A COLLATION AND OVERVIEW OF RESEARCH INFORMATION ON *COMBRETUM IMBERBE* WARWA (COMBRETACEAE) AND IDENTIFICATION OF RELEVANT RESEARCH GAPS TO INFORM PROTECTION OF THE SPECIES

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Combretum imberbe is currently not a protected tree in South Africa, although it has been proposed for listing on the protected tree list of South Africa. Protection is to be granted primarily because it has a livelihood and commercial value, and is not adequately protected by any legislature. Protection status will promote and provide incentives for the sustainable use of the species, which would otherwise be unsustainable.

C. imberbe is favoured for its durable heartwood which is used for a variety of functions including craft work, furniture production, building materials, fencing posts, and fuelwood. Trees with diameters ≥ 20 cm are harvested mostly for these purposes, except for fuelwood, for which smaller diameter (< 20 cm) stems are selected (Clarke 1997). Large mature trees are thus selectively harvested, both in communal areas and occasionally in protected areas, for subsistence and commercial use (Shackleton 1993, Clarke 1997). The extent of current exploitation and harvesting is unknown, but appears to be very selective and unsustainable, based on limited formal research and informal reportings. Although *C. imberbe* is exploited over much of its range, harvesting intensity is probably correlated with human densities. Other factors, though, such as local economics, market demands, availability of electricity in rural areas, among others, may also influence the purpose and rate of harvesting. There is thus an urgent need to elucidate the factors that are responsible for driving the demand for this wood.

In addition to the lack of current knowledge regarding the extent of harvesting and social-economic factors, there is a paucity of data on important biological aspects of *C. imberbe*. The processes and success of recruitment of *C. imberbe* are not well understood, nor are the threats to early life stages such as seeds and seedlings. Livestock, for example, are reported to pose a threat to the establishment of seedlings (Clarke 1997) yet the causal factors and dynamics are not clearly understood. Other factors such as rainfall, drought, fire, and competition may also affect seedling establishment and survival, which may be important for long-term population viability of this slow-growing tree. Apart from environmental influences, there are numerous anthropogenic factors that may negatively affect population stability, include grazing of emerging seedlings, suppression of small trees, as well as the reduction of seed producing trees through harvesting (Clarke 1997). A combination of these factors could lead to localised extinction of the species.

In the Bushbuckridge district in the Limpopo Province of South Africa, a recent study of harvesting impacts on *C. imberbe* showed that it sustained the greatest harvesting pressure compared to other large and more common tree species. The wood has numerous uses, with all size classes, and up to 20% of the plants, being harvested (Clarke 1997). With increasing stem diameter of *C. imberbe*, an increasing proportion of trees are harvested in communal lands (Clarke 1997), resulting in a decline in the number of trees per size class. Although recruitment potential is high, with 79% of the population having a basal diameter ≤ 20 cm (Clarke 1997), the harvesting rate appears to exceed the rate at which trees mature, both for seed production and use in the woodcraft industry (Clarke 1997). Such harvesting cannot be considered sustainable, as the number of individuals within a suitable size class for use in industries such as woodcraft is insufficient to satisfy the demand by craftsmen, despite the fairly high total densities of *C. imberbe.* The density of suitable trees (≥ 20 cm) for the woodcarving and furniture production was estimated at 2.2 ± 1.1 trees/ha, equating to 22% of the total standing crop (Clarke 1997). The majority of the population (79%) has stem diameters ≤ 20 cm (Clarke 1997). Such population characteristics are indicative of intense harvesting of large tree size classes. The harvesting of these reproductively mature size classes, for building and carving material, reduces both the rate and ability of population recruitment (Clarke 1997).

An increase in the number of homesteads, head of cattle and other livestock, cultivated plots, illegal immigrants from Mozambique, results in an increased demand for 61 - 65 cm diameter stems used for building fences and shelters. Based on the harvesting rate of 20.1% of the total population of *C. imberbe*, it was estimated that trees with basal diameter ≥ 20 cm could sustain harvesting for wood

carving alone for 62 years. When harvesting for fuel and construction materials is also considered, harvesting could only be sustained for a period of one year. This implies that the resource may already be depleted at present. Harvesting of stems $\leq$ 20 cm in diameter for fuel could be supported by the resource base for 2 years, assuming 100% recruitment of individuals into that size class (Clarke 1997).

C. imberbe is a fairly rigorous resprouter, while the proportion of old and recently harvested trees that either die or coppice is estimated at 12 and 88% respectively (Clarke 1997). The number of shoots produced from cut stems is negatively correlated with the height at which trees are harvested (Clarke 1997), while shorter shoots are produced when trees are harvested close to the ground. The height at which a tree is harvested is thus the most important factor influencing the coppicing ability of *C. imberbe*. Stump mortality generally results when trees are harvested close to the ground, thereby subjecting coppicing shoots to intensive livestock herbivory and fire damage (Clarke 1997). A harvesting height of one meter appears most advantageous to survival and coppicing potential. However, the coppicing ability of *C. imberbe* requires further investigation to determine the most effective harvesting technique that ensures maximal regrowth rates. Detailed knowledge regarding optimal harvesting techniques is essential to promote sustainable resource management, particularly since the resource base is currently experiencing pressure form over-exploitation.

Other threats to *C. imberbe* include increases in water stress, caused by reduced river flow by small catchment dams (O' Connor 2001). Diebacks increase with increasing distance from the riparian riverbanks, where individuals grow at their limits of water availability. Environmental factors such as fire, rainfall, drought and herbivory may also impact populations of *C. imberbe*, although their effects are still poorly understood.

In order to ensure the protection of this species within a relatively short period of time, research should focus on those aspects of its biology which can be manipulated or managed to established sustainable harvesting guidelines. Further, a thorough investigation of the species' population dynamics with the aid of simple population model may assist in directing future research effort to address environmental, anthropogenic factors or population parameters that have the most pronounce effect on population viability. Rapid assessment of population structure could be achieved by determining the distribution of size classes of regional populations, giving insight into the species' population status and response to harvesting pressures. Finally, a thorough investigation of the market for *C. imberbe* wood is required, and the factors that drive this market. With this knowledge, a more focused, purposeful and broader research programme can be initiated, which will ensure that those factors relevant to the protection of the species receive priority.

STATUS OF COMBRETUM IMBERBE

LEVEL OF PROTECTION

Combretum imberbe is currently not a protected tree in South Africa, although it has been proposed for listing on the protected tree list of South Africa (T. Stehle pers. comm.), which would afford it protection in terms of Section 12 of the National Forests Act, 1998 (Act No. 84 of 1998). Under this act, "*No person may (a) cut, disturb, damage, destroy or remove any protected tree; or (b) collect, remove, transport, export, purchase, sell, donate or in any other manner acquire or dispose of any protected tree, except under a licence granted by the Minister*." The act does not distinguish between live and dead trees, and hence even the removal of dead wood would be illegal. This may have implications for rural communities who rely on *C. imberbe* as a source of domestic fuelwood and income through the woodcarving industry.

In the lowveld region of the Limpopo Province of South Africa *C. imberbe* is considered a protected species under the Venda Nature Conservation and National Parks Act No. 20 (1986) (Clarke 1997). In

Namibia the Hereros and Ovambos attach special cultural and religious significance to the tree (Carr 1988).

