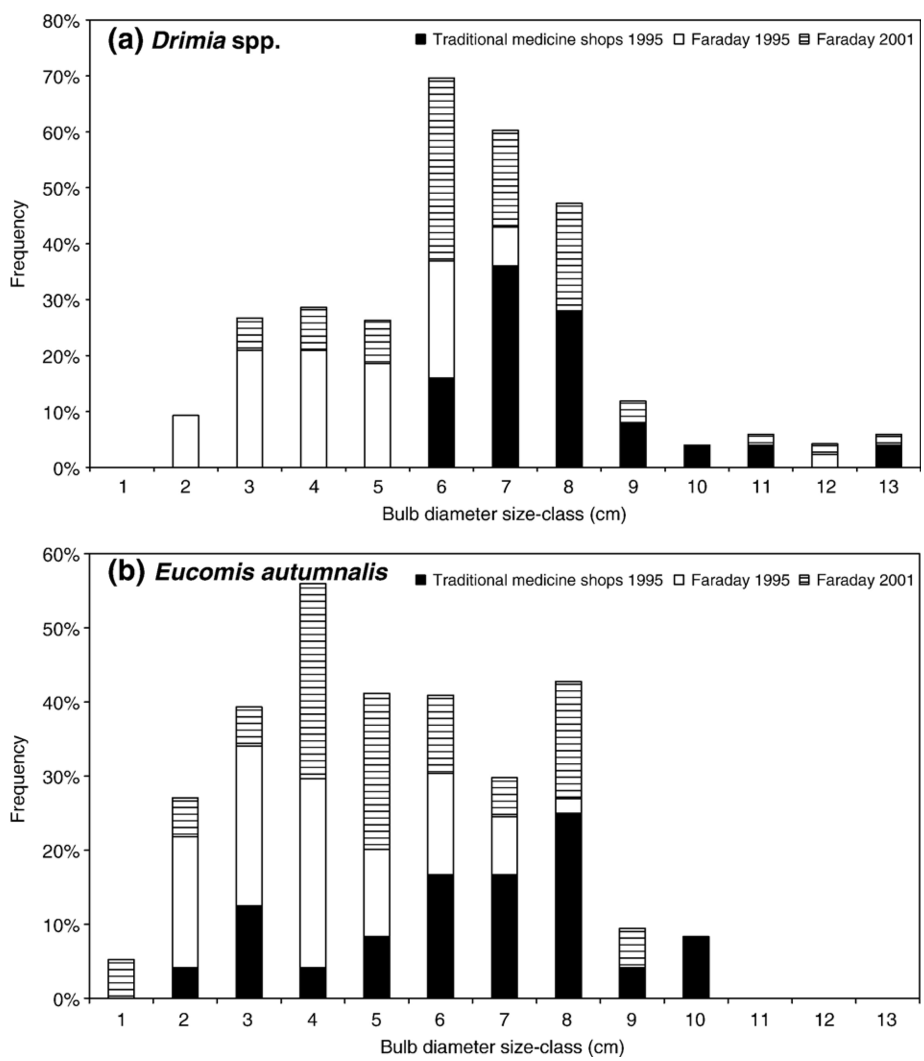
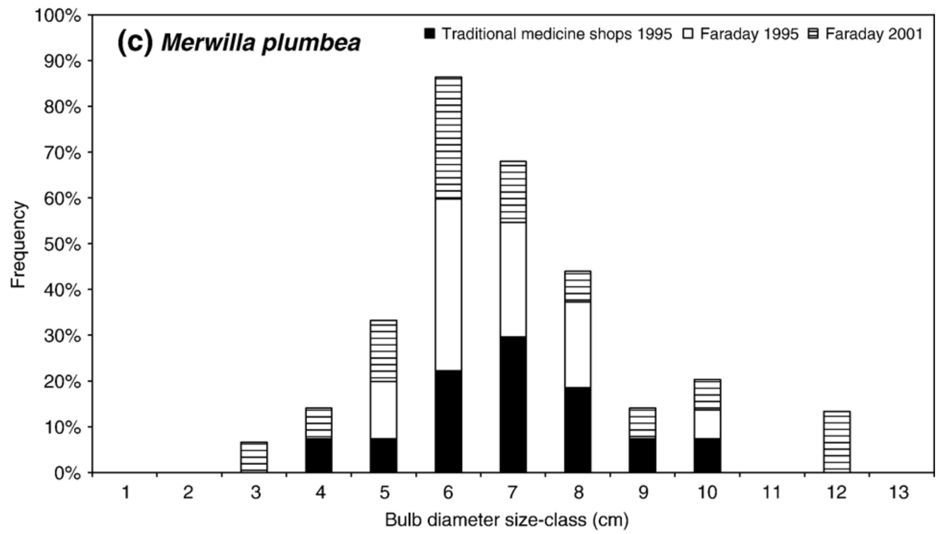


Fig. 3. Bulb/corm size availability in the traditional medicine shops and Faraday Street market between 1995 and 2001 for (a) *Drimia* spp., (b) *E. autumnalis*, (c) *M. plumbea* and (d) *Hypoxis* spp.



