Fuelwood harvesting and selection in Valley Thicket, South Africa

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Abstract

The Thicket Biome is the second smallest biome in South Africa, and is renowned for its high biodiversity. Yet, less than 5% of the biome is in formal conservation areas. Much of the currently intact thicket outside protected areas is threatened by land transformation to commercial agriculture or heavy use by rural communities. There is limited understanding of the ecological structure and function of thicket communities and their response to these human pressures. This paper reports on a study to characterize the woody communities in Valley Thicket and Thornveld surrounding a rural village. We also examined the demand and selection for specific woody species. There was a marked selection for key species for different uses, including fuelwood, construction timber, and cultural stacks. There was also strong selection for specific size classes of stem, especially those between 16–45 cm circumference. The density, biomass and species richness of woody species was reduced close to the village, and increased with distance away from human settlement. A similar trend was found for the basal area of preferred species, but not for the basal area of all species. The strong selectivity for both species and size class means that the anthropogenic impacts are not uniform within the woody strata, leading to marked changes in community structure and floristics at a local scale.

1. Introduction

Wooded ecosystems provide a range of goods and services to humankind in general, and to local rural communities in particular. Biological products such as timber, mushrooms, fruits, fuelwood, honey and medicines are harvested for direct household consumption, as well as traded on local and regional markets (Koziell and Saunders, 2001; Kaimowitz, 2003). The extraction of these resources raises concerns in relation to the ecological impacts on biodiversity and ecosystem processes, commonly within the desertification and deforestation paradigms. This prompts the search for quantification of sustainable harvesting limits and the appropriate institutional arrangements under which sustainable harvesting can be implemented (Crook and Clapp, 1998; Shackleton, 2001a).

Much research on the anthropogenic impacts on wooded ecosystems comes from the tropical forests of Amazonia and south-east Asia, with some contribution from African moist forests (e.g. Huang et al., 2003). In comparison, dry forests and savannas of Africa have been relatively neglected in terms of understanding their structure and functioning, and hence the poor ability to predict possible impacts of changing, or extractive, land uses. Anthropogenic disturbance can influence or even regulate forest and woodland structure, floristics, regeneration and ecosystem pools and fluxes. At the more arid end of the spectrum, woody biomass is a key resource with respect to both ecosystem structure and functioning, as well as to rural communities, especially for fuelwood (Pandey, 2002; Shackleton et al., 2004). In terms of ecosystem value, woody species are keystone elements through the provision of fodder for wild and domestic animals, nesting sites and habitats for avifauna and reptiles, micro-habitats for germination of other species, sub-canopy environments crucial for other species, and nutrient rich pools within a harsh landscape (Belsky et al., 1989; Jeltsch et al., 1996). With respect to fuelwood extraction, the debates over the sustainability of fuelwood extraction and its impacts on woody community structure and functioning, which were generated in tropical forests and moist savannas (e.g. Leach and Mearns, 1996; Benjaminsen, 1997), have been less widely examined in the more arid savannas, with a few notable exceptions (e.g. Nagothu, 2001; Pandey, 2002). The expectation is that fuelwood shortages and crises would be more severe in arid areas by virtue of there being a markedly lower standing woody biomass. Yet, the landmark work of Reid and Ellis (1995) dispelled the fuelwood crisis myth for the Turkana region receiving less than 400 mm mean annual rainfall. Sullivan (1999) demonstrated that in arid areas of Namibia (95 mm p.a.) environmental variability had significantly greater influence on woody community structure than impacts of rural communities, and Nagothu (2001), using a simple supply and demand model for fuelwood in arid India, indicated that woody productivity was more than sufficient to meet current measured demand.

Whilst the importance of woody biomass in arid landscapes and to local rural households is noted, research has largely focussed on whether or not total supply meets current demand (e.g. Benjaminsen, 1997; Abbot and Homewood, 1999). Thus, most fuelwood models exploring the balance between supply and demand treat fuelwood as a uniform resource (e.g. Sankhayan and Hofstad, 2001). Whilst there are a number of studies indicating that rural harvesters select for different species and size classes (e.g. Liengme, 1983; Campbell and du Toit, 1988; Shackleton, 1993; Abbot and Homewood, 1999), this is rarely factored into fuelwood models, or into debates regarding the impacts on the woody community structure or functioning.

In South Africa, the second smallest biome (3.3% of the land area), the Thicket Biome, is a peculiar mix of four arid and semi-arid, succulent vegetation types, concentrated, but not restricted to, the Eastern Cape province. Despite the aridity (most of the biome receives less than 500 mm p.a.), each is dominated by a dense woody stratum of between two and six metres tall (Everard, 1987; Low and Rebelo, 1996), although the historical elimination of large browsers has probably resulted in it becoming denser in recent times (Kerley et al., 1995 and Kerley et al., 1999). This biome has been recognized internationally for its high biodiversity (Cowling, 1983), and currently has several major international projects examining its extent, functioning and threats. Perceived large-scale threats are overgrazing and land transformation for agriculture and fuelwood extraction by rural communities. Generally, succulent thicket vegetation is regarded to have a low resilience (Kerley et al., 1995; Fabricius, 1997). Less than 5% of the Thicket Biome is within formal conservation areas (Low and Rebelo, 1996), and thus key conservation initiatives must take place within the areas where farmers and rural communities operate for their daily livelihoods. This requires information regarding the structure and functioning of Thicket vegetation types, and how this is changed through disturbances such as differential fuelwood harvesting across different species.

Within the context of the above, the objective of this study, as reported in this paper, was to characterize the woody structure and floristics of a typical sample of Valley Thicket vegetation exposed to continuous harvesting of a variety of resources (especially fuelwood), and to examine potential differential selectivity for species and sizes.

