Quantification of the resource base and impact of harvesting of coastal hardwood species by a rural community.

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Research report submitted in partial fulfilment of requirements for the degree of Master of Science in Quantitative Conservation Biology at the University of the Witwatersrand, Johannesburg.

Declaration

I declare that this research report is my own, unaided work. It is being submitted for the degree of Master of Science in Quantitative Conservation Biology at the University of the Witwatersrand, Johannesburg.

It has not been submitted before for any degree or examination at any other university.

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Johannesburg

26 February 1993.

SUMMARY

The study aimed: (1) to provide baseline data on aspects of wood utilisation in a resource area and a communal area in KwaZulu, (2) to investigate the effects of this wood utilisation on the resource base, and (3) to discuss the sustainability of current wood utilisation. Wood utilisation in this study refers to the harvesting of dead and livewood for fuelwood, building poles and fencing posts.

Harvesting of woody species for building and fencing was selective in both species and size class harvested. Five of the most common species in the area comprised ± 75 % of total harvest. Estimated harvest rates were 0.36 stems.ha^{-1}.y^{-1} (resource area) and 2.50 stems.ha^{-1}.y^{-1} (communal area).

Collection of fuelwood was reported to be not species selective. Only deadwood and the off-cuts from pole harvesting were collected. Current fuelwood harvest is 0.64 tonnes per capita per year.

A stage-structured model was created to simulate impacts of varying harvest rates on a known resource base in the resource area. The model was run for harvesting of (a) the five most preferred species, (b) the five most preferred species plus a group of eight secondary preferred species, and (c) each of the five most preferred species separately. The model did not simulate a multi-species complex and did not account for spatial diversity in resources or harvesting.

The present harvest rate recorded in the resource area was 808 trees.y^{-1}. This rate of harvest appears to be sustainable, based on available estimates of growth and recruitment, in the resource area. However, recruitment rates and growth and mortality rates of immature individuals used in the modelling exercise were of low reliability. Harvest rates in the resource area are likely to increase as more people colonise the area and resources become limiting in the communal area. The harvest rate of 3926 trees.y^{-1} recorded to occur in the communal area is not sustainable when simulated for the resource area.

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The present harvest rate recorded in the resource area was 228 trees.y^{-1}, with harvesting occurring in a limited area within the resource area. This rate of harvest appears to be sustainable, based on available estimates of growth and recruitment, in the resource area. However, recruitment rates and growth and mortality rates of immature individuals used in the modelling exercise were of low reliability. Harvest rates in the resource area are likely to increase as more people colonise the area and resources become limiting in the communal area. The harvest rate of 3926 trees.y^{-1} recorded to occur in the communal area is not sustainable when simulated for the resource area.

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INTRODUCTION

This study was initiated out of concern for the impact of wood harvesting presently occurring in a resource area north of False Bay in northern Natal. The wood harvesting occurring in the area was known to be for fuelwood, building poles and fencing posts. Such aspects as the species and sizes of trees impacted and whether harvest was of live or dead wood were unknown.

The resource area borders on Phinda Resource Reserve and a private farm on two sides and communal land on the other two sides. There was formerly a fence between the resource area and the communal land but this has, within the last three years, disintegrated. Due to the demand for wood in the communal area, this area has become overutilised and wood resources are becoming scarce. Local people living in the communal area have thus now begun to harvest in the resource area and concern : the persistence of utilised species in the resource area has grown. This study thus aimed to investigate aspects of wood use in order to answer the initial question of whether current harvest levels were sustainable.

The main objectives of the study were: (1) to provide an estimate of the standing crop of potentially harvestable trees in the resource area, (2) to quantify present harvesting pressure and harvest impacts in the communal and resource areas, (3) to compare estimated harvest rates with available resources in the resource area, and (4) to discuss the sustainability of present harvest rates in the resource area and factors which may limit harvest rates.

This research report is presented in the form of two manuscripts prepared for journal publication. Manuscript 1 is entitled: Quantification of the resource base of and harvest impact on coastal hardwood species by a rural community. This manuscript deals with the first two objectives of the study, presenting estimates of available resources, harvest rates and harvest impacts. The second manuscript is entitled: Evaluation of the potential sustainability of harvesting of coastal hardwood species by a rural community. This manuscript deals with objectives (3) and (4) through the creation of a model simulating harvest impacts on available resources. This manuscript also discusses areas in which more data are necessary for confidence in model results to be increased.

Manuscript 1

Quantification of the resource base of and harvest impact on coastal hardwood species by a rural community.

Keywords: Fuelwood, KwaZulu, rural development, wood harvesting.

ABSTRACT

The study aimed to provide baseline data on aspects of wood utilisation in a resource area in KwaZulu. Aspects of wood utilisation investigated were harvesting of live and deadwood for building, fencing and fuelwood.

Harvesting of woody species for building and fencing, carried out by men, was selective in both species and size class. Five common species in the area comprised ± 75 % of total harvest. Estimated harvest rates were 0.36 stems.$ha^{-1}.y^{-1}$ (resource area) and 2.50 stems.$ha^{-1}.y^{-1}$ (communal area).

Collection of fuelwood, carried out by women, was not species selective. Only deadwood and the off-cuts from pole harvesting were collected. Current fuelwood harvest is 0,64 tonnes per capita per year.

INTRODUCTION

Vegetation patterns and composition are determined by both biotic and abiotic factors. Abiotic factors such as climatic and edaphic factors determine vegetation patterns and composition at a regional scale (O'Connor 1985, Goodman 1990, Ellery, Scholes & Mentis 1991, Teague & Smit 1992). Local vegetation patterns can, however, be influenced by stress and disturbance due to biotic factors (Grime 1977). Biotic factors such as grazing, browsing, and wood gathering may be perceived by individual plants as stresses or disturbances. These practices will influence the structure and species composition of vegetation at a local scale, dependant on their intensity, frequency and timing (Higgins 1992).

High conservation priority indigenous dune and sand forests and wooded areas occupy only a small percentage of the Natal land area (Muir 1990). Rapid rural population growth and the subsequent increase in demand for wood has been found to intensify the pressure on forests and densely wooded areas (Bembridge & Tarlton 1988, Cawe & McKenzie 1989a, 1989c). Studies, starting with the first 1890 recommendation by Carlson (1939), have proposed the planting of woodlots so that the bulk of wood is not harvested from indigenous forests. Many of these so called "community" woodlots have failed due to confusion over management: questions of who is responsible for management and who has the right to harvest in the woodlot have not been clearly addressed. These woodlots have also been used for the benefit of powerful people, to the exclusion of members of the community (Gandar 1986, Bembridge & Tarlton 1988, Bembridge 1990, Muir 1990). Capital for the initiation of woodlots is unavailable in some areas and so the harvesting of indigenous trees continues on a large scale. One such area in which harvesting occurs is the proposed Makaza Nature Reserve (Dr. P. Goodman, Mkuzi Game Reserve) north of False bay in northern Natal.

Indigenous trees in this area provide a cheap, easily obtainable supply for some of the necessities of rural life: building materials, fuelwood and fences. Tree-cutting, however, has the potential to impact negatively, through stress or disturbance (described above), on the persistence of heavily utilised species in wooded areas where harvesting occurs (Liengme 1983, Gandar 1983a, b, 1984a, Chidumayo 1987, Cunningham, Cooper & Cawe 1988). In this article I present estimates of standing crop of available trees in the resource area and the impact of present harvesting pressures on this resource base.

The following objectives were defined for use in achieving the study aims: (The key questions and methods used in meeting these objectives are stated in each of the relevant sections)

1. Description of the woody plant communities of the resource area.
2. Identification of woody plants and woody plant parts used by local people.
3. Quantification of current resources for comparison with (a) future studies, and (b) present harvest rates.
4. Quantification of current wood harvest and harvest rates.

STUDY AREA

The study was based in the resource area with data collected in an adjacent communal area for comparisons.

Physical and Vegetation information

The resource area, referred to as the Makaza Nature Reserve, lies between 27°45' and 27°47'7''S and 32°22' and 32°27'30''E. It covers 15.7 km^2 and includes the Nemoro, Malelo and Pondweni districts bordering the Native Reserve No. 17638. The altitude varies between 20 m ASL in the south-east and 60 m ASL in the north-west. Rainfall in the area is approximately 750 - 800 mm per annum (Maud 1980). The geology appears to be fairly uniform, the area being entirely on Quaternary Argillaceous sand. There are a series of parallel dunes running on a north-east to south-west axis in the western area and the sands vary in depth with the dunes, as does woody species composition and density. In the east sand depth declines constantly, reaching a minimum at a vlei and watercourse and then increasing in depth further east.

The vegetation falls within Acocks' (1988) Veld Type No. 1, termed Coastal Forest and Thornveld, Zululand Palm Veld Type. It is characterised by open thornveld with numerous and extensive patches of [illegible] and is associated with sandy soil on a badly drained coastal plain. Sand forest patches consist of short, tangled vegetation. Important species mentioned by Acocks and found in forest patches within the study area are: *Brachylaena discolor*, *Kraussia floribunda*, *Cussonia* spp., *Dalbergia obovata*, *Tricalysia* spp., *Ochna natalitia*, *Ziziphus mucronata*, *Sclerocarya caffra*, *Combretum molle*, *Trichilia emetica*, *Cordia caffra*, *Syzygium cordatum*, *Landolphia kirkii*, *Maytenus senegalensis*, *Spirostachys africana*, *Euclea natalensis*, and *Albizia adianthifolia*.

There is little information about the thornveld in Acocks' classification. It appears, in the study area, to be characterised by *Acacia nilotica*, *A. gerardii*, *A. karoo*, *Maytenus heterophylla*, *M. senegalensis*, *Euclea divinorum* and *Ziziphus mucronata* (see TWINSPAN results). The thornveld in this area appears to be invading the vlei area: no evidence of mature trees in the vlei area was found on 1: 10 000 orthophoto maps dated 1979. Present vegetation surveys in this study revealed that the vlei area is characterised by ±3 m tall (250 - 400 mm circumference at base) *Acacia* species, predominantly *A. nilotica*.

Community information

No settlements occur within the resource area. All habitation occurs on the southern and eastern boundaries of the area. Settlements are rural kraals interspersed with areas of indigenous vegetation and farmlands. Most kraal occupants keep cattle which graze in the communal or resource areas. There is an extensive system of footpaths throughout the areas. Wood harvesting in the area has been historically and is at present uncontrolled.

METHODS

Aerial photographs (1: 250 000) and orthophoto maps (1: 10 000) were used to map and calculate the extent of discrete landscape units in the resource site. These units were recognised by members of the local human community (see interview results). Criteria for definition of the four landscape units included topography and vegetation density (visual colour) and patterning (clumping or more homogeneous distribution). The landscape units described were:

A. open canopy thorn and bush veld with a band of *Terminalia sericea* (517 ha);

B. open canopy thornveld with sand forest clumps on termite mounds in low vlei areas (285 ha);

C. closed canopy sand forest on dune tops (580 ha); and

D. closed canopy sand forest clumps in low areas between dunes (195 ha).

The following terms were used to describe the landscape units: Bushveld (Unit A), Thornveld (Unit B), Sand forest (Unit C), and Forest clumps (Unit D). The validity of the separation of these units according to species composition was assessed using detrended correspondence analysis (CANOCO, ter Braak 1990) and two way cluster analysis (TWINSPAN, Hill 1979).

These landscape units were recognizable in the field and sampling for resource base and harvesting impact was stratified with number of samples corresponding to the proportion of area occupied by each landscape type.

Aspects of present utilisation

Not all trees are equally attractive in terms of their potential for use as fuelwood or building material. Preferences in species and size classes were determined from interviews and inspection of harvest bundles.

1. Interviews

Interviews were carried out, aided by an interpreter, with people living in kraals along the southern boundary of the resource site. Interviews followed a standard questionnaire format (Appendix A), with questions covering wood utilisation (species and areas used), number of people living in the kraal, duration of occupancy of the kraal, alternative sources of fuel, lighting, or building materials.

2. Harvest bundles

Where permission was obtained, bundles of fuelwood, poles or laths transported out of the resource area were inspected. Bundles found at kraals during interviews (if harvested in the resource site) were also inspected. Species, circumference at base and apex, and length was recorded for each piece of wood in each bundle.

Vegetation sampling:

1. Resource base quantification

Key question: What is the amount of wood available for harvesting ?

