JASSA

Journal of Applied Science in Southern Africa
The Journal of the University of Zimbabwe

Volume 2, Number 2, 1996 **ISSN 1019–7788**

CONTENTS

TN 175 JOU

Zimbabwe: Z$30 **Africa: US15** **Elsewhere: US$20**

JASSA

Journal of Applied Science in Southern Africa
The Journal of the University of Zimbabwe

Vol. 2, No. 2, 1996
ISSN 1019–7788

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Published by University of Zimbabwe Publications
P.O. Box MP203, Mount Pleasant, Harare, Zimbabwe

Typeset by University of Zimbabwe Publications
Printed by Print Holdings (Pvt.) Ltd., Harare

Dynamics of mushroom *(Boletus edulis)* production in pine plantations in Zimbabwe

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Abstract

A three-year study of *Boletus edulis* mushroom (sporocarp) production was undertaken in *Pinus* plantations at two sites in Zimbabwe. The average sporocarp cap diameter was 22,86 cm, and fresh and dry weights were 206,86 g and 22,31 g, respectively. The total number of sporocarps counted was 16 881, representing 3 492 kg fresh weight. Average sporocarp productivity was 7,76 kg fresh weight/ ha/year. The site, year, thickness of the pine litter layer on the ground floor, pine regeneration (stems/ha), thinning stage and the percent age of light reaching the ground had a significant effect on sporocarp production, while *Pinus* species and age, soil type and aspect had no significant effect. The interactions of site x year, regeneration x light penetration, species x regeneration and year x regeneration had a significant effect on the abundance of sporocarps. Combining these results, young stands with moderate litter layer, and at least 20% light penetration, were more productive than other stands. Two peak sporocarp occurrence at the beginning and towards the end of each rainy season were observed, with very little sporocarp production during the drier months.

Key words: Mushroom, pine, silviculture, management, productivity.

Introduction

Pinus species were introduced into Zimbabwe in the 1890s (Barret and Mullin, 1968). They were planted to supply sawn timber, pulp and poles. Large-scale commercial planting commenced in the 1950s and 1960s. The area under exotic plantations in Zimbabwe is 104 000 ha, comprising mainly pines (76 000 ha), eucalypts and other hardwoods (28 000 ha). The major *Pinus* species are *P. patula, P. elliottii* and *P. taeda* ,(Forestry Commission, 1992).

Boletus edulis Bull.: Fr. has a symbiotic association with *Pinus* spp., with which it was probably introduced into Zimbabwe, as was the case with other pine mycorrhizal associates (Piearce and Masuka, 1992). Sporocarps of the fungus are highly rated on the gastronomic scale in Europe (Masuka, 1988; Sharp, 1988). They are shunned by local people in Zimbabwe, who have a deep suspicion of mushrooms associated with pines as elsewhere (Piearce, 1979), largely because of the occurrence of the poisonous *Amanita muscaria* (L.) Pers. and *Amanita pantherina* (DC.: Fr.) Krombh. *B. edulis* is being harvested on a commercial scale and some 10 tonnes of dried mushroom are exported annually (Piearce and Masuka, 1992). Ryvarden, Piearce and Masuka (1994) have most recently reviewed the occurrence of *B. edulis* in south central Africa.

The effect of seasons, and silvicultural and management factors on the occurrence and abundance of epigeous sporocarps has been undertaken in natural forests (Ohenoja, 1984, 1988; Dahlberg, 1991) but there is a paucity of information on the effect of these factors in planted forests in new environments. Surveys of sporocarps should be conducted over a period of three years or more, to yield significant information (Dahlberg, 1991). The frequency of occurrence and number of sporocarps are the most widely used productivity assessment parameters, although the biomass of sporocarps is a better measure (Hering, 1966; Murakami, 1988). Surveys of sporocarps should be conducted every 7-14 days, but even this period may result in 10-20% of sporocarps being missed (Hering, 1966).

The present study sought to establish the role of *Pinus* species silvicultural and management practices, and stand and edaphic factors in Zimbabwe on the

occurrence and abundance of *B. edulis* sporocarps.

