Mopane Woodland Management

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Introduction

Colophospermum mopane (Benth.) J. Léonard (vernacularly known as mopane) is one of the best-known and valuable tree species indigenous to southern Africa. Characteristics of *C. mopane* are described in publications by De Winter *et al.* (1966), Palmer and Pitman (1972), Ross (1977), Palgrave (1993) and Van Wyk and Van Wyk (1997). Timberlake (1995) extensively reviewed the literature on *C. mopane,* with additional reviews (including its management) in; Flower *et al.* (1996), Timberlake (1996), Timberlake (1996*) and Timberlake (1999). It is not the intention of this review to repeat the aforementioned literature surveys, but rather to highlight characteristics of the species relevant to its management and utilisation, as they relate to the objectives of this research project.

Taxonomy

Colophospermum mopane is a monotypic (African) genus of the subfamily Caesalpinoideae that is generally placed in the tribe Detarieae (Lock 1989). The species was formerly placed in the genus *Copaifera* L. with the genus *Colophospermum* being created by Léonard in 1949 (Léonard 1949). Breteler *et al.* (1997) recently suggested that *Colophospermum* be sunk under the monotypic genus *Hardwickia* Roxburgh that occurs in India. However, unconvincing evidence presented by Breteler *et al.* (1997) as pointed out by Léonard (1999) in a strong rebuttal and resultant confusion such a name change would have caused (Smith *et al.* 1998), argued convincingly for retaining the genus *Colophospermum.* Wessels *et al.* (1998) recently informally described three ecotypes of *C. mopane* from the Messina area of the Northern Province of South Africa. They showed that in addition to morphological and physiological features the fruits of the different *C. mopane* ecotypes differ (amongst themselves and from those of *C. mopane*) in colour, morphology, anatomy, size and mass. The ecotypes are currently being further examined by Wessels and co-workers by means of comparative DNA studies.

Distribution

C. mopane is a xeric species of the savanna woodland zone of south central Africa. It is the dominant tree over large tracts of comparatively clay-rich soils (without excessive waterlogging) in southern Africa within an altitudinal range of 300-1,000m and annual (unimodal) rainfall zone of 400-700mm with a long dry season (Timberlake 1995). According to Timberlake (1995) the species can be found up to 1,200m in Zimbabwe. Viljoen (1989) on the other hand reported that, in favourable sites, *C. mopane* could occur in areas with as little as 100mm of annual rainfall. The species occurs over approximately 550,000 km^2 of southern Africa (Mapaure 1994) and may form pure stands in certain localities. Although *C. mopane* is not recognised as a miombo woodland species, it is often closely associated with miombo woodland. Specifically, *C. mopane* occurs in northern Namibia; the Caprivi strip; north-eastern Botswana; south and west Zimbabwe and areas in the north; southern parts of Malawi; southern and central Mozambique; southern Angola and parts of the Northern and Mpumalanga Provinces of South Africa (Cole 1986; Mapaure 1994), with large and relatively undisturbed tracts in the northern half of the Kruger National Park. It appears that the distribution of *C. mopane* is determined by different factors in various parts of its range, though frost, soil type, minimum rainfall, length of the growing season and occurrence of competing plant species are thought to be important factors.

Phenology

C. mopane is a deciduous slow-growing species, with an erect narrow crown. The leaves are pinnate with two large leaflets that can vary considerably in size on the same tree (Wiggins 1997) and within a growing season (Potgieter and Wessels 1998). *C. mopane* drops its leaves in an irregular fashion from the onset of the dry season and is generally leafless from August to October. However, trees may retain their leaves between successive rainy seasons, depending on the amount and distribution of rainfall (Wessels *et al.* 2001b). In South Africa, flushing of *C. mopane* occurs after the first summer rains, usually during October and November. On the other hand, flushing is independent of rain in Namibia and Botswana (Wessels and Potgieter 1997; Styles and Skinner 1997b). Newly emerged *C. mopane* leaves are soft, succulent, and variously yellowish or red in colour, but become leathery with age (Potgieter and Wessels 1998). Styles and Skinner (1997b) report that the nutritious young leaves are utilized by ungulates. The characteristic 'butterfly wing' shaped leaves tend in the heat of the day to close up, hang down, and so cast relatively little shade.