Species composition and population structure of woody species were determined using stratified regular quadrat sampling. Standard forest biome sampling quadrats of 400m^2 were used (Van Daalen 1988). Circular quadrats were selected in favour of square ones due to the ease of laying out in dense vegetation. Quadrats were placed at 200 m intervals along transects running north-south across the resource area. Transects were sited at 250 m intervals along the S boundary. This method resulted in a sample size of 126 quadrats. Sampling was strictly according to this procedure in Bushveld, Thornveld and Sand forest. Quadrats in Forest clumps were sited in the centre of the closest clump and results for number of trees per hectare calculated using average area of a clump and number of clumps in the landscape unit. Number of clumps was estimated by randomly counting the number of clumps in 50 1 ha areas on a 1:10 000 orthophoto and extrapolating for the landscape unit.

Criteria measured or recorded for each tree in each quadrat were: species, circumference above basal swelling (in size classes of 50 mm increment), estimated height of pole potentially chopped from that tree, evidence of harvesting (estimated as the percentage of liveweight of the tree removed), evidence of coppicing (measured as the height of the coppice and number of stems) and an estimate of the age of the cut(s) (ie this season or previous to this season) if no coppicing was visible. Amount of deadwood per quadrat was estimated in number of pieces in classes of 50 mm circumference increment.

The available harvest in the area was divided into two components following the uses for which the wood is harvested: (a) fencing and building poles and (b) fuelwood.

a) Fencing and building resources

Total available resources for each landscape unit were calculated and from this the available resources for building and fencing were estimated. In order to do this, potentially harvestable species and selected size classes of each species were determined from interviews and inspection of bundles. Available resources in trees per hectare were calculated for each of these harvestable species, with the remainder of species being lumped in a "miscellaneous" category. Available standing crop in each size class for each species was calculated as basal area (BA) of trees per hectare, an index of biomass (Rutherford 1978) representing the physical area of the sample occupied by plant stems. BA was calculated for each size class using the following formula:

$$BA = N * (pi * (circ / (2 * pi))^2)$$

where N is number of trees per hectare in that size class, and circ is the average circumference of each size class. BA's were totalled for each species, for each landscape unit and for the resource area.

Basal areas for each size class for each species were converted to total biomass (TB) in tonnes per hectare for comparison with harvest data. An estimate of the lengths of poles (HT) obtained from each size class was needed to calculate volume of available resources. This was obtained by calculating the average length of pole found in each size class for each species and plotting these against size class. The plots were then smoothed using a weighted running average and an estimate of pole length read off. TB values were calculated using the following formula:

$$TB = D * N * (HT * (pi * (circ / (2 * pi)^2)))$$

where D is the density of that species in kg.cm^3 (van Wyk 1990), N is number of trees per hectare in that size class, HT is the estimated length of pole obtained from that size class, and circ is the average circumference of poles in each size class.

b) Fuelwood resources

An estimate of available fuelwood in each landscape unit was calculated from (a) deadwood (DW), measured as the total mass of pieces of harvestable size per hectare, plus (b) livewood (L), the number of fuelwood sized pieces remaining after poles have been removed after chopping a live tree. L is added since the remainder of branches not suitable for building or fencing poles is allowed to dry and used for fuelwood. L is measured as mass of harvestable pieces per hectare. DW was estimated for each size class as:

$$DW = N * (D * (HT * (pi * (circ / (2 * pi)^2))))$$

where N is the average number of pieces of deadwood in that size class, D is the average density of harvested species (900 kg.m^3, after van Wyk 1990), HT is the average length of fuelwood pieces in that size class, and circ is the average circumference of poles in each size class.

An estimate of L was calculated in 3 steps as follows: (1) an estimate of the average number of fuelwood pieces of each size class obtained from 10 trees of the most preferred species (2 of each species) in the size class 410 -

450 mm was made. An estimate for smaller and larger size classes was made from these data. These estimates were converted to tonnes per size class using the same formula as used to calculate DW. (2) For each landscape unit the number of trees harvested per size class per hectare was calculated from harvest data (see quantification of present harvesting). Results were then multiplied by the result of step (1). (3) Results for size classes were summed to give an estimate of fuelwood resulting from pole chopping in each landscape unit.

The values of DW and L were summed for the resource area and compared to estimate of fuelwood used.

2. Quantification of present harvesting

Key questions: What is the present extent of harvesting for building and fencing in the resource area ?

What is the present rate of removal of livewood and deadwood for use as building material and fuelwood from the resource area ?

Three broad zones of utilization exist in the area: (1) areas within the resource site which are "far" from settlement influences, (2) an area of intermediate harvesting along the southern edge of the resource site, close to settlements, and (3) an area of heavy utilization along the outside southern edge of the resource site, in the communal area. The width of area (2) was defined as the distance from settlements at which harvesting of building and fencing poles was no longer visible and was measured for each landscape unit.

a) fencing and building

Paths in both the communal area (starting at a kraal) and in Makaza (starting at the southern boundary) were followed and circular quadrats of 400 m^2 were placed every 50 m along the paths. Each quadrat was placed with the centre in the centre of the path. Paths in the communal area were followed until the next kraal was reached. Paths in Makaza were followed until no evidence of chopping was found for 10 consecutive quadrats. No sampling was done in Zone 1. This method of data collection allowed for estimates to be made of the extent of harvesting into each landscape unit in the resource area and an estimate of the number of trees harvested within the impacted area. Species, circumference, percentage of the tree removed, presence or absence of coppicing and an estimate of the age of cuts were recorded for each tree showing evidence of chopping.

This provided information on: (a) species harvested; and (b) number of trees affected per landscape unit, and, for the resource area, (c) distance into the resource area to which present harvesting of poles extends. This information was used to compare: (a) between utilization zones, to see if intensity of harvesting (measured in trees per hectare) in the resource area is tending toward intensity of harvesting in the communal area; and (b) with the resources available for each landscape unit and each species.

Harvesting of building and fencing poles has only been occurring over the past 3 years due to the lack of maintenance of the fence between the resource site and communal area. Estimates of age of cuts from harvesting could only reliably be placed into two categories: (a) cuts having been made in this season (ie after the end of the previous rainy season), and (b) cuts having been made in the previous two seasons. The number of trees exhibiting evidence of chopping in each of these categories were summed for each landscape unit and the proportions in each category calculated. These proportions were then multiplied by the values obtained for total harvest in each unit in order to determine the rate of harvesting in the two categories.

b) fuelwood

An estimate of rate of removal of deadwood from the area was calculated as: Average mass of fuelwood bundle * number of bundles used per year (from interview data) * number of kraals utilising resource site for fuelwood.

RESULTS

Vegetation description

1. Ordination

Results of the ordination according to species are presented in Fig. 1. The independent axis appears to represent elevation, with sites at low elevation close to the origin and sites of higher elevation further from the origin. As is evident from Fig.1, Thornveld is the most reliably separated according to species. Sand forest and Forest clumps cannot be reliably separated according to species, and Bushveld lies between Thornveld and the cluster of Sand forest and Forest clumps. The eigenvalue for axis 1 was 0.730 and 0.469 for axis 2, indicating that these axes account for 64.7 % of the species relationship expressed in the ordination.

2. Classification

Species abundance and sites were classified using TWINSPAN (Fig. 2). For presentation in this paper, classification was cut off at four groups as this was the number of groups recognised in the field study. The first division divides quadrats in Thornveld (n=33 quadrats) from quadrats in Bushveld, Sand forest and Forest clumps (n=93). Indicator species for this division were *Acacia nilotica* and *A. karoo* for quadrats in Thornveld and *Combretum molle, Euclea natalensis, Strychnos madagascariensis, Tricalysia lanceolata* and *Dichrostachys cinerea* for the remainder of the quadrats. Five quadrats were classified in Thornveld which were not recognised as being in Thornveld in the study. All of these sites were situated on the boundary between Thornveld and Bushveld in the resource area. The second division separates quadrats in Bushveld (n=28) from quadrats in Sand forest and Forest clumps (n=65). *Dichrostachys cinerea* and *Maytenus senegalensis* were given as indicator species for Bushveld and *Tricalysia lanceolata, Acacia burkei, Spirostachys africana* and *Dovyalis longispina* for Sand forest and Forest clumps. Again "borderline" quadrats which were recognised as being in different landscape units in the field study were found, in this case four quadrats. The third division separated Thornveld into two sub-units. The first (n=18), indicated by *Acacia nilotica*, corresponds to the open canopy thornveld described previously. The second (n=15), indicated by *Sideroxylon inerme, Maytenus heterophylla, Maytenus senegalensis* and *Dichrostachys cinerea*, corresponded to the sand forest clumps described previously.

As is evident from Figure 2, Sand forest and Forest clumps were not separated at the second level. This was expected, since both units represented sand forest and were recognised to have similar species composition. The difference between the units and the reason why they were separated in the field study was that unit D represented sand forest showing a clumped distribution on raised areas in depressions between dune series. The absence of trees between clumps in this landscape unit was possibly due to waterlogging in lower areas. Sand forest in unit C showed a more homogeneous distribution. This was important as the resources for wood harvest were relatively less in unit D as a result of the open areas between clumps, and thus needed to be calculated separately from resources in unit C.

Aspects of present utilisation

1. Summary of data from interviews

The average number of people per kraal in this area was 10 (n=12, range 7-15). There was a distinct division of labour in wood harvesting: the women collected fuelwood and the men collected fencing and building poles.

The positioning of kraals in relation to resources may be a factor influencing spatial aspects of harvesting. There were 12 kraals within 150 m of the southern boundary of the resource area. The spacing of kraals along the boundary of the resource area was not uniform. Of 12 kraals 8 occurred adjacent to Sand forest and Forest clumps, 3 adjacent to the western portion of the Bushveld area and 1 adjacent to the Thornveld area.

Of the 12 women in 6 kraals interviewed (2 women per kraal collect fuelwood), 10 collected fuelwood in Makaza and all used only deadwood. Areas most popular in the collection of fuelwood were Sand forest and Forest clumps (8 of the 10 women collected in these areas). Species preference was not marked. Size classes taken were: 1 - 2 m long, 150 - 350 m circumference. The average length of time one bundle of approximately 18.5 kg was said to last was 3 days (summer) and 2 days (winter). An estimate of 2 days was used in calculating the amount of fuelwood used in the area. None of the women interviewed perceived a shortage of fuelwood in the area, all noted immigration of people into the area in the preceding year and expressed concern for the future. Only one kraal used a paraffin stove. All used candles for lighting.

Six men were interviewed from 6 of the kraals along the resource area boundary. All men interviewed obtained poles for building and fencing in Makaza. Wood harvested for fencing posts and building poles was lumped in the analyses as species preference and size classes taken were similar. The species reported to be harvested were (in average order of preference): *Spirostachys africana*, *Terminalia sericea*, *Acacia burkei*, *Combretum molle*, *Tricalysia lanceolata*, *Albizia adianthifolia*, *Pteleopsis myrtifolia*, *Cleistanthus schlechteri*, *Galpinia transvaalica* and *Sapium integerrimum*. The preference of these species was reported to be governed by: (1) species reaching harvestable size classes, and (2) information communicated from father to son on the species that will last the longest before rotting or being eaten by termites. The size classes preferred were 1.5 - 3 m long, 50 - 150 mm circumference and 3 - 5 m long, 250 - 600 mm circumference.

All of the men interviewed noted the increasing rate of immigration into the study area and the resulting increase in demand for building materials. They also mentioned the possibility of harvest of poles for sale, but no-one admitted to practising or knowing anyone harvesting for sale. The impact of harvest for sale is thus unknown at this stage.

2. Summary of data from harvest bundles (23 bundles)

Building and fencing harvest consisted of poles and laths. Poles are defined above, laths are thinner, more pliable stems which are woven between the poles in building construction. Note that pole harvest results in the removal of the tree from the base, whereas branches may be harvested for laths. Laths are more commonly harvested from multi-stemmed species.

Twenty-three bundles of harvested poles and laths were inspected in the resource site and communal area. Bundles comprised 620 laths (50 - 150 mm in circumference and 3-5 m in length) and 351 poles (200 - 600 mm in circumference and 3-5 m in length). The species most commonly used for laths were *Tricalysia lanceolata* (29 % of all laths), *Euclea natalensis* (11 %), *Brachylena discolor* (10 %) and *Combretum molle* (5 %). Fifty-five percent of the lath harvest comprised these four species. The most commonly used species for poles were: *Spirostachys africana* (23 % of all poles), *Terminalia sericea* (21 %), *Acacia burkei* (13 %), *Euclea natalensis* (11 %) and *Combretum molle* (5 %). Seventy-three percent of the pole harvest comprised these five species.

