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Uncovering the cycad taxa (*Encephalartos* species) traded for traditional medicine in Johannesburg and Durban, South Africa

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Abstract

The bark and stems of *Encephalartos* species are used for traditional medicine across South Africa, and some species are traded in traditional medicine markets. The absence of characteristic plant parts such as leaves and cones in the chopped up market material presents a major challenge to the identification of the species traded. In this study, South Africa's two largest traditional medicine markets, Faraday in Johannesburg and Warwick in Durban, were surveyed to ascertain the source areas and species of *Encephalartos* in trade. Samples of stem fragments were purchased from vendors, identified to probable species and their stem diameter size class distributions determined using a specially designed size class chart. Species identification was undertaken by comparing trader citations of harvesting areas with the distributions of *Encephalartos* species in the province of KwaZulu-Natal (since all the specimens originated from KZN). The species most commonly recorded in the markets were identified as *Encephalartos natalensis*, *E. villosus* and *E. ghellinckii*; small quantities of what are likely to be *E. ferox* and *E. senticosus* were also observed. Following this study, the total number of South Africa's 37 *Encephalartos* species recorded as being used for traditional medicine is 25. Stem diameter size class distributions showed that most stem fragments came from sub-adult and adult cycads. Large arborescent species appear to be harvested by removing bark strips from adult individuals, while smaller arborescent and subterranean species are harvested by removing the entire plant. Regression relationships between stem tissue type and stem diameter for *E. natalensis* and *E. ghellinckii* indicate a strong, positive linear relationship of leaf base length and pith radius with stem diameter. Overall, this is the first known study that attempts to identify the cycad species traded in South African traditional medicine markets in conjunction with the size classes of the specimens in trade.

Keywords: Cycad; *Encephalartos*; Harvesting; Identification; Species-distribution group; Stem diameter size class; Traditional medicine trade

1. Introduction

Cycads are slow-growing, long-lived, perennial, dioecious plants that occur in most of the world's tropical and subtropical zones (Osborne, 1995; Golding and Hurter, 2001). The genus *Encephalartos* (Zamiaceae) comprises 66 species and is endemic to Africa (Donaldson, 2003; IUCN, 2011). The majority of species occur in southern Africa, and South Africa is a regional centre of diversity with 37 species (Donaldson, 2008). Within South Africa, the genus is distributed in a band along the coast from the Eastern Cape to KwaZulu-Natal and then north-eastwards into the Mpumalanga and Limpopo provinces (Donaldson, 2008). All species of *Encephalartos* are listed in CITES Appendix I, and 78% of the South African species are classified as threatened, which includes 12 Critically Endangered (CR), four Endangered (EN), and 10 Vulnerable (VU) species (Raimondo et al., 2009). All four cycads listed as Extinct in the Wild (EW) are *Encephalartos* species, three of which are endemic to South Africa (*Encephalartos brevifoliolatus*, *Encephalartos nubimontanus*, and *Encephalartos woodii*), and the fourth to Swaziland (*Encephalartos relictus*) (Raimondo et al., 2009).

Since their discovery in the 18th and 19th centuries, cycads have attracted considerable botanical and horticultural interest

Abbreviations: SCD, Stem diameter size class distribution; SDG, Species distribution group; SDr, Stem diameter; TM, Traditional medicine.

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worldwide and, as a result, many plants have been wild collected for private collections and botanical gardens (Pearson, 1907; Giddy, 1974; Osborne, 1995; Donaldson, 2003). The IUCN Red List of Threatened Species lists the global assessments of 305 cycad species (from families Cycadaceae, Stangeriaceae and Zamiaceae); of which population trends for 261 species are known (IUCN, 2011). Of these 261 species, the populations of 79% are in decline and only 21% are stable (IUCN, 2011). In South Africa, the illegal acquisition of wild cycads by unscrupulous collectors is the primary cause of the drastic decline in numerous species, and this issue has been of growing concern for several decades (Donaldson and Bösenberg, 1999; Golding and Hurter, 2001; Donaldson, 2008). Various conservation measures including restrictive legislation and monitoring programmes have been implemented to protect wild cycads in South Africa (Osborne, 1990; Giddy, 1995; Donaldson and Bösenberg, 1999), yet most of these have proven unsuccessful. Consequently, wild populations of numerous South African *Encephalartos* species have been decimated, especially those that were naturally rare at the time of their discovery (Donaldson, 2003). Threats to cycad populations in South Africa have increased substantially over the 20th century (Donaldson and Bösenberg, 1999), and continued to escalate, thereby jeopardising the existence of cycads in the wild (J.S Donaldson, pers. comm.). In 2006, for example, illegal collection resulted in the local extinction of the *Encephalartos laevifolius* (CR) population at Mariepskop, Mpumalanga, while >100 cycads were stolen from the sole population of *Encephalartos dyerianus* (CR) in 2008 (Donaldson, 2008). In recent years, many other South African *Encephalartos* species have also suffered severe population reductions, and the situation – now termed the 'cycad extinction crisis' – has reached a state where urgent action is required (M. Pfab, South African National Biodiversity Institute (SANBI) Scientific Authority, pers. comm., 2011).