SOURCE, TYPE AND GEOGRAPHIC LOCATION OF THREATS TO THE SPECIES

C. imberbe is favoured for its durable heartwood which is used for a variety of functions, most importantly being craft work, building material, fencing posts, and fuelwood. Large mature trees are selectively harvested, both in communal areas and occasionally in protected areas, for subsistence and commercial use (Shackleton 1993, Clarke 1997). It appears that *C. imberbe* is exploited over much of its range, although harvesting is probably less intense in areas of lower human densities, and hence sustainable, e.g. the Ghanzi area of western Botswana (Cole and Brown 1976). In areas such as the northern and eastern parts of the Limpopo Province of South Africa, e.g. Bushbuckridge (Clarke 1997) and Gazankulu (Liengme 1981, 1983), harvesting is intense, selective and unsustainable. The availability of electricity to communal villages may also affect the extent to which the people rely on wood for fuel and other domestic use.

Because of the diversity of its uses, the *C. imberbe* resource base experiences pressure from harvesting for fuel, building material, furniture and wood carving (Clarke 1997). Hence not all size classes of *C. imberbe* are utilised equally owing to the demand for different size classes (Clarke 1997). Larger trees with basal diameters ≥ 20 cm are generally harvested for furniture, building material and wood carving, while stems with diameters ≤ 20 cm are used for domestic fuelwood (Clarke 1997). In the Bushbuckridge district of the Limpopo Province, South Africa, Clarke (1997) found that *C. imberbe* experienced the greatest harvesting pressure, mostly for fencing and carving, compared to six other woody species, including *Acacia ataxacantha, Dalbergia melanoxylon, Berchemia zeyheri, B. discolor, Olea europaea* and *Spirostachys africana*. *D. melanoxylon* stems were presumably harvested more often for fuelwood (≤ 20 cm diameter) than any of the other species, although pressure on the *C. imberbe* resource for fuelwood was likely to increase (Clarke 1997). In some instances large specimens of *C. imberbe* have been harvested extensively from protected areas in the semi-arid lowveld of South Africa to supply local furniture trade, resulting in the near-absence of the species from the areas (Shackleton 1998). Furniture production therefore exerts great pressure on trees ≥ 20 cm diameter that are suitable for the industry.

Environmental factors such as fire and herbivory may also impact populations of *C. imberbe*. Fires are known to destroyed large trees (Carr 1988) but probably also effects younger size classes, including seedlings. The effect of fire is however not well documented and requires further investigation. Similarly, the effects of browsing are also poorly understood; seedlings may be destroyed by trampling by livestock (Clarke 1997), while intense defoliation by browsing may restrict tree growth (Shackleton 1993). Reduce water flow of seasonal rivers due to increased small catchments dams may also influence population demographics, causing diebacks of individual trees that occur at increasing distances from riverbanks (O 'Connor 2001).

SPECIES DESCRIPTION

TAXONOMY AND VERNACULAR NAMES

Combretum imberbe belongs to the Combretaceae family, which comprises a total of 20 genera and 500 species in the tropics and subtropics of the world. In southern Africa there are 41 species in five genera, including *Combretum, Pteleopsis, Quisqualis, Terminalia*, and *Lumnitzera* (Bredenkamp 2000). The name *Combretum* is a term used by Pliny (Greek philosopher) for a creeping plant, while *imberbe* means 'beardless' in Latin, referring to the lack of hairs on the plant (Venter and Venter 1996). The National tree numbers of *C. imberbe* in South Africa and Zimbabwe are 539 and 773 respectively (Coates Palgrave 1983, Carr 1988).

The vernacular names of *C. imberbe* in southern African countries are as follows:

South Africa: leadwood (English)(Coates Palgrave 1983), leadwood bushwillow (English)(Grant and Thomas 1997), hardekool (Afrikaans)(Coates Palgrave 1983), umBondwe omnyama (Zulu)(Carr 1988), uMangwenja (Zulu) (Venter and Venter 1996), mondo (Tsonga)(Carr 1988), mbimba (Tsonga)(Liengme 1981), mohwelere-tshipi (Northern Sotho), mondzo (Shangaan)(Liengme 1981), muheri (Venda) and motswiri (Pedi)(Grant and Thomas 1997).

Zimbabwe: muchenarota (Central Shona), mutsviri (Venda); umchenalota, umtswili (siNdebele); ubimba (chiTonga); monzo (Hlengwe), muyando and mbwele (Carr 1988, Sibanda 1992). Other vernacular names not listed above are given by Goldsmith and Carter (1981), namely: muchenarota, mutsviri, and ubimba.

Botswana: motshwere, mutswiri (Tswana)(Carr 1988)

Namibia: muywile (E Caprivi); munjondo (Kuangali and Diroko); omumborombonga (Herero) (Carr 1988).

GENERAL DESCRIPTION

C. imberbe is the largest sized tree of about 40 tree species or sub-species in the *Combretum* genus occurring in southern Africa (Van Wyk 1993). The growth form is generally a small to large winter-deciduous tree between 7 to 15 metres in height, and less commonly a shrub or multi-stemmed thicket in locations such as dry riverbeds (Coates Palgrave 1983, Viljoen and Bothma 1990). On sandy soils it may reach a height of 20m, being straight, single-stemmed and rather sparsely branched with a limited canopy spread (e.g. Botswana) (Carr 1988). Larger trees occurring in areas such as the lowveld (e.g. South Africa), may have a single main stem attaining a diameter of 1.5m, with heavy main branches commencing at 3 to 4 m above the ground to give a rather rounded crown reaching a height of 12-15 m, and a spread of 18-22 m (Car 1988). In Zimbabwe it occurs as a medium sized tree up to 15 m in height, the stem being fairly long and up to 50 cm in diameter (Goldsmith and Carter 1981). In the harvested area in the Bushbuckridge district of the Limpopo Province lowveld, *C. imberbe* has an average stem diameter (measured at 35 cm above the ground) of 28 $\pm$ 16 cm (mean $\pm$ standard error)(Clarke 1997). It has a non-aggressive root system (Venter and Venter 1996). The large tap roots and well developed lateral roots systems enable it to draw on ground water and to utilize the moisture held in surface soils after rains (Cole and Brown 1976).

The leaves are borne on current growth extensions and current laterals growing in the axils of the previous year's laterals (Carr 1988). Leaves are mainly oppositely arranged but may be in whorls of up to seven at the terminals of current laterals in axils of older growth. The lamina is elliptical to obovate, simple and small, ranging in size from 2.5 to 8 x 1 to 3 cm, and oppositely arranged (Palmer and Pitman 1972). The leaf petiole is 4 to 10 mm long (Coates Palgrave 1983), but averages 5 mm (Carr 1988). Leaves are characteristically grey-green in colour above, and yellow-green below (Carr 1988). The branchlets are opposite, stiff and often spine tipped (Goldsmith and Carter 1981).

The bark of old trees is generally medium to light grey in colour on the main stem, and characteristically fissured longitudinally and split transversely to a depth of 5 to 10 mm (Carr 1988). This produces a pattern of close and interlocking plates, approximately rectangular in shape, and with the majority with their main axes aligned longitudinally (Carr 1988).