Vegetation sampling

1. Resource base quantification

a) fencing and building resources

The distribution of total resources, in basal area per hectare, are presented in Appendix B. Note that the five most preferred species contribute a large proportion of total resources in each landscape unit (38 % in Bushveld, 10 % in Thornveld, 55 % in Sand forest and 29 % in Forest clumps). The number of individuals of the preferred species and their size class distribution in each landscape unit are presented in Appendix C as base values for comparison with future studies.

From these total resources the acceptable resources, the number and basal area of trees in the preferred size classes, are presented in Table 1 and 2 Note that the most favoured species for building and fencing, *Spirostachys africana*, shows the highest values of basal area per hectare in all landscape units. The second most favoured species, *Terminalia sericea*, shows the second highest basal area in all landscape units.

b) Fuelwood resources

Available deadwood resources in the resource area are presented in Table 3. Sand forest produces the greatest amount of deadwood per hectare. Available fuelwood resulting from the chopping of poles ("livewood") is presented in Table 4. Total fuelwood resources resulting as a by-product of harvesting of poles (at the present rate) is far greater than that contributed by deadwood. *S. africana* was included in the estimate of "livewood" (q ns on its use for fuelwood were omitted from interviews and should have been more thoroughly investigated). Even with this species omitted, however, fuelwood available as "livewood" is greater than deadwood in all landscape units.

2. Quantification of present harvesting

a) Building and fencing

Harvesting impact extended for the shortest distance into the resource area in the densest vegetation type (Sand forest), and the greatest in the least dense unit (Bushveld) (Table 5). The percentage of area utilised is the least for the unit showing the highest biomass (Sand forest). The total area impacted is 641 ha of the total 1570 ha.

The communal area showed the greatest number of trees per ha showing harvest impact (Table 6). The difference between number of trees showing harvest impact in the communal vs the resource area was significant for all landscape units (Bushveld: $t=4.063$, $DF=23$, $P<0.001$; Thornveld: $t=3.502$, $DF=23$, $P=0.002$; Sand forest: $t=2.271$, $DF=29$, $P=0.031$; Forest clumps: $t=5.110$, $DF=29$, $P<0.001$).

Harvesting of building and fencing poles in the resource area has been occurring only over the past 3 years. Harvest ($trees.ha^{-1}$) was calculated in two categories: (a) trees showing fresh harvesting signs, taken to be the previous season's harvest, and (b) trees showing old cuts or coppicing, taken to represent harvest during the preceding two seasons. Table 7 shows the number of trees harvested over the previous season and the preceding two seasons and the previous season's harvest as a percentage of the total harvest over the last 3 years. As calculated from this table and Table 5, the total harvest in the resource area over the last 3 years was 600 trees per year, 228 trees last season (0.36 trees.$ha^{-1}.y^{-1}$), and 372 trees over the previous two seasons (0.58 trees.ha^{-1} for two seasons). An estimate of harvesting rates in the communal area was made by calculating number of trees per hectare showing harvest impact and dividing by 10 (the best estimate of the number of years that pole harvesting has been occurring in the communal area). This gave an estimate of 2.5 trees.$ha^{-1}.y^{-1}$ in the communal area.

The five preferred species made up a smaller proportion of the harvest in the communal area than in the resource area (Table 8), and there are consistently more species harvested in the communal area compared to the resource area.

b) Fuelwood

Permission was obtained to weigh 3 fuelwood bundles. Their weights were 18, 22.5 and 15 kg respectively. the mean weight of fuelwood bundles harvested from the resource area was thus estimated as 18.5 kg.

DISCUSSION

Aspects of present utilisation:

Two aspects of present harvesting of poles emerged in this study which affect the comparison of available resources and harvesting in the resource area. The first of these is species choice. This is of importance because the most preferred species are also at present the most common species (although interview results showed species choice was not solely based on commonness or rarity). Under heavy levels of utilisation, when suitable trees of the preferred species used for poles begin to become less common, harvesters are faced with a decision either to walk further and look for more of the preferred species, or to accept less preferred species of the acceptable size classes. Both the interviews (N = 6) and results of species choice (see Table 7) support the latter; a harvester will accept a tree of a less preferred species in preference to walking further to find a more preferred species.

The second aspect is harvest rates, which appear to be changing over time. If the harvest over the last 3 years had been constant, one would expect last year's harvest to contribute 33.3 % to the total harvest for 3 years. As is evident from Table 8, a larger percentage of the harvesting has occurred in last season for all landscape units except Forest clumps. This implies that the average harvest removed from the area may be increasing. This is indirectly supported by the results of interviews in which accelerated levels of immigration into the area was noted by people already settled in the area.

These aspects are reviewed more fully in the second manuscript of the research report.

Fencing and building resources:

Stem basal areas calculated for each landscape unit were 9.43 $m^2.ha^{-1}$ for Bushveld, 7.61 $m^2.ha^{-1}$ for Thornveld, 12.47 $m^2.ha^{-1}$ for Sand forest and 5.43 $m^2.ha^{-1}$ for Forest clumps. Woody plant abundance expressed as basal area are low in comparison to those reported for *Celtis africana* dune forest (26.2 $m^2.ha^{-1}$), for mesic forest (31.33 $m^2.ha^{-1}$) in Hlatikulu forest reserve (Muir 1990), for Transkei forest (10-50 $m^2.ha^{-1}$, Cawe & McKenzie 1989b), and for mangrove and swamp forest communities (100$m^2.ha^{-1}$, Rutherford 1978). Basal areas calculated for the resource area are more comparable to those calculated for areas of the northern Transvaal *Burkea africana-Ochna pulchra* woodland (8.9 $m^2.ha^{-1}$, Rutherford & Kelly 1978) and Zambian wet miombo (*Brachystegia-Julbernardia*) woodland of (9.81 $m^2.ha^{-1}$, Chidumayo 1987).

In order to compare the above estimates of available resources for building and present harvest impacts in some meaningful way it is necessary to estimate the effects of present harvesting on available resources. The simplest method of estimation of use in this situation is an accounting-type model assessing annual harvest of live trees as a fraction of total resource availability, and thus calculating the number of years that the present standing crop would last at the present harvesting rates.

The present harvesting rate occurring in the impacted portion of the resource area was approximately 230 trees.yr^{-1}. Assuming no recruitment or growth of trees, the resource of preferred species will last 1300 years if preferred species only are harvested. If both preferred and secondary species are harvested, present resources will last 1870 years. Harvest in the resource area has, however, increased over the last season as compared to the previous two seasons and is very low (almost a factor of 10 lower) in comparison to harvest in the communal area. If the harvest rate in the communal area is extrapolated for the entire resource area, not only the present impacted portion, a worst scenario estimate of 3926 trees would be removed per year. At this rate harvesting of the preferred species alone could continue for 75 years and harvesting of the preferred and secondary species could be sustained for 110 years.

Obviously, this model and the estimates it produces are over-simplified: factors increasing the available resource base such as growth, coppicing or recruitment of trees are omitted, as are factors decreasing the available resource. The inclusion of these factors into a model of resource base and harvesting is carried out in the following draft manuscript.

Fuelwood:

The estimate of 18.5 kg for mean fuelwood bundle weight is fairly low when compared to other regions (24.15 kg in Ciskei (Bembridge & Tarlton 1988), and 29.95 kg in Gazankulu (Liengme 1983)). Bembridge and Tarlton, however, state that women collect smaller headloads more often when firewood is plentiful.

The current rate of removal of deadwood from the resource area is approximately 6.4 tonnes per kraal per year. This amounts to 76.4 tonnes per year, or 0.64 tonnes per capita per year. The total available resource of deadwood in the resource area is 1.56 $t.ha^{-1}$, yielding a total of 2500 tonnes for the resource area. At the present harvesting rate, and assuming no additional deadwood production, this resource will provide fuel for the people currently harvesting in the area for 33 years. Note, however that this estimate will vary if the number of people in the area (and thus the harvesting rate) does not remain constant or harvesting does not occur over the entire resource site. This estimate will also vary according to annual production of deadwood in the resource area. Rate of deadwood production for coastal areas has not been investigated. Rutherford (1978) estimates average annual production rate of live and deadwood as 4 - 5 % of total standing biomass in savannas. Shackleton (1993) provides estimates of deadwood of 0.7 - 3.9 % of total standing biomass (for harvested and unharvested areas respectively) in eastern-Transvaal savannas. Neither of these estimates provide information on the rate of deadwood production. The rate of deadwood production necessary to maintain the present harvest is further investigated in the following draft manuscript.

The per capita consumption of fuelwood depends primarily on the availability of wood and to a lesser extent on climate and social parameters (Gandar 1983a). Gandar (1983a) suggests a rule of thumb of one tonne per capita per year in rural Africa. Fuelwood use in the resource area is 0.64 tonnes per capita per year, a comparable value to published estimates for other wooded areas (see Table 9).

Most of the interviewees stated that they harvested no livewood for use as fuelwood, but that they did use wood remaining after building or fencing poles were chopped. From Tables 1 and 2 it is evident that the amount of wood potentially available after chopping of poles far exceeds the availability of deadwood in the resource area.

Questions concerning future harvest rates and impacts should be addressed by monitoring using the same methods as described in the present study, with results compared with results presented for this study.

SUMMARY AND CONCLUSIONS

1. Harvesting of woody species for building and fencing in the study area is carried out by men and is very selective, with approximately 75 % of the total harvest being of the five preferred species. These preferred species are, in order of preference *Spirostachys africana*, *Terminalia sericea*, *Acacia burkei*, *Euclea natalensis* and *Combretum molle*. Selection of size classes is equally selective, with building poles being of 200 - 500 mm circumference. Present harvest rates in the resource area are 0.36 trees per hectare per annum, in comparison to the 2.50 trees per hectare per annum harvested in the communal area.

2. Harvest of a single pole for building or fencing means the removal of the tree from the base. Branches remaining after the pole has been removed are left and may be collected later for fuelwood.

3. Collection of fuelwood is carried out by women and is not species selective. Only deadwood is harvested. Current fuelwood harvest is 6.4 tonnes per kraal per year (76.4 tonnes per year for the 12 kraals in the study).

4. Harvest of livewood for building and fencing appear to have increased over the last 3 years in the resource area, but are still almost a factor of 10 lower than harvest rates measured for the adjacent communal area.

5. The duration for which the resources of preferred pole species will last at the present harvest rates is 1300 years, or, if both Preferred and Secondary species are harvested, 1870 years. Note, however, that these estimates are unreliable as they are based on a static resource base and do not take into account regeneration, growth, or death.

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TABLE 1. Available standing crop of fencing and building resources in Makaza Nature Reserve. (Presented as number of trees per hectare ($no.ha^{-1}$) for each landscape unit).

Unit	Preferred species		Preferred + Secondary species	
	($no.ha^{-1}$)	total (no.)	($no.ha^{-1}$)	total (no.)
Bushveld	161	83087	199	102661
Thornveld	49	14048	307	87535
Sand forest	296	171929	356	206729
Forest clumps	152	29667	174	33846
Resource area	189	96679	273	129693

TABLE 2. Fencing and building resources in Makaza Nature Reserve. (Presented as basal area per hectare ($m^2.ha^{-1}$).

Species	Landscape unit				Resource area
	A	B	C	D	Total
Building poles					
Preferred species:					
Spirostachys africana	0.62	0.45	0.58	0.22	0.53
Terminalia sericea	1.16	0.04	0.34	0.02	0.52
Acacia burkei	0.03	0.08	0.83	0.20	0.36
Combretum molle	0.29	0	0.85	0.19	0.43
Euclea natalensis	0.04	0	0.26	0.28	0.14
Total ($m^2.ha^{-1}$)	2.14	0.57	2.86	0.92	1.72
Secondary species:					
Albizia adianthifolia	0	0	0.07	0	
Pteleopsis myrtifolia	0	0	0.38	0.11	
Galpinia transvaalica	0.15	0	0	0.03	
Sapium integerrimum	1.19	0	0.15	0.10	
Sideroxylon inerme	0.02	0.23	0	0	
Antidesma venosum	0.07	0	0	0	
Acacia nilotica	0	2.40	0	0	
Dalbergia obovata	0	0	0	0	
Total poles ($m^2.ha^{-1}$)	3.57	3.20	3.48	1.15	
Laths					
Tricalysia lanceolata	0	0	0.11	0	
Vepris reflexa	0	0	0.16	0.08	
Brachylena discolor	0.03	0	0	0	
Rhus gueinsii	0.01	0	0	0.03	
Total poles and laths	3.61	3.20	3.73	1.26	

TABLE 3. Fuelwood resources available (as dead wood) in each landscape unit. (Presented in tonnes per hectare, where the average weight of a 160 - 200 mm circumference piece is 0.9 kg, a 210 - 250 mm piece is 1.2 kg and a 260 - 350 mm piece is 2.3 kg).