While the removal of wild cycads by collectors is primarily responsible for their decline (Donaldson and Bösenberg, 1999; Golding and Hurter, 2001; Donaldson, 2008), the traditional medicine (TM) trade also negatively impacts wild populations (Donaldson, 2003, 2008; Cousins et al., 2011). In South Africa, *Encephalartos* species and *Stangeria eriopus* are harvested and traded for TM (Osborne et al., 1994; Donaldson, 2003) and in some cases over-harvesting has resulted in the extirpation of entire subpopulations (e.g. the type locality of *Encephalartos natalensis*) (J.S. Donaldson, pers. comm.). Collectively known as '*isiGqiki-somkovu*' in Zulu, *Encephalartos* species are currently sold in South African TM markets in the form of 'bark' strips and stem sections. In the literature, the term 'bark harvesting' generally refers to the practise of removing the outermost part of cycad stems (typically ca. 15 cm^2 sections) (e.g. Donaldson, 2008) (Fig. 1). In this context, therefore, 'bark' refers to the leaf bases attached to variable amounts of cortex tissue (called 'bark strips' in this paper). In recent years, increased harvesting of *Encephalartos* for TM has been noted at several localities across South Africa (Donaldson, 2003), and current trends show that whole *Encephalartos* stem sections are harvested in addition to bark strips (Cousins et al., 2011). Harvesting of *Encephalartos* for TM does not appear to be species-specific (Donaldson, 2003)

Fig. 1. Evidence of extensive bark harvesting for traditional medicine at a population of *Encephalartos natalensis* in KwaZulu-Natal. Photograph courtesy of Brent Coverdale.

and, prior to this study, 23 of South Africa's 37 *Encephalartos* species had either been observed in the wild with harvesting scars, had been observed in TM markets or had been recorded as being used for TM (Table 1). Since the genus is a major priority for conservation, an account of the species most affected by harvesting for TM would be valuable for the management of wild populations.

The primary aim of this study was to determine the species of *Encephalartos* traded at the two largest TM markets in South Africa. Most other ethnobotanical studies, e.g. Cunningham (1993), Mander (1998) and Williams et al. (2001) have listed all cycads traded for TM other than *S. eriopus*, as "*Encephalartos* spp.". A few exceptions where tentative identifications have been made include *E. natalensis* (Cunningham, 1988; Crouch et al., 2003; Ndawonde et al., 2007), *Encephalartos ghellinckii* (Crouch et al., 2003) and *Encephalartos villosus* (Ndawonde et al., 2007). Determining the actual species traded presents a major challenge to ethnobotanical studies on *Encephalartos* given the absence in the markets of characteristic plant parts typically used to identify cycads, such as leaves and cones. Furthermore, DNA barcoding techniques have not yet been developed to a stage where they can be reliably used for cycad identification (Donaldson, 2008). In addition to identifying the *Encephalartos* taxa traded, further objectives of this study included determining the size class distributions of the species

Table 1
South African *Encephalartos* species cited in previous studies as being used for traditional medicine or observed with harvesting-related stem damage in the wild. (LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered, EW = Extinct in the Wild).

Species	IUCN Red List status 2009 [a]	Province	Reference [b]
E. altensteinii	VU A2acd; C1	Eastern Cape; KwaZulu-Natal	1
E. caffer	NT A2	Eastern Cape; KwaZulu-Natal	2
E. cupidus	CR A2acd; B1ab(ii,iv,v)+2ab(ii,iv,v)	Mpumalanga	3
E. dolomiticus	CR C1	Mpumalanga	4
E. eugene-maraisii	EN C1	Limpopo	1
E. friderici-guilielmi	VU C1	Eastern Cape	5
E. ghellinckii	VU C1	KwaZulu-Natal	3; 6
E. heenanii	CR B2ab(ii,iv,v)	Mpumalanga	7
E. horridus	EN A2cd	Eastern Cape	2
E. hirsutus	CR A4acd; B2ab(iii,iv,v); C1	Limpopo	4
E. humilis	VU A2acd; C1	Mpumalanga	3
E. laevifolius	CR A2acde	Limpopo; Mpumalanga	3; 7
E. latifrons	CR A2ad; B2ab(ii,iii,v); C1+2a(i)	Eastern Cape	1
E. lebomboensis	EN A2acd; B1ab(ii,iii,iv,v)+2ab(ii,iii,iv,v)	KwaZulu-Natal	3;7; 8
E. lehmannii	NT B1,ab(v)	Eastern Cape	2;9
E. longifolius	NT B1ab(v); C1	Eastern Cape	2
E. natalensis	NT A2ad	KwaZulu-Natal	6;7;8
E. ngoyanus	VU A4acd; C1	KwaZulu-Natal	7
E. nubimontanus [c]	EW	Limpopo	10
E. paucidentatus	VU A2acd	Mpumalanga	7
E. transvenosus	LC	Limpopo	11
E. villosus	LC	KwaZulu-Natal; Eastern Cape	7;8
E. woodii [d]	EW	KwaZulu-Natal	3

[a] Raimondo et al. (2009).
[b] 1 = Donaldson (2003); 2 = Kemp (1985); 3 = Crouch et al. (2003); 4 = de Kock (2003); 5 = Donaldson and Bösenberg (1999); 6 = von Ahlefeldt et al. (2003); 7 = Arnold et al. (2002); 8 = Hutchings (1996); 9 = Tait (2010); 10 = Coetzer (2005); 11 = Ravele and Makhado (2009).
[c] Extinct in the wild due to cycad collecting within the last decade.
[d] Extinct in the wild since 1916.

in trade, as well as investigating the allometric relationships between stem tissue types and stem diameter as an aid to species identification and the size and stage classes harvested.