C. mopane's inconspicuous flowers, whose development was described by Krüger *et al.* (1999), appear after the leaves from December to March. However, due to unknown reasons, the production of flowers is highly irregular, (Wessels *et al.* 2001a). *C. mopane* fruits are indehiscent, flattened, reniform or obliquely semicircular and yellowish-brown. Wessels *et al.* (2001a) reported that fruits collected in the Messina area had an average length, width and thickness of 36.1 x 20.0 x 2.9 mm, and the seeds, fruits and pods had average dry masses of 0.214, 0.419 and 0.205g respectively. The fruit surface is covered with numerous, scattered resin glands. *C. mopane* seeds are usually reniform, laterally compressed and their surfaces are covered with numerous small reddish glands which are sticky. The pericarp of the fruit lacks the intricate structure of a typical legume and only opens along one side at a weakness zone of the ventral suture (Jordaan and Wessels 1999).

Reproduction

The ripe fruits of *C. mopane* appear from March to June; dispersal occurs mostly in May (Timberlake 1995). Jarman and Thomas (1969) suggested that *C. mopane* fruits are dispersed by wind. Styles and Skinner (1997b) conclusively showed that *C. mopane* diaspores are not dispersed by epizoochory, but rather by rainwash and wind. The contribution of wind in the dispersal of *C. mopane* fruits was confirmed by Wessels *et al.* (2001a) who documented an absolute maximum fruit dispersal distance of only 8m from the base of a parent tree. In addition, they found that the majority of *C. mopane* fruits (63%) were dispersed below parent tree canopies. This finding is significant in that Wessels and Potgieter (2001) observed that no seedlings survived under the canopies of parent trees. Average maximal dispersal distances ranged between 1.05 and 1.6 times tree height, depending on whether the fruits were dispersed from less than 2m or from more than 2m high on the parent tree canopy. Wessels *et al.* (2001a) could not find any post deposition dispersion by animals or wind, suggesting the importance of rainwash as a dispersal agent. They found that an average of 139 fruits m^{-2} were deposited, inferring an average of 1.39 million seeds h^{-1}.

Vegetative reproduction of *C. mopane* occurs rarely and the species reproduces primarily from seed. As with the majority of southern Africa's indigenous tree species, little is known about *C. mopane*'s regeneration requirements. Timberlake (1999) pointed out that during good rainy seasons, thousands of seedlings can be seen, but that saplings of 1-5 years are rarely encountered. Wessels and Potgieter (2001) recorded the survival of the 1996 cohort of *C. mopane* seedlings for 1,096 days in ten randomly placed permanent sample plots in mopane woodland on the Messina Experimental Farm (Northern Province, South Africa). The highest seedling mortality rate (39.1%) was recorded during the establishment period. Only 3.1% of the original seedling cohort reached an age of 1,096 days. At the onset of the study, there was an estimated 294,000 seedlings ha^{-1}, confirming the abovementioned observation of Timberlake (1999). They observed that stands of seedlings under parent plant canopies were the first to die out completely (as a result of changed microclimates and competition), which explains the generally observed absence of *C. mopane* seedlings below parent plants.

Mopane scrub also exhibits regeneration from underground stems that readily coppices, probably as an adaptation to a combination of periodic drought, frost, fires and damage from vertebrates. These underground roots are an important export product from Namibia (exploitation rate: 922 tonnes yr^{-1} and income to farmers: N$250 00 yr^{-1}) to eastern countries where they are used as decorations in fish tanks and households (Piepmeyer 1997). However, the export of this natural product should be handled with great care, as recent radiocarbon dating by the Council for Scientific and Industrial Research (CSIR) in Pretoria established that such an underground stem had an average age of 150 ±15 years (D.C.J. Wessels pers. comm.).