Unit	acceptable fuelwood size classes (mm) 160-200 ($t.ha^{-1}$)	210-250 ($t.ha^{-1}$)	>250 ($t.ha^{-1}$)	Total ($t.ha^{-1}$)	Total (tonnes)
Bushveld	1.02	0.31	0.09	1.42	734.1
Thornveld	0.54	0.20	0.10	0.84	235.2
Sand forest	1.59	0.51	0.12	2.22	1287.6
Forest clumps	0.52	0.31	0.16	0.99	193.1
Resource area				1.56	784.1

TABLE 4. Fuelwood resources available (as "livewood" leftovers from pole harvesting) in each landscape unit. (Presented in tonnes per hectare, where the average weight of a 160 - 200 mm circumference piece is 0.9 kg, a 210 - 250 mm piece is 1.2 kg and a 260 - 350 mm piece is 2.3 kg).

Unit	Acceptable fuelwood size classes (mm)				
	160-200 ($t.ha^{-1}$)	210-250 ($t.ha^{-1}$)	>250 ($t.ha^{-1}$)	Total ($t.ha^{-1}$)	Total (tonnes)
Bushveld	1.94	0.95	0.74	3.63	1875.0
Thornveld	0.75	0.38	0.30	1.43	398.3
Sand forest	4.55	2.39	2.07	9.01	1750.1
Forest clumps	0.43	0.22	0.17	0.82	477.3
Resource area				4.89	1395.5

TABLE 5. Building and fencing harvest impact in resource area. (Impact is measured in distance along paths to which harvesting is visible (m)).

Unit	Paths (N)	Mean distance (m)	sd (m)	% area impacted	Area (ha)
Bushveld	2	1300	350	65.4	338
Thornveld	4	425	152	28.1	80
Sand forest	3	566	85	27.6	160
Forest clumps	4	675	103	32.3	63

TABLE 6. Building and fencing harvest impact in resource area over 3 years and in the communal area over ± 10 years. (Impact is measured in number of trees showing evidence of chopping per hectare (no.ha^{-1})).

Unit	Resource area Quadrats (N)	Trees impacted (no.ha^{-1})	Communal area Quadrats (N)	Trees impacted (no.ha^{-1})
Bushveld	118	0.86	24	7.86
Thornveld	36	0.94	30	10.12
Sand forest	84	1.24	30	12.33
Forest clumps	58	0.56	25	6.55

TABLE 7. Percentages and totals of trees harvested over last season and the previous season in the resource areas (Harvest is presented as total number of trees (no.)).

Unit	Harvest previous season	Harvest preceding 2 seasons	Previous season as a % of total
Bushveld	136	156	46.6
Thornveld	22	53	29.3
Sand-forest	67	131	33.8
Forest clumps	3	32	8.6

TABLE 8. Selection of trees for building and fencing poles in the communal area and the resource area. (Where N is the total number of species harvested in that unit and % is the percentage of harvest made up by preferred species).

Area	Bushveld		Thornveld		Sand forest		Forest clumps	
	N	%	N	%	N	%	N	%
Resource	9	90.4	9	62.5	15	52.1	11	43.6
Communal	20	38.5	23	35	28	20	26	21

TABLE 9. Rates of fuelwood consumption in rural Africa. (After Gandar 1983a).

Area	Fuelwood consumption ($t.cap^{-1}.yr^{-1}$)	Reference
Jozannas nek, Transkei	0.27	Best 1979
Malefilone, Lesotho	0.29	Best 1979
Mhlabatini, Kwazulu (high grassveld)	0.62	Gandar 1982
Mhlabatini, Kwazulu (valley lowveld)	0.72	Gandar 1982
Gazankulu, mopane veld	0.76	Liengme 1983
Mashunka	1.12	Best 1979
Ciskei	1.14	Bembridge & Tarlton 1988

Captions to Figures:

Fig. 1: Correspondence analysis plot of sample sites according to species composition. Where ● represents samples in Bushveld, ○ represents samples in Thornveld, ■ represents samples in Sand forest, and □ represents samples in Forest clumps.

Fig. 2: Dendrogram of TWINSPAN classification of quadrats.

Where: ACBU = *Acacia burkei*, ACGE = *A. gerrardii*, ACKA = *A. karroo*, ACNI, = *A. nilotica*, ACRO = *A. robusta*, ALAD = *Albizia adianthifolia*, ANVE = *Antidesma venosum*, CAAE = *Cassine aethiopica*, COMO = *Combretum molle*, CONE = *Commiphora neglecta*, DICE = *Dichrostachys cinerea*, DOLO = *Dovyalis longispina*, EUNA = *Euclea natalensis*, MAHE = *Maytenus heterophylla*, MASE = *M. senegalensis*, PTMY = *Pteleopsis myrtifolia*, RHGU = *Rhus gueinsii*, SIIN = *Sideroxylon inerme*, SPAF = *Spirostachys africana*, STMA = *Strychnos madagascariensis*, TESE = *Terminalia sericea*, TRLA = *Tricalysia lanceolata*.

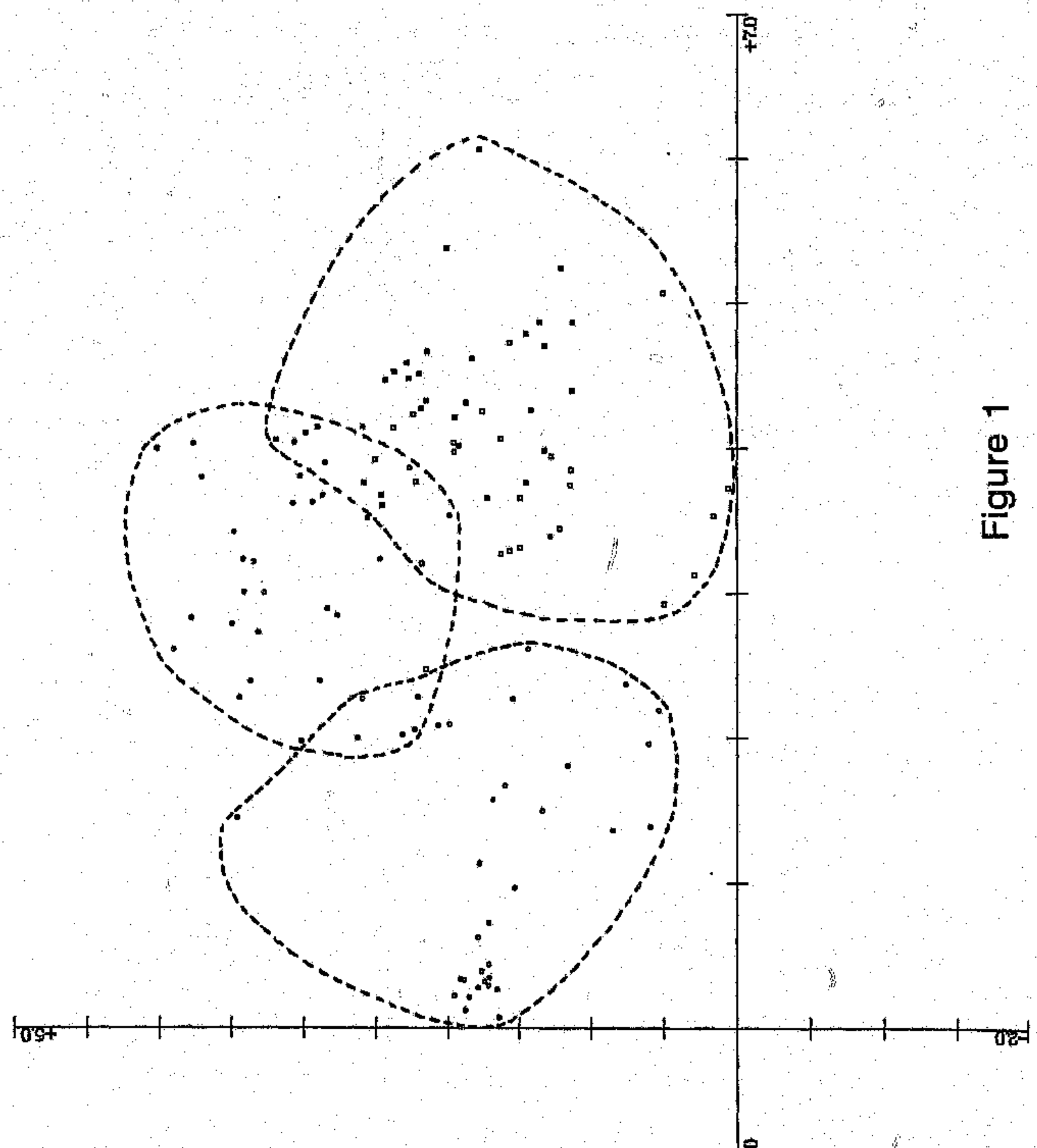
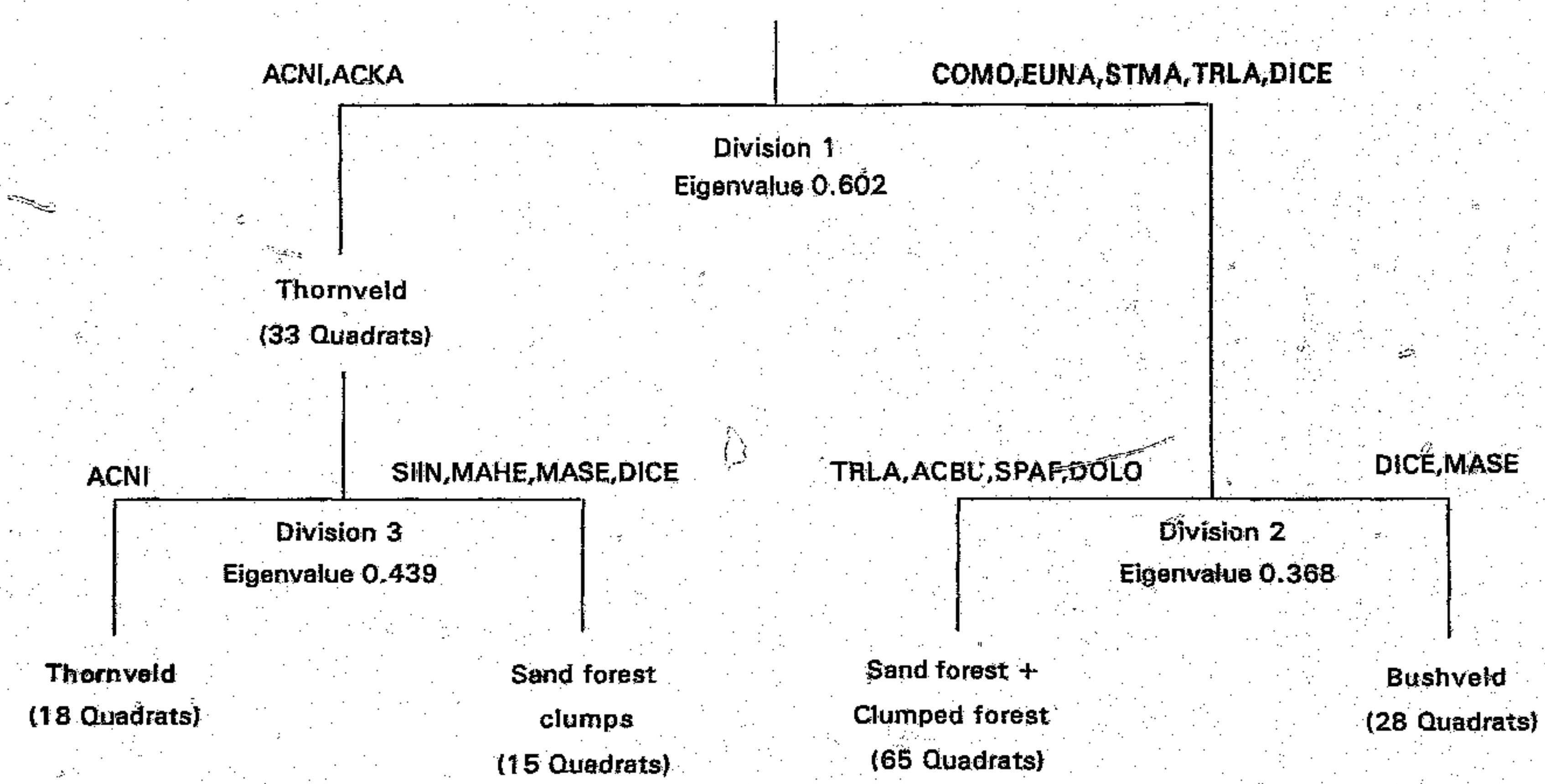


Figure 1



Positive preferentials for each group

Thornveld: ACGE,ACKA,ACNI,EUDI,MAHE

Bushveld: ACNI,ANVE,MASE,DICE,TESE

Sand forest: ACBU,ACRO,ALAD,CAAE,CONE
PTMY,RHGU,SPAF,TRLA,EUNA

Figure 2

<u>Appendix A</u>: Wood use questionnaire.