2. Methods

2.1. Study sites and market surveys

Surveys were conducted at two TM markets, namely the Faraday Street Market in Johannesburg, Gauteng Province and the Warwick Market in Durban, KwaZulu-Natal (KZN). Warwick is South Africa's largest TM market with between 400 and 500 traders (Mander, 1998). Faraday is the second largest TM market and is the wholesale and retail centre for trade in TM in Gauteng (Williams, 2003; Williams et al., 2007a,b). Pre-survey market familiarity visits were carried out at both markets to meet the traders, obtain permission to conduct formal interviews, become acquainted with the structure of the markets, and to decide on a suitable sampling strategy. At Warwick, the chairlady of the market identified all the traders selling *Encephalartos* and obtained their consent for the interviews. A questionnaire was designed by adapting the questionnaires from Mander et al. (2007) and Williams et al. (2007c) and included questions about harvesting areas and vernacular names of different types of cycads in an attempt to distinguish between species.

Due to the relative paucity of *Encephalartos* in the markets, all traders who sold *Encephalartos* were interviewed at both markets. The survey of Warwick was conducted on two consecutive week days in June 2009 using the questionnaire and with the assistance of a translator. Faraday was surveyed on weekdays twice monthly from April to July 2009. Many traders in Faraday were reluctant to volunteer information about the cycads, largely due to the illegal nature of the trade. Thus, a less formal approach was taken to collecting information from the traders at Faraday, which involved semi-structured interviews with consenting traders. At both markets, samples of *Encephalartos* stem pieces to the value of R10 (≈US$ 1.24 for April to July 2009) were purchased from each trader interviewed.

2.2. Anatomical measurements

R10 purchases of *Encephalartos* stem material from the markets typically comprised between one and six stem pieces. These pieces varied in size and composition from complete stem cross-sections containing all stem tissue types (leaf bases, cortex, vascular tissue and pith) to bark strips (i.e. leaf bases attached to a layer of cortex, and sometimes vascular tissue). The following measurements were taken for each specimen using digital Vernier callipers: radius or total length, and the length of each stem tissue type, which included leaf bases, cortex, vascular tissue and pith. The length of each tissue type was defined as a measurement of the subdivision of the stem radius occupied by the tissue (Cousins et al., 2011). These measurements were then used to explore the allometric relationships between the individual stem tissue lengths and stem diameter (SDr) using regression analyses. Only market samples that possessed all four stem tissue types were used for these analyses. The diameters of specimens that were incomplete cross sections were estimated using a specially designed SDr size class chart (see Fig. 4a in Cousins et al. (2011)). The chart consisted of five concentric circles corresponding with six SDr size classes. Stem fragments were placed onto the chart and the curvature of the outer leaf bases was visually matched with the corresponding circumference ring on the chart. In this way, an estimate of SDr was made, and hence the appropriate size class selected (Cousins et al., 2011).

2.3. Identification of the species in trade

A unique challenge to identifying the chopped up *Encephalartos* species sold in the markets is the absence of characteristic plant parts such as leaves and cones and the similar stem morphologies among the species in the genus. Various approaches to identifying the market samples were explored, including consultations with local cycad experts, detailed examinations of the stem morphologies of South African *Encephalartos* species in the literature, and visits to living collections in national botanical gardens. In particular, market samples were taken to the Durban and Nelspruit Botanical Gardens and compared with the cycads in the living collections of South African *Encephalartos* species in an attempt to match them based on their external stem morphologies. However, no conclusive identifications could be made. Since all the stem fragments were allegedly harvested in KZN, the next step was to compare the harvesting localities cited by the traders with the known distributions of *Encephalartos* species in KZN.

Distribution and Extent of Occurrence (EOO) data for all 12 *Encephalartos* species occurring in KZN were obtained from SANBI. Each harvesting locality cited by a trader was located on a topographical map and compared with the *Encephalartos* distributions. An assumption was made that if a trader cited a location as a harvesting area for a particular sample, and a species of *Encephalartos* was known to occur nearby, then the sample could be identified with a certain level of confidence depending on which other cycad species were known to occur there as well. This method not only provided a means of short-listing and identifying the species likely to be sold in the markets, but also gave an indication of the areas and associated species that were most popular amongst harvesters. Since the knowledge and perceptions of herbalists and herb traders have been acquired over many years of harvesting and trading medicinal plants (Cunningham, 1993), the information they provide about harvesting areas can be a valuable and relatively reliable tool for identifying species in trade.

Six species-distribution groups (SDGs) were delineated based on the trade records and species distributions (Fig. 2). Each SDG contained between one and three species that were likely to be harvested due to their intermediate or widespread distributions (Table 2), accessibility, or high local abundance. Some SDGs included multiple species due to overlaps in species' ranges. Three groups (groups 2, 3 and 4; Fig. 2) contained additional candidate species that were unlikely to be harvested; these species either had extremely restricted distributions (e.g. *Encephalartos cerinus*; Table 2), or came from a nearby neighbouring country (e.g. *Encephalartos manikensis* from Mozambique). Samples purchased from the markets were allocated to one or more SDGs depending on the harvesting areas cited by the traders. The samples within the groups were compared with one another using stem morphological characteristics to distinguish between species. These stem characters included the size, shape and colour of the leaf bases, the presence of 'wool' between the leaf bases, the colour of the stem tissues such as the pith, and the presence of burn marks on the external parts of the stem (indicating a cycad from a particular habitat type, e.g. a grassland species such as *E. ghellinckii*). All samples were photographed, and representative specimens of each of the five *Encephalartos* species that were identified were prepared as voucher specimens and lodged in the C.E. Moss Herbarium at the University of the Witwatersrand, Johannesburg (J).