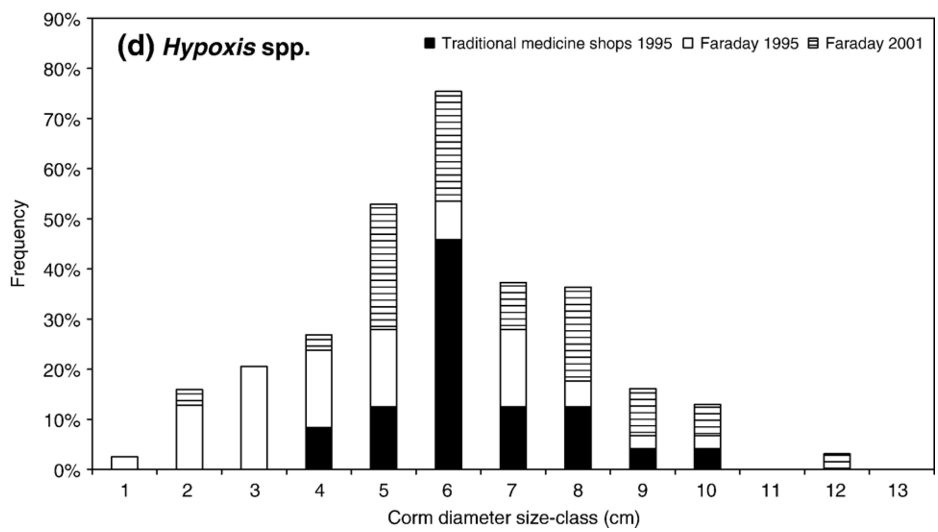


Fig. 3 (*continued*).

and *Hypoxis* has a swollen corm. The weaker regression relationships were for *E. autumnalis* and *M. plumbea* — species with dry, papery and flaky outer bulb scales ($r^2=0.811$ and 0.761 respectively) (Fig. 2b and c).

3.2. Mean size and mass of the species sold by traders

Drimia spp. bulbs sold in the shops in 1995 and the Faraday market in 2001 were mostly 6–8 cm in diameter, with the modes being 7 cm and 6 cm respectively (Fig. 3a). However, bulbs bought in Faraday in 1995 were mostly 3–6 cm in diameter. *Drimia* bulbs <6 cm were not recorded during the 1995 shop survey, but they were recorded in Faraday in 1995 and 2001. *E. autumnalis* bulbs were mostly 6–8 cm in the shops in 1995, compared to 4–6 cm in Faraday in 2001 (Fig. 3b). The modal diameters also declined from 8 cm to 4 cm. However, *E. autumnalis* bulbs bought from Faraday in 1995 were mainly 2–4 cm. *M. plumbea* bulbs were usually large and 6–8 cm in 1995 and 5–7 cm in 2001 (Fig. 3c). The modal diameter declined from 7 cm to 6 cm respectively and there were no incidences of bulbs <3 cm, as was the case with the other species. The corms of *Hypoxis* spp. sold in the shops in 1995 and the Faraday market were usually 5–8 cm in diameter and the modal sizes were 6 cm and 5 cm respectively (Fig. 3d). *Hypoxis* corms bought from Faraday in 1995 were 3–5 cm, and the mode was 3 cm.

Overall, there was a general decline in bulb diameter when comparing samples from the shops in 1995 and Faraday in 2001 (Fig. 3), but bulbs purchased from Faraday in 1995 were smaller than the bulbs recorded in Faraday in 2001 (except for *M. plumbea*) (Figs. 3 and 4). One-way ANOVAs comparing the mean bulb sizes in the shops and Faraday in 1995 (S 1995 and F 1995 respectively), and in Faraday in 2001 (F 2001) indicated that the mean diameters of *Drimia* spp., *E. autumnalis* and *Hypoxis* spp. were significantly different at $P<0.05$ (Fig. 4). However, the mean diameters of *M. plumbea* bulbs were not significantly different.

The Tukey HSD test revealed that *Drimia* bulbs bought from Faraday in 1995 (F 1995) were significantly smaller than the bulbs sold in Faraday in 2001 (F 2001) and in the shops in 1995