2. Study area

The study area comprised the communal lands (580 ha) surrounding Crossroads village (33°10′48″ S and 27°17’22″ E) in the Eastern Cape, South Africa. It is a mix of Valley Thicket and Eastern Province Thornveld vegetation types of Low and Rebelo (1996). Dominant woody species are a mix of short, single-stemmed trees and multi-stemmed bushes, with a mean height of less than 4 m. Abundant species include *Diospyros dichrophylla*, *Euphorbia triangularis*, *Maytenus heterophylla*, *Mystroxylon aethiopicum* and various species of *Rhus*. In cleared areas and disturbed sites *Acacia karroo* and *Azima tetracantha* dominate (Motinyane, 2002). The accumulated impacts of resource harvesting, livestock browsing and grazing, altered fire regimes, and cycles of clearance and subsequent abandonment of arable fields have resulted in a generally fragmented structure to the vegetation, except far from the village periphery.

Geologically the area is characterized by sandstone and mudstone of the Lower Beaufort Series (Karroo System). Soils are composed of a combination of grey or brown litholic soils of the Mispah series and brown fine sandy clay loam overlying partly decomposed sedimentary rocks at depths of less than 40 cm. These soils frequently contain gravel and weathered stones. The altitude at the site is 296 m a.s.l. Mean annual rainfall is 510 mm (82 yr mean measured at Peddie town, 20 km west), ranging between 270 and 740 (CV=31%), and is concentrated between November and April.

The village comprises 172 households, with 1081 residents, of which 61% are unemployed or at school. Typical of the rural areas of the Eastern Cape province, there is only limited arable agriculture due to the arid and variable climate, shallow soils and high human densities due to forced relocations during the apartheid era. This makes rural communities dependent upon cash remittances from household members working in urban areas, State pensions, and local natural resources (Motinyane, 2002).

3. Methods

3.1. Woody community structure and composition

Woody community structure was characterized by means of 36 systematically distributed belt transects (4×60 m) sited using a grid. Transects were sited 350 m apart, and ran parallel to the contour. Transects that overlapped with current arable lands, livestock stockades, or houses were omitted. All woody stems greater than 6 cm basal diameter were enumerated in terms of height, basal circumference (350 mm above-ground level) and species. If the stem had previously been chopped below 350 mm and was coppicing, all stems above the minimum size class were still measured at 350 mm. If it had been chopped above 350 mm, then a single stem was measured at 350 mm. Plant specimens were identified at the Selmer Schonland Herbarium, Grahamstown, with names following Arnold and De Wet (1993). Visual estimates of the percentage of the stem that has been removed were made (0=no chopping; 1=⩽30% removed; 2=31–60% removed; 3=60–90% removed; 4=100% removed coppicing; 5=100% removed, no coppice), and a note made of the relative proportions dead, alive and coppicing. Aspect was measured using a compass, position on slope (top, upper scarp, middle, lower scarp and bottom) was based on a visual assessment, and total percentage cover by woody species was made based on visual estimates. Three subplots (2×2 m) were sampled per transect in which a total count was made of all stems less than 6 cm basal circumference.

Community Analysis Package (v1.41) was used to perform the floristic analysis. A correspondence analysis, using a Principal Component Analysis technique, based on species frequency was performed using the 32 species (of a total of 50) having greater than two occurrences in the data set and the unknown and unidentified categories omitted. The technique, described in Kent and Coker (1992), reduces the variability within the data matrix of species and plots. Duplication between species and plots is removed by creating fewer orthogonal or uncorrelated components. Eigenvalues are calculated which indicate the relative contribution of each component to the total variation; the higher the eigenvalue, the greater that components contribution.

3.2. Woody biomass

Woody biomass was calculated after determining allometric relationships between stem circumference (at 350 mm above-ground level) and dry mass. Between 11 and 20 stems of various sizes for five of the key species (*Acacia karroo*, *Coddia rudis*, *Diospyros dichrophylla*, *Olea europaea* subsp. *africana*, and *Ptaeroxylon obliquum*) were felled, dried, and weighed, after first measuring the basal circumference, total height, and height of the main stem. Felled trees were separated into leaves, branches and trunk, air dried for 4 weeks, and then oven-dried at 85 °C for 15 days. A composite allometric equation was derived from these five species combined and used to determine the biomass of other species in the sample plots.

3.3. Demand for wood

A 100% household census was done to document the level of fuelwood use. During the household interviews information was obtained on the fuelwood and construction species collected from the surrounding lands, along with quantities. Household informants were asked to indicate the amount of each resource they used per day or per week, as well as seasonal differences. This was then weighed with a spring balance to the nearest 0.1 kg. The vernacular names of preferred plant species selected for each resource group were recorded. Field trips were undertaken with knowledgeable community members to gather both specimens and household knowledge of the plant names recorded.

3.4. Selection of woody species and size classes

The ratio between demand and supply percentages of species was calculated to determine if there was active or random selection for individual species. The percentage of cut stems per species, as a percentage of total cut stems, was an index of demand, while the percentage of all stems per species, as a percentage of total stems, was used to indicate availability. While the ratio of demand to availability occurs within a range, cut-off points were selected as follows: >1.25=preferred, <1.25 and >0.80=random, and <0.80 and >0.20=avoided. Size classes with a value of zero are not utilized. Defining certain species as avoided, on the basis of a low preference ratio, does not imply that they are not used at all, but simply that they are used in a proportion much less than their relative availability in the environment.

A similar analysis was conducted to assess selection for particular size classes. Size classes were categorized into 5 cm increments to 70 cm, 10 cm increments to 100 cm circumference and all remaining stems between 100 and 200 cm circumference were grouped into category 18. Category 1 contained all stems less than 6 cm. The proportion of cut stems (100% harvesting), of a size class as a percentage of total cut stems was used to calculate demand, while the ratio of all stems, of a size class, as a percentage of total stems was used to calculate availability.