Ecology

Ecologically, *C. mopane* can be considered a secondary coloniser that is physiologically well adapted to dry conditions. Mopane woodlands are very variable in character and may contain stands of trees up to 20 m high (Van Wyk 1993), colloquially termed “cathedral mopane” (Fanshawe 1969). More usually *C. mopane* ranges from about 10m (Palgrave 1977), to low scrub attaining only 1-2 m and dwarf mopane (Potgieter and Wessels 1998). The principal cause of these dissimilarities appears to be soil variation, particularly depth and pH with best growth on deeper fertile soils, often of granitic origin. O’Conner’s (1992) investigation of the relationships between gradients in the composition and structure of woody vegetation and environmental factors highlighted soil types as important determinants of mopani veld in the Northern Province of South Africa. *C. mopane* readily produces shoots from the rootstock when damaged by humans, fire, drought or large animals. The trunk of mature specimens is often forked and is normally 400-700mm in diameter (Timberlake 1999). Gelens (1996) reports that the shrub-like form of mopane can also be induced by people and is not always a site-related phenomenon. Wessels and Potgieter (1997) reported on the unusual occurrence of the natural grafting of *Boscia albitrunca* onto *Colophospermum mopane* and *Combretum imberbe* in northern Namibia.

C. mopane has a markedly shallow (usually around 300-1200mm deep) extensively spreading root system (Thompson 1960; Smit 1994; Timberlake 1995), but can extend much deeper in deep soils. Smit (1994) reports that the fine roots (<5.0mm) are largely confined to the first 400 mm of soil, while course roots (>5.0mm) penetrate deeper. The root biomass of *C. mopane* is exceptionally high (mean: 17 354 kg ha^{-1}) and exceeds the leaf biomass of 1023 kg ha^{-1} (Smit 1994; Smit and Rethman 1998b). Roots of *C. mopane* trees are able to utilise soilwater at a matric potential lower than that of grasses (<-1 500 kPa) (Smit 1994). This finding probably explains the poor grass layer in mopane woodland, which according to Timberlake (1999) generally consists of *Aristida* and *Eragrostis* species. Nitrogen fixing nodules have not been found on the roots of *C. mopane* (Grobbelaar and Clarke 1972; Corby 1974). However, Jordaan *et al.* (2000) recently reported on bacteria that infect the fine roots of *C. mopane*, that resembles rhizobia. They cause continuous degeneration of infected roots and stimulates the development of new lateral roots. Jordaan and coworkers (2000) proposed that such root clusters be regarded as primitive root nodules. Additionally, Högberg and Piearce (1986) observed that the fine roots of *C. mopane* are endomycorrhizal.

Mopane woodland is unusual in that it generally occurs in monospecific stands that support a relatively poor shrub layer. It provides woodland cover where few other tree species occur (Timberlake 1996*). Timberlake (1999,1995) commented on the comparatively low alpha and gamma diversities of mopane woodlands. These characteristics of mopane woodland give reason for concern as it is predicted that climatic changes can lead to the southward expansion of this biodiversity poor vegetation type and that *C. mopane* could colonise the southern part of the Kruger National Park (NBI 2001). Mopane woodland stands are often even-aged in appearance, indicative of episodic or cohort recruitment (Wessels and Potgieter 2001). In some regions distinct two-storey woodland develops with 2-3m tall scrub as the main ground cover stood over by scattered trees 10-15m high. Reported densities for mature mopane woodland range from a few trees per hectare in arid northwestern Namibia (Viljoen 1989) to 481 trees ha^{-1} in southeast Zimbabwe (Kelly and Walker 1976), to 2,289 trees ha^{-1} in mopane woodland in northern South Africa (Cunningham 1996). According to (Timberlake 1995) typical *C. mopane* tree densities are around 200 - 400 trees ha^{-1}.

Little has been published on the occurrence of smaller animals in mopane woodlands. Some such studies are on small mammals in Zimbabwe by Linzey and Kesner (1997a 1997b); on bird species associated with mopani veld in the Northern Province of South Africa by Styles (1995); geographical size variation and utilization of the leopard tortoise *Geochelone pardalis* in SubSaharan Africa by Lambert (1996) and the effect of ground-spray on lizards by Lambert (1994).