3. Results

3.1. Harvesting areas and species traded

Traders cited a wide range of harvesting areas, all within KZN and many cited multiple areas since they purchased stock from gatherers who collected plants in various regions within KZN. Ninety-six percent of traders at Warwick provided the names of harvesting areas compared to only 40% at Faraday. Furthermore, 54% of the Faraday traders who knew the origin of their *Encephalartos* stock said they obtained it from Durban, which implied that it had come from the Warwick market. Consequently, relatively few samples from Faraday could be identified with a high degree of certainty. At Warwick, Ndwedwe (within group 2; Fig. 2) was the most frequently cited harvesting area (82% of traders), and *E. natalensis* and *E. villosus* occur there. Other commonly cited areas included Umhlabuyalingana (group 4; Fig. 2) (18%) where *Encephalartos ferox* occurs; Umkomaas (group 3) (18%) where *E. natalensis*, *E. villosus* and *E. ghellinckii* occur and Nongoma (group 2) (14%), where *E. natalensis* and *E. villosus* occur.

At Faraday, *E. natalensis* appears to be the dominant species sold (78%), with smaller quantities of *E. ghellinckii* (11%) and *Encephalartos senticosus* (11%) also traded (Fig. 3). At an informal visit to the Faraday market after the surveys were completed, one trader was observed selling *Encephalartos ngoyanus* stem pieces. Since the source areas of 65% of the specimens from Faraday were unknown, these stem fragments were tentatively identified by comparing their morphological characteristics with those of the samples that had already been identified. Seventy-eight percent of these samples were subsequently identified as one of three possible species: *E. senticosus*, *E. natalensis* and *Encephalartos lebomboensis* (Groups 1, 2, 3 and 6 respectively; Fig. 2). Over half the samples from Warwick were identified as *E. villosus* (52%), but *E. natalensis* was also prevalent (28%). There were also small quantities of *E. ghellinckii* (10%) and what appeared to be *E. ferox* (10%). The overall results for the two

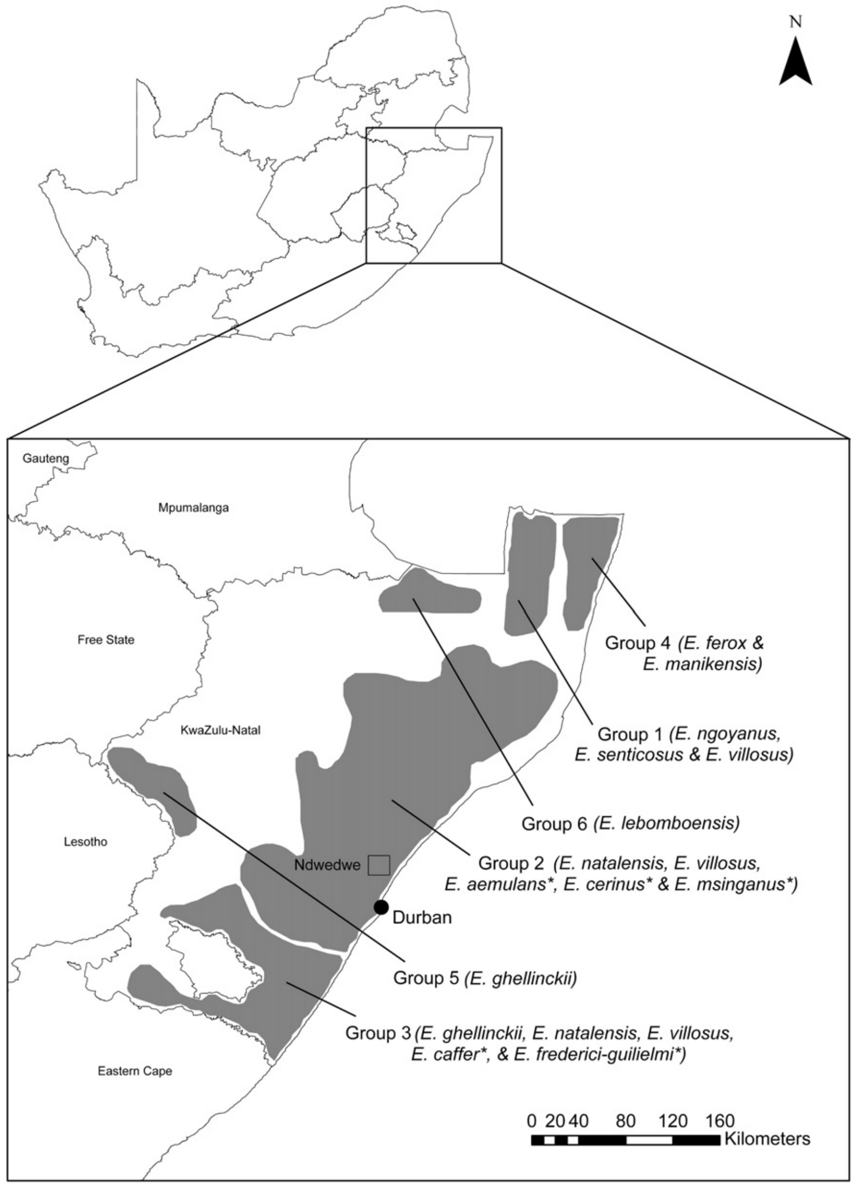

Fig. 2. The six species-distribution groups (SDGs) identified in KwaZulu-Natal. Species with asterisks have restricted distributions (unlikely to be traded) and species without asterisks have intermediate or widespread distributions (likely to be traded). Note: *Encephalartos manikensis* in Group 4 occurs in Mozambique and not in South Africa.

markets combined suggest that *E. natalensis* is the most common *Encephalartos* species in TM markets in South Africa.