The percentage species harvested in each size class was calculated to indicate which size classes of particular species were preferred and the extent to which they had been removed. All chopping categories were included (0=no harvesting; 1=<30%; 2=31–60%; 3=61–90%; 4=100% with coppicing and 5=100% harvesting without coppicing).

A linear regression analysis was performed to test the relationship between distance to the nearest house and harvesting.

4. Results

4.1. Woody community composition

A large proportion of the sampled area contained small multi-stemmed shrubby species such as *Coddia rudis*, *Ehretia rigida*, *Maytenus heterophylla* and *Diospyros dichrophylla*. The old lands now revegetated with *Acacia karroo*, were also distinguishable. Many forest and thicket pockets with distinct dominant species assemblages were evident. Small riverine forest pockets dominated by species such as *Pleurostylia capensis*, *Olea capensis*, *Euphorbia triangularis* and *Cussonia spicata* and *M. heterophylla* are evident in the ordination plot (Fig. 1). Because species composition tended to be distinct in the different heterogeneous thicket and forest pockets, these did not form distinct clusters in the resulting ordination. Heavily harvested and degraded sites are easily distinguished in the ordination plot, dominated by *Coddia rudis*, *Scutia myrtina*, *Maytenus heterophylla* and *Ehretia rigida*. The mean number of woody species per transect was 9.4±0.8, with a range from 5 to 20 species. The total number recorded across the 36 sample transects was 50 species.

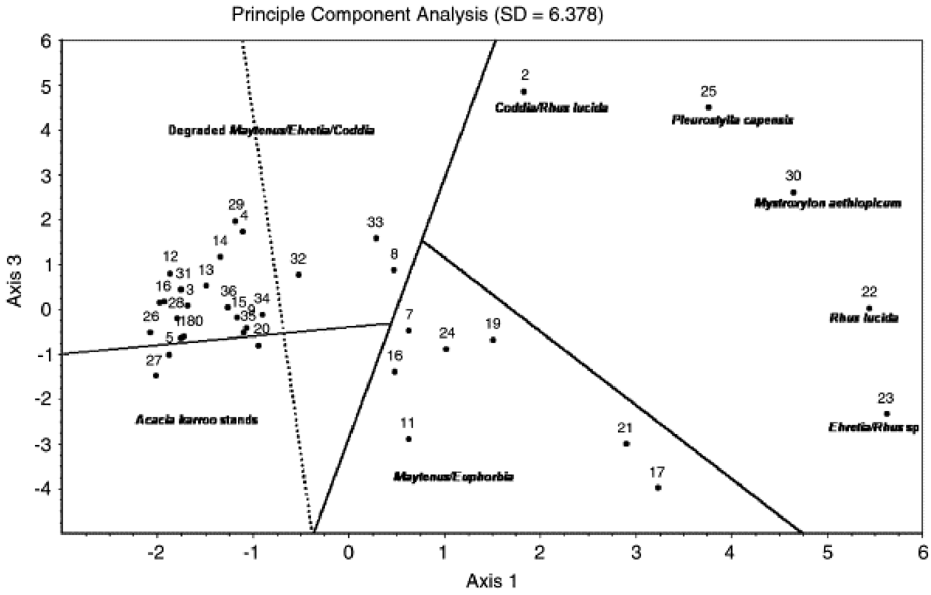

Fig. 1. PCA plot of woody vegetation types at Crossroads village, Eastern Cape.

Sample transects on the lower left of the axes (1 and 3) are those with a low diversity of species and a lower number of stems. Samples on the upper right are those with greater species diversity and a greater number of stems. Transects have been grouped and labelled according to their dominant species. Axis 1 of the PCA plot is correlated with increasing woody basal area, which was a function of both distance from the village and slope position. Samples indicated on the right side of the dotted line of the plot all have a basal area of greater than 10 m^2 ha^{-1}. Eigenvalues indicated that the relative contribution of each component was low, with the first three axes accounting for 15.3%, 12.8% and 9.7% of the variance, respectively. The heterogeneous forest pockets are easily distinguishable, while the remaining transects have formed a rather indiscrete collection of points that makes interpretation difficult.

4.2. Woody community structure

The basal area per transect was highly variable because of the heterogeneous nature of the vegetation. While many transects along the slopes were sparsely vegetated (0.1 m^2 ha^{-1}) with small stems, some dense forest and thicket pockets (51.1 m^2 ha^{-1}) with many large stems were situated along river margins and in upper reaches of stream catchments. The mean basal area was 12.7±2.5 m^2 ha^{-1}. Two thirds of the transects had a basal area of less than 10 m^2 ha^{-1}.

The size class distribution of the woody stems exhibited an inverse J-shaped profile, typical of a stable population (Fig. 2). A greater proportion of the stems in the small and intermediate size classes were cut, than in the very small and large categories.

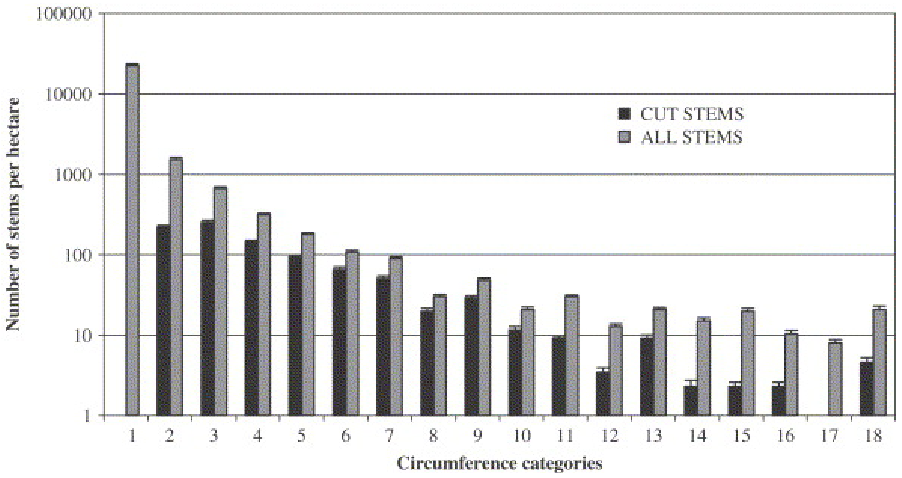

Fig. 2. Size class profile of all woody species, indicating difference between total stems and cut stems (see Table 4 for circumference categories).