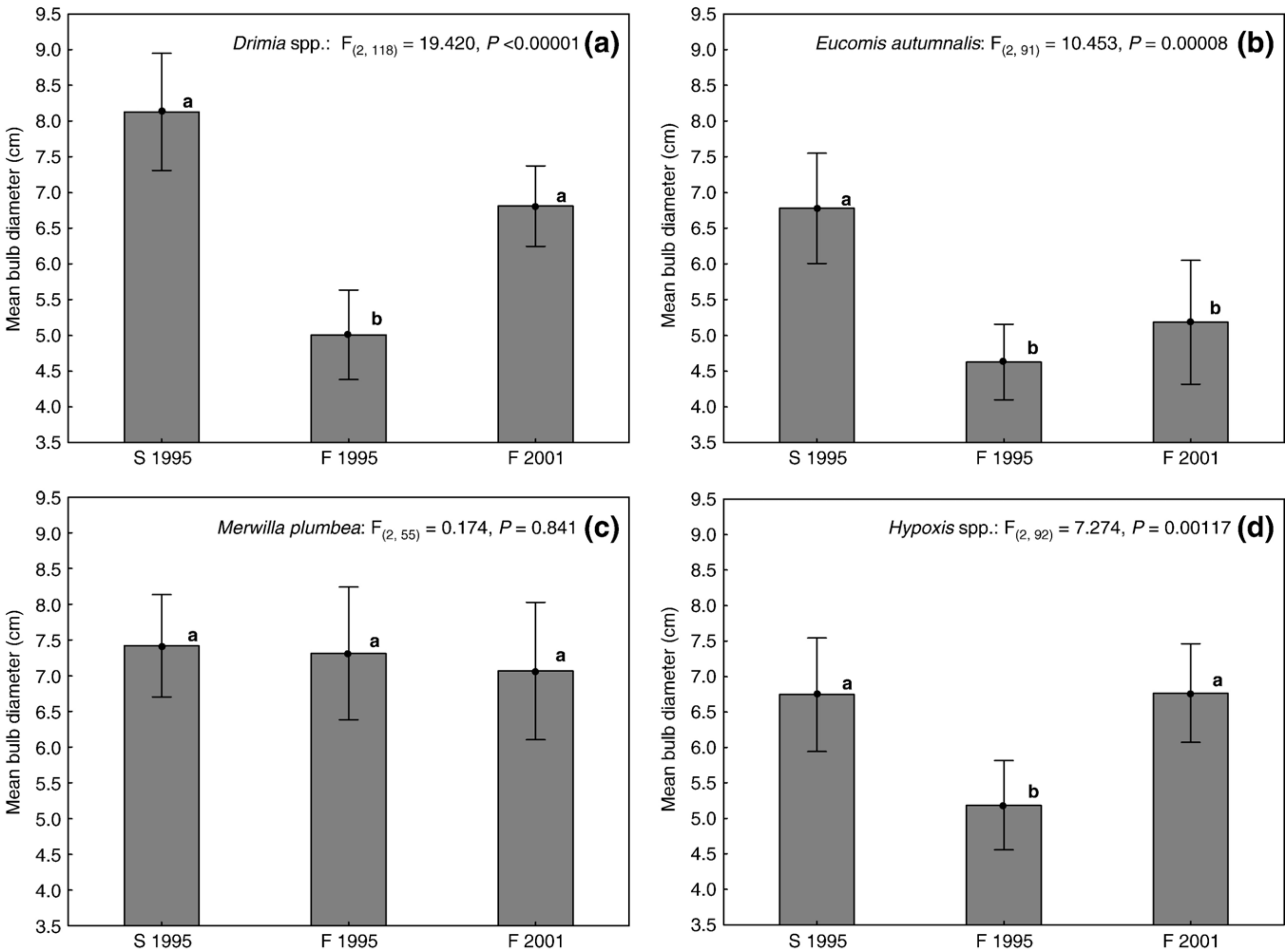


Fig. 4. Mean (±95% confidence interval) bulb diameters for species sold in the Witwatersrand traditional medicine shops in 1995 (S 1995) and the Faraday market in 1995 and 2001 (F 1995 and F 2001 respectively). Results of one-way ANOVAs are also included. Means with the same letters are not significantly different (Tukey HSD, $P<0.05$).

(S 1995) ($P=0.0004$ and 0.0001 respectively) (Fig. 4). However, *Drimia* bulbs sold in the shops in 1995 were not significantly bigger than those recorded in Faraday in 2001 were ($P=0.068$). The results for *Hypoxis* spp. were similar to *Drimia* spp., with bulbs sold in the shops and Faraday in 1995 and 2001 being significantly larger than bulbs bought in Faraday in 1995 ($P=0.020$ and 0.005 respectively). *E. autumnalis* bulbs bought from Faraday in 1995 and present in Faraday in 2001 were significantly smaller than the bulbs in the shops in 1995 ($P=0.0006$ and 0.0307 respectively) (Fig. 4). However, *E. autumnalis* bulbs sold in Faraday in 1995 were not significantly smaller than the bulb sizes present in Faraday in 2001 ($P=0.64$). While the mean bulb diameters of *M. plumbea* declined very slightly between 1995 and 2001, the differences in the means were not significant for any of the samples.

While there appeared to have been a decrease in the prevalence of larger bulbs (as indicated by the mean and modal diameters) between S 1995 and F 2001, these differences were only significant for *E. autumnalis*. Additionally, mean diameters for three of the four bulb species showed that bulbs bought from Faraday in 1995 were smaller than bulbs sold in the shops in 1995 and even in Faraday in 2001 (Fig. 4). One explanation for

Table 2
Differences in the mean (±SD) mass of the individual bulbs/corms sold in the shops and Faraday in 1995

Species	Mean individual bulb mass ±SD (kg)		*t*-value	*df*	*P*
	Shops 1995	Faraday 1995			
Drimia spp.	0.335±0.170	0.092±0.157	6.22	74	<0.000001
Eucomis autumnalis	0.284±0.204	0.096±0.100	5.39	74	0.000001
Merwilla plumbea	0.490±0.316	0.394±0.247	0.99	36	0.330
Hypoxis spp.	0.254±0.204	0.148±0.160	2.26	59	0.028

Table 3
Mean (±SD) length, number of individual plants per bundle and mass per bundle of the woody rootstocks sold in the traditional medicine shops in 1995

Species	Mean root length (cm)	Mean no. plants/bundle	Mean mass/bundle (kg)
	±SD	±SD	±SD
Scabiosa columbaria	6.9±1.8	25.3±8.3	0.066±0.083
Dianthus mooiensis	7.6±1.9	25.1±10.1	0.065±0.028

No equivalent data were collected for plants sold in the Faraday market in 2001.