C. imberbe generally flowers from November to March (Carr 1988, Coates Palgrave 1983, Venter and Venter 1996), although flowering has been recorded as early as August (Carr 1988). In the arid Kaokoveld in Namibia flowering has been recorded in April for a particular specimen, which at the same time also bore large quantities of ripe fruit, possibly because of rains during the preceding month (Carr

1988). The inflorescences are borne on current growth laterals, either as a single spike or a branched panicle at the terminals, or as single spikes (or bifurcated) in the axils, some distance back from the terminal (Carr 1988). Individual spikes may reach a length of up to 50 mm (Exell 1970)(range of 40 to 80 mm given by Coates Palgrave 1983), are light brown in colouration, contiguously lepidote, but otherwise glabrous (Carr 1988). Up to 30 bisexual flowers are borne on a spike (Carr 1988). The flowers are initially green white becoming cream to yellow coloured and scented (Carr 1988, Venter and Venter 1996).

The fruit is a four-winged indehiscent pseudocarp (Bredenkamp 2000), either sub-circular or more often D-shaped in outline (Carr 1988) with the length and width seldom exceeding 1.5 x 1.5 cm (Carr 1988, Coates Palgrave 1983). Fruit is glabrous except for densely spaced scales, and is characteristically pale yellowish-green when mature, drying to a light brown colour, which sometimes persists into the next flowering season (February to June or on to December) (Coates Palgrave 1983). The fruiting period extends from February to August (Venter and Venter 1996), with fruit usually ripe by April (Carr 1988). A single seed, measuring 9.5 x 3.5 mm, is contained within each fruit (Carr 1988). Within the genus *Combretum*, the fruits of *C. imberbe* are the smallest with a weight of 86 $\pm$ 11 mg, with the seed accounting for approximately 44.8% of the fruit weight at 38 $\pm$ 9 mg (Ernst and Tolsma 1990).

The heartwood is dark brown in colour, close-grained, very hard and heavy (air-dry mass of 1200 kg/m^3, Venter and Venter 1996; 1230 kg/m^3 at 12% moisture content, Goldsmith and Carter 1981), and durable (Carr 1988, Coates Palgrave 1983). Because of these characteristics the wood is termite- and borer-proof, with dead wood weathering away very slowly, unless ignited by a veld fire (Carr 1988). The sapwood is fairly narrow and brownish yellow in colour, but also close-grained and hard (Carr 1988). Growth rings are however poorly defined (Goldsmith and Carter 1981). Dead branches may remain on the tree, or the whole tree may remain standing long after it is dead (Palmer and Pitman 1972, Goldsmith and Carter 1981).

DISTRIBUTION AND ECOLOGY

GEOGRAPHIC DISTRIBUTION, CLIMATE, SOILS, HABITAT TYPES

C. imberbe is restricted to the African continent, reaching its northern distribution limit in Tanzania, and southern limit in KwaZulu-Natal in South Africa (Venter and Venter 1996). In Namibia *C. imberbe* occurs across the northern portion of the country, including the Caprivi Strip in the east and the Kapupa valley in the Kaokoveld in the northwest, and as far south as the Swakop River valley near Swakopmund (Carr 1988). It also occurs across the northern portion of Botswana, as far south as Ghanzi in the west, and the Botletle River in the centre, and then across the eastern parts as far south as Gaborone (Carr 1988). The southern most limits in South Africa, primarily in the Limpopo Province, are roughly along a line joining the following towns: Zeerust, Rustenburg, Hammanskraal, Groblersdal, Roosenekal, Origstad and Barberton. In KwaZulu-Natal it occurs in the Ndumu Game Reserve, while in Swaziland there are records from Mlawula and Siphofaneni. The species also occurs in Angola, Zambia, Mozambique, and Malawi (Carr 1988).

C. imberbe occurs in various types of woodland along seasonal watercourses (O' Connor 2001) and open grassland (Brynard 1964, Venter and Venter 1996), between low to medium altitudes (Carr 1988, Coates Palgrave 1983). It is considered a savanna species or mixed woodland species (Coates Palgrave 1983), and occurs in a variety of habitats ranging from arid (Namib Desert) to moist savanna, where rainfall may be as high as 750 mm per annum (Carr 1988). In the Limpopo Province lowveld *C. imberbe* occurs at higher densities along river fringes where soils are deeper, finer textured and more eutrophic than coarse dystrophic upland soils (Clarke 1997). It is thus common on alluvial soils but only occasionally on heavy clay soils (Venter and Venter 1996). In the Limpopo Province lowveld there is a definite local preference for basalt soils (Grant and Thomas 1997). In the Shurugwi Communal Area in Zimbabwe, *C. imberbe* occurs within riverine habitats, termitaria veld, and in rocky areas such as kopjes and rocky riverbanks, preferring heavy sandy soils, but also dolerite derived soils (McGregor 1991).

BIOLOGY

MEANS OF SEED DISPERSAL

The fruits are anemochorous and belong to the aerodynamic type defined as tumbler, i.e. not rotating on a consistent axis during descent (Ernst and Tolsma 1990). *C. imberbe* is thus wind dispersed, with a fairly wide dispersal range of approximately 50 m from the parent tree (Hughes et al. 1994). In some cases the release of fruit may extend up to the next flowering season, which may be an adaptation to escape ground fires (Ernst and Tolsma 1990). An extended period of fruit dispersal may assist in reducing potential fire-damage to at least some proportion of the seed population produced in a particular year (Ernst and Tolsma 1990). There is no information in the literature on the extent of seed production by mature trees, or how this is influenced by environmental factors such as rainfall and drought.

The distribution and density of a tree species is proportional to its seed dispersal agent; wind dispersal agents will transport seeds further than those with ballistic or unaided dispersal mechanisms (Hughes et al. 1994). The implication of this is that the harvesting potential of a tree species will depend on its seed dispersal range. The larger the dispersal range the greater the possibility of the seeds encountering favourable microsites for germination and the more dispersed a population will be over a given area, thereby reducing the probability of harvesting as a harvester's search time will be increased (Clarke 1997).

EFFECTS OF SEED PARASITES/PREDATORS

Very little information could be obtained on this aspect in the literature, except that rodents are partial to the seeds when cultivated (Venter and Venter 1996). Carr (1988) reports that seeds collected from the ground may have as much as a 35% infestation rate by parasites, but does not mention which species is responsible for the damage. Considering that the fruit is anemochorous, it is most probable that fruits or seeds that are ingested by animals, will not survive to become seedlings. There is still a lack of information on the factors that affect seed survival, and should be investigated should it become apparent that this life stage is critical to the survival of *C. imberbe* populations. The use of a simple demographic model may assist in determining the relative importance of seed, and seedling survival, compared to other life-history attributes, for ensuring population recruitment and long-term survival.

SEEDLING ESTABLISHMENT AND SURVIVAL

There is no information available about this aspect of *C. imberbe's* biology in the literature, although Clarke (1997) asserts that trampling by domestic livestock may destroy seedlings and thereby reduce the regeneration potential of the species. In communal lands in the Bushbuckridge District, Clarke (1997) found that the establishment of *C. imberbe* seedlings may be favoured where intense grazing reduces competition from grasses. There is however a paucity of data on the minimum conditions that ensure seedling establishment for this species, and whether this differs between different land uses or harvesting intensities. The effect of environmental variables such as rainfall, grass competition, and drought, among others should also be determined. There is also no indication as to what constitutes a suitable germination site for dispersed seeds.