1. How long have you been living in this area ?

2. How long has (a) fuelwood collection and (b) pole harvesting been occurring in the communal area ?

3. Where do you collect wood ? (communal area or resource area, and where in the resource area).

4. What do you collect wood for ? (eg firewood, fences, building, carving/curios)

A. Fuelwood questions:

5. How many people do you collect wood for ?

6. How long will this wood last ? (in winter / summer in days)

7. What are the best trees (species) to collect ? (Ranked)

8. What is the best size of tree to collect ? (circ / height)

9. Do you collect livewood, if yes, when and where ?

10. Do you collect the leftovers from when trees are chopped for poles ?

11. Do you use any fuels other than wood ?

B. Building questions:

12. What are the best trees (species) to collect, why ? (Ranked)

13. What is the best size of tree to collect ? (circ / height)

14. If there are none of these trees (species) in this area, will you rather walk 30 mins to find another of these trees or will you rather take another tree (species).

15. Are there any trees (species) which you will not use for building ? Why ?

Appendix B: Total resources in Makaza Nature Reserve. (Presented as basal area per hectare ($m^2.ha^{-1}$)).

Species	Landscape unit A	B	C	D	Mean for resource area
Poles					
Preferred species:					
Spirostachys africana	1.36	0.58	1.02	0.39	0.98
Terminalia sericea	1.46	0.04	0.97	0.03	0.85
Acacia burkei	0.10	0.11	3.25	0.40	1.30
Combretum molle	0.50	0	1.31	0.34	0.69
Euclea natalensis	0.13	0.01	0.32	0.40	0.21
Total ($m^2.ha^{-1}$)	3.55	0.75	6.87	1.57	4.04
Secondary species:					
Albizia adianthifolia	0	0	0.16	0	
Pteleopsis myrtifolia	0	0	0.64	0	
Galpinia transvaalica	0.20	0	0	0.17	
Sapium integerrimum	0.24	0	0.17	0.08	
Sideroxylon inerme	0.12	0.52	0	0	
Antidesma venosum	0.25	0	0	0	
Acacia nilotica	0	2.76	0	0	
Dalbergia obovata	0.05	0	0	0	
Total poles ($m^2.ha^{-1}$)	4.31	3.83	7.84	1.82	
Laths					
Trichalysia lanceolata	0	0	0.18	0.11	
Vepris reflexa	0	0	0.57	0.01	
Brachylena discolor	0.17	0	0.24	0.08	
Rhus gueinsii	0.23	0.05	0.19	0.14	
Miscellaneous species	4.80	2.78	4.54	3.27	
Total resources ($m^2.ha^{-1}$)	9.43	7.61	12.47	5.43	7.77

Appendix C: Number and size class distributions of individuals of the five preferred species in each landscape unit. Note that data on secondary preferred species is available form the author.

TABLE 1: Number of individuals of the preferred species in each landscape unit. Numbers (No.) and standard errors (SE) are presented in number per hectare (No.ha^{-1}).

Species	Landscape Unit							
	Bushveld		Thornveld		Sand forest		Forest clumps	
	No.	SE	No.	SE	No.	SE	No.	SE
S. africana	56.3	29.5	88.8	45.7	117.7	35.1	72.0	22.9
T. sericea	161.1	48.2	23.3	19.3	67.7	22.7	17.0	10.3
A. burkei	8.3	5.6	7.8	6.9	165.3	31.4	57.0	14.9
E. natalensis	83.3	21.0	6.0	2.3	138.7	31.3	208.0	38.6
C. molle	44.4	12.3	2.6	1.7	118.5	28.3	76.0	23.2

TABLE 2a: Number of individuals of *S. africana* in each size class in each landscape unit. Presented in Numbers of individuals (No.).

Size class (mm)	Landscape unit Bushveld	Thornveld	Sand forest	Forest clumps
0-50	31.4	11.4	5	11.4
51-100	7.9	12.9	17.1	6.4
101-150	21.4	12.9	22.9	0.7
151-200	15.7	6.4	37.9	4.3
201-250	9.3	0.7	19.2	4.3
251-300	3.6	7.1	15.0	1.4
301-350	5.0	10.7	9.3	3.6
351-400	0.7	5.7	11.4	3.6
401-450	7.1	3.4	1.4	5.7
451-500	7.1	3.4	2.9	7.1
501-550	8.6	4.3	3.6	3.6
551-600	3.6	1.4	2.1	5.6
> 600	15.0	2.1	7.1	8.6

TABLE 2b: Number of individuals of *T. sericea* in each size class in each landscape unit. Presented in Numbers of individuals (No.).

Size class (mm)	Landscape unit Bushveld	Thornveld	Sand forest	Forest clumps
0-50	141.0	0	13.6	1.4
51-100	8.6	1.4	5.7	0
101-150	12.9	1.4	3.6	0.7
151-200	35.7	0	5.0	0.7
201-250	25.7	2.1	7.1	0
251-300	3.6	0.7	11.4	0
301-350	6.4	0.7	6.4	0
351-400	0.7	0.7	2.1	0
401-450	14.3	0.7	6.4	0
451-500	12.9	0	2.1	0.7
501-550	15.7	0	0.7	0.7
551-600	7.1	0	0.7	0.7
> 600	4.3	0	13.6	0.7

TABLE 2c: Number of individuals of *A. burkei* in each size class in each landscape unit. Presented in Numbers of individuals (No.).

Size class (mm)	Landscape unit Bushveld	Thornveld	Sand forest	Forest clumps
0-50	1.44	0	7.1	1.4
51-100	0.7	0.7	5.7	1.4
101-150	1.4	1.4	13.6	0.7
151-200	0	1.4	26.4	0
201-250	0.7	0.7	18.6	2.9
251-300	1.4	0.7	12.1	2.1
301-350	0	1.4	11.4	2.1
351-400	0	1.4	15.7	2.1
401-450	0.7	0.7	4.3	4.3
451-500	0.7	0.7	6.4	5.7
501-550	0	0	7.1	7.1
551-600	0	0.7	2.9	3.6
> 600	1.4	0.7	52.0	10.7

TABLE 2d: Number of individuals of *E. natalensis* in each size class in each landscape unit. Presented in Numbers of individuals (No.).

Size class (mm)	Landscape unit Bushveld	Thornveld	Sand forest	Forest clumps
0-50	244.0	12.9	89.0	121.0
51-100	9.3	0	4.3	10.7
101-150	0.7	2.1	4.3	10.7
151-200	2.1	1.4	5.0	6.4
201-250	0.7	0	20.7	3.6
251-300	0.7	0.7	2.1	7.9
301-350	0	0	1.4	10.7
351-400	0	0	3.6	7.1
401-450	0	0	5.0	10.0
451-300	0.7	0	0.7	4.3
501-550	0	0	1.4	4.3
551-600	0.7	0	0	4.3
> 600	1.4	0	0.7	5.7

TABLE 2e: Number of individuals of *C. molle* in each size class in each landscape unit. Presented in Numbers of individuals (No.).

Size class (mm)	Landscape unit Bushveld	Thornveld	Sand forest	Forest clumps
0-50	27.1	8.6	9.3	14.2
51-100	5.7	0	9.3	2.9
101-150	4.24	0	3.6	4.3
151-200	5.7	0	15.0	5.6
201-250	6.4	0.7	20.0	2.3
251-300	1.4	0	10.7	4.3
301-350	4.3	0	6.4	3.6
351-400	0	0	15.7	4.3
401-450	3.6	0	17.9	6.4
451-500	2.1	0	3.6	3.6
501-550	1.4	0	4.3	3.6
551-600	3.6	0	2.1	4.3
> 600	4.2	0	9.2	7.1

Manuscript 2

Evaluation of the potential sustainability of harvesting of coastal hardwood species by a rural community.

Keywords: KwaZulu, plant population model, sustainable harvesting.

ABSTRACT

A stage-structured model was created to simulate impacts of varying harvest rates on a known resource base. The model was run for three scenarios: harvesting (a) the five most preferred species, (b) the five most preferred species plus a group of eight secondary preferred species, and (c) each of the five most preferred species separately. The model did not simulate a multi-species complex and did not account for spatial diversity in resources or harvesting.

Present harvest rates of 808 trees.y^{-1}, at rates at which each of the species are presently being harvested, appear to be sustainable, based on available estimates of harvest rates and recruitment, in the resource area. However, recruitment rates and growth and mortality rates of immature individuals used were of low reliability, and harvest rates in the resource area are likely to increase as more people colonise the area and resources become limiting in the communal area. The harvest rate of 3926 trees.y^{-1} recorded to occur in the communal area is not sustainable when simulated for the resource area.

INTRODUCTION

The concept of sustainability has become an increasingly popular one invoked in the discussion of human impacts on the environment and used in the formulation of environmental policy (Shea.man 1990). Definition of the term "sustainable", however, appears problematical: sustainability is difficult to measure and thus to define explicitly (Brown *et al* 1987). The term "sustainable" has been used to describe such diverse topics as economic development, agricultural production, social equity and biodiversity (Ekins 1989, Foy 1990, Shearman 1990). The definition of this term affects the interpretation of results of the present study. It is thus necessary to develop a conceptual framework of sustainability at the systems level, in which the study results, at a population level, may be viewed.

Species composition and species diversity relationships have been used to infer system stability (Frank & McNaughton 1991), such that the greater the number of species in a system and the greater the connectance between these species, the more resilient that system will be to disturbance (Pimm 1984, Walker 1988). Both Shackleton (1993) and Higgins (1992) noted that in an area in the Eastern Transvaal in which fuelwood harvesting (including harvesting of livewood) and grazing has been occurring for "several decades", the harvested sites show a marked reduction in number of species of woody plants recorded in comparison to adjacent unharvested areas. Following the above relationships between species diversity and system resilience, it follows that this marked reduction in species may result in a decrease in the resilience of the system to disturbance. This decrease in resilience and the continuation of disturbance pressures (through harvesting, grazing and natural disturbances) may be detrimental to the long term survival of the system. Sustainable use of the system must thus aim at use of aspects of the system, but with the maintenance of those portions of the populations of impacted species necessary for the survival of each species and thus the maintenance of species diversity. The term "sustainability" as used in this study is that described above.

In order to arrive at a decision on whether the resource area under investigation in this study will provide adequate sustainable harvests, it is necessary to compare available resources and present harvesting rates in a meaningful way. This was attempted by the creation of a simulation of the impacts of harvesting on the resource base over time, and viewing the survival potential of the harvested species at recorded harvesting rates.

The aims of this report were thus to provide a framework for use in estimating, with the described confidence, the impact of present harvesting rates on the population composition and biomass of the group of (a) preferred and (b) secondary harvested species in the resource area. And secondly, to identify possible factors limiting harvest in the resource area.

STUDY AREA

The study area was as described in Manuscript 1.

PROCEDURE

Data on total available resources, total available harvestable resources and present rates of harvesting were derived from Manuscript 1. These data were used as input variables for the modelling of building and fuelwood resources under varying harvesting regimes. Simulations ran over 100 years. This time span allowed the long-term effects of harvesting to be viewed. Note, however, that the probability of management philosophies and harvest rates remaining constant for this length of time is low. Graphical representation of size class composition thus included estimates for fifty years for comparison. The model was run for three scenarios: (a) harvesting of the five preferred species identified in Manuscript 1, (b) harvesting of the preferred species plus a group of secondary preferred species (see Manuscript 1), and (c) harvesting of each of the preferred species separately at rates presented in Manuscript 1.