Sample transects on the lower left of the axes (1 and 3) are those with a low diversity of species and a lower number of stems. Samples on the upper right are those with greater species diversity and a greater number of stems. Transects have been grouped and labelled according to their dominant species. Axis 1 of the PCA plot is correlated with increasing woody basal area, which was a function of both distance from the village and slope position. Samples indicated on the right side of the dotted line of the plot all have a basal area of greater than 10 m^2 ha^{-1}. Eigenvalues indicated that the relative contribution of each component was low, with the first three axes accounting for 15.3%, 12.8% and 9.7% of the variance, respectively. The heterogeneous forest pockets are easily distinguishable, while the remaining transects have formed a rather indiscrete collection of points that makes interpretation difficult.

4.3. Woody biomass

There was a significant relationship between stem basal circumference and dry wood mass for each of the five species individually as well as pooled across all species (Table 1). The relationship for the multi-stemmed bushes (*Coddia rudis* and *Diospyros dichrophylla*) was weaker than that for trees that are normally single-stemmed

Table 1.

Allometric relationship for five key species, and one across all five combined

Species	Relationship	r^2	*P*	*N*
Acacia karroo	Log (dry wood mass)=3.062*Log (circ)−0.304	0.79	< 0.0001	14
Coddia rudis	Log (dry wood mass)=0.62*Log (circ)+2.23	0.30	< 0.05	20
Diospyros dichrophylla	Log (dry wood mass)=1.09*Log (circ)+1.93	0.36	< 0.01	19
Olea europaea subsp. *africana*	Log (dry wood mass)=2.82*Log (circ)+0.16	0.81	< 0.0001	14
Ptaeroxylon obliquum	Log (dry wood mass)=2.538*Log (circ)+0.42	0.82	< 0.0001	11
Combined	Log (dry wood mass)=2.74*Log (circ)+0.15	0.77	< 0.0001	39

4.4. Demand for wood

Fuelwood was used as the primary energy source, and collected by 88% of the households. Mean fuelwood consumption was 502.6±29.3 kg $capita^{-1}$ $annum^{-1}$. Other significant uses of wood included construction timber for fences and livestock stockades (85%), and wood stacks maintained by women for cultural purposes (*Igoqo*; see Cocks and Wiersum, 2003) (56%). Demand for fencing and stockade wood was estimated at 140.1±117.5 kg $capita^{-1}$ $annum^{-1}$. Stockade branches, while making up a large proportion of harvested wood mass, were mostly small branches, that were likely to be a part of larger stems harvested for other purposes. Demand for timber for cultural stacks was calculated as 63.7±6.7 kg $capita^{-1}$ $annum^{-1}$. Together these three uses constituted 92.5% of the estimated total per capita annual demand for wood of 764 kg.

4.5. Species selection

From the household interview data 21 species were listed within the top three most preferred species for fuelwood, but by far the most common was *Acacia karroo* (66% of households), followed by *Rhus dentata* (28%) (Table 2). These two species were also the most commonly cited ones for cultural stacks. In comparison, *Olea europaea* subsp. *africana* and *Ptaeroxylon obliquum* were preferred for fencing and stockade poles. *Coddia rudis* was the most commonly used species for branches to pack between the upright posts for livestock stockades.

Table 2. Household preferences (% of respondents listing species within top three) for woody species for different use categories (only species cited by >1% of households are listed)

Species	Fuelwood	Cultural stacks	Stockade branches	Stockade poles	Fencing
Acacia karroo	66	22	4	0	0
Brachyleana ilicifolia	17	15	0	0	1
Coddia rudis	12	0	80	0	0
Diospyros dichrophylla	0	0	2	0	0
Ehretia rigida	0	9	3	6	0
Maytenus capitata	11	11	0	0	0
Olea europaea subsp. *africana*	9	11	0	28	26
Ptaeroxylon obliquum	0	0	0	32	31
Rhus dentata	28	22	17	0	0
Rhus refracta	0	0	1	0	0
Scutia myrtina	20	9	0	0	0
Total number of species cited per use category	21	18	6	21	6

From the stem ratio analysis, there was positive selection for particular species (χ^2=51.7; df=28; *P*<0.004). Species selection was evident for 44% of the available woody species (including 23 species grouped as miscellaneous), either preferred or avoided. The remainder were harvested in proportion to their occurrence. No evidence of harvesting was measured in 70.6% of all stems. The remaining 29.4% had some degree of chopping. Only 20.7% of all stems had greater than 75% harvesting, although 70.7% of chopped stems had greater than 75% chopping. Coppice regrowth was measured in 35% of all chopped stems, while 28.8% of all chopped stems had no coppice regrowth, or were dead.