Although *C. mopane* produces copious amounts of fruits, it does not have a permanent seed bank. The orthodox seeds of *C. mopane* can be stored, but there is a rapid decline in viability after four years of storage under controlled conditions (Wessels pers. comm.). Jordaan and Wessels (1999) studied the germination of *C. mopane* seeds and proposed that the aril may fulfil and advantageous role during fruit opening and imbibition. Venter and Venter (1994) described the cultivation of mopane. Seeds of *C. mopane* germinate easily (ranging from 70-90% within two weeks under laboratory conditions), but seedlings are prone to damping off (Palmer& Pitman 1972) and should be sowed in well-drained soil and carefully watered. Mushove (1993) concluded that seedlings of *C. mopane* raised in 220x200mm polythene containers can attain plantable size 60 days after sowing. Smit (1994) found that the best germination results were obtained from *C. mopane* fruits collected at the end of the growing season, with the lowest germination from fruits harvested during the middle of the winter season. Choinski & Tuohy (1991) reported that *C. mopane* seeds can germinate under a wide range of conditions; however, they found the best germination at a water stress of -0.14 Mpa. Henning and White (1974) reported on the effect increased soil nitrogen and phosphorus and moisture content have on the growth of *C. mopane* seedlings.

There is little information on growth rates of *C. mopane* under various conditions, which is a major limitation in the ability to manage and utilize mopane. Recent radiocarbon dating by the CSIR in Pretoria established that a tree at the Messina Experimental Farm with a trunk diameter of 89 mm and a height of 7 m was 42 years of age (Wessels *et al.* 2001b), confirming the assumption of Timberlake (1999) that mature trees are 100-200 years old. Cunningham (1996) determined an average tree age of 25 years for mopane woodland in the Alldays area and a diameter growth rate of 590mm yr^{-1}, which should generate to present average circumferences within 24 years. However, over *C. mopane*'s distribution range, soil type and rainfall, wildfire, herbivory by mopane worms and vertebrates are likely to affect growth rates and growth forms of mopane as well as seed production (Styles 1993a; Ditlhogo *et al.* 1997; Styles and Skinner 2000; Kennedy 2000; Smallie and O'Connor 2000). Mushove *et al.* (1995) found that growth ring widths of *C. mopane* varied between sites, depended on tree size, with soil nutrient and moisture availability as important factors for the rate of tree growth. Smith and Shah-Smith (1999) examined *C. mopane* trees for evidence of physical damage caused by browsers, humans and other factors as well as visual signs of fungal colonisation. Their results suggest that the severity of physical damage had a relatively small influence on the activity of fungi colonising and utilising *C. mopane* heartwood. They concluded that heartwood degradation is not detrimental to the health of *C. mopane* trees.

Mopane woodland uses

Mopane woodland provides many benefits and is of great economic importance in the areas where it occurs, in addition to mopane worms. The tree provides a valued timber and is consequently widely used in the construction of huts, fencing and kraals (Madzibane and Potgieter 1999; Mashabane *et al.* 2000). Mopane woodland's ethnobotanical and ethnomedicinal uses in South Africa have been documented by various workers (Liengme 1981; Liengme 1983; Mabogo 1990; Madzibane and Potgieter 1999; Mashabane *et al.* 2000; Mashabane *et al.* 2001; Potgieter *et al.* 2001). As *C. mopane* wood burns slowly and produces good coals (Tietema *et al.* 1991), it is extensively used as firewood by rural communities within the SADC region where an estimated 79 million people depend on biomass fuels as their main source of fuel (Karekezi and Ewagata 1994). A good quality charcoal is produced from *C. mopane* wood and is widely utilised in countries like Zambia (Chidumayo 2000), where in rural areas the primary energy source is firewood and charcoal is predominantly used as fuel source in urban areas. Cunningham (1996) investigated mopane woodland for sustained charcoal and firewood production in the northern part of South Africa. He estimated a total biomass of 23,668 kg ha^{-1} with a potential charcoal biomass of 14,787 kg ha^{-1} for mopane woodland. At a harvesting rate of 25%, he estimated the mean available charcoal biomass to be 3,697 kg ha^{-1}. Cunningham (1996) suggested a harvesting model that would ensure sustainable harvesting for up to 60 years, with negligible effects on browsing ungulates. He suggested that such harvesting could benefit browser by distributing available browse proportionally over the year and foresaw an increase in grass production and consequent carrying capacity for grazers.