Methods and materials

Study sites and Pinus species management

The two study sites (Table 1) are in the major *Pinus*-growing areas of Zimbabwe. *Pinus* species seed is sown in soil collected from a mature pine stand and humic soil, mixed in the ratio 1:3, to ensure adequate mycorrhisation (Piearce and Masuka, 1992). Seedlings are raised in pots in the nursery during the period June to December, and transplanted soon after (December-February). The initial field espacement commonly used is 2,2 x 2,2 m, giving 2 066 trees/ha. Three stem reductions (50%, 33% and 33%) are carried out when trees are 5-7, 11-13 and 17-19 years old, respectively. In addition, one-third crown-pruning operations are conducted 7, 13 and 18 years after planting, as routine silvicultural practices. Management operations such as weeding are also conducted during the early growth phases of the trees, usually until canopy closure. Trees are harvested at maturity, generally 25 to 30 years after planting.

Sample plots and assessments

Stratified random sampling procedures were used to identify plots. The plots were then inspected, before selection for study. The combinations of parameters sought were: *Pinus* species (S1 = *P. patula*, S2 = *P. elliottii*; S3 = *P. taeda)*; pine litter layer thickness on the forest floor (L1 = ≤5 cm, 5≤L3,<9 cm, L3 = >9 cm); regeneration in stand (R1 = absent, R3 ≤100 stems/ha, 100 ≤R4<400 stems/ha, R4 ≥400 stems/ha); thinning stage (T1 = 1 033 stems/ha, T2 = 688 stems/ha, T3 = 459 stems/ha); age of stand (A1≤10 years, A2≥10 years); light penetration to the forest floor (G1≤20%, 20 ≤G2<40 and G3≥40%); soil type (O1 = brown loam, O2 = black loam and O3 = red loam); and aspect (E1 = eastern, E2 = western, E3 = northern and E4 = southern). The possible treatment combinations were as shown in Table 2.

Table 1: Climatic data for the collection sites

Locality	Altitude (m)	Latitude (S)	Longitude (E)	Mean annual rainfall (mm)	Mean annual temperature (°C)
Nyangui	2 100	18° 11'	32° 49'	1 350,0	16,8
Stapleford	1 760	18° 44'	32° 49'	1 835,6	14,3

Table 2: The possible treatment combinations

P. patula	P. elliottii	P. taeda
S1 L1 R4 T3 A3 G3 O3 E4	S2 L3 R2 T3 A3 G3 O3 E2	S3 L1 R2 T2 A3 G2 O2 E4
S1 L3 R3 T2 A3 G3 O1 E1	S2 L2 R2 T3 A3 G3 O2 E2	S3 L1 R4 T1 A2 G2 O2 E1
S1 L2 R4 T2 A3 G3 O1 E4	S2 L2 R2 T1 A2 G3 O2 E2	S3 L2 R3 T1 A2 G2 O2 E2
S1 L2 R1 T1 A2 G2 O1 E4	S2 L1 R2 T2 A3 G2 O3 E4	S3 L1 R3 T1 A2 G3 O3 E2
S1 L3 R4 T2 A3 G2 O3 E1	S2 L2 R2 T3 A3 G3 O3 E1	S3 L1 R1 T2 A3 G2 O3 E2
S1 L3 R4 T3 A3 G3 O1 E4	S2 L1 R1 T3 A3 G2 O2 E3	S3 L2 R2 T2 A3 G2 O3 E2
S1 L3 R4 T3 A3 G3 O1 E1	S2 L2 R3 T3 A3 G2 O2 E4	S3 L2 R3 T3 A3 G3 O3 E3
S1 L2 R4 T3 A3 G2 O3 E1	S2 L2 R1 T2 A3 G3 O2 E1	S3 L1 R2 T2 A3 G2 O2 E1
S1 L3 R4 T1 A2 G3 O1 E4	S2 L2 R3 T3 A3 G3 O2 E1	S3 L2 R2 T3 A3 G3 O2 E2
S1 L2 R1 T1 A3 G2 O2 E4	S2 L1 R1 T1 A3 G2 O2 E2	S3 L1 R1 T1 A3 G2 O3 E3
S1 L3 R4 T3 A3 G3 O3 E4	S2 L1 R2 T2 A3 G3 O2 E2	S3 L1 R1 T1 A2 G3 O2 E3
S1 L3 R1 T2 A3 G3 O1 E4	S2 L1 R3 T2 A3 G2 O3 E3	S3 L1 R3 T1 A2 G3 O3 E1
S1 L3 R4 T2 A3 G3 O3 E4	S2 L2 R1 T2 A3 G3 O2 E2	S3 L1 R1 T3 A3 G3 O2 E1
S1 R3 R2 T1 A3 G2 O3 E2	S2 L1 R1 T1 A2 G3 O2 E1	S3 L2 R1 T3 A3 G3 O2 E2
S1 L3 R1 T1 A3 G2 O2 E4	S2 L2 R4 T1 A2 G3 O3 E4	S3 L2 R1 T3 A3 G2 O3 E2
S1 L3 R3 T2 A3 G2 O1 E4	S2 L2 R1 T1 A3 G2 O3 E2	S3 L3 R2 T3 A3 G3 O2 E1