Selected species (in order of preference ratio) included *Rhus lucida*, *Zanthoxylum capensis*, *Pleurostylia capensis*, *Maytenus heterophylla*, *Mystroxylon aethiopicum*, *Cassine papillosa*, *Carissa bispinosa*, *Tarchonanthus camphoratus* and *Scutia myrtina* (Table 3). All had a higher proportional representation in the cut stem population than the uncut population, indicating active selection for these species. Avoided species were *Pappea capensis*, *Ptaeroxylon obliquum*, *Olea capensis*, *Chaetacme aristata*, *Rhus spinosa*, *Acacia karroo*, *Euphorbia triangularis*, *Diospyros dichrophylla*, *Coddia rudis*, *Azima tetracantha*, *Cussonia spicata* and *Calpurnia sericea*. This group includes several species that were supposedly preferred according to the interview data. Several species were avoided because of their soft wood, such as *Cussonia spicata* and *Euphorbia triangularis*. Finally, *Buddleja saligna*, *Phyllanthus viridiflora*, *Grewia occidentalis*, *Ehretia rigida*, *Olea europaea* subsp. *africana* and *Brachylaena elliptica* appear to be harvested in proportion to their occurrence.

Table 3. Species selection based on the ratio of proportions of cut and uncut stems (ranked by species preference)

Species	No. of stems	Tot. cut stems	% of total stems	% of cut stems	Ratio cut:total	Selection
Unknown[a]	34	31	1.3	3.9	3.1	Preferred
Rhus lucida	146	105	5.4	13.2	2.5	Preferred
Zanthoxylum capensis	13	8	0.5	1.0	2.1	Preferred
Pleurostylia capensis	117	70	4.3	8.8	2.0	Preferred
Maytenus heterophylla	302	144	11.3	18.1	1.6	Preferred
Mystroxylon aethiopicum	131	56	4.8	7.0	1.5	Preferred
Cassine papillosa	40	17	1.5	2.1	1.5	Preferred
Carissa bispinosa	13	5	0.5	0.6	1.3	Preferred
Tarchonanthus camphoratus	61	23	2.3	2.9	1.3	Preferred
Scutia myrtina	218	82	8.1	10.3	1.3	Preferred
Miscellaneous[b] (23 species)	77	26	2.9	3.3	1.2	Proportional
Buddleja saligna	21	7	0.8	0.9	1.1	Proportional
Phyllanthus viridiflora	66	21	2.4	2.6	1.1	Proportional
Grewia occidentalis	29	9	1.1	1.1	1.1	Proportional
Ehretia rigida	255	76	9.4	9.6	1.0	Proportional
Olea europaea	136	38	5.0	4.8	1.0	Proportional
Brachylaena elliptica	49	13	1.8	1.6	0.9	Proportional
Pappea capensis	9	2	0.3	0.3	0.8	Avoided
Ptaeroxylon obliquum	14	3	0.5	0.4	0.7	Avoided
Olea capensis	10	2	0.4	0.3	0.7	Avoided
Chaetacme aristata	18	2	0.7	0.3	0.4	Avoided
Rhus spinosa	38	4	1.4	0.5	0.4	Avoided
Acacia karroo	165	16	6.1	2.0	0.3	Avoided
Euphorbia triangularis	83	6	3.1	0.8	0.3	Avoided
Diospyros dichrophylla	63	4	2.3	0.5	0.2	Avoided
Coddia rudis	524	24	19.4	3.0	0.2	Avoided
Azima tetracantha	25	1	0.9	0.1	0.1	Avoided
Cussonia spicata	20	0	0.7	0.0	0.0	Not used
Calpurnia sericea	27	0	1.0	0.0	0.0	Not used
Total	2704	795	100.0	100.0		

[a] Species in the category Unknown, include those stems that were 100% dead (cut and uncut) and could not be identified.
[b] The category Miscellaneous includes all species that contained less than 1% of the total measured stems (23 species).

4.6. Size class selection

There was a positive selection for particular size classes (χ^2=38.3; df=16; P<0.001). Stems larger than 55 cm and smaller than 10 cm circumference were avoided or not used, although 22.7% of all stems fully harvested occurred in size class 2 (6–10 cm). The preferred size class of stems fully harvested was between 16 and 45 cm Of all stems, 77% occurred in categories where active selection occurs. The remaining stems were harvested in proportion to their occurrence. Similarly, 29.4% of all stems had been harvested to 100%, of which 54.8% were coppicing and 45.2% were dead or not yet coppicing. Complete harvesting occurred on 80.5% of all cut stems between 6 and 25 cm, while 41.0% of stems harvested completely were in size classes 4–7 (16–35 cm). Size classes 2–5 accounted for 80.5% of the harvested stems (Table 4). Although not necessarily actively sought after relative to their abundance they were preferred with respect to all size classes. These size classes were the smallest and hence the easiest to harvest by chopping and therefore most useful for fuelwood. The three smallest size classes (2–4) contributed 80.3% of the total number of stems occurring around the village (Table 4), indicating an abundance of small woody stems, while the supply of larger stems was sparse. Only 13.4% of the remaining harvestable stems occurred within the preferred size class (16–45 cm). The highest percentages of uncut stems were within the smallest size class category, while all categories were harvested to some extent.

Table 4. Number of stems in different size categories (regardless of species) and those cut ranked according to selection of size categories

Circumference category		No. of stems (>6 cm)	No. of cut stems (>6 cm)	Total stems (%)	Cut stems (%)	Ratio total:cut stems	Selection
6	(26–30 cm)	94	57	3.5	8.1	2.3	Preferred
5	(21–25 cm)	155	81	5.7	11.2	2.0	Preferred
7	(31–35 cm)	78	44	2.9	5.5	1.9	Preferred
4	(16–20 cm)	271	125	10.0	16.2	1.6	Preferred
9	(41–45 cm)	42	25	1.6	2.4	1.5	Preferred
8	(36–40 cm)	26	17	1.0	1.4	1.4	Preferred
3	(11–15 cm)	577	217	21.3	30.4	1.4	Proportional
10	(46–50 cm)	18	10	0.7	0.6	0.9	Proportional
11	(51–55 cm)	26	8	1.0	0.8	0.8	Proportional
12	(56–60 cm)	11	3	0.4	0.2	0.5	Avoided
2	(6–10 cm)	1324	190	49.0	22.7	0.5	Avoided
14	(66–70 cm)	13	2	0.5	0.2	0.4	Avoided
15	(70–80 cm)	17	2	0.6	0.2	0.3	Avoided
13	(61–65 cm)	18	8	0.7	0.2	0.3	Avoided
16	(81–90 cm)	9	2	0.3	0.0	0.0	Not used
17	(91–100 cm)	7	0	0.3	0.0	0.0	Not used
18	(100–200 cm)	18	4	0.7	0.0	0.0	Not used
Total	2704	507	100.0	100.0			