Game farming (a concept that was developed in southern Africa) and ecotourism are important economic activities in large parts of southern Africa's mopane woodlands. In this respect *C. mopane* plays a crucial role as its foliage is an important browse for many wild herbivores, including elephant (Lewis 1987; Styles 1993a; Cunningham 1996; Ben-Shahar 1998; Styles and Skinner 2000); eland (Cunningham 1996); kudu (Styles 1993; Cunningham 1996); impala, which feed on fallen leaves and fruits of *C. mopane*

(Cunningham 1996), and other bush wildlife. Dekker (1996) calculated coefficients of competition for different ungulates on the Messina Experimental Farm. These coefficients were used to calculate replacement values in terms of livestock and browser units that can be applied in the calculation of stocking rates for game ranches in mopani veld. *C. mopane* leaves are high in crude protein (8-16%; Bonsma 1942), with relatively high calcium and phosphorous levels (Bonsma 1942; Timberlake 1995). It is also a valued domestic fodder for livestock such as cattle (Bonsma 1942) and goats (Styles and Skinner 1996a), for both commercial and rural farmers. Foliage and seedpods are an important source of browse during the dry season as leaves of *C. mopane* remain on the tree during this period when little other forage is available. Styles and Skinner (1997a) found that green *C. mopane* leaves were most palatable over summer and that senescing leaves were at their most palatable in late winter/early spring, thus maintaining many herbivores before the spring leaf flush. Dekker and Smit (1996) reported that the total leaf DM in different plant communities on the Messina Experimental Farm, Northern Province, South Africa ranged from 1,224 kg ha^{-1}to 2,672 kg ha$^{-1,}$ with *C. mopane* contributing between 10 and 81%, to the total DM in the different plant communities. In some parts of its range, *C. mopane* has been known to avert large-scale livestock and game losses (De Jager 1995) from drought, a common occurrence in southern Africa. (For human uses of mopane woodland products, see above - please check in rest of document you will put together.

Several studies were undertaken in India on the suitability of using *C. mopane* in the re-vegetation of barren land. Jain and Muthana (1982) as well as Muthana and Jain (1984) reported on the performance of the species under saline irrigation conditions in nurseries. Shankarnarayan and Kumar (1986) reported low *C. mopane* seedling densities during a trial aimed at establishing different tree and shrub species on shifting sand dunes in India. Sharma *et al*. (1989) investigated the suitability of *C. mopane* for introduction into arid zones in India. Another study undertaken in India by Hussein *et al.* (1990) could not show any significant differences between *C. mopane* trees growing in saline sodic soils to which gypsum was added or withheld. Together with other tree species, *C. mopane* was investigated in India for the rehabilitation of gypsum-mine spoil (Rao and Tarafdar 1998).

Due to extensive human utilisation and absence of management practices, large parts of southern Africa's mopane woodlands have been heavily degraded or totally devastated, with serious socio-economic (Mubita 1995) and environmental consequences. Tafangenyasha and Campbell (1998), for example, ascribed erosion patterns in the Hwange National Park, Zimbabwe to past human activity, and present maintenance, by local high concentrations of a native grazer. Van der Walt (1997) discussed the value for grazing and erosion of mopani veld in South African. Erkkila and Lofman (1999) reported on the annual forest cover change in northern Namibia (-0.5% in the eastern part) between 1981 and 1992. Information on the ecology of *C. mopane* is consequently important for possible future reforestation projects in regions like northern Namibia where most of the natural vegetation has been cleared (Mubita 1995) and southern Angola (Neto 2000) where the mopane woodland is being over utilised. As similar problems may extend to other countries in the SADC region, there is a dire need for research to address these problems.