Table 4
Estimated quantities of bulbs purchased per annum by the Johannesburg traditional medicine shops in 1995 and the Faraday market traders in 2001

	Drimia spp.	*Eucomis autumnalis*	*Merwilla plumbea*	*Hypoxis* spp.
Muti shops 1995				
% traders sold species ($n=50$)	78	78	76	62
Est. no. bags purchased by 189 traders in 1995 (bags a^{-1})	1961	1695	1350	445
Modal diameters present (cm)	7	8	7	6
Est. no. of IE bulbs a^{-1}	386 513	233 910	266 085	125 268
Faraday 2001				
% traders sold species ($n=100$)	60	21	25	39
Est. no. bags purchased by 164 traders in 2001 (bags a^{-1})	443	121	135	422
Modal diameters present (cm)	6	4	6	5
Est. no. of IE bulbs a^{-1}	124 705	69 490	38 003	169 686

The number of individual equivalent (IE) bulbs was determined from the number of bulbs per bag for the modal diameters present in the markets.

this result concerns the time when the F 1995 survey was conducted, namely in the winter months between July and September. Traders usually can't purchase new stock during winter because of bulb dormancy and they sell plants harvested in the previous growing season. If larger bulbs are preferred by customers and sold first, then proportionally more small bulbs remain — and it was from this stock that bulbs were sampled.

The increased prevalence of smaller bulbs in Faraday during the winter of 1995 is supported by evidence of a decrease in the mean mass of the individual bulbs (Table 2). However, no equivalent data on bulb masses were collected for bulbs sold by the traders in Faraday in 2001. Similarly, no size data were recorded for the woody rootstocks of *S. columbaria* and *D. mooiensis* in 2001. In 1995, however, there were ≈ 25 individual plants per bundle, with each bundle weighing around 66 g (Table 3).

3.3. Estimated quantities purchased annually

The number of 50-kg bags of bulbs estimated to have been purchased between 189 shops in the Witwatersrand in 1995 was highest for *Drimia* spp. (1961 bags a^{-1}) and lowest for *Hypoxis* spp. (445 bags a^{-1}) (Table 4). *Hypoxis* spp. was also the least common of the four bulbs sold in the shops, with only 62% of the vendors selling the species. *Drimia* spp. was similarly estimated to be purchased in the largest quantities (compared to the other bulb species) between the 164 traders in Faraday in 2001 (443 bags a^{-1}), compared to only 121 bags a^{-1} for *E. autumnalis* (Table 4). *S. columbaria* and *D. mooiensis* were less prevalent than the bulb species, and were sold in smaller quantities in both the shops and Faraday (Table 5).

At face value, these results would *appear* to show there to have been a marked decrease in the quantities harvested annually and sold to the shops and Faraday traders between 1995 and 2001 (Table 4). However, the quantities are not practically comparable given contrasts in the type of trade conducted in the shops and Faraday, the clientele served, differences in the numbers of traders selling the species and, the temporal changes in species availability and demand. Furthermore, traders from shops had few storage constraints and a habit of stock-piling certain species, especially those that were scarce. Traders in Faraday, by contrast, were limited by capital and capacity to the quantity of plants they could buy and sell. While Faraday is the largest street market in the province, the traders there are not the only wholesalers of traditional medicine and they represent one component of the wholesale supply chain. More important to this study is the relative order of magnitude of the annual purchases when comparing species. Additionally, a focus of this paper was to describe a procedure for translating the *quantity* (i.e. bags a^{-1}) purchased, into the *number* of individuals harvested to identify the extent of resource depletion.

3.4. The number of Individual Equivalents

A relatively strong positive relationship existed between bulb diameter and the number of bulbs per 50-kg bag ($r^2=0.818$, $P=0.017$) (Fig. 5). This relationship was used to calculate the number of Individual Equivalent (IE) bulbs harvested annually from the number of 50-kg bags estimated to be purchased. The bulbs were equivalent in diameter to the individuals most prevalent in the markets in 1995 and 2001 (i.e. from the modal diameter).

Based on the modal diameters, estimates for the number of IE bulbs harvested and for sale in the Witwatersrand shops in 1995 ranged from 125 268 bulbs all ≈ 6 cm in diameter, to 368 513 bulbs that were ≈ 7 cm in diameter for *Hypoxis* spp. and *Drimia* spp. respectively (Table 4). By contrast, estimates for the number of bulbs sold to Faraday traders in 2001 ranged from 38 003 *M. plumbea* bulbs ≈ 6 cm in diameter, to 169 686 *Hypoxis* spp. bulbs ≈ 5 cm in diameter (Table 4).