P. patula is grown at Nyangui in a monoculture, and there were no T3 treatments except S1 L3 R4 T3 A3 G3 O1 E4. In each of the treatments, there were three replicate one-hectare plots, separated by at least 100 m. Sporocarps occurring in each plot were counted every week from January 1991 to December 1993. The data on total mushroom counts were transformed using natural logarithms and analysed by the General Linear Models in SAS Release 6.06.

Sporocarp biomass

All sporocarps occurring in one-hectare plot of *Pinus patula* at Stapleford forest were collected during the first week of January 1993. Mushrooms could not be collected from Nyangui because of logistical problems. Mushroom (cap) diameters were individually measured and corresponding fresh and dry weights were determined. Specimens were dried in an oven at 72 ^{0}C for 48 hours before being weighed. Data on mushroom weights and diameters were analysed using regression modules in Minitab Release 8.2.

Results

Sporocarp diameter and weight

The average cap diameter of 146 sporocarps was 12.61 cm (SE 8.054), and fresh and dry weights were respectively, 206,86 g (SE 71.089) and 22,31 g (SE 2.052). The ratio of dry weight to fresh weight was 1: 9.27. There were significant positive linear correlations of fresh weight to dry weight ($r = 0.63$, $P = 0.001$), cap diameter to fresh weight ($r = 0.73$, $P = 0.001$) and cap diameter to dry weight ($r = 0.81$, $P = 0.001$).

The regression equations were:
Fresh Weight = 82,13 + 5,56 (Dry Weight)
Cap Diameter = 8,03 + 0,21 (Dry Weight) and
Cap Diameter = 8,24 + 0,02 (Fresh Weight).