3.2. Relationships between stem tissue length and stem diameter

The strongest regression relationships between SDr and tissue length were generally for pith and leaf base length (Fig. 4a,b). The relationship between leaf base length and SDr is of particular importance as it can be used as a predictor of approximate SDr size class (Cousins et al., 2011). Specimens that are incomplete stem cross-sections, such as bark strips and very irregularly-shaped stem fragments, are often difficult to allocate to size classes. For such samples, leaf base length can be used together with the regression relationship in Fig. 4b in Cousins et al. (2011) to predict SDr and hence the appropriate size class. Since almost all specimens have leaf bases, the size class of virtually any sample can be estimated using this method.

3.3. Stem diameter size class distributions

Stem diameter size class distributions (SCDs) were constructed for the three most prevalent species in the markets (*E. natalensis*, *E. villosus* and *E. ghellinckii*) (Fig. 5). The SCDs were then compared with the actual field-measured SDr ranges of adult plants of these species (Table 3). For all three species, the majority of specimens were assigned to intermediate size classes and only a few were from individuals with diameters <15 cm or >26 cm. For *E. ghellinckii* there were no specimens from plants with SDrs >30 cm (Fig. 5). These results suggest that most of the cycads harvested for TM are sub-adult or adult plants, although there appear to be few very large adults harvested.

Table 2
Distribution in KwaZulu-Natal (KZN), IUCN Red List status, Extent of Occurrence (EOO) in South Africa, and the number of quarter-degree squares (QDS) occupied in KZN by the twelve KZN *Encephalartos* species. (Note: the number of QDS occupied is in KZN only, and not the number occupied in the whole of South Africa).

Distribution in KZN (not South Africa)	*Encephalartos* species	SA IUCN Red List status 2009 [a]	Approximate number of QDS occupied in KZN [b]	EOO (km^2) in South Africa
Widespread (>10 QDS)	*E. ghellinckii*	VU C1	11	23,900
	E. natalensis	NT A2ad	14	47,700
Intermediate (3–10 QDS)	*E. ferox*	LC	7	43,000
	E. senticosus	VU A2acd	4	1,200
	E. ngoyanus	VU A4acd; C1	6	1,400
	E. villosus	LC	6	14,000
Restricted (1–2 QDS)	*E. aemulans*	CR B1ab(v)+2ab(v); C1	2	12
	E. caffer	NT A2	1	34,600
	E. cerinus	CR A2acd; B1ab(i,ii,iv,v)+2ab(i,ii,iv,v)	1	10
	E. msinganus	CR B1ab(iii,v)+2ab(iii,v); C1+2a(ii)	1	2
	E. friderici-guilielmi	VU C1	1	17,200
	E. lebomboensis	EN A2acd; B1ab(ii,iii,iv,v)+2ab(ii,iii,iv,v)	4	450

[a] Raimondo et al. (2009).
[b] Based on Scott Shaw (1999), Pooley (1994) and JD Bösenberg (ArcView polygons, pers. comm., 2009).

4. Discussion

4.1. Harvesting areas and species traded

Encephalartos species are sold in TM markets in the form of bark strips and stem fragments, usually without the plant parts that are commonly used to identify the species, namely leaves and cones (Cousins et al., 2011). The stems of subterranean and arborescent taxa can usually be distinguished due to differences in their morphologies, but differentiating the stems of species within these groups is difficult. The most accurate way to identify species in the markets would be to use DNA barcoding techniques. DNA barcodes can be used to uniquely identify an unknown specimen to species, particularly when diagnostic morphological features are absent (Sass et al., 2007). However, while pilot studies on the development of Amplified Fragment Length Polymorphism (AFLP) techniques for cycads have shown potential, the technology has not yet been developed to a stage where it can be implemented (Donaldson, 2008). A DNA barcoding initiative that aims to develop a molecular phylogeny for the genus *Encephalartos* is currently being undertaken, the results of which will be a major step forward in cycad identification if the study proves to be successful (Rousseau, 2010).

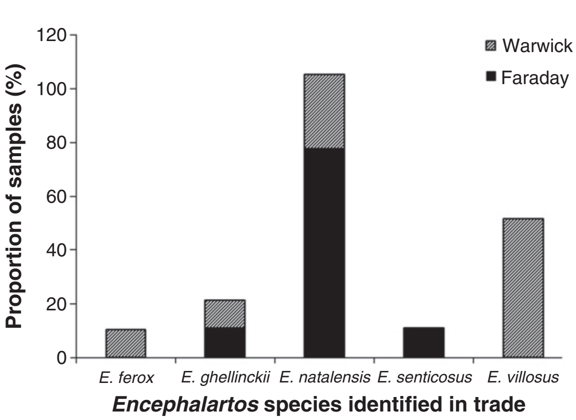

Fig. 3. The prevalence of the five *Encephalartos* species identified in trade at Faraday and Warwick.