When cultivated, Carr (1988) suggests that the complete fruit is soaked in water for a few hours before being sown in seedling trays filled with river sand, with the seeds pressed level with the sand and then covered with a thin layer of sand (Venter and Venter 1996). If kept moist, the seeds germinate within 7 to 15 days (Venter and Venter 1996). Carr (1988) reports that only 3 - 5% of seeds germinate, and hence many seeds need to be sown. There is also high mortality among seedlings in the seedbed (Carr 1988). This suggests that seedling establishment and survival may be rare event in wild populations.

GROWTH RATES

C. imberbe is considered to be one of the slowest-growing trees in the lowveld of South Africa and is capable of reaching a considerable age (Palmer and Pitman 1972). The highest recorded age is 1070±40 years, as determined by carbon dating by the National Physical Research Laboratory of the Council for Scientific and Industrial Research (Carr 1988). No further information could be attained on this aspect in the literature. However, when cultivated it may grow fairly fast; a tree planted in the Limpopo Province of South Africa grew six meters in 15 years (Palmer and Pitman 1972).

AGE TO MATURITY

No information could be attained on this aspect in the literature, although trees with stem diameters ≥ 20 cm may produce fruit (Clarke 1997).

ASSESSMENT OF POPULATION STRUCTURE AND HEALTH

Clarke (1997) found that the population of *C. imberbe* in the Limpopo Province Lowveld was unstable, and attributed this to low success of recruitment events brought about by frequent rotation of grazing cattle, harvesting, fire and climatic fluctuations. Shackleton (1993) has shown however that the stability of woody populations is probably rarely attainable in an environment characterised by large climatic fluctuations, even under low pressure from fire, herbivory and harvesting. Unstable populations are presumably caused by fluctuating recruitment and/or mortality rates, which appear to be the norm in semi-arid environments characterised by large fluctuations in the timing and intensity of controlling variables (Shackleton 1993). No indication of population stability is available for *C. imberbe* in other parts of southern Africa. However, anthropogenic factors that may affect population stability negatively include grazing of emerging seedlings and suppression of small trees, and the reduction of seed producing trees through harvesting (Clarke 1997). A combination of these factors, may thus lead to localised extinction of the species.

Changes in the structure of tree population generally occur before species compositional changes and the loss of valuable species (Harper 1977). Population structure is therefore a useful indicator of the effect of management strategies (Shackleton 1993). Knowledge of structural changes may also identify situations of declining recruitment (Shackleton 1993). Determination of population structure is best achieved with size or stage class distributions rather than age class data, the latter being unreliable for savanna areas because growth rings are not directly related to age, but reflect fluctuating environmental conditions (Shackleton 1993). Stage or size class distributions are also better indicators of reproductive output than age classes (Werner and Caswell 1977, Shackleton 1993). The stability of a population can be determined by examining quotients, which are calculated between successive size classes to facilitate graphical interpretation of population stability (Shackleton 1993). Quotients that are approximately constant between successive size classes indicate a stable population, whereas fluctuating quotients represent an unstable population. Although projections of size class distribution may infer stability, the absolute densities of size classes may be declining due to sustained harvesting pressure. Hence, if harvesting pressure across the different size classes is proportional to the relative densities in each size class, then no change will be detected in the size class distribution when absolute densities are declining (Shackleton 1993). Thus, while structural analysis should complement species compositional analysis, it should be related to trends in absolute densities and vice versa (Shackleton 1993).

TREE DENSITY

Limited details on the density of *C. imberbe* trees on communal lands were found in the literature and are reported here. Details on the density of specific stage classes of trees are not available, but rather for all growth stages combined. Clarke (1997) derived density estimates by transect methodology for five rural villages in the Bushbuckridge district of the Limpopo Province lowveld. It was found that the density of *C. imberbe* differed significantly between rural villages, averaging 72 ± 42 (mean ± standard error) trees/ha (all stage classes combined), with a range of 16 ± 15 to 163 ± 46 trees/ha. These densities are significantly greater than those at unharvested areas, such as the Wits Rural Facility and Hoedspruit Nature Reserve where densities were 0.30 ± 0.43 and 0.07 ± 0.11 trees/ha respectively (unpublished data from C.M. Shackleton in Clarke 1997). These differences are considered attributable to the location of the tree population with respect to distance from suitable habitat, with higher densities being associated with riverine fringes. In the Gwanda district in Matabeleland, South Province of Zimbabwe, *C. imberbe* occurs at a density of 0.16 trees/ha (Sibanda 1992). The density of *C. imberbe* thus differs markedly between regions, and even within the same regions. Although the factors that may influence such differences may be numerous, and would include both environmental and anthropogenic factors, an investigation of tree densities and the local factors that could influence these may identify underlying correlations.

DEMOGRAPHY AND MORTALITY WITH DISTURBANCE

EFFECTS OF LANDUSE

Bush encroachment

Little information could be found on this aspect in the literature. In communal lands it appears that establishment of *C. imberbe* seedlings may be favoured where intense grazing has reduced competition from grasses, which could be interpreted as the initial stages of bush encroachment (Shackleton 1993, Clarke 1997).

Application of herbicide

There appears to have been no research conducted on *C. imberbe's* response to herbicide application, or the extent to which herbicides are applied to areas in which the species occurs.

Clear felling

No information could be attained on this aspect in the literature. However, *C. imberbe* trees are not tolerated in arable lands of sorghum and millet in Zimbabwe, where they may serve as roosting-sites for crop-damaging bird species (Sibanda 1992). No details on the extent of such removal is however available.

EFFECTS OF FIRE

Large trees ignited by veld fires may be completely destroyed, while hollow-centred trees with openings to the centre where old branches have broken away are particularly vulnerable to fires (Carr 1988). The level at which trees are harvested may also increase the susceptibility of the remaining stump to grass fires. If coppicing stumps are harvested above the height of the grass sward, resprouting shoots should escape veld fires (Clarke 1997). However, should the new shoots burn in a fire while the heartwood remains undamaged, then there is still potential for coppicing to resume again, and particularly if the tree was harvested above the grass sward (Clarke 1997).

Independent factors such as fire and herbivory, may reduce the density of trees in the smallest size class, which are vulnerable to such influences (Clarke 1997). It is possible that a combination of these factors, coupled with harvesting, can reduce the ability of *C. imberbe* to replenish its population at a rate equivalent to that with which it is harvested (Clarke 1997). However, detailed knowledge regarding the role of fire, even in context of these other factors, is not available and could not be found in the literature searched. It may be suggested that, in order to obtain a minimal indication as to the role of fire on the dynamics of *C. imberbe* and its associated woodlands, databases (if available) of reserves where controlled burning is practiced, should be reviewed and the data analysed if possible. This would depend largely on whether the details of controlled burning were recorded accurately and objectively to ensure quality data. Such data may be available for some of the larger reserves such as the Kruger National Park, but possibly also for smaller reserves.