Sporocarps produced during the study period

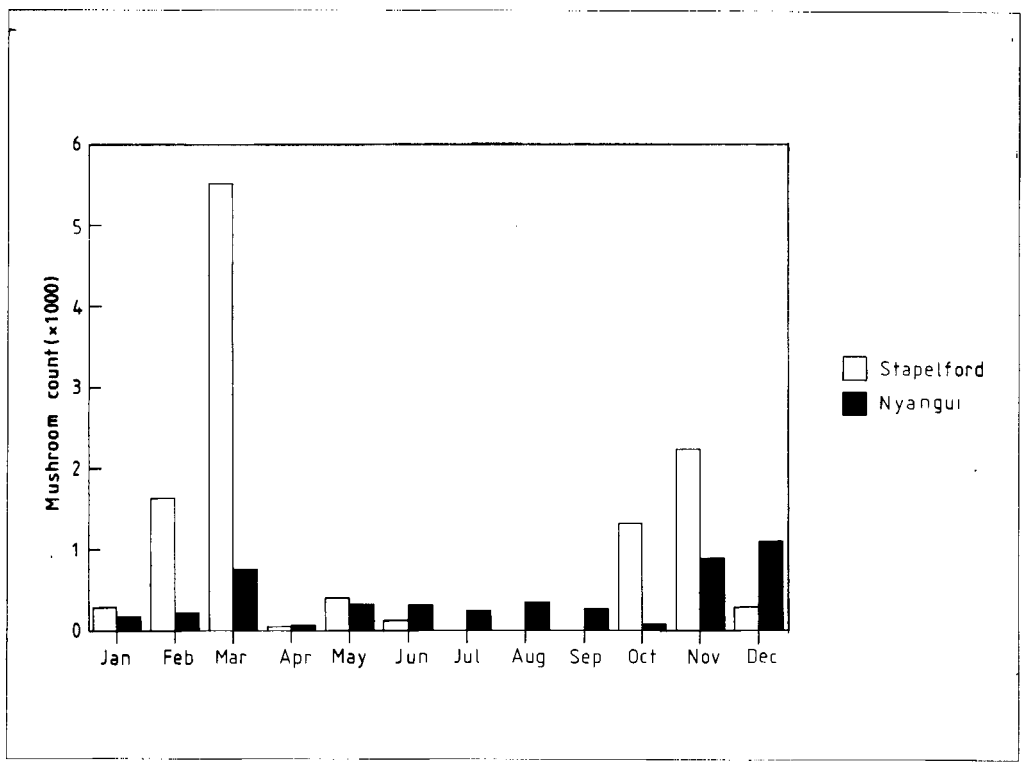

Figure 1: Summary of sporocarp productivity during the study period

There were distinct sporocarp productivity peaks at both sites, during October-November-December, and February-March, generally at the beginning and towards the end of the rainy season (Fig. 1). At Stapleford sporadic sporocarp occurrences were observed after March, until June, but there were no mushrooms from July to September. Sporocarp production tended to occur throughout the study period at Nyangui, although there were very few collections in April and October.

The mean number of sporocarps/ha/year was 43 (8,89 kg fresh weight/ha/yr) at Nyangui, and 28 (5,79 kg fresh weight/ha/yr) at Stapleford. Average sporocarp production was 37/ha/yr (7,76 kg fresh weight/ha/yr) at both sites. Generally, there were more sporocarps per plot in higher productivity months.

Factors affecting sporocarp production

Low sporocarp productivity from April to September coincided with low mean monthly rainfall and low mean number of rain days in a month at Stapleford (Fig. 2). There were no facilities to enable rainfall records to be taken at Nyangui during the study period.

The general linear model best describing variations in sporocarp production during the study period was found to be: Log (Mushroom Count) = (site/ year/ species/ litter/ age/ thinning/ light/ soil/ aspect/ site x year/ age x light/ layer x age/ regeneration x light/ species x regeneration/ year x regeneration) (DF = 40, P = 0,001).

Significant differences in the number of sporocarps among treatments (Table 2-3) were due to site (P 0,05), year (P = 0,001), amount of pine litter layer on the forest floor (P = 0,05), regeneration in the stand (P = 0.001), thinning stage (P = 0,05) and light penetration (P = 0,001). The interactions of site x year (P = 0,001, Fig. 3), regeneration x light penetration (P = 0.05, Table 5) and species x regeneration (P = 0.001, Table 6) were also significant. There were more sporocarps/ha at Nyangui than at Stapleford. Overall, there was an increase in sporocarp production during the study period. More