In the absence of characteristic plant parts, the first step recommended for identifying species sold by vendors in TM markets is to compare trade records of harvesting localities with the known distributions of the species (Williams, 2005). Using this approach, samples of *Encephalartos* stems purchased in the markets were grouped together into six species-distribution

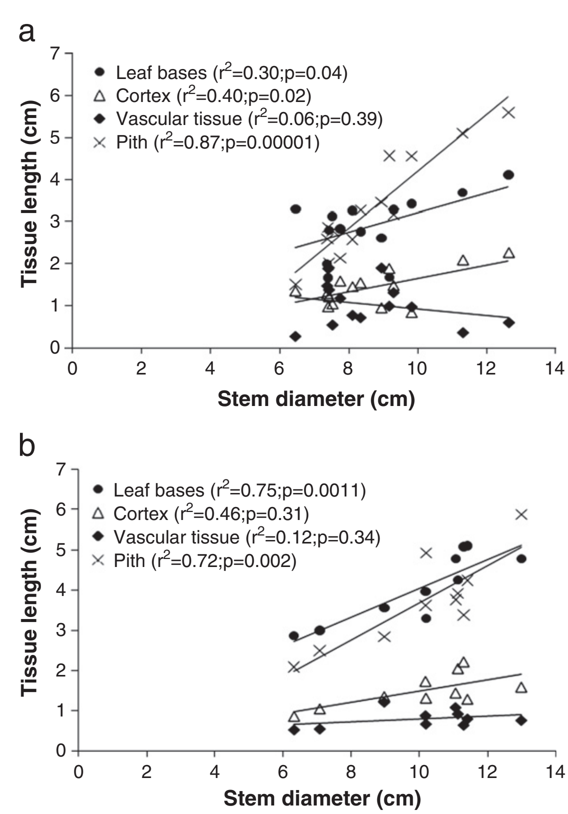

Fig. 4. Relationship between stem tissue length and stem diameter for market samples of (a) *Encephalartos natalensis* (n = 11) and (b) *E. ghellinckii* (n = 10). (L = Leaf bases, C = Cortex, V = Vascular tissue and P = Pith).

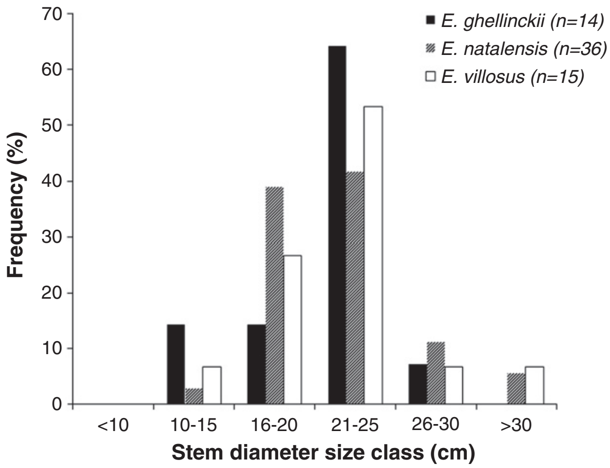

Fig. 5. Stem diameter size class distributions (SCD) estimated for the specimens of three identified *Encephalartos* species from Faraday and Warwick.

groups (SDGs) according to the harvesting localities cited by the traders. Thereafter, the stem morphologies of the samples within each SDG were compared to distinguish between the species occurring in those areas. This method was most effective for samples where traders could cite the specific area where the plants had originated, but less effective for samples where traders were unsure about the origin of the stock and cited multiple possible harvesting areas. While the SDG method provided a simple means of identifying market specimens, the results should be treated with caution since identification was not always conclusive. If comprehensive descriptions of leaf bases and internal *Encephalartos* stem anatomy had been available in the literature, it may have assisted with distinguishing between species and aided the identification of specimens from unknown harvesting localities.

The majority of medicinal plants supplied to the TM markets in KZN come from wild populations on communal lands where grassland and forest resources are easily accessible (Mander, 1998). However, popular species that are no longer available in communal areas are harvested on forestry estates, commercial farms and in protected areas (Mander, 1998). Relatively few cycad populations occur in formal conservation areas in KZN, and all Endangered (EN) and Critically Endangered (CR) cycad species in the province occur outside protected areas (Threatened Plant Conservation Unit, 2004). In this study, the most highly cited harvesting area for *Encephalartos* was the local municipality of Ndwedwe, where both *E. natalensis* (NT, Near Threatened) and *E. villosus* (LC, Least Concern) occur. A large proportion of traders (48%) at both markets also cited harvesting areas where *E. ghellinckii* (VU, Vulnerable) is known to occur. *Encephalartos ghellinckii* and *E. natalensis* both occur in >10 quarter-degree squares (QDS) in KZN and therefore have fairly widespread distributions compared to other KZN *Encephalartos* species. *Encephalartos villosus* has an intermediate distribution in KZN, occupying a minimum of 6 QDS in the province (Table 2). The relatively large distributions of these three species may account for their high prevalence in the markets, since the assumption is that the wider a species' distribution, the more likely it is to be accessible to harvesters.