EFFECTS OF HARVESTING

Harvesting may be directed at both live and deadwood, the latter the result of mortality of individual trees or branches. Owing to a paucity of data pertaining to the natural production of deadwood in savanna ecosystems, it is not possible to conclusively determine the value of deadwood as part of the ecological system or its contribution to sustainable livelihoods (Shackleton 1998). Hence, the opportunity to make objective recommendations concerning the conditions and controls for sustainable harvesting of deadwood, is hampered. Currently there is a great demand in communal lands for wood, with a wide range of uses extending from fuelwood to carving. The extent of utilisation of a tree species thus depends on the diversity of its uses. *C. imberbe* has a wide range of uses, and coupled with is relatively low density (Clarke 1997) and slow growth (Coates Palgrave 1983) compared to other tree species, may be subject to rapid short-term over-utilisation.

Harvesting in particular has a marked impact on the basal diameter size class distributions of most woody species (Shackleton 1993). High density of trees in the smallest size class (<5 cm) is indicative of a healthy recruitment rate, which may serve as a buffer against the effects of harvesting. However, because of *C. imberbe's* slow growth rate (Coates Palgrave 1983), recruitment into the large size classes will be gradual (Clarke 1997). In the Bushbuckridge district, frequently used species in the woodcraft industry are *Berchemia zeyheri, B. discolor, Olea europaea*, and *Spirostachys africana*, while *Acacia ataxacantha* and *C. imberbe* are species used as alternatives (Clarke 1997). *C. imberbe* however sustains the greatest number of uses and the greatest harvesting pressure than the other tree species, with all it size classes and 20% of the plants being harvested (Clarke 1997). The recruitment potential is however high with 79% of the population having a basal diameter of $\leq$ 20 cm (Clarke 1997). Since the harvesting rate appears to exceed the rate at which trees mature, both for seed production and use in the woodcraft industry, harvesting cannot be considered sustainable (Clarke 1997). Although the total densities of *C. imberbe* may be high, the number of individuals within a suitable size class for use in the woodcraft industry is insufficient to satisfy the demand by craftsmen. Small trees cannot be harvested as a substitute for larger trees, as no item of value can be produced from such trees. This selective harvesting of trees wit basal diameter $\geq$ 20 cm, which are capable of seed production, for construction and carving material, reduces both the rate and ability of population recruitment (Clarke 1997).

With increasing stem diameter of *C. imberbe*, an increasing proportion of trees are harvested in communal lands (Clarke 1997). There is thus a decline in the number of trees per size class (based on basal diameter) following the smallest size class comprising seedlings (basal diameter < 5cm) on communal lands. Apart from harvesting, this decline is also related to density-dependent factors such as competition and light availability, and other density-independent factors such as fire and grazing (Clarke 1997). Trees with diameters < 20 cm are widely harvested, although trees with a diameter of 61 - 65 cm are harvested most frequently, with 60% of all stems removed (Clarke 1997). An increase in the number of homesteads, head of cattle and other livestock, as well as cultivated plots, results in an increased demand for 61 - 65 cm diameter stems used for building fences and shelters. At one out of five villages in the Bushbuckridge district all the stems in this age class were harvested (Clarke 1997). In another village up to 21% of the standing crop of trees < 5cm were harvested, which because of the high human population, could be to increase fuel supply prompted by diminishing deadwood reserves (Clarke 1997). Assuming that trees with diameters < 20cm are deficient of enough heartwood to produce the smallest carved items (such as walking sticks and salad servers), an estimated 2.2 ± 1.1 trees/ha are available for harvesting for use in the wood craft industry (Clarke 1997). This equates to approximately 22% of the total standing crop of *C. imberbe*, with the majority of the population (79%) having stem diameters < 20cm (Clarke 1997). Such population characteristics are indicative of intense harvesting of large tree size classes.

In communal lands of the Bushbuckridge district *C. imberbe* has a biomass of 62 ± 17 kg/ha, ranging from 5 ± 2 to 207 ± 121 kg/ha, (Clarke 1997). Based on harvesting rates in that area at the time, where 20.1% of the total population of *C. imberbe* was harvested, it is estimated that trees with a basal diameter ≥ 20 cm could sustain harvesting for woodcarving alone for 62 years. If harvesting for fuel and construction materials is also considered, which may have a dramatic impact on the resource base, then the harvesting intensity of stems ≥ 20 cm could only be sustained for a period of one year. This implies that the resource may already be depleted at present. Harvesting of stems ≤ 20cm in diameter for fuel could be supported by the resource base for 2 years, assuming that all individuals of 11 - 19 cm are recruited into the ≥ 20cm size class.

Harvesting for woodcraft is generally most intense within a 350m radius from a village or rural settlement (Griffon et al. 1993). Shackleton et al. (1994) found that *C. imberbe* is an obligate sensitive species, exhibiting a marked decline in abundance with increasing proximity to a rural settlement. Under the prevailing management system and increasing human pressures, it is possible that woody species that are sensitive to harvesting are at risk from local extinction within such communal areas (Shackleton et al. 1994).

COPPICING ELICITED AS A RESULT OF HARVESTING

Information on the coppicing response of *C. imberbe* is limited in the literature, although some elementary results are available from a study conducted in the Bushbuckridge district of the Limpopo Province lowveld. These include responses such as number and length of coppice shoots, relative to the height at which live trees are harvested. Coppicing regrowth from harvested stumps in *C. imberbe* is high, while the proportion of old and recently harvested trees that either die or coppice is estimated at 12 and 88% respectively (Clarke 1997).

The number of shoots produced on *C. imberbe* trees is negatively correlated with the height at which trees are harvested (Clarke 1997). However, the length of the longest shoot is positively correlated with the height of both old (> one year) and recently (< one year) harvested stems. Hence shorter shoots are produced when trees are harvested close to the ground. There is also a positive correlation between the number of shoots produced and the length of the longest shoot of old and recently harvested stems. Apical dominance is thus prevalent between shoots, with old harvested stumps having fewer but longer shoots than recently harvested stumps (Clarke 1997). The contribution of coppicing to the regeneration of harvested trees is however high (Clarke 1997)

The height at which a tree is harvested is thus the most important factor influencing the coppicing ability of *C. imberbe*, followed by tree diameter. Stump mortality generally results when trees are harvested close to the ground, thereby subjecting coppicing shoots to intensive domestic livestock herbivory and fire damage (Clarke 1997). A harvesting height of one meter appears most advantageous to survival and coppicing potential. Shackleton et al. (1994) suggest that the potential longevity of the wood resource may be greatly improved if an adequate interval is allowed before a stump is reharvested. Most woody species are negatively affected by disturbances such as harvesting, with a significant decrease in stem density, basal area, biomass, height, seedling density, and species richness, with increasing disturbance intensity (Shackleton et al. 1994). However, the regeneration potential appears strong despite significant disturbance, with seedling densities remaining high and coppicing being fairly rigorous (Shackleton et al. 1994).

EFFECT OF WATER STRESS

O' Connor (2001) investigated the effect of small catchment dams on the downstream vegetation of a seasonal river within the Kolope-Setonki subcatchment of the Limpopo river, Limpopo Province, South Africa. Agricultural dams had increased the amount of catchment affected from 2% to 50% between the years 1955 and 1987, and are believed to have curtailed the flow during years of poor flow (O' Connor 2001). *C. imberbe*, which occurred at an elevation of 0 to 4 m above the river and distances of up 60 m from the river, experienced a mortality of 10%, while the remaining live trees had lost an average of 8% canopy volume (63% had lost none of their canopy volume while 7% lost > 50%)(O' Connor 2001). Dead *C. imberbe* trees occurred at greater distances and elevation from the river than individuals that were alive. Of *C. imberbe* trees (n = 46) that had established on hydromorphic grasslands for < 32 years that had gradually desiccated, 65% had died while the remainder had lost 41% of their canopy volume, owing to water stress once they had reached half the circumference (mean of 85 cm) of individuals in the riparian zone (O' Connor 2001). The conditions of the grasslands appear, however, not no be suitable for continued growth of trees, as they were formerly inimical to woody species (O' Connor 2001).