Model format

The model format was that of a stage-structured model in a spreadsheet format using Quattro Pro, Version 4.0. A stage-structured model was chosen as selection of stems for harvesting for building or fencing poles is dependant on size and not necessarily on age. See Appendix A for formulae and basic spreadsheet construction of the model.

Assumptions

Several assumptions made in formulating the model:

1. The model assumed no spatial diversity in resources or harvesting.

2. The model assumed harvest was of numbers of stems from a stand of available stems of preferred and secondary species. It did not simulate a multi-species complex. The use of the term "population" in this model thus refers to the total number of stems being simulated in the resource area, unless otherwise specified.

3. In harvesting of more than one species, the model assumed no ranking of species preference and also assumed all stems to be of equal value for harvesting if they fe. in a preferred size class. Different size classes, however, were of different value for harvest and were modelled as such.

4. Harvest of an individual tree was assumed to be the effective removal of that tree from the population to yield one pole of that size class. Each stem of a multi-stemmed individual was modelled as a single stem with no difference in the growth rates of these individuals and true single-stemmed individuals. After removal of a stem, there was presumed to be a gap which was filled by a coppice or seedling in the next year. Only a single seedling or coppice was assumed to grow to maturity in the place of a harvested stem and growth rates of coppice and seedlings of comparable size were assumed to be equal.

5. The model assumed no density dependant feedback factors such as compensatory re-growth.

6. The model assumed that all trees in the acceptable size classes were of the "right" structure, ie have straight trunks, and would be acceptable for poles. For the most preferred species this was probably an acceptable assumption, since the structure of trees of these species in the resource area were straight, single-stemmed plants. For the secondary species, however, this assumption is less likely to hold. There would thus be some proportion of the acceptable size classes not suitable for harvesting as poles. This proportion was unknown.

Input parameters

1. Initial population estimates

The initial estimates of numbers of individuals in the population were taken to be the sum of the total number of individuals in each size class of (a) the preferred species, (b) the preferred and secondary specie and (c) each of the preferred species (Obtained from Manuscript 1: resource quantification).

The preferred species for harvesting in the study area were: *Spirostachys africana*, *Terminalia sericea*, *Acacia burkei*, *Euclea natalensis* and *Combretum molle*. The secondary species were: *Albizia adianthifolia*, *Pteleopsis myrtifolia*, *Galpinia transvaalica*, *Sapium integerrimum*, *Sideroxylon inerme*, *Antidesma venosum*, *Acacia nilotica*, and *Dalbergia obovata* (Manuscript 1).

2. Recruitment

Gaps in forest canopies affect the ... of seeds and the growth rates and survival of plants in them (Augspurger 1984, Welden *et al.* ... Seedlings of members of the Combretaceae (*T. sericea* and *C. molle*) are known to requir... ...e established (Lamb & Ntima 1971, Augspurger 1984, Kwesiga & Grace 1986, Carr 19... ... Yeaton (1988) reported that *T. sericea* only established in open sites and never under other individuals of the same species or other species trees in semi-arid savanna.

Recruitment into the population was calculated following the above observations such that the removal of an individual through death or harvesting created a gap which was filled by a single seedling to replace that individual. The possibility of more than one seed germinating in this gap and competition and self-thinning occurring were not considered. Note that self thinning, referred to as a general principle (Harper 1977a, White 1980), has recently come under criticism (Weller 1987, Osawa & Sugita 1989, Lonsdale 1990, Weller 1990, Kohyama 1992). The present density of trees was thus assumed to be a "saturation" density which could not be exceeded.

3. Size classes

Modelling of available resources took the form of a stage-structured model with recruitment of individuals from one stage to the next dependent on their growth rate (in circumference increment per year). Individuals of preferred and secondary species were divided into size classes of 50 mm increment in circumference and the number in each class was summed. These classes were then grouped according to general morphological character for the assignment of recruitment, growth or mortality values. The groupings were: seedlings (0-50 mm circumference, size class 1), saplings (60 - 200 mm, classes 2-4), mature harvestable trees (210 - 600 mm, classes 5-12), and mature trees too large to be harvested (> 610 mm, size class 13).

4. Growth rates

Recruitment of stems from one size class to the next depends on their growth rates. Published data on the growth rates of indigenous trees are sparse and publications available report that growth in terms of annual diameter increment is very variable (Breitsprecher & Bethel 1990, Van Daalen, Vogel, Malan & Fuls 1991). Data on growth rates are absent for the resource area. Estimates of growth rate were thus made using available data for Hlatikulu Forest Reserve (HFR), northern Zululand and Nylsvley Nature Reserve (NNR), northern Transvaal. The average annual growth rate calculated from tree-ring data and used in modelling of the HFR harvest resources is an increase in diameter of 3.35 $mm.yr^{-1}$ (Muir 1990). This area, however, receives an annual rainfall of approximately 800 $mm.yr^{-1}$ in comparison to the 750 $mm.yr^{-1}$ in the resource area. Published growth rates of savanna species in NNR receiving approximately 600 $mm.yr^{-1}$ vary between 0.4 and 4.1 $mm.yr^{-1}$, with an average of 2.5 $mm.yr^{-1}$ (Rutherford & Kelly 1978). The estimate of annual growth rate used in this model was a 3.0 $mm.yr^{-1}$ increase in diameter, or an increase in circumference of 9.4 $mm.yr^{-1}$. A mature tree thus took 5 years to pass through a 50 mm size class in this model.

There is evidence for differential growth rates between seedlings and saplings and mature trees (Moll & Woods 1971, Childes & Walker 1987, Muir 1990, Swaine *et al* 1990). Trees move through the smaller classes relatively quickly and "accumulate" in the more mature classes. The estimated growth rate of seedlings (in diameter increment) in HFR was 5.0 $mm.yr^{-1}$. The growth rate of seedlings and saplings is expected to be slightly less for the resource area and was thus estimated at 4.0 $mm.yr^{-1}$, an increase in circumference of 12.5 $mm.yr^{-1}$. An estimate of four years was thus used for seedlings and saplings to pass through a size class. Note that there exists a facility in the model for changing growth rates in the event that more reliable data become available.

Since estimates of growth rates were unreliable a sensitivity analysis was run to investigate the effects of using "high" and "low" growth rates published for HFR and NNR for the resource area.

5. Harvesting

Not all size classes were equally acceptable for harvest (Manuscript 1). Graphical representation of the number of individuals harvested in each of the acceptable size class, for each species, in each landscape unit (from harvest data) showed roughly bell-shaped curves with the peak of the curve over the size classes of 360 - 400 mm and 410 - 450 mm circumference. Total harvest estimates used in the model were thus distributed amongst harvestable size classes following a bell-shaped curve.

Upper and lower limits of harvest rates used in the simulations were set as present harvest rates (Manuscript 1) from the communal and resource area respectively. These rates were 2.5 $trees.ha^{-1}.y^{-1}$ (an estimate of 3926 $trees.y^{-1}$ if extrapolated for the resource area) for the communal area and 228 $trees.y^{-1}$ for the resource area. Note, however, that this estimate of 228 $trees.y^{-1}$ was for the portion of the resource area close to the communal area and presently showing harvest impact (641 of the total 1570 ha). This figure was extrapolated for the entire resource area, (assuming that harvest from the resource area will be at the same rate as harvest from the area under current utilisation) giving a result of 808 $trees.y^{-1}$, as a low estimate of harvesting.

The above harvest simulations assumed equal harvesting of each species. This is known to be incorrect (Manuscript 1, harvest bundles). The present harvest was thus divided amongst the preferred species according to the percentages they comprised and the model run using initial population estimates of each of the preferred species. The model was run for the preferred species to investigate effects of present harvest on that species.

RESULTS

Figure 1 shows the model output of a 100 year simulation for the preferred species with no harvesting. Fig. 1a. and b. show a decrease in both biomass and numbers of trees in the resource area. This is due to the difference between model recruitment rates (estimated following the gap recruitment concept) and measurement of the actual number of seedlings evident in the field study (where germination of a seed may not depend on the death of an individual). The difference is 1.59 tonnes per hectare in comparison to the total biomass of 12.4 tonnes per hectare. This difference in model and actual seedling numbers is also visible in the number of trees in the size class of 0 - 50 mm circumference in Fig. 1c. The model results were similar for preferred + secondary species.

The annual rate of production of deadwood necessary to maintain the present harvest for fuelwood is 0.5 % of total biomass. Note that this is if all deadwood produced is of harvestable size.

A sensitivity analysis was run on the model to investigate the effects of low and high estimates for each of the recruitment, growth and mortality values of the population. Variation of a single variable at a time showed that only changes of the recruitment and growth rates of seedlings and saplings and the death rate of seedlings varied the model output of biomass by > 0.1 tonne per hectare, in comparison to the 10.8 tonnes per hectare of harvestable species available in the resource area. The model was then run to simulate a "worst case scenario" using those estimates for growth and morality rates which resulted in a decline in total biomass when simulated independantly as described above (Table 1: "Low estimates"). This resulted in a biomass decrease of 9000 tonnes in the resource area or 5.7 $tonnes.ha^{-1}$.

Simulations of harvesting were run at two harvest levels: (a) the present level observed in the resource area, and (b) present harvest level observed in the communal area. Note that the total number of trees in the resource area remains constant at all iterations due to the replacement of an individual dying through harvesting or natural causes by a seedling in the next season.

Scenario (a) Preferred species:

When harvesting was 808 trees per year the total biomass was reduced by 0.3 tonnes per hectare and the numbers of trees in the size classes of larger than 400 mm showed a decline, while the numbers of trees in the seedling and sapling classes showed an increase (Fig 2a.). When the "low" estimated values for growth and mortality were used at this harvest rate there was a 6.3 tonnes per hectare decrease in total biomass and a similar decrease in the numbers of trees in the harvested size classes (Fig. 2b.).

When harvesting was increased to the level recorded for the communal area (with low estimates of variables used) a decrease in total biomass of 3.5 tonnes per hectare resulted. The population structure at this harvesting level was markedly changed with no trees occurring in the size classes of > 500 mm circumference, and the number of seedlings increasing (Fig. 3b.). At medium estimated values for growth and mortality a 3.2 tonne per hectare decrease occurred in total biomass and a decrease in the number of individuals in the harvestable size classes occurred (with corresponding increase in the number of seedlings and saplings, Fig. 3a.).

Scenario (b) Preferred + secondary species:

A harvest of 808 trees using "low" estimates of values resulted in a 1.3 $t.ha^{-1}$ decrease in total biomass and a decrease in the harvested size classes. A harvest of 808 trees using medium estimates resulted in a 1.2 tonne per hectare decline in total biomass and little observed impact on population structure.

When harvest rates equal to those observed in the communal area and "low" values were used there was a 4.5 tonne per hectare decline in total biomass. At this harvest rate trees of larger than 550 mm circumference disappeared from the population and the number of seedlings and saplings increased markedly. At this harvest rate and medium values the decline in total biomass was 1.9 tonnes per hectare. There was an observed decline in the numbers of individuals in the harvested size classes and an increase in seedlings and saplings.

The simulations thus showed an impact on total biomass at low or high harvest levels, when either preferred or preferred + secondary species were harvested. The disappearance of harvested size classes from the population occurred only when high levels of harvesting and low estimates of growth and high estimates of mortality were used. According to the model, the present harvest rate of 808 trees per year appears to be sustainable when preferred + secondary species are harvested.

Scenario (c) Simulation of each of the preferred species in isolation:

At the present harvest rate of 808 trees per year and recorded proportions for each species, the following harvests were simulated: 186 stems of *Spirostachys africana*, 170 stems of *Terminalia sericea*, 105 stems of *Acacia burkei*, 89 stems of *Euclea natalensis*, and 40 stems of *Combretum molle*. Where the "medium" estimates of growth and mortality rates were used the total decline in biomass was 0.2 - 0.3 tonnes for the resource area and little to no impact was observed on population structure. Where "low" estimates of variables were used the decline in biomass was 0.1 - 0.4 tonnes for the study area. All species showed varying declines in the numbers of individuals in the harvestable size classes and increases in the numbers of individuals in the immature size classes. No species showed the decline to zero in the numbers of individuals in any size class at present harvest rates. When harvest rates occurring in the communal area were used in simulations *Combretum molle* showed a biomass decrease of 55 % but no disappearance of size classes. *Terminalia sericea*, *Acacia burkei* and *Euclea natalensis* all showed the disappearance of size classes of > 400 mm circumference and a biomass decrease of > 75 %. *Spirostachys africana* showed a biomass decrease of 60 % and a large decline in the numbers of individuals in the harvested size class.