Since *E. villosus* has subterranean stems, harvesting this species would likely involve digging up the entire plant. Although *E. villosus* exhibits relatively fast population growth, continuous and periodic harvesting of adults leads to a rapid decrease in population size (Raimondo and Donaldson, 2003). *E. natalensis* and *E. ghellinckii* are both arborescent species and may therefore be more popular amongst harvesters since less effort is required to harvest stem material from them. Cunningham (1988) noted that the cycads sold in the TM markets of KZN in the 1980s were most likely to be *E. natalensis*, and both *E. natalensis* and *E. ghellinckii* have subsequently been recorded in trade at Warwick (Crouch et al., 2003). Illegal bark harvesting was highlighted as a threat to *E. natalensis* in a management plan for cycads in KZN in 2004, and the type locality of this species has recently been extirpated due to bark harvesting (J.S. Donaldson, pers. comm.). Wild populations of *E. natalensis* should therefore be carefully monitored and conservation measures implemented to prevent local extinctions occurring throughout its range.

Specimens resembling *E. senticosus* (VU A2acd) and *E. ferox* (LC) (species not previously recorded as being used for TM) were recorded in the Faraday and Warwick markets respectively (Fig. 3). Hence, this study brings to 25 the total number of South African *Encephalartos* species used for TM. *Encephalartos friderici-guilielmi* (VU) did not appear to be sold, however, one trader cited the Kokstad district as a harvesting area, where the distribution of *E. friderici-guilielmi* is known to overlap with that of *E. ghellinckii*. Due to the marked similarity of the stems of these two species, there is a possibility that the samples identified as *E. ghellinckii* were actually *E. friderici-guilielmi*. However, besides the single citation of the Kokstad area, all other samples identified as *E. ghellinckii* came from areas where *E. friderici-guilielmi* does not occur; hence, it is unlikely that this species was encountered in the markets. *E. friderici-guilielmi* is possibly traded in the markets of the Eastern Cape, where most of its range occurs. Donaldson (2003) notes that the *E. friderici-guilielmi* population at Tsolo in the Eastern Cape has been severely affected by harvesting for TM, and harvesting of *E. friderici-guilielmi* also occurs in the Alfred Nzo region of the Eastern Cape (D.C. Ricketts, Senior Environmental Officer, pers. comm.). While there were no citations of harvesting localities for *E. lebomboensis* (Group 6, Fig. 2) in this study, Ferreira (2003) reported evidence of a serious degree of harvesting at the populations of the Mananga variant of this species. Monitoring of the populations at this site is therefore also recommended.

Table 3
Actual maximum field-measured stem diameter (SDr) ranges of the three *Encephalartos* species for which size class distributions (SCD) were constructed (derived from Goode (1989) and Grobbelaar (2004)).

Species		Stem diameter (cm)
E. ghellinckii	- High altitude form	30–40
	- Low altitude form	25–35
	- Transkei form	25–30
E. natalensis		30–40
E. villosus		20–30

4.2. Relationship between stem tissue length and stem diameter

Regression analyses show that for *E. ghellinckii* and *E. natalensis* there is generally a strong and significant relationship between SDr and pith radius as well as SDr and leaf base length (Fig. 3). These strong relationships are likely because the leaf bases and pith of a cycad stem constitute the greatest part of the SDr. There was generally a weak relationship between cortex and SDr, which was only significant in *E. natalensis* ($r^2=0.40$; $p=0.02$; Fig. 3a). There was no significant relationship between SDr and vascular tissue (Fig. 3a). Cortex and vascular tissues constitute only a small proportion of the stems of cycads, hence the weak relationship between their lengths and SDr. The relationship between leaf base length and SDr is of particular significance in terms of its practical application. The SDr size classes of some market samples such as bark strips and very irregularly-shaped specimens are difficult to determine accurately using the size class chart. For these samples, an initial size class can be selected using the chart, after which the generalised regression relationship in Fig. 4b in Cousins et al. (2011) can be used to re-evaluate the selection. The categories of leaf base length (bark thickness) and corresponding predicted stem diameter size class in Table 4 in Cousins et al. (2011) can also be used as a quick method to estimate the stem diameter of an *Encephalartos sp*. stem fragment.

4.3. Size classes of the species in trade

Obtaining information on the size of plants traded in TM markets provides valuable insight on the species-specific impacts of harvesting on plant populations (Williams et al., 2007a). A preponderance of certain size classes may reflect what is available in the wild or what is preferentially targeted by harvesters (Williams et al., 2007a). A high prevalence of individuals in smaller size classes may, for example, indicate that larger plants are no longer available, and that gatherers have resorted to harvesting smaller plants. Hence, the life history stages that are affected by harvesting may become evident when examining SCDs (Williams et al., 2007a). Measurements of SDr or stem height are often made on the basic assumption that SDr or stem height is positively correlated with plant age (Cunningham, 2001). Cycads, palms and tree ferns generally have apical meristems on unbranched stems that grow upwards rather than increasing in diameter as they mature (Cunningham, 2001). Hence, stem length rather than SDr is a more accurate measure for assessing the population structure of these groups of plants (Cunningham, 2001). However, since the cycad stems that are sold for TM are sliced up and sold as stem pieces or bark strips, there is no way of determining the length of the stem they were originally harvested from. Hence, SDr was used in this study to elucidate the life history stages targeted by harvesters.