The number of estimated IEs varied depending on the diameter class selected *and* the quantity traded. Fig. 6 presents additional scenarios for the number of bulbs bought by shops in 1995 and the Faraday traders in 2001. The calculations are for the same quantities (bags a^{-1}) listed in Table 4, but are adjusted depending on the diameter of the most prevalent size-classes.

Table 5
Estimated quantities of *Scabiosa columbaria* and *Dianthus mooiensis* purchased per annum by the Johannesburg traditional medicine shops in 1995 and the Faraday market traders in 2001

	Scabiosa columbaria	*Dianthus mooiensis*
Muti shops 1995		
% traders sold species ($n=50$)	58%	60%
Estimated no. bags* purchased by 189 traders in 1995 (bags a^{-1})	208	306
Est. no. of individual plants harvested	1 040 000	1 530 000
Faraday 2001		
% traders sold species ($n=100$)	6%	8%
Estimated no. bags* purchased by 164 traders in 1995 (bags a^{-1})	26	45
Est. no. of individual plants harvested	130 000	225 000

*Bag = volume equivalent to a 50-kg size bag.

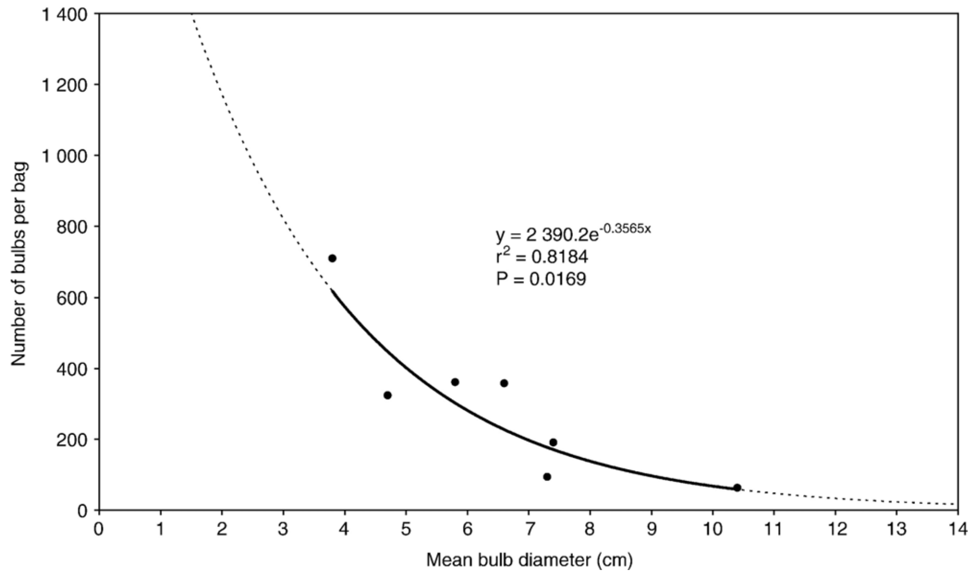
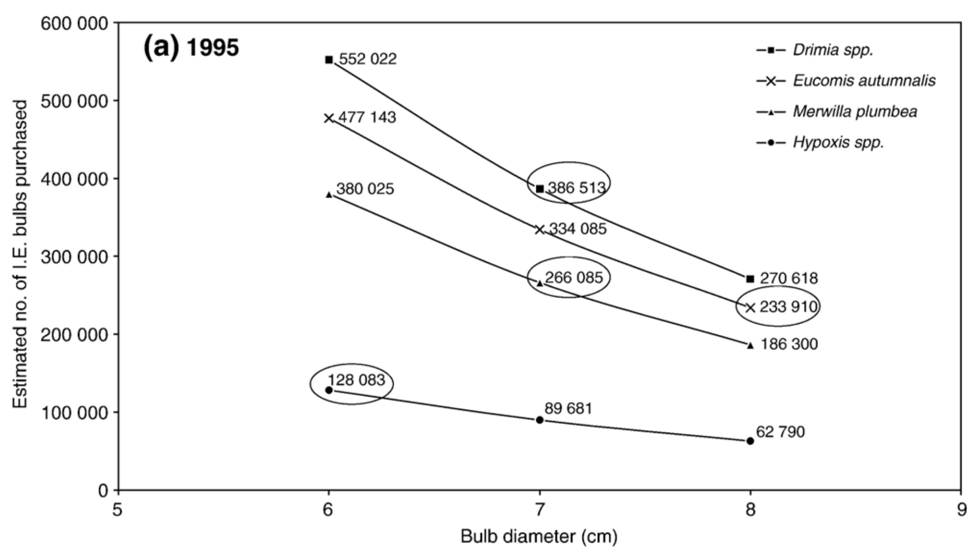


Fig. 5. The regression relationship for the number of bulbs contained in a 50-kg size bag depending on the bulb size [Graph derived from raw data in Cunningham (1988), Table 5, for seven species].