Essentially, the extent of mortality or dieback of *C. imberbe* was not related to its estimated water requirement. Dieback increased significantly with increasing distance from the water, but only weakly for larger individuals at greater elevation above the river, growing at their limits of water availability (O' Connor 2001). Dieback occurred almost exclusively on large trees well above and away from the river, which experienced the greatest water stress. The population structure of *C. imberbe* was characterised by a reverse J-curve, indicating that recruitment into the smallest size class (0 – 200 mm stem circumference) was successful, but that progression into the larger size classes was constrained (O' Connor 2001). It was postulated that the cumulative impact of small dams on the extent of river flow is responsible for the dieback in *C. imberbe* and an associated tree, *Faidherbia albida*. Other species such as *Schotia brachypetala* and *Xanthocercis zambesiaca* experience negligible diebacks and no mortality (O' Connor 2001). O' Connor (2001) suggested that the effect of lateral downslope movement of saline water into the dryland-riparian ecotone on the mortality of *C. imberbe* warrants further investigation, considering the important influence of groundwater chemistry on riparian species.

MORTALITY CAUSED BY HERBIVORES

No information on this aspect could be found in the literature, except that Viljoen and Bothma (1990) concluded that the number of woody plants, including *C. imberbe* among others, that were heavily utilised or killed by elephants (*Loxodonta africana*) in the northern Namib Desert was insignificant compared to the total number of trees utilized. Most of the dead woody plants were killed by causes other than elephants (Viljoen and Bothma 1990). While bark utilisation scars were found on trees such as *Acacia albida, A. erioloba*, and *Colophospermum mopane*, none were found on *C. imberbe* (Viljoen and Bothma 1990).

EFFECTS OF DROUGHT

No information on the effects of drought on *C. imberbe* could be found in the literature.

EFFECTS OF FROST

Virtually no detailed information on the effects of frost on *C. imberbe* could be found in the literature, except that Venter and Venter (1996) state that it only occurs in frost-free areas.

ECONOMIC VALUE

CONSUMPTIVE USES

Indigenous woodcraft industry

C. imberbe is a commercially valuable species favoured primarily for its durable heartwood, which is much sought after in the woodcarving industry (Clarke 1997). The wood is popular for sculpture- and lathe-work (Venter and Venter 1996) and furniture production (Shackleton 1993, Shackleton 1998), the latter becoming increasing popular (Venter and Venter 1996). In the Bushbuckridge district the average woodcarver and furniture maker uses between 6 to 50 and 10 to 150 trees per annum respectively, of several species, although the extent of species exploitation is still uncertain (Clarke 1997). *C. imberbe* is used as an alternative species by a large number of woodcraftsmen in the area, who frequently used species such as *Berchemia zeyheri, B. discolor, Olea europaea*, and *Spirostachys africana* (Clarke 1997). Here woodcarving is a key component of the local tourism industry and provides economic support for a large proportion of the rural community (Clarke 1997).

C. imberbe is a species most at risk from over-utilisation compared to the other species that are used in the woodcarving industry, at least within the communal lands of the Limpopo Province lowveld. All size classes and as much as 20% of *C. imberbe* trees are harvested here (Clarke 1997). It has however, a strong recruitment potential as 79% of the population has a basal diameter ≤ 20cm.

Fuelwood

C. imberbe is considered an excellent fuelwood that burns slowly with little smoke, but with a high calorific value (Liengme 1983, Carter and Goldsmith 1981, Carr 1988, McGregor 1991, Venter and Venter 1996). *C. imberbe* is a preferred fuelwood species, among others, in the lowveld of the Limpopo Province of South Africa (Clarke 1997), and in Zimbabwe (Sibanda 1992). Fuelwood is used primarily for cooking, heating bath water and heating the home during winter (Mashabane et al. 2001). In the Lowveld district of the Limpopo Province, South Africa, *C. imberbe* is mixed with other woods such as *Colophospermum mopane*, *Combretum* species, and *Grewia caffra,* among others, for cooking (Mashabane et al. 2001). It is also favoured for brick burning (McGregor 1991).

In Gazankulu, Limpopo Province, *C. imberbe* made up an average of 2.6% of the weight of a total of 42 species there were harvested for fuelwood, which was significantly lower than for *Colophospermum mopane* and *Combretum apiculatum*, representing 39% and 23.0% of the total weight respectively (Liengme 1983). The current weight that these species contribute to fuelwood collected is unknown. In the Bushbuckridge district it is estimated that *C. imberbe* trees with stems ≤ 20 cm in diameter, the typical size for fuelwood, will only sustain harvesting for two years. Depending on the accuracy of this prediction, the fuelwood supply may already be depleted at present. The status of *C. imberbe* as a fuelwood species should therefore be re-evaluated to determine the extent of current use, particularly in areas where sampling has previously been conducted.

Building materials

C. imberbe is a commercially valuable species in southern Africa (Shackelton 1998). The durable stems, which are resistant to attack by termites and borers, are used for fencing posts in rural areas (Goldsmith and Carter 1981, Venter and Venter 1996). Railway sleepers were previously made from straight-stemmed specimens, while it was also used as in the mining industry as baulks, pit props, and poles (Palmer and Pitman 1972, Goldsmith and Carter 1981, Venter and Venter 1996). Liengme (1983) estimated that *C. imberbe* comprised only 0.05% of the total volume of wood used in building living-huts in rural areas of the north-eastern region of the Limpopo Province, where it is primarily used for the main supporting poles of the huts. This is significantly lower than other species such as *Colophospermum mopane*, which represented 97% of the wood volume. In the Lowveld district of the Limpopo Province, South Africa, *C. imberbe* is usually used to supplement *Colophospermum mopane*, which is used as the main constituent of palisade fences (Mashabane et al*.* 2001).

The intensity of wood harvesting is expected to increase because of the escalating demand for agricultural land and the slow infrastructural development of villages, resulting in the indigenous vegetation becoming insufficient to maintain the needs of the communities, and hence over-utilisation of woody species will occur.

Utensils

Prior to the advent of iron hoes, Africans used the wood of *C. imberbe* for making hoes (Palmer and Pitman 1972). Trunks are also used to make traditional grain stamping mortars (Liengme 1981, Venter and Venter 1996, Van Wyk and Gericke 2000).

Other uses

Other uses for *C. imberbe* are fairly numerous. Root bark boiled in water is used for tanning leather (Venter and Venter 1996). The ash can be used to sediment clay out of drinking water, which also contains a high percentage of lime, making it suitable as a substitute for lime to whitewash buildings (Palmer and Pitman 1972, Venter and Venter 1996). When this whitewash is mixed with milk or buttermilk, it is reputed to be waterproof (Palmer and Pitman 1972). The ash may also be used as a toothpaste (Clarke 1997). Walking sticks and furniture are also made from sizeable trees (Clarke 1997). In Zimbabwe a number of used are listed by Goldsmith and Carter (1981), including: inlay work, ornamental carving, machine bearings, turnery, pistol grips, small furniture, toy making, and trinket boxes.