4.7. Species and size class selection

Considering size class selection on an individual species basis (Table 5), it appears that for many of the preferred species harvesting occurred on all the stems in a particular size class. Empty cells indicate no stems occurred in that size class. *Rhus lucida*, *P. capensis*, *M. heterophylla* and *C. papillosa* in particular had high percentages of stems harvested. Species including *E. rigida*, *B. saligna* and *Grewia occidentalis* had high harvesting percentages within the favoured size class categories (4–9). *Zanthoxylum capensis*, *T. camphoratus, Scutia myrtina* and *Mystroxylon aethiopicum* experience 100% harvesting in at least one size class. *Rhus lucida, E. rigida, P. capensis, Olea europaea* subsp. *africana* and *Maytenus heterophylla* had greater than 50% of stems with some evidence of harvesting.

Table 5
Percentage stems with harvesting per size class, arranged by deceasing mean harvesting percentage. Preferred species are highlighted and preferred size classes are indicated

Species	Size class																		Mean
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Unidentifiable cut/dead stems[a]		85.7	100.0	100.0	100.0	100.0				100.0	50.0								90.8
Rhus lucida	0.0	27.3	50.0	66.7	80.0	75.0	80.0	83.3	85.7		100.0		100.0					100.0	70.7
Ehretia rigida	0.0	18.3	35.0	40.0	55.6	100.0	75.0		100.0			100.0							58.2
Pleurostylia capensis		25.0	64.7	45.8	57.1	100.0	50.0	100.0	66.7	100.0	0.0	100.0	66.7	0.0	50.0	100.0	0.0		57.9
Olea europaea subsp. *africana*	0.0	5.9	26.7	53.8	80.0	50.0	100.0		100.0	100.0	50.0	0.0	100.0	0.0			0.0	100.0	51.1
Maytenus heterophylla	0.0	28.2	61.7	61.8	52.9	71.4	80.0	50.0	50.0		50.0		100.0			0.0			50.5
Cassine papillosa	0.0	27.3	100.0	50.0	66.7	100.0	100.0	0.0	0.0										49.3
Buddleja saligna	0.0	18.2	0.0	66.7		100.0		100.0			100.0		0.0						48.1
Grewia occidentalis	0.0	35.7	10.0	33.3	100.0		100.0												46.5
Scutia myrtina	0.0	29.8	31.5	48.9	42.9	50.0	71.4		66.7				100.0		0.0				44.1
Zanthoxylum capensis	0.0	66.7	0.0	50.0					100.0										43.3
Brachylaena elliptica	0.0	6.9	50.0	60.0	66.7	50.0													38.9
Tarchonanthus camphorates	0.0	37.5	33.3	33.3	66.7	100.0	0.0												38.7
Mystroxylon aethiopicum	0.0	22.2	57.9	63.2	63.6	28.6	14.3	33.3	100.0		0.0	0.0			0.0	100.0			37.2
Olea capensis		0.0	100.0	0.0	0.0		0.0				100.0								33.3
Miscellaneous[b]	0.0	20.0	38.5	40.0	60.0	40.0	42.9	66.7	33.3	50.0	0.0	0.0	0.0	50.0	50.0			0.0	30.7
Ptaeroxylon obliquum	0.0	0.0	0.0	0.0	0.0	100.0			100.0										28.6
Acacia karroo	0.0	0.0	12.5	16.7	27.3	100.0	66.7	0.0											27.9
Phyllanthus viridiflora	0.0	29.5	75.0	0.0															26.1
Carissa bispinosa	0.0	57.1	16.7																24.6

[a] Species in the category Unknown, include those stems that were 100% dead (cut and uncut) and could not be identified.
[b] The category Miscellaneous includes all species that contained less than one percent of the total measured stems (23 species).

4.8. Biomass and availability of preferred woody stems

Biomass, number of stems and basal area was calculated for a number of different harvesting and preference categories to reflect the amount of wood available (Table 6). While a large amount of wood was available, only a small proportion was of the preferred species and size classes (2554.1±822.9 kg ha^{-1}) and of this, only 912±297.5 kg ha^{-1} was not harvested completely. Only 380±82.9 stems per hectare of the preferred species had no harvesting.

Table 6.

Mean amount of available wood per hectare (stems greater than 6 cm circumference)

Category	Biomass (kg ha^{-1})±SE	No. of stems ha^{-1}±SE	Basal area (m^2 ha^{-1})±SE
All stems	No allometric equation	3 129.7±296.7	12.7±2.5
Stems selected (incl. cut)	17 433.2±4 250.5	2 353.0±267.15	
Stems selected (excl. cut)	11 358.4±2 923.5		
Preferred species	7 910.9±2 793.9	1 313.1±212.4	5.1±1.4
Preferred species and size classes	2 554.1±822.9	503.8±121.7	2.92±0.8
Uncut species	912±297.5	379.6±82.9	2.0±0.5
Species not avoided	9 243.5±2 763.4	1 897.6±239.1	6.3±1.4
Species and size classes not avoided	3 733.0±1 084.6	1 181.8±195.0	4.3±0.9
Acacia karroo	1 060.1±604.0	528.8±246.8	0.8±0.3
Ptaeroxylon obliquum	242.6±8.4	233.3±95.6	0.7±0.3
Olea europaea subsp. *Africana*	2424.5±1141.1	246.4±61.9	1.1±0.3
Coddia rudis	21.5±3.1	682.3±98.5	1.1±0.2
Dead wood	1 011.4±405.1		

The mean available biomass before cutting was determined as 17 433±4251 kg ha^{-1}. By incorporating the chopping category into this calculation, the actual mean standing crop, available for harvesting, was 11 358±2924 kg ha^{-1}, i.e. a 35% reduction. The mean was highly skewed by two or three transects with large biomass. The median value was 3 476 kg ha^{-1}. The mass of available deadwood for the same data set was calculated to be 1 011±405 kg ha^{-1}.