Management

Two types of management of *C. mopane* have been reported in the literature - thinning and coppicing: Coppicing studies on *C. mopane* (Tietema *et al.* 1988; Tietema 1989; Tietema *et al.* 1991; Mushove 1992; Erkkila and Siiskonen 1992; Mushove and Makoni 1993; Mushove 1992, 1997) have shown that:
Check what Mushove 1997 has to say on coppicing in his contribution

- Mopane coppices readily.
- Pole production from seedlings takes twice as long as from coppice.
- Diameter growth of coppice shoots is linear up to seven years.
- Weight gain at five years is around 1t ha^{-1}yr^{-1} at a density of 10,000 shoots ha^{-1}.
- A predicted 12 kg per tree of 750mm diameter at 10,000 trees ha^{-1} after 15 years,
- 22kg per tree and 950mm diameter at 1,000 trees ha^{-1} and
- 92kg per tree and 170mm diameter at 1,000 trees ha^{-1}.
- Desired diameter classes (50-250mm basal diameter) is achievable within 5-10 years.
- In Namibia, the best growth could be achieved by restricting coppice growth at 1 to 2 stems per

rootstock.

- In Zimbabwe, 20 to 80% of stumps had coppice shoots, 3 months after cutting.
- Trees coppiced at a height of 1m produced the most and tallest coppice shoots compared to those coppiced at a height of 100mm.
- Coppicing is season selective, occurring in the wet as opposed to the dry season.
- Sprouting is activated at a slower rate in large and tall stumps than in small and tall stumps.
- The best time to coppice is just before the onset of the summer rains.

Thinning studies on *C. mopane* (Coe 1991, 1992; Scholes 1991;Smit and Swart 1993;Smit (1994); Gelens 1997; Smit 1997; Smit and Rethman 1998a; Smit and Rethman 2000) have shown that:
Check what Smit 1997 has to say on thinning in his contribution

- In eastern Botswana, one year after thinning *C. mopane* stands from 8,000 to 1,500-3,400 stems ha^{-1} resulted in increased basal area growth of 11 to 21%.
- Thinning frequently has little effect on tree height but mainly results in a redistribution of basal area increment amongst fewer stems.
- Desired pole sizes will be faster produced, in spite of a reduction in production per hectare.
- Poor regeneration by coppicing may result from extensive cutting, due to competition from grasses.
- It results in increased vegetative growth, flowering and seed bearing by the remaining trees.
- It results in a reduction of available browse at peak biomass, but that a better seasonal distribution of browse by trees from low tree density plots is displayed.
- Trees within low-density plots formed larger and heavier fruits, however, the seeds did not differ in their potential to germinate.
- The rate of seedling establishment did not differ between tree thinning treatments.
- Drastic colonization of bare soil by herbaceous plants resulted from increasing tree-thinning intensities.
- The highest grass DM yields were recorded where all *C. mopane* trees were removed. However, some desirable grass species preferred canopied sub-habitats.
- Few soil variables changed significantly as a result of the various tree thinning treatments.
- Mean evapotranspiration water losses were generally much higher in treeless plots (grass only plots).
- Cleared mopane thicket or shrubland (c. 10,000-13,000 stems ha^{-1}) could revert to its original basal area (c. 5.5m^2 $ha^{-1)}$ after 14 years.

Stander and Nott (1992) described a method for the monitoring of tree species in an arid environment to assess degrees of utilisation, density and height structure at desired precision levels. Smit (1994) developed various computer models that can predict and estimate various aspects related to the thinning of *C. mopane*, and a leaf quantification technique. Potgieter, *et al.* (1997) described a partial ringbarking method for increasing fodder availability. Pretorius (1993) commented on the improvement of mopani veld by establishing pioneer grasses on reclaimed soil and techniques that can be implemented to prevent soil erosion. Styles and Skinner (1996a) and Van der Merwe (1990) studied the utilisation of mopani veld by goats. Van der Merwe (1990) recommended that a combination of cattle and goats for the optimal utilisation of mopani veld the Messina area, Nothern Province, South Africa. Goats were found to be effective in controlling regrowth of *C. mopane* stumps after bush clearing (without chemical control) on the Messina Experimental Farm (J.J. Jordaan pers. comm.). Reliable data from growth and yield trials are highly relevant to successful mopane management (Flower *et al.* 1997), and the results from these studies provide information that can be incorporated in the future development of models to assess growth and yield variation across a range of site conditions.