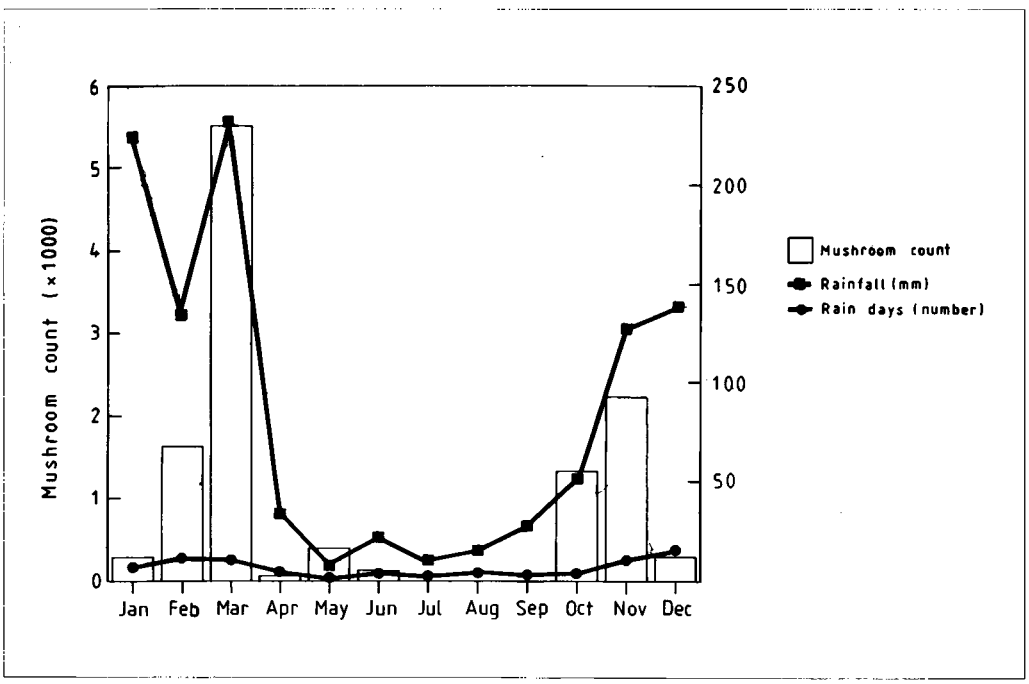

Figure 2: Mean monthly rainfall and rain days and sporocarp production at Stapleford during the study period

sporocarps were found in younger plantings, generally less than 13 years old, and those in the first and second thinning stages. Moderate amounts of litter (5-9 cm deep) were more conducive to sporocarp production than little or abundant amounts of litter. Most sporocarps were found in *P. patula* plots, followed by *P. taeda*, and were least in *P. elliottii*, although the differences were not statistically significant.

Table 3: Sporocarp productivity (un-transformed data) and probability levels (transformed data)

Factor		Number of sporocarps	Fresh weight (kg)	MS	P
Site				2,065	0,140^{x}
	Stapleford	12 194	2 522,45		
	Nyangui	4 687	969,55		
Year				15,210	0,000^{xxx}
	1990	2 829	585,21		
	1991	5 056	1 045,88		
	1993	8 996	1 860,91		
Species				1,551	0,193$^{n.s.}$
	P. patula	11 304	2 338,35		
	P. elliottii	2 151	444,96		
	P. taeda	3 426	708,70		
Age (years)				0,283	0,862$^{n.s.}$
	< 10	5 668	1 172,48		
	> 10	11 213	2 319,52		
Regeneration (stems/ha)				5,379	0,000^{xxx}
	0	4 215	871,91		
	>1 but<100	3 202	662,37		
	>100but< 400	2 737	566,18		
	> 400	6 727	1 391,55		
Thinning (years)				3,979	0,015^{x}
	5-7	8 448	1 747,55		
	11-13	6 250	1 292,88		
	17-19	2 183	451,58		
Light penetration (% reaching ground)				6,420	0,001^{xxx}
	0- 20	365	75,50		
	>20but< 40	8 580	1 774,86		
	> 40	7 936	1 641,64		
Litter layer (cm deep)				3,021	0,041^{x}
	0-5	5 934	1 227,51		
	>5but< 9	6 754	1 397,13		
	> 9	4 193	867,36		
Soil type				1,755	0,155$^{n.s.}$
	Brown	2 396	495,64		
	Black	5 160	1 067,40		
	Red	9 325	1 928,96		
Aspect				1,535	0,180$^{n.s.}$
	Easterly	6 089	1 259,57		
	Westerly	3 341	691,12		
	Southerly	2 598	537,42		
	Northerly	4 853	1 003,89		

Where, $^{n.s.}$ not significant at P = 0.05.^{x} significant at P = 0,05, and ^{xxx} significant at P = 0,001