No evidence was found that the wood is used for charcoal production.

FEED FOR LIVESTOCK AND GAME

Fruit and seed

No indication as to the value or digestibility of the fruit or seed of *C. imberbe* to livestock, game or other vertebrate and invertebrate animal species could be found in the literature.

Leaves and shoots

In Mopane Veld in the Limpopo River valley, where *Colophospermum mopane* is the dominant tree species (Acocks 1988), *C. imberbe* was found to display a long leaf carriage period (Dekker and Smit 1996). New-season leaves appeared during mid-November, with leaf senescence only beginning in July the following year. Dry leaves thus remained until October, with leaves only being absent during the first half of November. Although this long leaf carriage period should make *C. imberbe* a valuable fodder tree, most leaves are carried above 2 m, which is beyond the reach of small- to medium- sized browsing ungulates. Its browse value is however also lower than that of other *Combretum* species, with leaves and twigs containing only 4% protein (McGregor 1991). Young leaves are eaten more readily by game animals than mature leaves (Venter and Venter 1996), presumable because these have higher protein content. Venter and Venter (1996) point out that young trees should be protected against defoliation by livestock and game during the first two years, although they did not indicate which size classes this group encompasses. Nonetheless, this suggests that in communal areas with livestock, overgrazing of young *C. imberbe* trees may have negative impacts on their growth. High browsing pressure could thus retard the growth of recruitment trees into the reproductive population, thereby extending the growth period to reproductive age.

In Zimbabwe the leaves are used as browse by cattle during November and December (Sibanda 1992). In the Gwanda District in Matabeleland, *C. imberbe* trees are pollarded during the dry season and especially in the drought years to provide browse to cattle (Sibanda 1992). The majority of trees are thus secondary or tertiary growth, within a height range of 1.5 to 2.5 m, which is within reach of most domestic animals (Sibanda 1992). The pollarding of trees may have thus have a similarly vegetative effect on recruitment potential as intense browsing of young trees. Clarke (1997), suggests that rotational grazing in communal lands may serve as a management strategy that allows for the establishment of a stable population of *C. imberbe*, assuming that the rate at which cattle are rotated is sufficient for seedling establishment. Although an unstable population is not necessarily an undesirable state, and indeed appears to be the norm for semi-arid savannas (Shackleton 1993), there are no data available on the period needed for seedlings to establish themselves and ensure that there is maximal recruitment into the next size class.

MEDICINAL USES

Traditional medicine is estimated to still play a vital role in the lives of 70-80% of the population of developing countries worldwide (Botha et al. 2001). The significance of *C. imberbe*'s contribution to medicinal uses, both in terms of quantity and importance, is uncertain. Hutchings (1989), for example, did not report *C. imberbe* as a traditional medicinal plant, primarily among the Zulu, Xhosa and Sotho in South Africa. It used for human consumption only, and mostly in a magical sense (Arnold et al. 2002). A number of medicinal uses are reported in the literature. The roots are also used to make a decoction that is taken orally to treat diarrhea, while an infusion made from root bark is used for the treatment of bilharziasis (Venter and Venter 1996). The roots of *C. imberbe* are mixed with those of *Colophospermum mopane*, and *Combretum zeyheri* and boiled in water to produce a decoction to treat stomach ache (Mashabane et al. 2001). There is unconfirmed information that suggests that *C. imberbe* is used with *Sclerocarya birrea* subsp. c*affra, Diospyros lycioides, Combretum erythrophyllum* and other species to restore or revive fertility in Vhavenda women (Mabogo 1990). Only roots that grow horizontally, and especially those that cross footpaths, may apparently be used for this purpose (Mabogo 1990). Green leaves placed on hot coals produces a smoke that can be inhaled to relieve coughs, colds (Venter and Venter 1996) and other chest complaints (Mabogo 1990). An infusion made from the plants flowers is used to treat coughs (Venter and Venter 1996).

FOOD FOR HUMAN CONSUMPTION

The gum of *C. imberbe*, which exudes from damage inflicted to the stem, is edible (Palmer and Pitman 1972) and is included in the diet of the Bushman (Story 1958, Venter and Venter 1996).

NON-CONSUMPTIVE USES

ECOLOGICAL SERVICES

C. imberbe is used as a source of shade by livestock, but hardly for browse as it has a low protein content (Venter and Venter 1996). It is regarded as an indicator species of good grazing areas and sweet veld (Venter and Venter 1996). For game farms it is suggested that scattered groups of 5 to 25 individuals can be planted at suitable sites in grazing camps to provide protection for numerous small animas and nesting sites for birds (Venter and Venter 1996). No indication as to other ecological services provided was found in the literature.

CULTURAL VALUE

Very little information was attainable in this regard. The Hereros and Ovambos in Namibia attach special cultural and religious significance to the tree, although aesthetic aspects are not highly regarded in rural areas of southern Africa (Carr 1988).

TOURISM/AESTHETICS

No information was obtainable in the literature regarding *C. imberbe's* aesthetic value, nor has this been determine in monetary terms.

BIODIVERSITY VALUE

CONTRIBUTION TO BIODIVERSITY PATTERNS AND PROCESSES

No information with respect to *C. imberbe's* contribution to biodiversity patterns and processes could be found in the literature. It does however serve as an important nesting tree for hole-nesting birds, such as the vulnerable southern ground hornbill (*Bucorvus leadbeateri*), which selects large hollowed out specimens of *C. imberbe* (Yoval Erhlich *pers. comm.*). African white-backed vultures (*Gyps africanus*) also use the tree in which to construct their nests in the lowveld region of Swaziland (Monadjem 2001).

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

C. imberbe is a slow growing tree (Coates Palgrave 1983) occurring at relatively low densities compared to other woody trees in some parts of its distributional range (Clarke 1997). Owing to its favoured hard wood, which is extremely durable, it is frequently used for a variety of functions, extending from fuelwood to building material and wood carving (Clarke 1997). It therefore experiences the greatest harvesting pressure by harvesters, where demand is estimated to exceed the supply of wood from natural populations (Clarke 1997). The demand for its wood is unlikely to decrease in time, and especially for craft production, which is an important means of promoting self-sufficiency, and alleviating poverty and unemployment in rural communities (Clarke 1997). Further, rural development projects, such as the woodcraft industry, cannot be sustained in the hope that traditional practices will ensure sustainable use. There is a definite need to investigate means of improving the sustainability of harvesting to ensure protection of the species, but which also acknowledges the needs of those people who's livelihoods depend on this sensitive resource.

Little data is available on the biology and ecology of *C. imberbe*, despite the intense harvesting that it is subjected too. A preliminary investigation has indicated that *C. imberbe* is declining where there is harvesting for fuelwood, building material and carving wood, and is hence unable to sustain the removal of large (≥ 20cm) and small (≤ 20 cm) trees (Clarke 1997). In order to obtain the wide array of biological data that is needed to complete our understanding of this species, several decades of research would be required; an undertaking that may outlast the species itself. Clearly, in order to ensure the protection of the species within a relatively short period of time, research should become more focused on those aspects of its biology which can, or should, be manipulated or managed in order to established sustainable harvesting guidelines. Two approaches to achieving this end are proposed here. These include a simple, yet effective, demographic population model of *C. imberbe*, and secondly a field-based research effort at establishing the distribution of size classes of a fairly large number of regional populations across its southern African distributional range. These initiatives would provide an understanding of the species' population status and response to harvesting pressures, across an array or environmental and anthropogenic influences. With this knowledge, a more focused, purposeful and broader research programme can be initiated, which will ensure that those factors relevant to the protection of the species, receive priority. In this manner the spending of research funds could also be optimised.