A universal size range cannot be used to infer the age/life history stage for all cycads (J.S. Donaldson, pers. comm.). Raimondo and Donaldson (2003) classified *Encephalartos cycadifolius* (a dwarf, multistemmed, semi-subterranean South African cycad) based on SDr as seedlings and juveniles (1–4 cm and 4–24 cm respectively), while sub-adult and adult plants (>24 cm) were classified according to the number of stems present. Since the majority of the market specimens appear to be from arborescent species, these age classes were adapted accordingly. However, *E. villosus* is the exception, as it has a subterranean stem, but its SDr range is comparable to that of arborescent species (Table 3) and was therefore grouped with these species. The age classes appropriate for arborescent cycads are: juveniles (<10 cm), sub-adults (10–20 cm) and adults (>20 cm) (Raimondo and Donaldson, 2003; J.S. Donaldson, pers. comm.). The size class distributions of *E. natalensis*, *E. villosus* and *E. ghellinckii* indicate that most of the samples from these species came from plants in intermediate size classes of SDrs between 16 and 25 cm. Relatively few specimens came from plants >26 cm in diameter (Fig. 5), and this suggests that for these, and probably most other cycads, stem material is harvested primarily from sub-adult and adult plants.

The high altitude form of *E. ghellinckii* reaches approximately 40 cm in diameter, while the low altitude and Transkei (Eastern Cape) forms are smaller, with SDrs reaching 35 and 30 cm respectively (Table 3). Populations of the high altitude form growing within the boundaries of the KZN Drakensberg National Parks are considered reasonably safe from harvesters and cycad collectors at present (Goode, 2001); however, populations of the more accessible lowland forms are at greater risk of over-harvesting and should be more closely monitored. The vulnerability of the lowland forms of *E. ghellinckii* appears to be corroborated by the preponderance of individuals of 21–25 cm SDr and the paucity of those >25 cm. The high prevalence of intermediate and smaller individuals of *E. ghellinckii* therefore suggests that the lowland form is being harvested more intensively than the less accessible high altitude form.

Stems of *E. natalensis* can attain diameters of up to 40 cm (Table 3), yet few specimens from large plants of this species (i.e. >26 cm) were encountered in the markets (Fig. 5). Nevertheless, the majority of *E. natalensis* samples (63%) were bark strips, which suggests that they came from larger plants (Cousins et al., 2011). The harvesting technique for *E. natalensis* appears to involve cutting and peeling off bark strips in such a way that variable quantities of vascular tissue are removed as well. Harvesting of stem material from large arborescent species such as *E. natalensis* is therefore likely to take the form of slicing sections of bark from the stems of mature plants and removing the entire stem in the case of suckers and/or juveniles, since it is easier to remove bark strips from large plants than to cut down the entire stem. During an interview at Warwick, one trader displayed a large (±1.5 × 0.5 m) bark strip from an *E. natalensis* plant from which smaller pieces were being cut to be sold (pers. obs.). The high prevalence of *E. natalensis* bark strips in the markets implies that relatively large individuals of this species are still available (Cousins et al., 2011).

Other *Encephalartos* species where the adults are smaller than those of *E. natalensis*, e.g. the lowland forms of *E. ghellinckii* as well as species with subterranean stems such as *E. caffer*, *E. ngoyanus* and *E. villosus*, are likely to be harvested by removing the entire plant regardless of its size class. This is certainly the case with *S. eriopus*, another subterranean-stemmed South African cycad, which is sold for TM in considerable quantities (Osborne et al., 1994; Crouch et al., 2000; Williams et al., 2007b). Cycad populations are especially sensitive to the loss of adult plants, since they are extremely slow-growing, and replacing adult individuals may take many decades (Raimondo and Donaldson, 2003; Octavio-Aguilar et al., 2008). Harvesting entire plants effectively removes those individuals from the population, whereas individuals from which only bark is harvested have a much greater probability of surviving (provided the bark removal is not too extensive). Harvesting of smaller species and those with subterranean stems is therefore likely to have a much more severe impact on their populations than larger arborescent species.

5. Conclusion

The Durban and Johannesburg traditional medicine markets appear to be supplied by *Encephalartos* species that are harvested primarily in the province of KwaZulu-Natal. The species with the most widespread distributions (*E. natalensis*, *E. villosus* and *E. ghellinckii*) are believed to be the most frequently traded. *E. ferox* and *E. senticosus*, two species not previously known to be used for TM, also appear to be traded. Most of the stem material sold in the markets was from plants in intermediate SDr size classes (16–25 cm), which suggests that mostly sub-adult and adult cycads are harvested. The majority of *E. ghellinckii* samples appear to be from the lowland forms of this species, which are more vulnerable to harvesting than the less accessible high altitude form. The shape and tissue constituents of market samples from smaller arborescent *Encephalartos* species (e.g. the lowland forms of *E. ghellinckii*) and subterranean species (e.g. *E. villosus*) imply that these cycads are harvested by removing the entire plant. Larger arborescent species (e.g. *E. natalensis*) appear to be harvested primarily by peeling bark strips off adult individuals.

Field studies to determine and monitor the level of impact that harvesting for TM is having on the populations of frequently traded *Encephalartos* species (*E. natalensis*, *E. villosus* and *E. ghellinckii*) would be valuable for informing conservation and management decisions. The municipality of Ndwedwe in KwaZulu-Natal is of particular concern, as it appears to be a harvesting hotspot for *E. natalensis* and *E. villosus*. Monitoring and effective management of the cycad populations in this region is therefore strongly recommended.

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