Table 4: Analysis of variance for interaction patterns in sporocarp production

Factor	DF	MS	P
Site x Year	2	14,685	0,001^{xxx}
Age x Light Penetration	1	0,036	0,845$^{n.s.}$
Layer x Tree Age	2	1,355	0,237$^{n.s.}$
Regeneration x Light Penetration	3	3,016	0,022^{x}
Species x Regeneration	6	3,945	0,000^{xxx}
Year x Regeneration	6	1,668	0,101$^{n.s.}$

Where, $^{n.s}$ not significant at P = 0,05, ^{x} significant at P = 0,05, and ^{xxx} significant at P = 0,001

Table 5: Regeneration x light penetration effect on sporocarp production (untransformed means)

Light penetration (%)	Regeneration (stems/ha)			
	0	<100	<400	>400
< 20	-+	–	–	365
< 40	2 361	1 793	884	3 542
> 40	4 215	3 202	2 737	6 727

+ plots with this combination not found

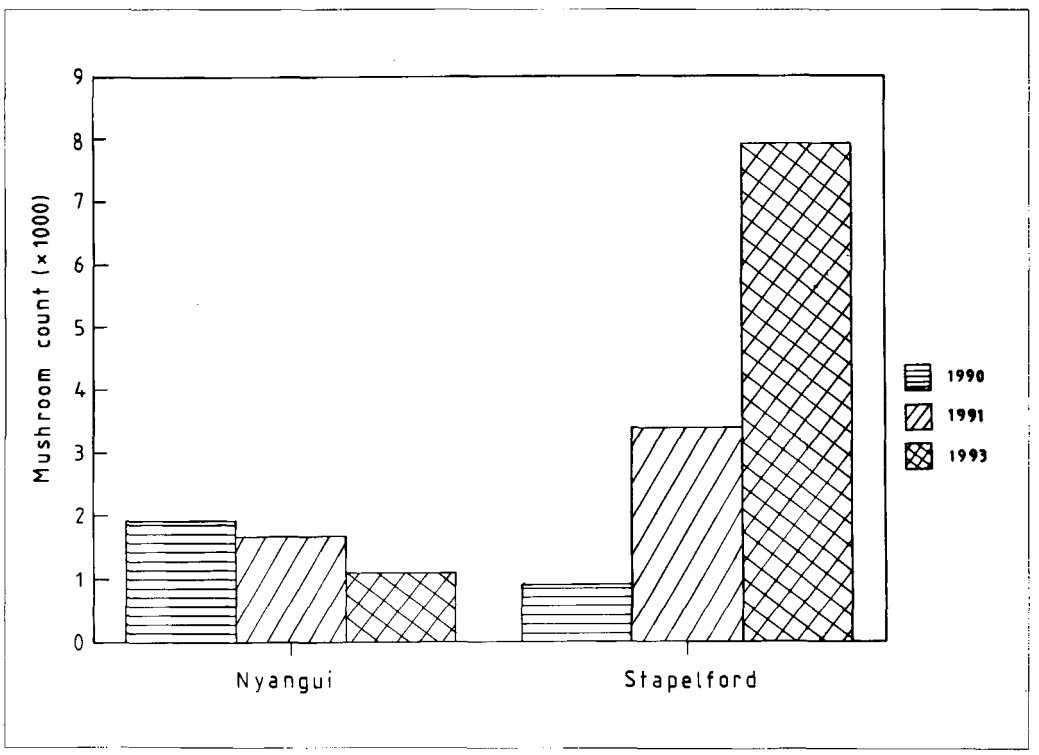

Figure 3: Interaction of site and year on sporocarp production

The number of sporocarps counted increased at Stapleford and decreased at Nyangui, during the three-year study period (Fig. 3). There was an increase in the productivity of sites with increasing light penetration, within each regeneration category (Table 5). Generally, moderate amounts of regeneration (100-400 stems/ha) resulted in better sporocarp productivity in *P. elliottii* and *P. taeda*, unlike *P. patula* plots (Table 6).