DISCUSSION

Limitations of the model:

Regeneration of harvested species is a major factor driving the model. The use of gap replacement concept to calculate regeneration in the model may be criticized, since the assumption that a gap created by the harvest of a tree is filled by a recruit of a harvestable species the next season may not hold. This assumpti n 'akes no account of competition for gaps by less preferred species or pulses in recruitment due to environmental factors. The occurrence of pulses in recruitment of plants has been recorded (Harper 1977b, Clark 1992) and may have an influence on population structure with uneven distributions of individuals moving through the classes over time. This will influence the number of individuals in the harvestable size classes.

The gap recruitment concept also assumes that the seed bank is not a limiting factor in recruitment. This assumption may hold at high densities of mature trees, but may become less probable where density of mature trees reaches a low level and seed production is relatively less. Persistence of seeds in the seed bank may result in a lag before this limitation becomes visible, the lag being dependant on the persistence of the seeds (Baskin & Baskin 1989).

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This gap recruitment concept may be particularly problematical for *A. burkei*. This species was never observed to coppice after harvest in the study area (all other preferred species were observed to coppice). The contribution of coppicing to the regeneration of this species may thus be considered to be zero. The number of seedlings observed in the present population of this species is very low (< 10 seedlings.ha^{-1} in comparison with the other preferred species for which values of 30 - 255 seedlings.ha^{-1} were recorded) in all landscape units except Thornveld (Manuscript 1). The mean recruitment rates using gap regeneration for *A. burkei* were 7 seedlings.ha^{-1} (with a range of 5 - 12 seedlings.ha^{-1}). Observed recruitment for *A. burkei* was only within this range for Thornveld and possibly Sand forest. Regeneration for this species may thus be a limiting factor to harvest and requires further investigation. In [illegible] *africana* and *T. sericea* only one landscape unit (Sand forest and Forest clumps respectively) was observed in which present recruitment was less than model recruitment. For *E. natalensis* and *C. molle* recorded recruitment was consistently higher than model recruitment for all landscape units.

Growth and death rates of seedlings and sapling [illegible] portant variables in the model, showing the most impact on the model output in the sensitivity analysis, and were estimated with low confidence. More investigation of growth and death rates is thus vital for confidence in the model output to be increased. For greater confidence to be placed on growth rate estimates more direct measurements need to be made. This can be done by: (1) the use of growth rings in calculating age and thus growth rate. These are considered unreliable (Lilly 1977) but may be used with suitable care in interpretation; or (2) long term monitoring of permanent remeasurement quadrats. This method is more reliable (Muir 1990) and should be implemented if a long-term study of resources is undertaken.

Interpretation of model output: Deadwood:

Estimates of deadwood production for comparison with the model output are absent from current literature. The annual production of dead and livewood of Northern Transvaal savannas has been estimated as 4 to 5 % of total biomass (Rutherford 1978). Production of deadwood is, however, unknown. Following the above data, production of deadwood as a proportion of total production will need to be 0.125 to 0.1 for present wood harvest to be sustained. It is possible that the deadwood production is in excess of this proportion. If, however, demand for deadwood increases significantly the annual deadwood production of 0.5 % of total biomass will not be sufficient to maintain harvest. If the annual production of harvestable deadwood is not more that 0.5 % of total biomass then alternative sources of fuel will have to be used.

Interpretation of model output: Livewood:

The immediate effects of harvesting may not be the disappearance of species observed by Shackleton (1993) and Higgins (1992), but the disappearance of a number of size classes from the populations of particular species. In this case the species may be maintained in the population if the fraction to be removed, the harvestable yield, is not required for the maintenance of community composition and structure (Geldenhuys 1980, Muir 1990). This may be important in the study area, since the production of seeds by saplings (trees of < 200 mm circumference) is possibly very low (Enright & Watson 1991) and size classes impacted by harvesting are the mature trees of 200 to 500 mm circumference. As long as mature individuals of this size or larger survive in the population and produce seeds, the gaps created by the removal of trees within the harvested size classes will potentially be filled by seedlings. If, however, all available trees in the harvestable size classes are removed then the number of trees entering the size classes too large to be harvested will be zero. After time the trees within the size classes too large to be harvested will grow old, may produce lower seed yields (Enright & Watson 1991) and will die, removing the source of new recruits into the population.

This scenario may, however, have a low probability of occurring since there is probably a buffer of individuals in the harvestable size clases that are of an unsuitable structure for building or fencing poles (ie not straight) but will still produce seed. In this case the population structure (number of individuals in each size class) may become skewed, with large numbers of individuals in the small size classes and few individuals in the larger size classes, resulting in a "young" population. This may not be detrimental to the persistence of the species in that area. This scenario has a greater probability of occurring for the less preferred species since there appear to be a larger proportion of individuals of unsuitable structure in the harvestable size classes of these species than of the preferred species. This buffer would thus be greater for the less preferred species. In the case of the preferred species, where the unharvestable buffer may be very small, two factors may become important: (a) that of dispersal and spatial patterning (see Busing 1991), and (b) that of competition.

Concerning dispersal and spatial patterning, there may be areas in which, by chance, all of the individuals in the harvestable size classes are of a suitable structure and thus may be harvested. In this case the survival of the species in that area will depend on the dispersal distances of the species. If the dispersal distances are small the species will have a greater probability of becoming extinct in patches of its former range. If these patches of extinction increase in size and join due to the limitations if dispersal and lack of recruitment of unsuitable structure trees the species will have a greater probability of becoming extinct in the entire area. Spatial heterogeneity may also strongly effect the assumption of gap regeneration used in the model.

The second factor, that of competition, may become important if the seedlings or saplings of the preferred species have a high probability of being outcompeted by non-harvested species. Gaps created by the removal of trees of the preferred species may be colonised by non-harvested species, with the result that the number of recruits of the preferred species may decline below the level necessary for survival of the species (where, again, dispersal may play a part). In this way the species may decline and become extinct in the area. Factors such as competition and dispersal were not accounted for in the model and their effects are unknown.

Spatial patterning of harvesting may be an important factor in species persistence in the resource area as harvesting occurs in a band of increasing width at the southern border of the resource area. When harvesting is intense, all available trees of the harvestable species and size class are potentially removed in this area. In the absence of sufficient, suitably dispersed trees of sizes too large to be harvested there may be insufficient recruitment to sustain the population in this area. Little regeneration may occur and harvesters will be forced to travel further into the resource area to obtain suitable poles. In this way the band of little or no recruitment of harvestable species may be widened until it impacts the entire resource area.

Preference shifts are known to occur as species become scarce in an area (Manuscript 1, aspects of present utilisation). The effect of these shifts and when they occur is not known and may be an important factor in survival of heavily utilised species.

Comparisons with published harvest rates:

Note that the comparison of present harvest rates with published literature must be viewed with one aspect in mind: both studies used for comparison refer to harvest of wood for furniture building and such uses. The sizes accepted are much larger, with a smaller range, than in the present study. Harvesting in these studies is thus "more selective" in size classes accepted, harvest quotas will thus be relatively less in comparison with the present study.

In a simulation of harvest in Hlatikulu Forest reserve in northern Zululand, Muir (1990) recorded harvest impacts in total number of stems for each forest type and did not differentiate between species. Muir stated that 10 species carried 90 % of utilisation pressure. These values were converted to harvest in stems per hectare using Muir's estimates of area covered by each forest type for comparison with the present study. Results are presented in Table 2.

The present harvest rates of the five preferred species in the resource area are 228 stems per year, that is 1 stem.3 $ha^{-1}.y^{-1}$. This harvest rate is very high when compared to harvest rates recorded by Muir (1990), particularly considering the low basal areas recorded for this study and the fact that Muir's harvest estimate is for 10 species and this study estimate is for 5 species.

In a study on the utilisation of individual species in the Transkei, Cawe and McKenzie (1989b) suggest a utilisation rate of 1 stem.45 $ha^{-1}.y^{-1}$ for *Podocarpus henkelii*, a common Transkei forest species with a diameter increment of 3.35 $mm.y^{-1}$ and a basal area per hectare of 12.1 $m^2.ha^{-1}$. These researchers suggest a utilisation rate of 1 stem.107 $ha^{-1}.y^{-1}$ for the slower growing (diameter increment of 1.63 $mm.y^{-1}$, basal area per hectare of 3.2 $m^2.ha^{-1}$) *Ocotea bullata* (Cawe & McKenzie 1989a, b). Note that the size classes harvested in both of the previous studies are within the range of size classes harvested in the present study.

From harvest data (Manuscript 1), the present rate of harvesting of each of the preferred species in the resource area was calculated and is presented in Table 3. These harvest rates are high in comparison to the rates proposed for Transkei forests, particularly considering the basal areas and growth rates of these species in comparison to those of the Transkei species. Note that the disappearance of size classes did not occur when these species were modelled individually (scenario c), although all species showed a decline in the number of individuals in the harvestable size classes. Note, however, the limitation in using the gap regeneration concept to *A. burkei*, as previously discussed.

CONCLUSIONS

1. From the model results it appears that present harvest rates of 808 trees per year, at the rates at which each of the preferred species are presently being harvested, are sustainable in the resource area.

2. There are, however, two cautionary notes which must be considered when viewing these results: (a) present estimates of recruitment rates and growth and mortality rates of immature individuals were made with low confidence, and (b) harvest rates in the resource area are likely to increase as more people colonise the area and resources become limiting in the communal area.

3. The harvest rate occurring in the communal area, when simulated for the resource area, is not sustainable.

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TABLE 1. "Medium" and "low" estimates of growth and mortality used in harvest simulations. Where growth rates are presented in mm circumference increment per year and mortality rates are presented as a fraction.

Variable	"low" estimate	"medium" estimate
Growth rate: seedlings and saplings	15.7	12.5
Mortality: seedlings	0.20	0.14
Mortality: saplings	0.06	0.05
Growth rate: mature trees	6.6*	9.4
Mortality: mature trees	0.02	0.01

* = growth rate for trees in Nylsvley Nature Reserve (Rutherford & Kelly 1978).

TABLE 2. Harvest rates proposed for 3 different forest types in Hlatikulu Forest Reserve. Calculated from Muir (1990), where BA is Basal Area in $m^2.ha^{-1}$ for all species in that forest type.

Forest type	Harvest rate	BA $m^2.ha^{-1}$
Mesic forest	1 stem. 13 $ha^{-1}.y^{-1}$	37.7
Xeric forest	1 stem. 8 $ha^{-1}.y^{-1}$	31.3
Heywoodia forest	1 stem. 7 $ha^{-1}.y^{-1}$	49.0

TABLE 3. Present rate of harvesting of preferred species in the resource area. Where BA is Basal Area in $m^2.ha^{-1}$ for that species in the resource area.