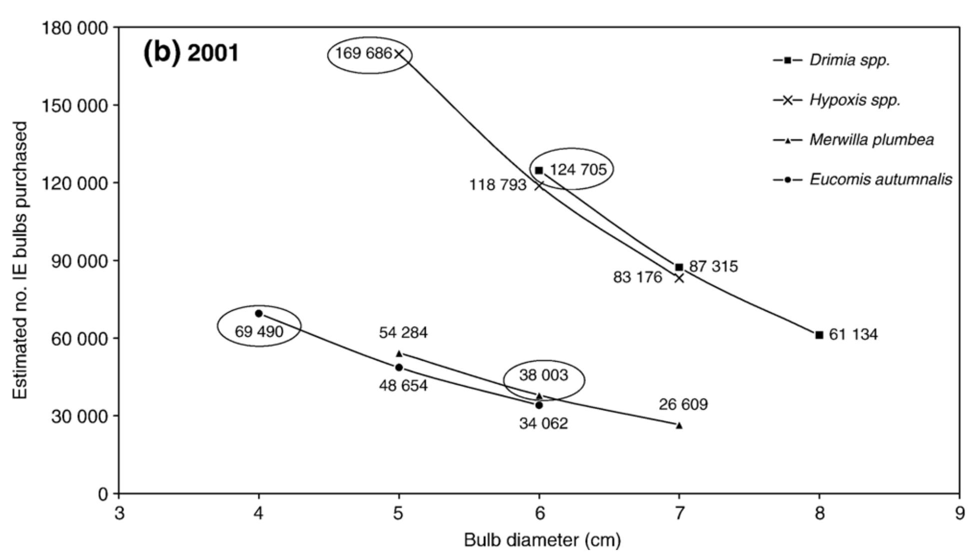


Fig. 6. Scenarios for the number of individual equivalents (IE) purchased by (a) the *muti* shops in 1995 and (b) the Faraday market in 2001, depending on the three most prevalent diameter classes. Encircled estimates represent the modal diameters recorded.

The estimates encircled in Fig. 6 are those listed in Table 4; however, the graphs illustrate how the order of magnitude of the number of individual bulbs harvested changes depending on the bulb diameter selected.

By selecting a particular bulb diameter on which to make the IE estimates, one is assuming (by this method) that *all* of the bulbs estimated to be harvested are this size. Hence, the smaller the bulb sizes selected, the more IE bulbs will be estimated from the quantity traded annually. However, bulbs are obviously not all from one diameter class and so the actual number of bulbs harvested annually will vary from the IE estimates depending on the preponderance and range of size-classes in the markets. Despite this caveat, the IE estimate provides a starting point for quantifying the annual extent of resource depletion.

The size of the whole plants of *S. columbaria* and *D. mooiensis* was not a critical factor in estimating the number of Individual Equivalents. The mean number of individual plants per bundle of these species was ≈ 25 and the number of bundles per 50-kg bag was 200 (Cunningham, 1988). Thus estimates for the number of individual plants sold to the shops in 1995 ranged from 1.04 to 1.53 million for *S. columbaria* and *D. mooiensis* respectively, and to traders in Faraday from 130 000 to 225 000 individuals (Table 5).

4. Discussion

Size-class distributions allow for the identification of poorly-represented life history stages (Hall and Bawa 1993). By recording and reconstructing information on species size-class selection from market surveys, an opportunity is presented to assess the impact of harvesting on plant populations (Cunningham, 2001). Assuming that bulb diameter is positively correlated with plant age and fitness, then life history stages that may be affected by harvesting may become apparent when reconstructing the frequency of bulb diameter distributions. Furthermore, the prevalence of certain size-classes may be representative of what is available in the wild or what is preferentially targeted by harvesters.

In South Africa, research has been conducted on germination rates and seedling establishment for some important bulb species (e.g. Kulkarni et al., 2005; Sparg et al., 2005). However, there are few studies that record assessments of harvesting impacts based on size-class selection *and* population age structures for medicinal plants [except, for example, some tree species (Botha et al., 2002, 2004), species used by communities in Lesotho (Letsela, 2004) and *M. plumbea* (Williams et al., 2006)]. This makes it difficult to construct models that predict the rate of population decline should deterministic factors that currently endanger plant populations persist. There is evidence that plant size is correlated with plant fitness, and an inordinately large proportion of the genes of a plant population may be descended from a very small number of individuals from a previous generation (Weiner and Solbrig, 1984). Thus, the removal of large, reproductive individuals from a population has a detrimental impact on the fitness of a plant population, especially since larger individuals tend to produce larger quantities of seed (Cunningham, 2001). To optimise harvesting efficiency and income, however, gatherers generally select plants from dense stands as well as the largest individuals from within the population (Cunningham, 2001). The size and proportion of the bulbs harvested therefore has important implications for plant recruitment and the perpetuation of species in a community.