Despite this body of information there appears to be no published information on stand establishment or mortality. Given the economic importance of this multi-purpose woodland, surprisingly little basic ecological information is available on which to base management prescriptions. Little known aspects of the biology of mopane include factors determining differences between shrub and tree mopane, factors determining its distribution, mopane growth rates and mortality, and the nutritional value of leaves at different times of year and on different soil types.

Mopane woodland management and the mopane worm

Two species of Saturnid moths, *Imbrasia belina* and *I. maia* (synonym: *Gonimbrasia*), have edible caterpillars that feed almost exclusively on the mopane tree *Colophospermum mopane*. Originally, the mopane worm used to be an important food source mainly for the rural communities occurring within the range of mopane woodland, but it is now widely eaten across southern Africa where it has become an important trading commodity. (For a review of the socioeconomic literature on the mopane worm, see above). Although both species feed on other trees species, they do not reach the densities at which they occur on mopane. The life cycle of the *I. belina* on mopane under field conditions is well known (Oberprieler 1995; Ditlhogo 1996). Peaks in abundance of both species are between November-January (major) and March-May (minor), though population numbers vary from year to year at any single locality. Consequently the areas from which the caterpillars are harvested vary from one year to the next. Individual trees or sizeable patches of trees can be almost totally denuded by these larvae, but usually only one brood per year is found on any individual tree (Van Voorthuizen 1976). The defoliation pressure exerted by the caterpillar has been found to affect the fecundity of the tree, though this was size dependent with the largest trees being least affected (Ditlhogo *et al.* 1996). The oviposition behaviour of the moths has been found to be density-dependent with more egg clusters laid on bigger trees with increasing moth density (Ditlhogo *et al.* 1996). At low mopane tree densities smaller trees may therefore experience less defoliation pressure, with implications for management of the woodland for other purposes.

The abundance of the caterpillars is, apparently, declining (Roberts 1998) as a result of increasing exploitation and a decline of selective harvesting (Hobane 1995) and a general increase in pressure on mopane woodlands. Bartlett (1996) also reports of the disappearance of the mopane moths from parts of Botswana after heavy harvesting. Suggested threats to mopane worm abundance, in addition to over-harvesting, include deforestation of mopane woodland, and increasing drought. However, the absence of mopane worms from certain regions of mopane woodland has not been satisfactorily explained. Areas where caterpillars occur yearly have been noted to have low ant predation and high browse quality in contrast to regions where caterpillar are rare and sporadic in their occurrence (Styles and Skinner 1996). Other possible factors include soil type, rainfall or a combination of these (Styles and Skinner 1996). An assessment of the current status of mopane worms across southern Africa and studies of its population biology are imperative to provide the baseline data that are essential to reliably determine sustainable levels of use and to inform natural resource management programmes such as CAMPFIRE in Zimbabwe (Child 1996). While the precise influence on larval populations has yet to be clarified, increased harvesting pressure may have wider effects on the mopane ecosystem itself. Mopane trees may be felled or branches lopped to facilitate harvest of the worm. The tallest mopane trees may be most at risk as they are the most heavily laden with caterpillars that are beyond the reach of harvesters. Although mopane trees are in no danger of becoming scarce, selective destruction of the tallest individuals may have profound consequences for the abundance of mopane worm and other mopane herbivores such as elephant and various host-specific insects. Research into the extent of tree felling for gathering mopane worms and the effects of this practice on mopane worm populations and other resources provided in mopane woodland is needed to ensure continued supply of these resources.

Perhaps the greatest impediment to the further commercialisation of mopane worms is their temporally restricted abundance. If it is possible to raise mopane worms artificially through simple domestication programs then the seasonal dependence on the market and the degree of exploitation on the natural occurrence of the worms would be reduced. *Imbrasia belina* has been successfully raised under laboratory conditions in Zimbabwe (Member Mushongohande, personal communication with J. Ghazoul) and Botswana (Allotey 1997 - this reference is missing).

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