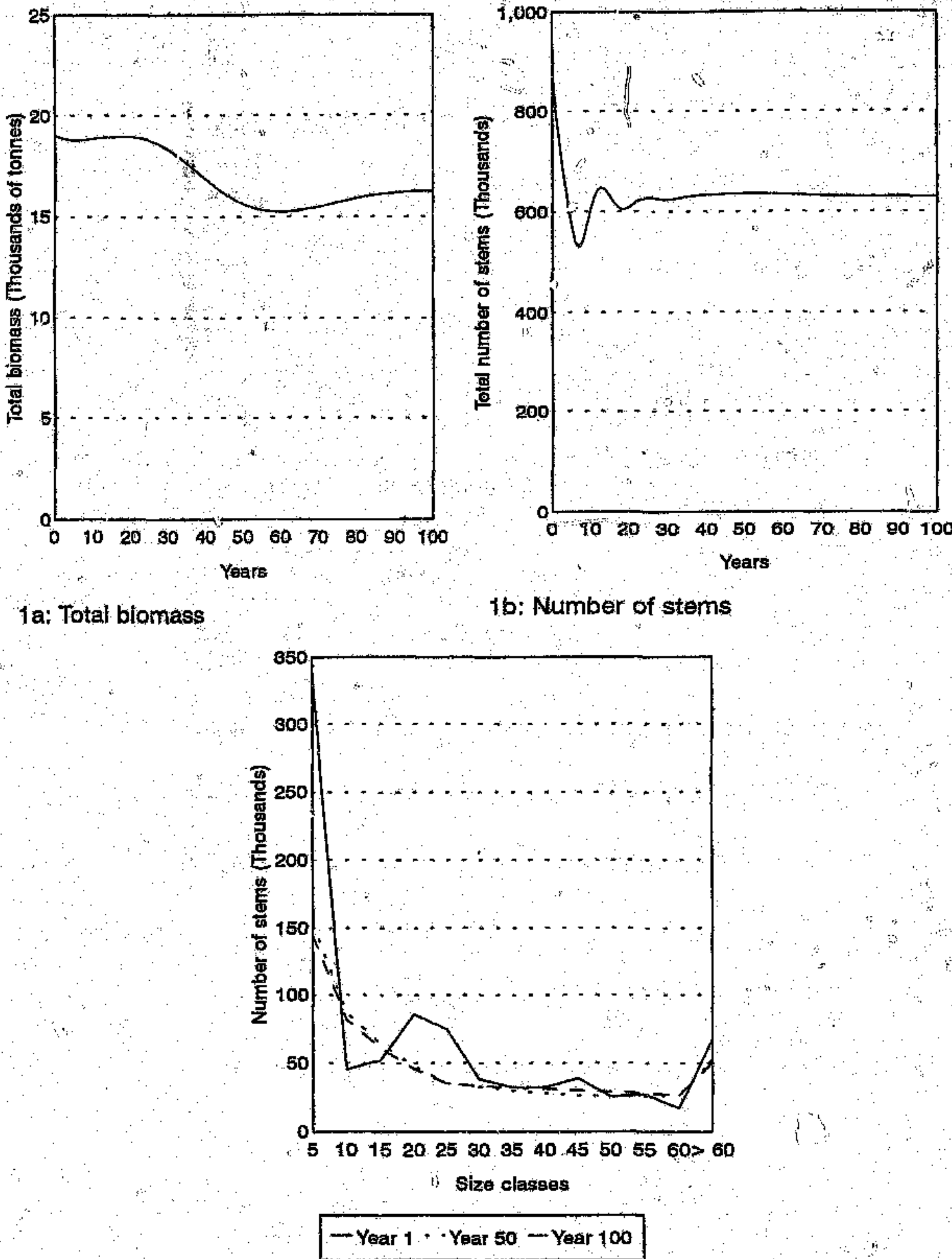
Species	Harvest rate	BA $m^2.ha^{-1}$
S. africana	1 stem.12 $ha^{-1}.y^{-1}$	0.98
T. sericea	1 stem.13 $ha^{-1}.y^{-1}$	0.85
A. burkei	1 stem.22 $ha^{-1}.y^{-1}$	1.30
E. natalensis	1 stem.26 $ha^{-1}.y^{-1}$	0.21
C. molle	1 stem.56 $ha^{-1}.y^{-1}$	0.69

Captions to figures:

<u>Fig 1</u>: Model output for a 100 year simulation of preferred species in the resource area, with no harvesting occurring.

<u>Fig 2</u>: Model output for 100 year simulations of preferred species in the resource area, with a harvest rate of 808 trees per year.

<u>Fig 3</u>: Model output for 100 year simulations of preferred species in the resource area, with a harvest rate of 3962 trees per year.

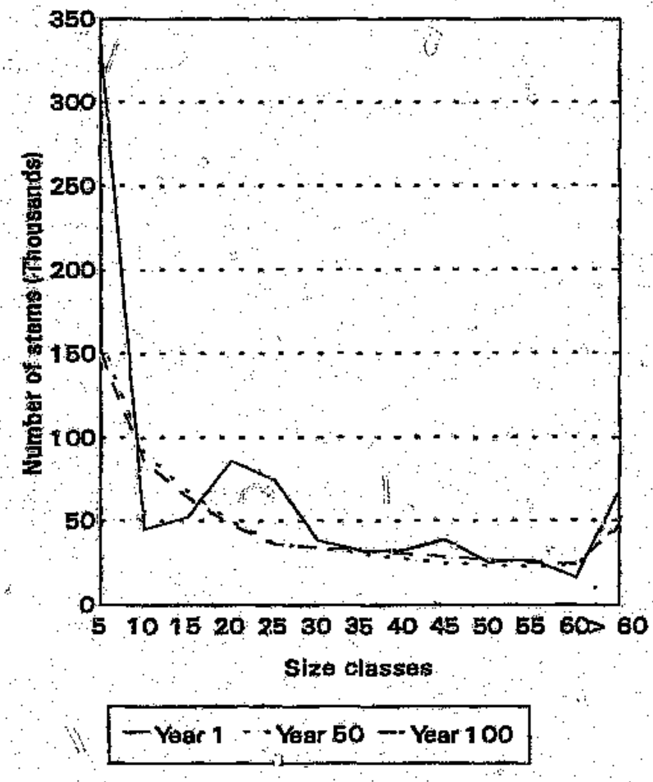


1a: Total biomass

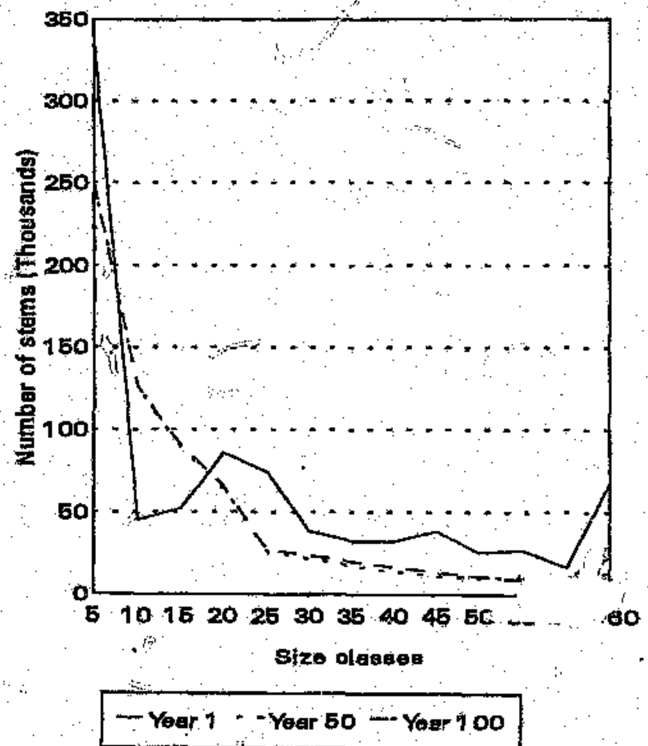
1b: Number of stems

1c: Population structure

Figure 1

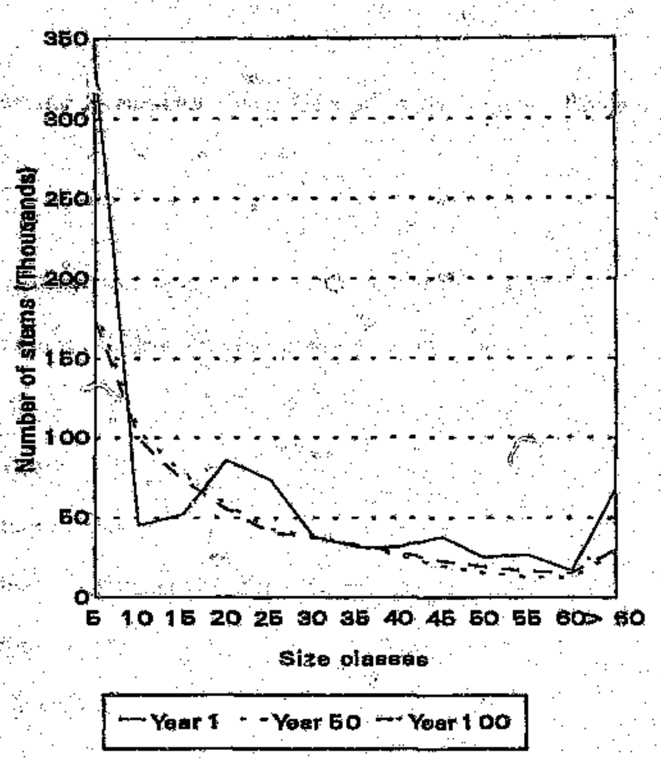


2a: "Medium" growth and death rates

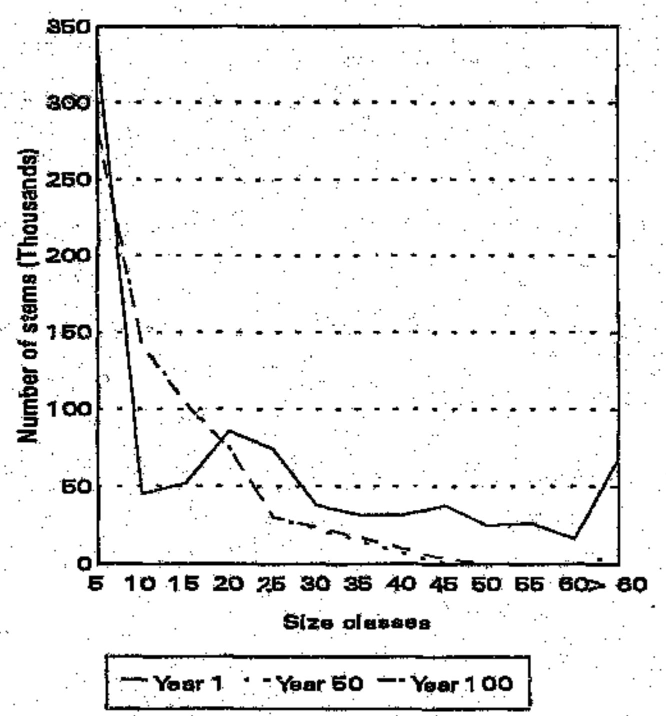


2b: "Low" growth and death rates

Figure 2



3a: "Medium" growth and death rates



3b: "Low" growth and death rates

Figure 3

Appendix A: Formulae and spreadsheet construction of model. Figures in bold could be altered.

INPUT DATA

Growth rate: seedlings and saplings:	**1.25**	$cm.y^{-1}$
(centimetres circumference increment per year)		
Mortality: seedlings:	**0.14**	of individuals
Mortality: saplings:	**0.05**	of individuals
Growth rate: mature trees:	**0.94**	$cm.y^{-1}$
(centimetres circumference increment per year)		
Mortality: mature trees:	**0.01**	of individuals
Production of deadwood:	**0.5**	% of biomass

HARVEST DATA

Deadwood harvested per year:	**76.4**	tonnes
Number of poles harvested per year:	**0**	stems
Simulation estimates: Resource area:	808	stems
Communal area:	3926	stems

ALLOCATION OF HARVEST TO SIZE CLASSES (Calculation based on bell-shaped curve shown by data)

Size class	Number of stems harvested
210-250 mm (class 5)	(Pole harvest per year * 5) / 100
260-300 mm (class 6)	(Pole harvest per year * 10) / 100
310-350 mm (class 7)	(Pole harvest per year * 15) / 100
360-400 mm (class 8)	(Pole harvest per year * 20) / 100
410-450 mm (class 9)	(Pole harvest per year * 20) / 100
460-500 mm (class 10)	(Pole harvest per year * 15) / 100
510-550 mm (class 11)	(Pole harvest per year * 10) / 100
560-600 mm (class 12)	(Pole harvest per year * 5) / 100

FORMULAE (Iterated for 100 years)

Seedlings (class 1)

$$N = (N_1 - (N_1 * M)) - (N_1 / G) + R$$

Saplings (classes 2 - 4)

$$N = (N_1 - (N_1 * M)) - (N_1 / G) + (N_2 / G)$$

Mature trees (classes 5 - 12)

$$N = (N_1 - (N_1 * M)) - (N_1 / G) + (N_2 / G) - (H)$$

Mature trees (class 13)

$$N = (N_1 - (N_1 * \text{death})) - (N_1/\text{growth}) + (N_2/\text{growth})$$

Where: N is the number of stems in that size class at year t + 1; N_1 is the number of stems in that size class at year t; N_2 is the number of stems in the previous size class at year t; M is the mortality of that size class; G is the number of years taken to move through that size class (calculated from growth rate as G = 5 / growth rate); H is the harvest for that size class calculated from total harvest; R is the number of recruits in year t (calculated as number of individuals in sapling and mature size classes at year 1 minus number of individuals in sapling and mature size classes in year t).

An estimate of total biomass was calculated for each year as the sum of total biomass in each size class, where biomass for each size class was calculated as biomass of an individual in that size class (see Manuscript 1: Resource base quantification) multiplied by the number of individuals in that size class.

Production of deadwood per year was calculated as total biomass multiplied by the percentage of deadwood produced per year. The total biomass of deadwood necessary to sustain present harvest levels was taken to be that percentage that resulted in > 0 tonnes of deadwood remaining after harvest in each year.