There was no significant relationship between distance from the village periphery and basal area of all stems or just uncut ones (Table 7). There was, however, a weak positive relationship with the attributes of woody community, and preferred species density or biomass, with the most significant being with preferred stem biomass (r^2=0.30;P<0.005) and density of stems of preferred species (r^2=0.17;P<0.05).

Table 7.

Regression analysis of woody attribute relative to distance from village periphery

Attribute		*F*	r^2	*P*
Basal area	All stems	1.21	0.04	>0.05
	Uncut stems only	0.31	0.01	>0.05
	Preferred species	6.44	0.16	<0.05
	Preferred stems (species and size class)	8.00	0.25	<0.01
Density	All stems	7.02	0.18	<0.05
	Uncut stems only	7.65	0.19	<0.01
	Preferred species	4.68	0.12	<0.05
	Preferred stems (species and size class)	5.17	0.17	<0.05
Biomass	Preferred species	6.21	0.16	<0.05
	Preferred stems (species and size class)	10.37	0.30	<0.005

5. Discussion

A range of plant communities was identified around Crossroads village. The slopes below the village tended to be highly impacted with a few scattered trees and bushes, such as *Maytenus heterophylla*, *Ehretia rigida* and *Coddia rudis*. Some steeper areas showed signs of soil erosion. The upper reaches of the streams were vegetated with pockets of *Euphorbia* thicket. These pockets had high levels of harvesting of useful species such as *Olea europaea* subsp. *africana*, *Mystroxylon aethiopicum* and *Tarchonanthus camphoratus*. The lowest sites, furthest from the village, were vegetated with forest and thicket pockets. These contained a range of tree species, including *Rhus lucida*, *Rhus spinosa* and *Olea europaea* subsp. *africana.*

The derivation of allometric equations for common species allowed estimation of biomass, something which has not been done before for Valley Thicket. The results indicated weaker relationships for multi-stemmed bushes than for single-stemmed trees, similar to the findings of Chidumayo (1993) and Shackleton (1997) from moister savannas. It would be useful if a greater range of species were covered, including from sites where there are less human and livestock impacts.

The extremely dense and almost impenetrable nature of Valley Thicket (Kerley et al., 1995) has deterred quantitative characterization of community structure using attributes such as basal area, density or biomass. Consequently, there is a dearth of comparative data against which to evaluate the results of this study. Penzhorn et al. (1974) undertook destructive sampling of 10 protected and 10 open plots in the Xeric Succulent Thicket of Addo Elephant National Park (approximately 100 km west of the study site) and recorded a mean total (including wood, twigs and leaves) fresh biomass of 184±33 t ha^{-1} and 85±8 t ha^{-1} in the protected and open areas, respectively. This would equate to between 45 and 97 t ha^{-1} dry mass. This is markedly higher than the mean of 17.4 t ha^{-1} recorded during our study, but not unsurprisingly since our study was in harvested communal land, not a National Park, and our data do not include the mass of leaves. The range in dry wood mass across the 36 plots of our study was from 0.012 to 73.2 t ha^{-1}. In terms of woody plant density, Motinyane (2002) recorded a strong gradient of increasing density with increasing distance from human settlement. Close to settlement woody plant density was approximately 300 stems ha^{-1} and 3 km away it was over 5 000 stems ha^{-1}. This is comparable to the mean of 3 130 stems ha^{-1} recorded by us, with a similar relationship with proximity to the village.

A negative relationship was evident between the amount of useful wood and proximity to the village, as has been shown in numerous studies (Grundy et al., 1993; Banks et al., 1996; Luoga et al., 2001; Motinyane, 2002). The amount of harvesting decreases with distance as the most favoured species are removed first from accessible areas. In Crossroads village, only a few small forest and thicket pockets remained that had not been impacted by harvesting. Several dense pockets that had the least impact were composed of species that are avoided, including *Olea capensis*, *Chaetacme aristata* and *Rhus spinosa*. Brouwer et al. (1997) showed that while households initially collect further away from the village to obtain preferred species, a point is reached when the opportunity costs become too great and they will switch to lower quality wood to spend less time collecting. This trend is especially prevalent in smaller households with fewer women, and suggests that harvesting of fuelwood is not necessarily associated only with species availability, but also labour availability.

While rural communities show a marked preference for dead wood, increased demand frequently results in the harvesting of live stems to satisfy their wood needs (Shackleton, 1993). This practice has clearly been found to occur through a process of active selection of species and size classes, although not always the case (e.g. Campbell and du Toit, 1988). This study has demonstrated that species selection is active, with preferred species being *Rhus lucida*, *Zanthoxylum capensis*, *Pleurostylia capensis*, *Maytenus heterophylla*, *Mystroxylon aethiopicum*, *Cassine papillosa*, *Carissa bispinosa*, *Tarchonanthus camphoratus* and *Scutia myrtina*. In Xeric Succulent Thicket Bembridge and Tarlton (1990) recorded active selection for *Acacia karroo* as the most favoured species, followed by *Olea europaea* subsp. *africana*, *Schotia* spp, *Olea capensis* and *Ptaeroxylon obliquum*.