Most of the bulbs sold by the traders were within the size ranges and limits recorded by other authors as typical for the species in the wild. *Drimia elata* bulbs typically range from 4 to 10 cm in the wild (Pooley, 1998), and 82% of the bulbs recorded in the markets were 4–10 cm (Fig. 3a). Only 5% of the measured *Drimia* bulbs were >10 cm. The mean diameter of *Drimia* spp. decreased between 1995 and 2001 (8.1 ± 1.6 cm to 6.8 ± 2.4 cm respectively) (mean ± SD), but the differences were not significant (Fig. 4a).

E. autumnalis are reported to grow to 10 cm in diameter (Pooley, 1998; Crouch et al., 2005), but are often 5–10 cm (Mander et al., 1995). No *E. autumnalis* bulbs >10 cm were measured in the markets (Fig. 3b), but overall only 51% were 5–10 cm. There was a significant decrease in the mean diameter of the bulbs present in the shops in 1995 compared to Faraday in 2001 (6.8 ± 2.2 cm and 5.2 ± 2.2 cm respectively) (Fig. 4b), thus indicating that harvesting for the trade has probably had a significant negative impact on the resource base. In Mpumalanga in 1997, Botha et al. (2001) recorded *E. autumnalis* bulbs to be 7.5 ± 0.5 cm (mean ± SE) in diameter. However, no bulbs <7 cm were recorded during her survey — possibly indicating that larger bulbs were still quite accessible to harvesters at the time.

Another noteworthy result from the 1997 Mpumalanga study (Botha et al., 2001) was that the diameter range of *Hypoxis* spp. was 9–12 cm (mean ± SE = 10.6 ± 0.6 cm), which is higher than the average diameter range recorded for the genus in the Witwatersrand (Figs. 3d and 4d). Crouch et al. (2005) reported *H. hemerocallidea* corms growing to diameters of 2.5–7 cm, but they can also get as big as 10 cm (Hawker et al., 1999). Only 1% of the *Hypoxis* spp. corms recorded in the Witwatersrand markets were >10 cm diameter and 77% were 2–7 cm (Fig. 3d). The ANOVA indicated no significant change in the mean corm diameters between 1995 and 2001 (6.7 ± 1.5 cm and 6.8 ± 2.0 cm respectively). These results, and those from the Mpumalanga study, therefore seem to indicate that large corms at the high end of the size-class range were still prevalent in the markets up to 2001.

M. plumbea is usually the largest of the bulb species in the markets. The mean mass of individuals in the shops in 1995 was 0.49 ± 0.32 kg (Table 2). The bulbs are generally known to grow to 10–20 cm in diameter, and even up to 30 cm (Mander et al., 1995; Pooley, 1998; Douwes et al., 2001; Crouch et al., 2005), however no individual bulbs >13 cm were recorded in the Witwatersrand markets (Fig. 3c). It is possible, however, that records of *M. plumbea* bulbs being >15 cm are for bulb clusters rather than individuals. The mean diameter of the bulbs sold between 1995 and 2001 did not change significantly (7.4 ± 1.5 cm and 7.1 ± 2.7 cm respectively) (Fig. 4c), and the sizes are similar to those recorded in Mpumalanga in 1997 (Botha et al., 2001), namely 7.6 ± 0.6 cm (mean ± SE). Like *Hypoxis* spp., there were no obvious changes in the availability and prevalence of larger bulbs in the Witwatersrand markets up to 2001.

Over time, there is often a progressive decline in the bulb diameters of heavily exploited species (Cunningham, 2001), which can be mirrored in bulb diameter frequency distributions recorded in medicinal markets. Our results served to confirm: 1) that harvesters extracted bulbs from the known range of size-classes typical for the species; 2) that large bulbs at the upper end of the size-class range are known to have been present in the markets during surveys conducted between 1995 and 2001; and 3) that the absence and/or decline of large bulbs recorded in future surveys would indicate erosion of the resource base. There are no data to gauge the extent of this decline in the Witwatersrand markets prior to 1995, except for anecdotal evidence from the traders. However, there was a significant decrease in the mean size of *E. autumnalis* bulbs between 1995 and 2001 ($P = 0.031$). *Drimia* spp., while exhibiting no significant difference in mean diameter, also appeared to be declining in size ($P = 0.068$) (Fig. 4). Given the popularity of bulb species and the volumes reportedly harvested in KwaZulu-Natal, Mpumalanga and the Witwatersrand (Mander, 1998; Botha et al., 2001; Williams, 2003), a more significant negative shift in the prevalence of larger bulbs would be expected if markets were to be re-surveyed in future. An implication of the decline in availability of larger bulbs is that greater quantities of smaller bulbs have to be harvested to be equivalent to the volume usually sold. With the demand for bulbs not likely to decline in the near future, the pressure on existing plant populations and their fitness is significant.