Population modelling could serve as an initial step towards understanding the dynamics of the population, and allows for simple manipulation of a hypothetical population to determine the effects of selective harvesting of size classes on population viability, as well as the effects of changes in recruitment potential. Matrix population models, for example, are a suitable means of conducting "if…then" scenarios on a hypothetical population. Further, a sensitivity analysis would assist in highlighting those population parameters that have the most profound effect on the population's viability. The identification of these vital population parameters will ensures that future research can be directed at those aspects of *C. imberbe*'s biology, which are most critically needed to develop sustainable harvesting methods.

An assessment of size class distribution to determine the impact of harvesting can be achieved by sampling along gradients, radiation out from the centre of communal villages where harvesting will be most intense, to areas further away where harvesting is low or non-existent. Such a sampling design, where plots at different points along the gradients, can be combined with distance sampling methodologies (Buckland et al. 2001) for estimating tree abundance. This will provide a rapid assessment of the population structure and status, and insight into regeneration patterns (Cunningham 2001). By comparing the status of several populations, rather than a single or few populations, it may become evident which regional populations are seriously compromised by harvesting and hence require immediate management intervention. Such an assessment may also identify possible trends in size class distributions in relation to environmental and anthropogenic factors.

In addition to these two research directions, there is also an urgent need to establish the nature of the market for *C. imberbe* wood, and the forces that drive it. Data is needed on the amounts of wood being harvested, and for which purposes, the size of the market for wood carvings and other products, the sellers and buyers, and the socio-economic environment in which these operate.

RESEARCH GAPS OF RELEVANCE FOR CONSERVATION AND SUSTAINABLE USE POLICY

There are essentially two fields of knowledge that are urgently needed on *C. imberbe*, which include a better understanding of some of its biological characteristics and secondly, and understanding of the socio-economic factors that drive the market (commercial and subsistence) for it wood. Respective research gaps for each are discussed below:

BIOLOGICAL CHARACTERISTICS

1. **Can the rate of harvesting previously harvested stems (rotational harvesting) be increased by cutting stems at a specific height**, or by cutting only trees with a specific diameter, or if coppiced shoots are selectively removed? It has been determined that the length of the longest coppice shoot following harvesting is positively correlated with the height of the harvested stems, and that there is also a positive correlation between the number of shoots produced and the length of the longest shoot (Clarke 1997). Apical dominance is thus prevalent between shoots, with old harvested stumps having fewer but longer shoots than recently harvested stumps (Clarke 1997). Shackleton (2000) states that rotation time can be minimised between harvests if a lower cutting height is advocated (for species other than *C. imberbe*, which was not tested), resulting in fewer shoots and contributing to earlier establishment of apical dominance. Too low a cutting height is however disadvantageous to *C. imberbe* trees (Clarke 1997). Such knowledge regarding optimal harvesting techniques is essential to promote sustainable resource management; particularly since the resource base is currently under pressure form over-exploitation.

2. **A re-assessment of the study area used by Clarke (1997) in the Limpopo Province, South Africa, may provide valuable information on demographic changes of the *C. imberbe* population studied there**, and determine whether the predictions made regarding the sustainability of the harvesting have been realized. Based on harvesting rates in the Bushbuckridge District in the Limpopo Province, Clarke (1997) estimated that trees with a basal diameter $\geq$ 20 cm could sustain harvesting for woodcarving alone for 62 years, but that if harvesting for fuel and construction materials was also considered, then the harvesting intensity of stems $\geq$ 20 cm could only be sustained for a period of one year. This implies that the resource may already be depleted.

3. **What are the minimum conditions required to ensure successful germination and establishment of seedlings in natural populations?** How is establishment influenced by herbivory (of both tree seedlings and competitive grasses) and harvesting, and environmental influences such as rainfall, fire and drought, considering that recruitment from seed in resprouters is generally infrequent and irregular (Cunningham 2001).

4. **What period is needed to ensure that seedlings are able to establish and escape grazing** to maximise recruitment in areas occupied by livestock or where there is rotational grazing?

5. **What is the minimum reproductive age of *C. imberbe***, which currently appears to be unrecorded, and minimum seed production capacity of reproductively mature size classes?

6. **What is the rationale for extended periods of fruit dispersal**; if this is indeed to assist in reducing potential fire-damage to a proportion of the seed population produced in a particular year (Ernst and Tolsma 1990), then fire management may have to be considered in the management plan for the species, in order to ensure maximal recruitment.

7. **The density of *C. imberbe* differs markedly between regions, and even within the same regions.** An investigation of regional or site-specific tree densities and the local factors that could influence these may identify underlying correlations.

8. **How do environmental factors such as rainfall, drought, herbivory and fire influence the survival of different size classes of *C. imberbe*?** Can these factors be expected to influence *C. imberbe* as they may affect similar tree species, in which case a comparative study could be conducted to establish similarities. This may avoid the need to conduct intensive field-research and possible duplication of results.

SOCIO-ECONOMICS

1. **What are the socio-economic characteristics of the wood harvesters?** Are they forced into wood harvesting through poverty or is it a highly profitable undertaking. Are harvester's casualties of the Extension of Security of Tenure Act, refugees from neighbouring African countries, or commercial operators.

2. **Who generates the most profit from wood sales?** Is wood sold directly from the harvester to the final buyer, or are there additional traders (middlemen) involved?

3. **Is the market demand driven, poverty driven, or other?** If there is a demand for wood, are there discernable seasonal trends in the amount of wood harvested and sold?

4. **What are the characteristics of the market?** Who are the buyers of wood products such as carvings, or furniture? Which socio-economic class do they represent? Are they foreigner visitors or resident citizens? Where are wood products sold, locally or internationally?

5. **Does increased tourism, for example, increase the demand for wood carvings and other wood products?** How do tourism destinations, such as Kruger National Park, and smaller private reserves contribute to the sustainability or growth of the markets. Do these enterprises support or encourage the selling of wood products?

6. **What proportion of wood harvested is used for subsistence and commercial use?** Subsistence use would involve harvesting for fuelwood and other non-profit domestic uses. The furniture trade is a large consumer of wood, rural wood carvers use between 10 and 150 trees per annum (Clarke 1997). How much is thus being utilised by commercial furniture trades, where furniture is produced in factories?

7. **Is harvesting localized or extensive?** Is subsistence harvesting restricted to the periphery of communal areas, or are harvesters extending their search for wood? What means of transport are being use to move wood, and how does this impact the resource base?

8. **To what extent is *C. imberbe* harvested by private land owners or game reserves?** Game lodges are reported to extract large quantities of *C. imberbe* for structural development. Is this wood obtained locally or imported from other areas, or obtained from traders? How much wood is harvested to supply such developments?

9. **Is there a cultural demand for fires**, or would the availability of electricity in rural areas alleviate pressure on the fuelwood resource?

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