Table 6: Species x regeneration effect on sporocarp production (untransformed means)

Species	Regeneration (stems/ha)			
	0	<100	<400	>400
P. patula	2 916	907	936	6 545
P. elliottii	627	1 207	183	137
P. taeda	672	1 091	1 618	45

Discussion

The sporocarp productivity peaks found in the present study, at the beginning and end of the rainy season, corroborate earlier observations in pine plantations in Zimbabwe (Sharp, 1988; Piearce and Masuka, 1992). The correlation between dry weight and fresh weight is in agreement with earlier empirical evidence (Piearce and Masuka, 1992). Mean sporocarp diameter reports (Sharp, 1988) were higher than those found in this study. A larger sample, with more variability in sporocarp sizes, was collected in the present study. The sporocarp diameters are, however, within the range reported for this species (Ryvarden *et. al*, 1994).

Dahlberg (1991) found average production of sporocarps of mycorrhizal fungi in the range 3,4-14,6 kg dry weight/ha/yr, while local estimates were 2 kg fresh weight/ha/yr (Sharp, 1988). Average sporocarp productivity was found to be 0,83 kg dry weight/ha/yr (7,76 kg fresh weight/ha/yr). Repeated biomass determinations of sporocarps during several years of study (Ohenoja and Koistinen, 1984), and a once-off collection (Ohtonen and Markkola, 1989) gave similar results. The major factors influencing variation in sporocarp production in a native forest were the number of rain days, precipitation, relative tree growth, biomass of trees, sporocarp production in previous year and temperature (Dahlberg, 1991), but native and introduced planted forests generally, have different silvicultural and other management prescriptions and objectives. Sporocarps were generally recorded throughout the year, except for the months July-September at Stapleford, so temperature might not be a major determinant in sporocarp production.

There were conflicting local results on the productivity of sites (Sharp, 1988; Piearce and Masuka, 1992). Combining the effects of tree age, stage of thinning and amount of regeneration in stands (Tables 3-6) it would appear that optimum sporocarp production occurs in young stands, less than 13 years old, with low to moderate amounts of litter layer, and moderate regeneration and light penetration. The predominance of *B. edulis* at certain growth stages of trees may indicate mycorrhizal succession (Piearce and Masuka, 1992). The pattern of occurrence and distribution of sporocarps may not reflect the extent, biomass or vigour of the fungus mycelium (Dahlberg, 1991) nor the status of the mycorrhizal symbiosis of roots (Markkola, Cibula and Vare, 1990).

The area planted to pines in Zimbabwe is 79 000 ha, potentially yielding some 807,4 tonnes (fresh weight) of *B. edulis* a year. It might not be feasible to harvest sporocarps in all forests because of accessibility, logistics and economic problems. There is a buoyant demand for timber locally and regionally, and the area under pines is increasing at the rate of 2% per annum (Masuka, 1992). Studies have been recommended (Piearce and Masuka, 1992) to manipulate the background mycorrhizal fungi to improve growth and survival, drought tolerance, disease resistance and to extend the range of pines into more marginal areas. The effects of these on the occurrence and abundance of *B. edulis* are not known.

The effect of frequent picking of sporocarps on productivity in subsequent seasons could not be established during the study period. Furthermore, sporocarp counts increased at Stapleford and decreased at Nyangui during the study period. The effects of site disturbance and picking frequency and intensity on the state and efficiency of the mycorrhizal association and tree growth are also not known. Forests in the southern part of the pine-growing area of Zimbabwe are known to be less productive than northern forests. This is presumably due to other factors and not the pine species, as originally thought (Masuka, 1988).

Conclusions

Silvicultural and management factors are major determinants of sporocarp productivity, although weather factors may broadly define within-season occurrences. It would appear that young stands with moderate litter layer, and at least 20% light penetration are more productive than other stands. Generally, two peak occurrences of sporocarps were observed, starting in late October or early November, suggesting that these could be the start dates for economic harvesting of *B. edulis*. Harvesting operations could be terminated around April, as there is little sporocarp production thereafter. *P. taeda* plantings, generally considered to be unproductive in the southern estates, should also be scouted for *B. edulis*. The extent, distribution, vigour and life cycle of mycelia of *B. edulis*, and the contribution of *B. edulis* to tree growth should be ascertained.

ACKNOWLEDGEMENTS

Technical assistance was provided by Mr. T. Mangezi and his staff. Mr. P. Gapa provided statistical advice for which I am grateful.

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