Insight into market practises when resource becomes limited was gained from comparing the mean bulb diameters sold by traders in the shops and Faraday in 1995. The shop and Faraday surveys were conducted from April to October and July to September 1995 respectively. Bulb stocks in the markets are depleted during winter because of bulb dormancy and consequent reduced harvesting activities. Fresh bulbs typically start arriving from September. There appears to a tendency for the larger bulbs to be sold first, as evidenced from the significant differences in the mean bulb diameters measured for *Drimia* spp., *E. autumnalis* and *Hypoxis* spp. in the shops and Faraday (Fig. 4). Smaller bulbs were more prevalent in Faraday because the larger individuals had been sold earlier on. And, while the sizes of the *individual* bulbs sold at Faraday were smaller, the actual mass of a sale of a quantity of bulbs was significantly greater — especially for *E. autumnalis* and *Hypoxis* spp. (Williams, n.d.). Traders therefore compensate for the lack of bigger bulbs by selling more smaller ones that equate to approximately the same volume per sale to a customer.

The regression analyses between bulb diameter and mass generally show a strong positive relationship (Fig. 2), especially for species like *Drimia* spp. that tend to remain fleshy and do not have papery, flaky outer bulb scales like *E. autumnalis* and *M. plumbea* do. As bulbs age, the number of leaf scales increases and the bulbs increase in diameter and mass. For species where the most peripheral bulb scales become dry and flaky, there is greater variability in bulb mass with increased diameter.

Precise measures of the quantities sold are not possible but recognition of the order of magnitude is necessary if resource management alternatives are to be seen in perspective (Cunningham, 1988). Results indicated that *Drimia* spp. is the most heavily traded bulb on the Witwatersrand (Table 4). In 1995, *E. autumnalis* was also purchased in large quantities, but the magnitude of purchases (bags a^{-1}) relative to other species had dropped by 2001, possibly because of declining availability due to dwindling wild stocks. The market share of *Hypoxis* spp. appeared to have increased — perhaps because of the publicity it received after a series of media releases in 1997 that proclaimed its healing properties (Drewes and Horn, 1999). In 1995, some shop traders considered *Hypoxis* a "useless line" and bought less than 1 bag a^{-1} to meet demands. A result of the publicity was the proliferation of "*illicit phytomedicines of questionable quality*" that depended on wild harvesting to supply the market (Hawker et al., 1999), hence increasing its market profile and the quantities harvested.

The large differences in the quantities estimated to be purchased by traders in 1995 and 2001 does not imply that the amount harvested and the demand had dropped (Table 4). However, the intra-species quantity differences put species management into perspective and inform the relative urgency of conservation measures. The shops and Faraday represent different sectors of the market chain, hence the annual throughput will differ in each sector. Furthermore, traders in Faraday are not the only wholesale suppliers of medicinal plants in the region. In 1995, Faraday probably supplied 31% of the stock to shops (Williams et al., 2000). In 2006, one shop trader estimated that <40% of the bulbs he bought were from Faraday (C. Dorasamy, pers. comm.), the remainder being purchased from harvesters that went directly to the shop. A speculative question worth considering, is whether the annual volumes sold through Faraday account for ≤40% of the Witwatersrand trade?

The response of plants to exploitation and the implications of declining productivity under high frequency or intensity of exploitation are critical to policy development for particular species (Cunningham, 1988). To be able to estimate the number of individuals harvested annually is therefore an invaluable tool for resource managers. Conservation efforts could subsequently be directed at high priority species where many individuals are damaged or removed by gatherers of medicinal plants. Ideally, knowledge of how many plants are harvested annually would be used in conjunction with demographic data for the species so that the impact of harvesting can be more thoroughly assessed.

Mander (1998) estimated that 73.2 tonnes and 95.5 tonnes of *E. autumnalis* and *M. plumbea* respectively were traded per year in the Durban medicinal plant trade, equating to approximately 428 000 and 432 000 equivalent bulbs used per year respectively. Comparable figures for equivalently smaller bulbs (≈ 6 cm) were estimated for both these species in the Witwatersrand shops in 1995 (Fig. 6a). It was also estimated that shops in 1995 bought ≈ 1961 bags of *Drimia* spp. Assuming that all the individual bulbs were equivalent in size to the modal diameter of 7 cm, then the number of Individual Equivalent bulbs estimated to be bought in 1995 was 386 513 (Table 4, Fig. 6a). The scenarios for the number of Individual Equivalent bulbs in 2001 bought by traders in Faraday are less (Fig. 6b), but Faraday represents one sector of the medicinal plant trade in the region. And, as the prevalence of larger bulbs declines in the markets, so the number of smaller bulbs harvested increases and the scenarios for the number of bulbs traded annually changes (Fig. 6).

In conclusion, the intention was to demonstrate how bulb size records collected during market surveys can be used to assess the extent of resource exploitation and the condition of the resource in the wild. The approach presented moves away from discussing harvesting impacts in terms of the mass sold, and uses instead the prevalence of bulb diameter size-classes as a surrogate for estimating what size of bulbs might be present in wild populations and the number that are potentially removed by harvesters. The magnitude of the trade and the number of plants harvested subsequently informs species specific conservation action that needs to be taken. From the results, it was evident that the size of *E. autumnalis* bulbs in the markets decreased significantly between 1995 and 2001, that *Drimia* spp. is the species most in demand in the region and, that the number of individual bulbs harvested annually is very high. These species warrant practical conservation action to mitigate the effects of further unsustainable exploitation for both the Witwatersrand markets and the rest of the country.

Acknowledgements

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