Acacia karroo, *Azima tetracantha*, *Calpurnia sericea*, *Chaetacme aristata*, *Coddia rudis*, *Cussonia spicata*, *Diospyros dichrophylla*, *Euphorbia triangularis*, *Olea capensis*, *Pappea capensis*, *Ptaeroxylon obliquum* and *Rhus spinosa* were actively avoided. While many of these species are not of any particular use in households, it was surprising that *Ptaeroxylon obliquum* and *Acacia karroo* were avoided since they have been shown to be preferred species in the area (Bembridge and Tarlton, 1990; Motinyane, 2002). However, at Crossroads *Acacia karroo* and *Ptaeroxylon obliquum* stems were in a size class lower than preferred having probably been previously cleared for construction timber, highlighting the need for a temporal dimension to selection studies. Choice of species depends on the type of woodland and the relative abundance thereof (Campbell and du Toit, 1988; Abbott and Lowore, 1999; Shackleton et al., 2004), which could provide an explanation as to why species selection in Crossroads village differs from other studies. *Rhus lucida* was the most favoured species, having the highest preference ratio, while *Rhus spinosa* is avoided.

It has previously been found that *Olea europaea* subsp. *africana* and *Ptaeroxylon obliquum* are highly sought after species (Dyer, 1996), but not so in our study. This may be due to current reduced availability due to heavy past selection and land transformation, and subsequent shift to alternative species such as *Rhus lucida*, the next most favoured species. Since these species have a large number of stems in the lowest size classes, this could be a possible explanation. However, *Ptaeroxylon obliquum* has 100% harvesting in its two largest size classes (6 and 9), while *Olea europaea* subsp. *africana* has very high levels of harvesting in all the larger size classes (7, 9, 10, 13 and 18) and partial harvesting in the smaller ones (3, 4 and 5). There were thus few remaining stems of these species available in their preferred size classes, making their scarcity an explanation for them not being selected actively, since the stems are clearly sought after. The large number of stems in the small, avoided size class categories (<15 cm) would have caused this preference ratio to indicate that they were not preferred, since these size classes are rarely cut.

When the cut stump data are compared to survey data collected from households, which describes the frequency at which households cited various species as the preferred species for different uses, it is clear that perceived and actual preferences differ substantially. *Coddia rudis*, possibly because of its abundance, is popular for the construction of stockades. *Acacia karroo* was the most frequently cited species for fuelwood (66% of households) and for ritual purposes (40% of households). This could conflict with supply estimations as a result of the fact that *Coddia rudis* occurs at much higher densities than harvested, *Acacia karroo* stems occur at below favoured size classes and *Ptaeroxylon obliquum* is scarce due to previous harvesting. These factors could thus have influenced the estimations of selection preference ratios. Campbell and du Toit (1988) ascribe the indiscriminate selection of species to past deforestation and the previous removal of preferred species. The differences observed between cited species preference and measured species preference in this study could thus be an indication of a perceived change in availability of species, while measurements are indicative of selection processes over a longer time frame. The study could thus be measuring species selection over the past few years, while wood collectors have adapted to shortages and are now utilizing wood accordingly. Shackleton (1993) also found some discrepancies between interview data and selection estimated from cut stumps.

Paralleling the active selection of certain species was the equally strong selection for certain size classes. The sought after size classes were between 16 and 45 cm circumference, or 5–14 cm diameter. Whilst stems larger and smaller than these dimensions will be used, and make important contributions to the fuelwood resource, they are not preferred. Larger stems are harder to harvest, and frequently require splitting before being added to the fire, which requires effort and time. Smaller stems are useful as kindling, but do not make adequate coals required to maintain a fire and provide even heat. Preference for these intermediate sizes has been recorded elsewhere (Liengme, 1983; Grundy et al., 1993; Shackleton, 1993; Abbot and Homewood, 1999; Abbott and Lowore, 1999). This has implications for woodland management since particular cohorts are being removed at a faster rate than others.

The overall demand for fuelwood of 503 kg capita^{-1} yr^{-1} is within the range of similar studies in southern Africa, although below the mean. Shackleton (1993) reported a mean annual per capita use of 687±49 kg across 18 studies from southern Africa. More recently, Abbot and Homewood (1999) reported an annual per capita demand of 525 kg in southern Malawi. Consumption data from India indicate it to be lower than that in Africa, although still with a wide range (Pandey, 2002).

Although there was marked selection for species and size classes, most of the cut stumps were coppicing. It is this coppicing ability that confers marked resilience on African savannas subject to numerous and intense perturbations, including harvesting by humans. It also represents an opportunity for sustainable management. Abbott and Lowore (1999) estimated the regrowth period for fuelwood coppice to reach approximately 5 cm diameter in size would be 5 years. Shackleton (2001b) reported similar harvest intervals (3–5 years) for regrowth of *Terminalia sericea*, depending on cutting height, original stem size, and number of coppice shoots per stump.

In summary, Valley Thicket clearly provides a heterogeneous mixture of species and size classes. While household surveys indicate that only a few species are favoured, the field data demonstrated that a wider range of species are harvested, although the analysis of cut stems also includes wood for construction. It is also evident that species and size class selection is active, where certain species and size classes are selected in greater abundance than their relative occurrence, others are avoided and the remainder are harvested in proportion to their occurrence. Certain size classes have concurrently been harvested to the extent where 100% of the stems in that size class have been cut. While many of these are regenerating by coppice regrowth and through seedlings, the size class profile of useable woody stems has been altered. Stems that fall within the most favoured size classes are becoming scarcer, especially closer to the village. Some intact pockets remain at the furthest extent of the communal lands, which are presently being impacted. Old lands now revegetating with *Acacia karroo* are an indication that Valley Thicket is able to regenerate after severe disturbance although this species is acting only as a pioneer and with appropriate management and increased utilization of alternatives, a limited wood supply could be maintained from a range of species.

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